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Barrytown Mineral Sands Mine Hydrological Impact Assessment

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EXECUTIVE SUMMARY

The Barrytown mineral sands deposit under dairy / dairy support grazing land north of Canoe Creek is proposed for sand extraction to a depth of approximately 9 m below grade. The total potentially affected area is 63 ha, within which an extraction area of 34 ha would be traversed at one time or another by the active pit and backfilled. Extracted ore-bearing gravels would be transported by slurry pipeline to the processing plant along the farm's southern boundary. Mining starts in the southwest of the area, and progressively moves eastwards on 100 wide strips. Each subsequent strip of mining is located north of the previous strip. Mining along each strip is always from the west to the east.

The project area lies on a strip of coastal and alluvial deposits at the foot the Paparoa Range. The principal drainages are Canoe Creek, Collins Creek (which defines the southern boundary) and Deverys Creek further north. The farm is extensively drained with a network of open drains, plus a further pattern of swales installed during humping and hollowing development. The farm known as the Cowan Block relatively evenly sloping to the coast, extending from about 20 m above mean sea level (AMSL) at the eastern State Highway 6 (SH6) boundary to elevations of 2.5 m AMSL at the Canoe Creek Lagoon margins in the west. A thin coast zone of foredune and high energy shingle beach encloses the coastal lagoon further west against the Tasman Sea.

The principal water course of the project area is Collins Creek, which has an approximate catchment area of 2.1 square kilometres (km^2) and a mean flow of 94 L/s. Flow stage monitoring sites have been established upstream of SH6 and the lower creek at farm ford approximately 400 m upstream of the creek mouth.

The Cowan Block farm is underlain by Holocene age creek alluvium and the coastal Nine Mile Formation containing the mineral sands proposed for extraction, as successive raised terraces from the east into the Tasman Sea in the west. The coastal flats' sediments host an unconfined and progressively semi-confined groundwater system with mixed clay, silty, sandy gravel deposits. Site-specific groundwater level surveys & monitoring, aquifer testing, groundwater sampling for analysis, and intensive drilling investigations have characterised the groundwater systems in addition to the previous hydrogeological investigations.

Proposed sand extraction would entail the lowering of water table in the mine excavation to up to 10 m below ground surface in the deepest active excavation zone via a sump pump to achieve suitable working conditions for mineral sand extraction. A groundwater model was developed to represent the local hydrogeological system and mining operation. The model was founded on precautious assumptions with the aim of providing an upper range estimate of groundwater inflow rates to the mine excavation and hence a conservative assessment of potential adverse effects. Model results indicate that groundwater inflow rates could range from 25 L/s to 200 L/s depending on deposit permeability and depth of excavation. Surrounding groundwater levels, hydraulic gradients and hydrologically connected water bodies (creeks, wetlands and freshwater lagoons) could be affected by radiating water table lowering as a result of in-pit pumping in the absence of a water management system to avoid adverse hydrological impacts.

Groundwater quality investigations have shown that groundwater beneath the Cowan Block farm is depleted in dissolved oxygen, allowing some dissolved metals concentrations to become naturally elevated. Discharge of groundwater with elevated metals to surface water bodies could potentially cause adverse effects on ecological health in the absence of an appropriate water management system. The presence of clay deposits in the overburden material in some parts of the site are likely to cause high levels of turbidity in water pumped from the mine excavation during some periods of the mine life; this also has the potential to cause adverse effects in receiving surface water bodies. The material backfilled into the mine excavation may temporarily contain elevated concentrations of a limited number of metals dissolved in the pore water, as a result of the minerals processing, but the potential for this to cause adverse water quality effects is very low, even on a temporary basis.

A water management system has been developed to manage water on the site such that adverse effects on surface water bodies and wetland extent can be avoided with a high level of certainty. The water management system will implement the following cascading water management strategy:

Priority 1: Minimise the net rate of groundwater pumping from the mine excavation.

Priority 2: Return groundwater pumped from the mine excavation to the aquifer at the mine boundary when mining within the influencing distance of a wetland or sensitive surface water feature.

Priority 3: Return water pumped from the mine excavation via the treatment system directly to the water bodies that might otherwise be depleted.

Priority 4: Augment the water bodies that might otherwise be depleted with water from Canoe Creek at up to 63 L/s.

Priority 1 of the strategy will be achieved by design of the mine operation to minimise the area of open excavation below the static water table at any given time and minimising the pumping depth in the excavation, as far as practically possible.

Priority 2 will be implemented by infiltration trenches installed along key parts of the site boundary, supplemented with injection wells if required, to maintain the pre-mining median groundwater levels in these areas. Maintaining the pre-mining median water level will avoid any reduction in the normal extent of the wetlands, will avoid adverse changes to the wetland hydrological regime and will avoid a reduction in the median flows of springs beyond the site boundary. Infiltration of water to ground adjacent to the Northern Boundary Drain and Collins Creek will minimise the potential for flows in these watercourses to be reduced by groundwater pumping from the excavation and help to avoid adverse hydrological effects.

Priority 3 will be implemented by treating water pumped from the mine excavation to the highest practicably achievable standard and discharging treated water which meets appropriate standards to surface water bodies that would otherwise be depleted.

Priority 4 will be implemented by taking water from Canoe Creek at up to 63 L/s and conveying this flow to infiltration systems at the site boundaries and/or directly to surface water bodies that might otherwise be depleted if a) the volume of treated water available for discharge from the minewater treatment ponds is inadequate or b) the quality of treated water does not meet appropriate standards for direct discharge. Water which does not meet appropriate quality standards will be discharged to ground and land in the Canoe Creek catchment to avoid adverse surface water quality impacts.

The volumes of water required to maintain groundwater levels at the site boundary and flows and water levels in sensitive local surface water bodies has been assessed with the help of a site-specific, calibrated groundwater model. Model results and the broader hydrological assessment indicate that the proposed water management system will avoid potentially adverse changes in the local hydrological system.

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1 Introduction

1.1 Background

TiGa Minerals & Metals Pty Ltd proposes to develop mineral extraction facilities in the Barrytown area, Grey District in the West Coast region. The proposed mineral extraction will comprise an excavator extending to a maximum depth of approximately 10 m, feeding a processing plant. The proposed extraction area covers 34 ha of pastoral farmland between the Northern Boundary Drain and Collins Creek on the Coates' property also known as the "Cowan Block", Barrytown coastal flats.

The deposition of sand, gravel and heavy minerals by long-shore drift at the same time as the uplift of the coastline by tectonic uplift, and to a lesser degree minor eustatic sea-level changes, have left a sequence of raised shorelines (stand lines) across the coastal flats tiered roughly parallel with the modern shoreline. Heavy minerals have been concentrated along the shorelines by coastal hydrodynamic processes facilitating proposed sand extraction and processing for garnet, ilmenite, other Rare Earth Elements and gold.

This report details the investigation in 2022 in support of environmental assessments of sand extraction effects. It covers mineral and hydrogeological drilling investigations, time-series water table monitoring, water sampling, analysis for water quality characterisation, monitoring of Collins Creek flows and hydraulic testing and modelling of the groundwater system. The report identifies potential hydrological effects associated with the proposed activity and sets out a water management system which implements the effects management hierarchy by avoiding adverse hydrological effects.

1.2 Report Purpose and Scope

The purpose of this report is to assess the hydrological impact of the proposed mining operation through the following work to:

- Review and collate previous work on hydrological setting of the proposed mining operation,
- Detail the field investigations conducted in 2022,
- Assess the results of field investigations, and
- Review and describe the proposed mining operation with respect to its potential hydrological impact.

2 Site Setting

2.1 Information Sources

A set of existing information was available for the Barrytown coastal flats project from the following sources –

- Coffey Partners (1991) - Water Management Study,
- Analysis of previous studies into the subject matter such as airborne geophysical data by Vidanovich (2008),
- Review of the provisional hydrological assessment of sand extraction between Burke Road and Canoe Creek (Rekker, 2020), and
- The assessments within other discipline areas such as erosion & sediment control, ecology and mine planning.

2.2 Site Location

Barrytown Flats are located on the South Island's West Coast (see Figure 1), south of the Punakaiki River mouth. The flats lie to the west of State Highway 6 (SH6), which runs between the district centres of Westport and Greymouth. The Flats lie within Grey District, although the nearest locality of Punakaiki lies in Buller District, with the Punakaiki River marking the district boundary. The Coates Property is located between SH6 and the Tasman Sea coastline north of Canoe Creek. The Coates' property is approximately delineated by the Northern Boundary Drain to Rusty Lagoon in the north, and by Collins Creek in the south (see Figure 2).

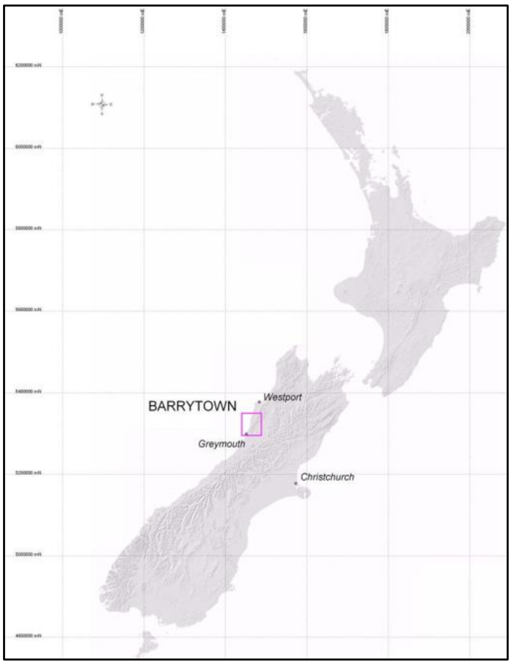

Figure 1: Location of Barrytown on the South Island West Coast

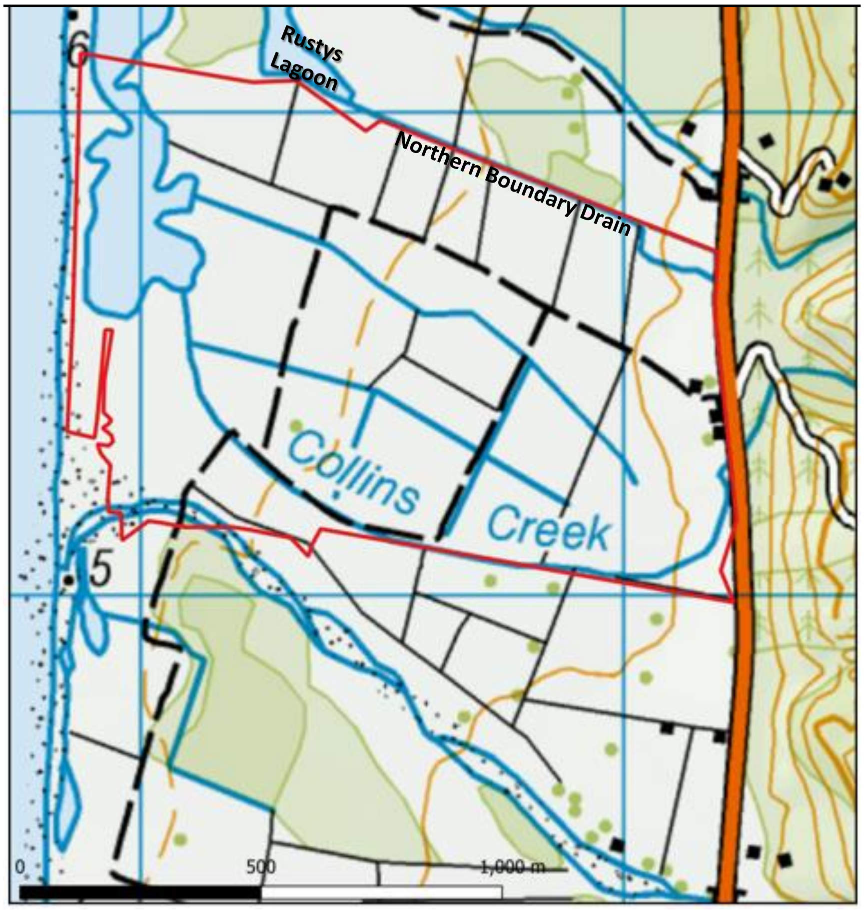

Figure 2: Coates Property (Cowan Block) outlined in red, 1 km is distance between blue grid lines

The sand extraction area identified in economic geological analysis and mining feasibility studies, including environmental considerations, encompassed a smaller land area occupying the western parts of Cowan Block, as illustrated in the LiDAR topographic relief map of Figure 3. The PB-1 and PB-2 bores marked indicate the location of pumping bores (PBs) used in aquifer testing. The remaining bore locations indicated with smaller print “PZ” and “TAC” numbers relate to smaller diameter monitoring piezometers installed for level and groundwater quality monitoring.

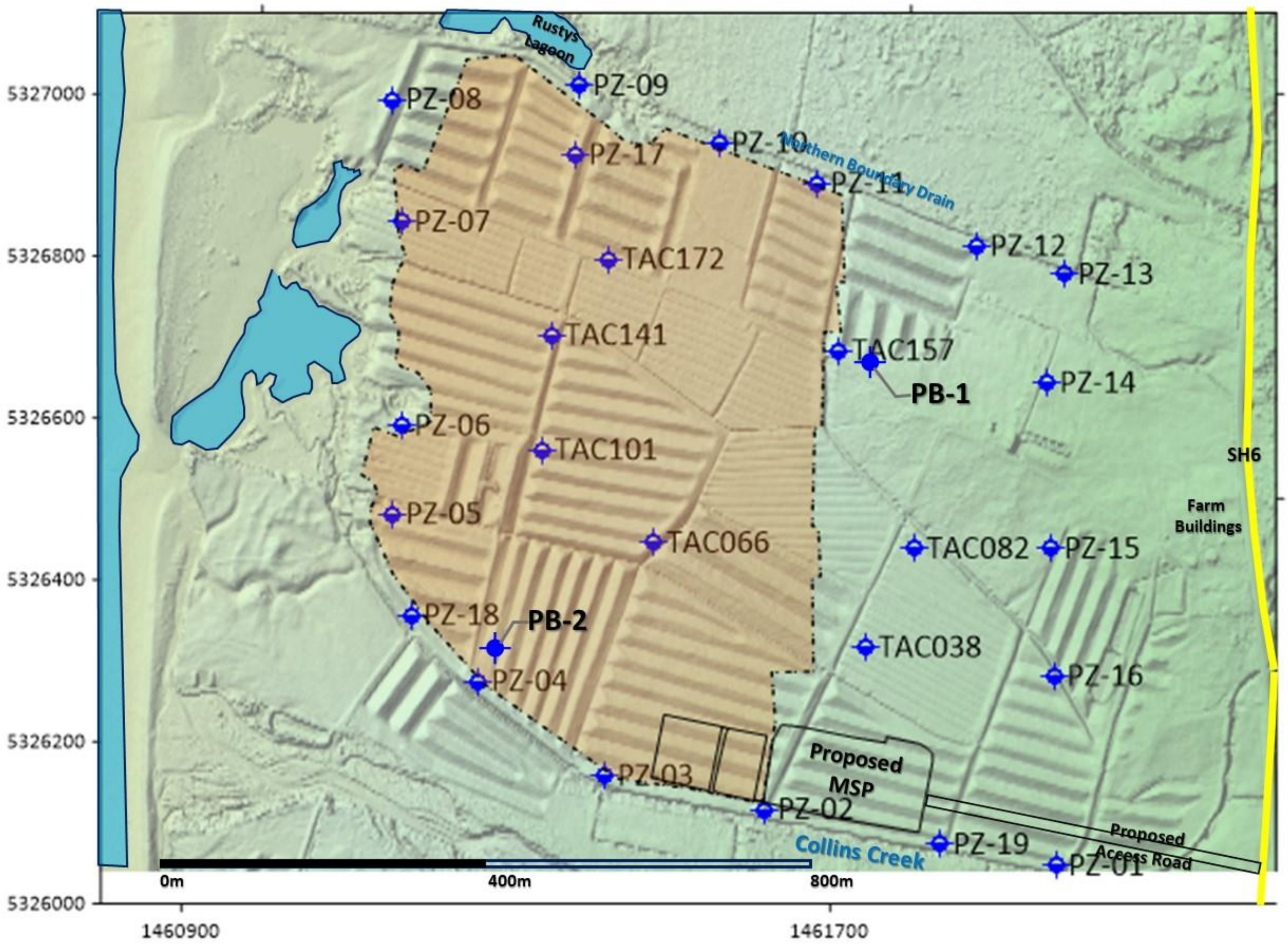

Figure 3: Red shaded mineral sand extraction area, plus processing plant (MSP), access road and groundwater investigation bores with numbers

The mineral sands would be extracted from within the red shaded area in Figure 3 and conveyed to the proposed processing plant. The processing plant is connected to SH6 by the proposed single lane access road. The proposed sand extraction area is approximately 34 ha, although internal offsets and infrastructure such as water management and processing would further diminish that area.

2.3 Climate

The West Coast is New Zealand’s wettest region, and this may be attributed to its exposure to the predominant westerly airflow over the country combined with the orographic effect of the Southern Alps. Annual rainfall totals at relatively high elevations regularly exceed 10,000 mm, with low elevation coastal locations typically recording between 2,000 and 3,000 mm of rainfall annually. Temperatures in lowland areas remain mild throughout the year, with temperatures less than 0°C and greater than 25°C occurring infrequently compared to most other regions of New Zealand (Macra, 2013).

2.3.1 Rainfall

Rainfall, in particular, is highly variable spatially in the coastal flats footing the Paparoa Range due to orogenic influences on the magnitude of rain falling at different sites across the area. Moisture-laden air masses passing over the Tasman Sea are forced to rise over foothills and main Paparoa Range. The coastal plain fringing the Tasman Sea receives approximately 2,700 mm per annum while the peaks of the Paparoa Range slightly inland receive over 6,000 mm per annum.

In the Barrytown area, all rainfall stations are historic having not been continued to the present day. The last station at Punakaiki Rocks (F21132) ceased in March 2004. The closest continuing rainfall station from August 2002 is Greymouth Aerodrome Electronic Weather Station (EWS) in Greymouth, approximately 30 km to the south. Greymouth at the aerodrome is in a similar topographic setting to the proposed mining area. The next closest rainfall and climate station is Westport Aerodrome (F11752 and F11754) at distance of 54.8 km to the northeast. The Reefton EWS is not relevant to Barrytown because of Reefton's position in an inland basin and within a rain shadow provided by the Paparoa Ranges.

The Barrytown rainfall record of complete calendar years from 1973 to 1989 averaged 2,728 mm per annum. Punakaiki Rocks, 9.3 km to the north at the Pancake Rocks averaged 2,584 mm per annum from 1983 to 2003. A fragment of rainfall record at the Punakaiki River station 4 km away averaged 2,498 mm from 1962 to 1971. For the short year-long period of overlap of simultaneous measurement at Barrytown and Punakaiki Rocks stations, the regression correlation coefficient R^2 was 0.95 with Barrytown receiving on average 190 mm per annum more rainfall, possibly due to Barrytown being located at higher elevation (30 m AMSL) and closer to steep foothills. The Barrytown former rainfall station lay 3 km to the south of the mining area and within the Barrytown locality.

The comparison between annual rainfall totals at Barrytown and Westport Aerodrome for the 16-year period (1972-1989) during which concurrent records were measured indicated a looser correlation than for the nearby Punakaiki Rocks station, with a coefficient R^2 of 0.48 and Barrytown on average having about a 1,020 mm per annum more rainfall.

Rainfall is relatively evenly distributed throughout the year as evident from the monthly mean totals at Westport, Reefton and Greymouth sites in Table 1 below.

Table 1: Monthly & Annual Rainfall data for the period 1981–2010

Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Ann**
Greymouth	209	161	177	195	197	238	198	192	209	225	197	252	2,452
Reefton	146	106	117	143	167	200	169	173	177	196	162	189	1,943
Westport	158	128	136	142	171	230	139	192	184	209	168	190	2,046

Note: Month labels abbreviated to first three letters; "Ann" = Annual Rainfall; Reefton lies in a distinct rain shadow area.

Figure 4 illustrates the highly variable distribution that is not captured in comparing rainfall totals for the three population centres in Table 1. Westport and Greymouth lie near sea level, while Reefton lies within a distinct rain shadow area imparted by the Paparoa Ranges, despite its elevation. The effects of orogenic influence and rain-shadowing in terms of modelled median annual rainfall totals in colour flood is shown in Figure 4.

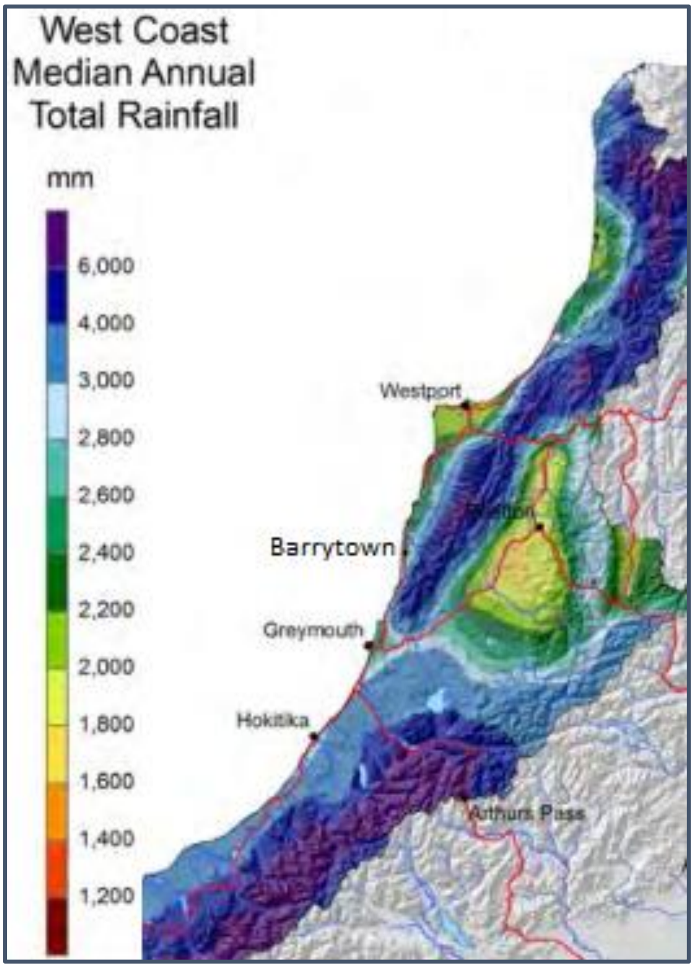

Figure 4: NIWA map colour flood of median annual rainfall

Dry spells are quite uncommon (see Table 2) in most areas of West Coast but can occur throughout the region when a persistent (blocking) anticyclone becomes established over the South Island. The rarity of dry spells contributes to the consistency of flow regime in rivers draining the Paparoa Range foothills as expanded on in the Hydrology section. In general, dry spells are more likely in autumn and winter as shown in Table 3.

Table 2: Dry spell frequency, duration and seasonal distribution

Station location	Frequency	Mean duration (days)	Max. duration (days)	Max duration date
Greymouth	One every 19 months	17	39	6/2/2013 to 16/3/2013
Reefton	One every 11 months	18	40	6/2/2013 to 17/3/2013

Note: 'dry spells' are referred to as periods of fifteen days or longer with less than 1 mm of rain on any day.

Table 3: Seasonal distribution of Dry Spells

Seasonal distribution of Dry Spells	Summer	Autumn	Winter	Spring
Greymouth	25%	30%	35%	10%

Reefton	22%	36%	31%	11%

Note: 'dry spells' are referred to as periods of fifteen days or longer with less than 1 mm of rain on any day.

2.3.2 Evaporation

Evaporation and evapotranspiration are measured at the Westport EWS. Compared to the measured rainfall at Westport, the measured or calculated annual median evapotranspiration is small as per Table 4.

Table 4: Median Evaporation / Evapotranspiration Measurements for Westport (1996-2018)

Evaporation / Evapotranspiration Measurement	Value (mm/year)
Total Penman Potential Evapotranspiration	816
Total Priestley-Taylor Potential Evapotranspiration	723
Total Penman Open Water Evaporation	750

Precipitation substantially exceeds evapotranspiration at Westport, and presumably also Barrytown where precipitation totals are higher. The imbalance in rainfall and evaporation leads to the tendency of the soil-moisture balance to remain in surplus which leads to soil draining laterally and vertically for lengthy durations of the hydrological year. This contrasts with east coast of the South Island soils, which display a distinct deficit period during summer and late summer - autumn. Such deficits relating to dry spells in Barrytown soils are brief and infrequent, even for low profile available water capacity (also known as field capacity) soils.

Indeed, the average number of days per annum of soil-moisture deficit for the period 1996 to 2018 were 3 days in Greymouth and 6 in Westport. Most of the West Coast region, including Barrytown, has an annual soil-moisture deficit mean period of less than 5 days.

2.3.3 Climate-Driven Soils Drainage

Much of the coastal flats can be classed as poorly drained. The Fundamental Soil Classification maps the Flats' soils as orthic, and divided into:

- Orthic Brown in elevated positions, primarily as a strip following SH6 and covering elevated terraces, and
- Orthic Gley in low elevation flats and wetlands fringing the coastline

Gley soils are mottled and strongly affected by waterlogging, typically in high water table zones. Gley soils are also associated with reduced or low dissolved oxygen soil water. Brown soils are associated with iron oxides weathered from the parent material. Brown soils are less likely to be waterlogged, although this may occur in high precipitation, even in well-drained settings. Figure 5 highlights the distribution of gley and brown soils across the Barrytown Flats.

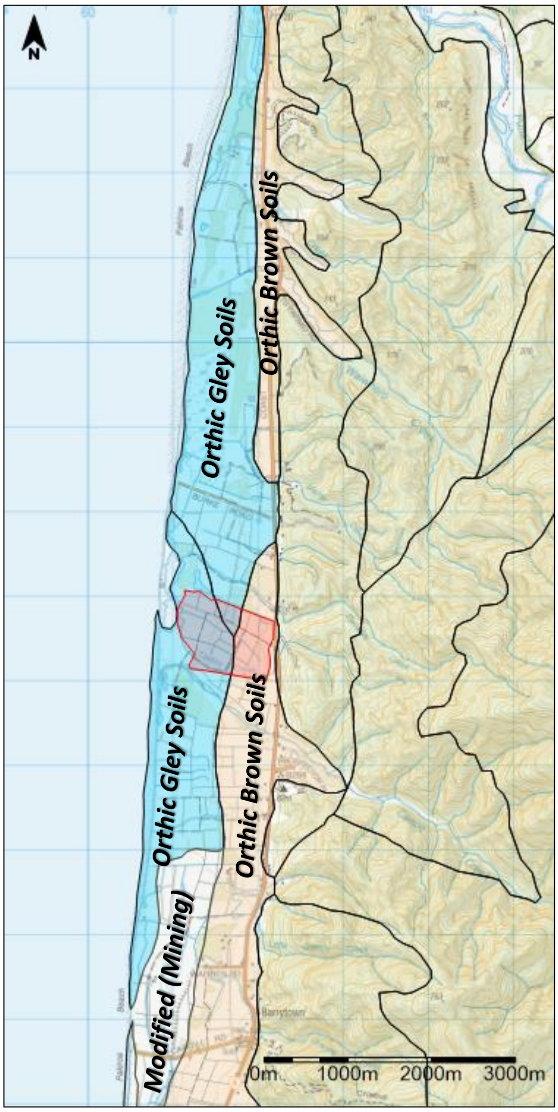

Figure 5: NZ Soil Classification of Barrytown Flats, Coates property shaded red[1]

The distribution of gley and brown soils across the Barrytown Flats is a reasonable indication of drainage and the relative position of the water table. Gley soils are found across the Flats wherever the relief is low and water table shallow. Brown soils are found in a slightly more elevated belt running along the base of the coast foothills where the water table is 2 to 5 m belowground surface, but not shallow enough to flood the subsoil leading to mottling.

Land use is also determined by soil classification and associated drainage. Much of the land upon orthic gley soils displays poor drainage, hampering the development of good pasture. The poor drainage properties in the lower relief parts of the Barrytown Flats have led to the increasing use of 'hump and hollow' and excavation of open drains to carry out rudimentary pasture drainage and soil improvement (Brown, 2004). Open drainage channels are excavated into soils in the gley soil zones to reduce water logging and lessen surface flooding. The main drains are marked by blue solid lines internal to the Cowan Block in Figure 2. The humping and hollowing within the Cowan Block is evident in the LiDAR topographic mapping of Figure 3.

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[1] **Note: gley = light blue and brown = tan soils**

2.4 Geology

2.4.1 Regional & Basement Geology

The Canoe Fault is a significant local displacement juxtaposing basement Carboniferous Karamea Batholith granitic intrusives plus late Palaeozoic Greenland Group meta-sediments against softer Tertiary sandstones such as the O'Keefe Formation (Blue Bottom Group). Two thirds of the Barrytown Flats are underlain by O'Keefe Formation muddy sandstone and the southern third is underlain by Karamea granitic basement. Granite Creek and Little Granite Creek have their headwaters in the Karamea granitic batholith rocks. In the far south of the foothills encompassing the landward flank of the coastal flats, the basement strata are primarily the Ordovician age Greenland Group indurated greenish-grey bedded sandstones and mudstones.

The Barrytown creeks north of Canoe Creek have their headwaters in softer, more erodible O'Keefe Formation silty sandstones. Scarce intersections with basement strata have been made in mineral resource or environmental drilling through the coastal flat deposits. Notably, O'Keefe Formation silty clay weathered basement was encountered at a depth of 24 m below ground at Burke Road, approximately 400 m west of SH6. At the coastline end of Burke Road, the 30 m drill hole WS32000 terminated in Nine Mile Formation sandy gravel without reaching a similar basement intersection.

2.4.2 Holocene Sedimentology

The mineral sands that are the focus of mining proposals comprise post-glacial coastal sand and gravel deposits grouped Stratigraphically within the Nine Mile Formation (Suggate, 1989, see Figure 6). The mineral sands are considered to have been set down in a series of north – south trending pro-grading strand lines. The sediment supply for deposition of the sands is inferred to have been marine long-shore drift originating from the south.

The proposed sand extraction area comprises a series of post-glacial strand lines extending from the foot of a Late Pleistocene sea cliff (coincident with SH6) and a staircase of up to four terraces that have prograded westward to the present-day coastline. During the formation of strand lines, heavy minerals were concentrated within the surf-washed zone into lenticular black sand leads. These terraces and coastal gravelly sands are stratigraphically grouped within the Nine Mile Formation of Holocene to Late Pleistocene age (i.e., Recent to 14,000 years Before Present). The Nine Mile Formation contains marine placer mineral concentrations of ilmenite, gold and associated heavy minerals (epidote, garnet, titano-magnetite, zircon and trace monazite). The heavy minerals contain fractions with high magnetic susceptibility that were revealed in the Total Magnetic Intensity (TMI) channel of a recent airborne geophysical survey (Vidanovich, 2008).

Coffey Partners (1991) noted the following facies-related subdivisions within the Nine Mile Formation –

1. Transgressive Beach Deposits,
2. Elevated Beach Terrace, and
3. Recent Foredune.

The transgressive beach deposits tend to be more sand dominated but include gravel-sized grains in a fine to medium sand matrix. The transgressive beach deposits also tend to be found in the western, seaward portions of the coastal flats. Conversely, the elevated beach terraces tend to have higher proportions of gravel, while still being dominated by a sand matrix. The elevated beach terraces tend to be located parallel and in closer proximity to the eastern edge of the coastal flats.

Suggate (1989) also noted the presence of Holocene alluvial Fans, which are evident and significant in the geology of the Cowan Block. A lobe of the Canoe Creek alluvium is mapped in Figure 6 draping over transgressive and elevated mineral sand/gravel deposits within the Cowan Block. This was separately designated by RSC Consultants as the Eastern Gravel Overburden in the Cowan Block geological model delineated from geological modelling with the 195 Aircore drill logs undertaken in mid-2022.

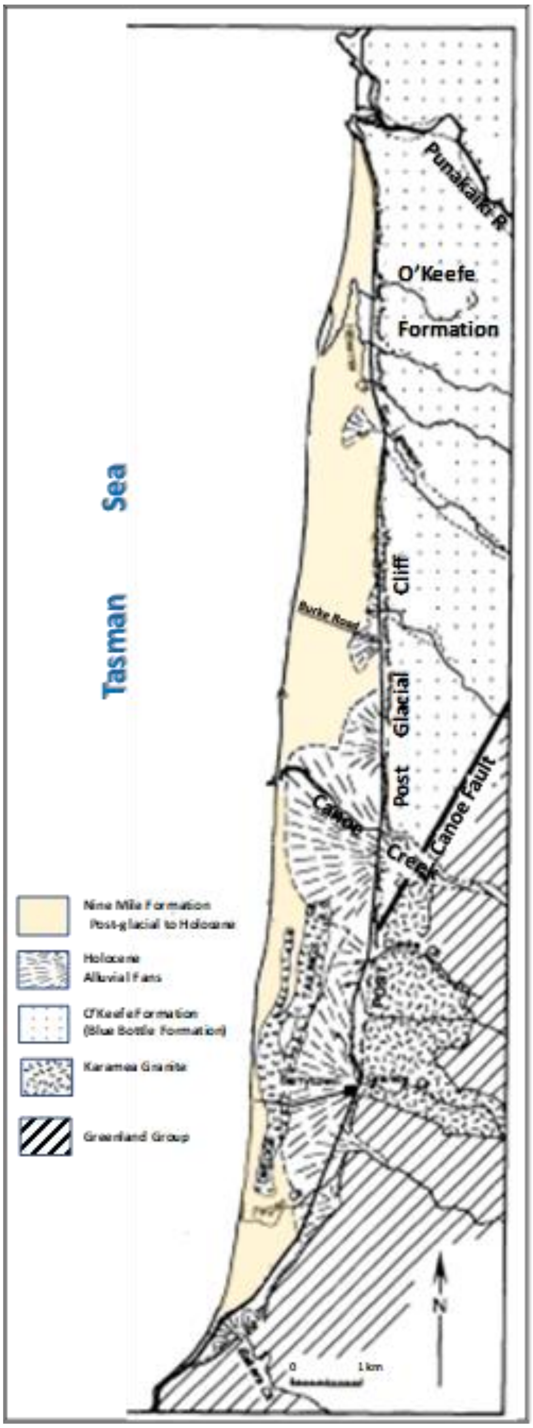

Figure 6: Mapping of local geology and Barrytown coastal Flats - Nine Mile Formation deposits (Suggate, 1989)

It is important to note that the hydrogeological interpretation of the Cowan Block that the Eastern Gravel Overburden is highly variable with significant silt and clay content in addition to alluvial sand and gravel components this results in bulk groundwater permeability distribution within the groundwater system being less predictable. Figure 7 illustrates the distribution of “mineral sand” that is primarily transgressive beach deposits beneath the western half of the Cowan Block, with the “Eastern Gravel Overburden” being equivalent to the Canoe Creek alluvium and using the scheme of strata differentiation developed by RSC Consultants.

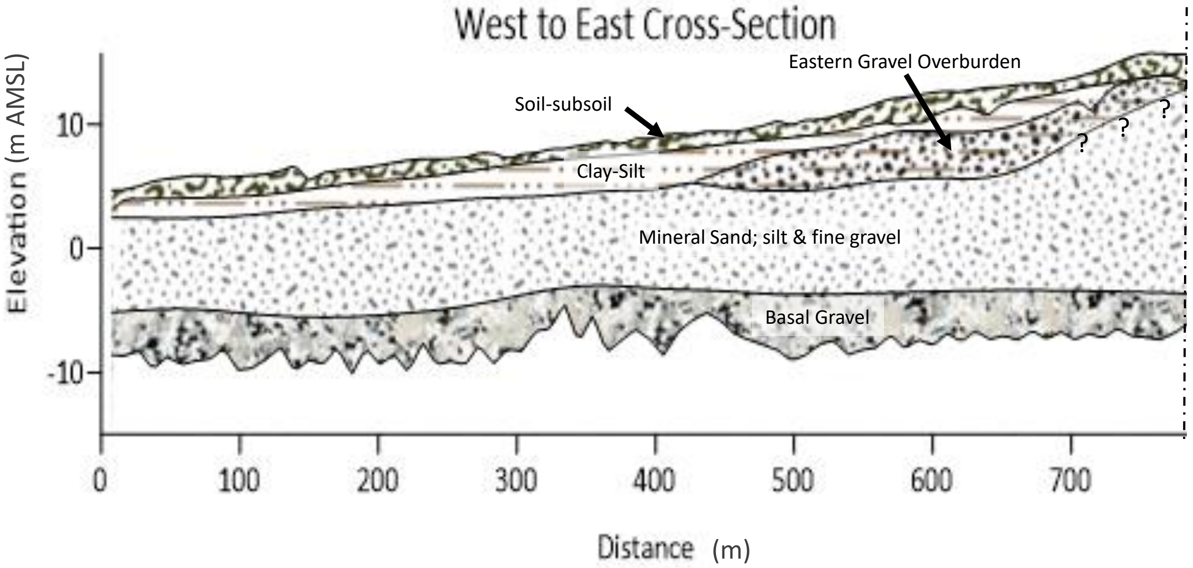

Figure 7: Subsurface profile from west to east across the core of the proposed sand extraction area (RSC Consultants' data)

Modern coastal deposits have formed between the area of minerals sands (underlying Cowan Block pastures) and the Tasman Sea. This coastal transition is made up of lagoon sediments, wetlands, foredunes and coarse beach aggregate, plus the alluvial fan of the Canoe Creek hapua[2]. These modern sediments are somewhat mobile, and highly mixed in terms of grain size and composition. Beach deposits are re-worked by wave actions, flooding at the Canoe Creek mouth and periodic ocean storms. Dunes are shaped and reshaped by wind action. Wetlands have a role in laying down layers of proto-peat and peat comprising dead wetlands vegetation.

2.5 Hydrology

2.5.1 Setting

The hill backdrop to the Barrytown flats is dissected by 17 individual stream and creek catchments. Canoe Creek is the largest of these at 23.4 km^2 and has headwaters at the Paparoa Range crest to an elevation of 1,220 m AMSL. The remaining smaller creek catchments (e.g. Waiwhero and Hibernia) to the north of Canoe Creek share an interfluve spur with the lower Punakaiki River. Granite Creek and Fagan Creek are the main catchments draining the face of the coastal range south of Canoe Creek and adjacent to the Barrytown settlement. Fagan Creek is notable as a very steep watercourse that adjoins headwaters with Canoe Creek on the flanks of the Paparoa Range peak, Mt Ryall at 1220 m AMSL.

There are several springs along the southern boundary of the proposed mining area which are used by the neighbouring landowner for stock water and for water tank top-up in dry weather. Access for inspecting or quantifying the springs was not obtained, so knowledge on them is limited to information provided in a previous consent hearing, aerial photography or LiDAR elevation data. Anecdotal information indicates that flows from these springs vary in accordance with the hydrology of Canoe Creek.

2.5.2 Previous Hydrometric Programmes

None of the creek catchments crossing the Barrytown Flats are routinely gauged, although spot gauging was undertaken on all creeks crossing SH6 in the winter and spring of 1990. The DSIR Water Resources Survey and West Coast Regional Council shared the tasks in operating the relatively brief hydrometric programme for Westland Ilmenite reported in Coffey Partners (1991). This included the installation of flow measurement

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[2] Beach barrier estuary, typically formed in gravel aggregate.

stations at Canoe, Lawsons (Waiwhero) and Hibernia creeks at their respective crossings of SH6 in May 1990, plus the installation of a staff gauge at Deverys Creek. The last recovered hydrometric flow data was taken in late October 1990, indicating a brief period of recording of not quite six months. Figure 8 maps the 17 creek catchments with estimated catchment areas upstream of SH6. Table 5 lists 17 instantaneous gaugings made on the same day (22 August 1990) which was preceded by five days of no rain and considered to approximate baseflow hydrological conditions by Coffey Partners (1991).

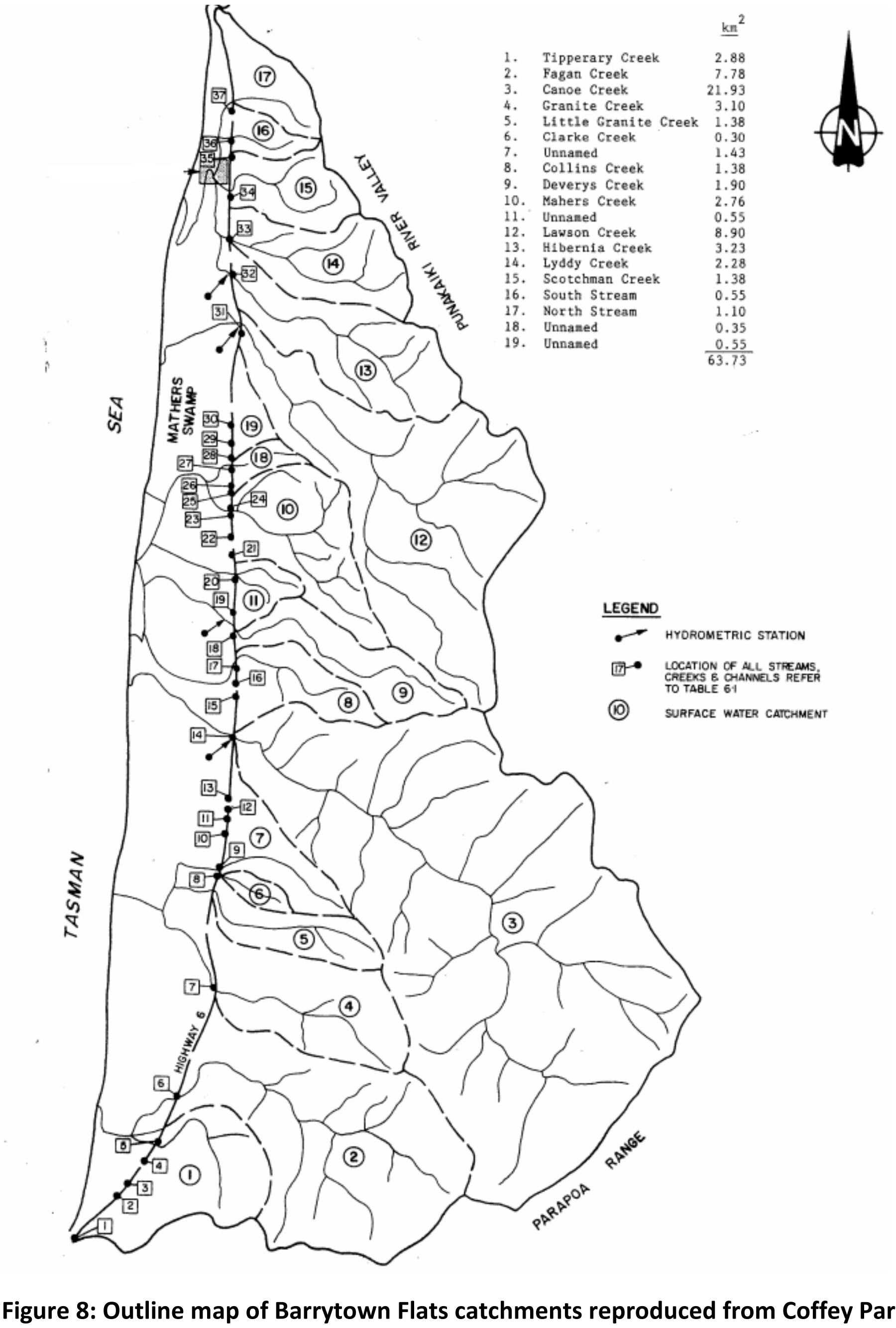

Figure 8: Outline map of Barrytown Flats catchments reproduced from Coffey Partners (1991)

Table 5: Instantaneous flow measurement data across the Barrytown Flats creek catchments (from Coffey Partners, 1991)

Catchment No.[1]	Catchment	Gauging Locality on SH6[2]	Area (km^2)	22/8/90* Gauging Campaign Flow rates (L/s)	Instantaneous Specific Runoff ($L/s/km^2$)
1	Tipperary Creek	@5	2.88	60	20.83
2	Fagan Creek	@6	7.78	0	0
3	Canoe Creek	@14	21.93	1,400	63.84
4	Granite Creek	@7	3.1	10	3.23
5	Little Granite Creek	?	1.38	0	0
6	Clarke Creek	@8	0.3	2	6.67
7	Unnamed Creek-7	@9	1.43	25	17.48
8	Collins Creek	@17	1.38	30	21.74
9	Deverys Creek	@18	1.9	50	26.32
10	Maher Creek	@23	2.76	18	6.52
11	Unnamed Creek-11	@20	0.55	3	5.45
12	Lawson Creek	@31	8.9	260	29.21
13	Hibernia Creek	@32	3.23	30	9.29
14	Liddy Creek	@33	2.28	10	4.39
15	Scotsman Creek	@34	1.38	8	5.80
16	South Creek	@36	0.55	3	5.45
17	North Creek	@37	1.1	2	1.82

Note: [1] Reproduced from Figure 15 and Table 6.1 of Coffey Partners (1991); * 22 August 2020 preceded by 5-day period of no rain. [2] see Figure 8; Collins Creek, which adjoins the proposed sand extraction area, is shaded for emphasis.

The last column of Table 5 is instructive on the baseflow characteristics of the respective catchments. The spot gaugings were conducted following five days without rain, which is considered a dry period for this part of the West Coast as discussed previously. The two largest creek catchments, Fagan and Canoe creeks displayed contrasting hydrological responses. Fagan Creek with a 7.78 km^2 catchment area upstream of SH6, granite bedrock and steep profile exhibited no flow. Canoe Creek with a 21.93 km^2 catchment area, variable geological strata and significantly less steep profile exhibited 1,400 L/s of baseflow. Canoe Creek also has the highest calculated specific low flow runoff of 63.8 $L/s/km^2$, twice that of Lawson Creek despite being normalised for catchment area.

Low baseflow characteristics are associated with high gradient, quartzose or crystalline basement rock catchments on the West Coast. While lower gradient, sedimentary or alluvial accumulations in the upstream catchment are more commonly associated with higher baseflow and hence higher specific runoff values under baseflow conditions.

2.5.3 Additional Hydrological Estimations

Auto-correlated hydrological indices for the Barrytown Flats catchments are contained within the Booker & Whitehead (2017) online national hydrological estimations, within both the New Zealand River Maps (Booker & Woods, 2014) and the Ministry for the Environment data coverage titled River Flows (Booker, 2015). These estimations attempt to extend measured hydrology from catchments with continuous flow recording to ungauged catchments. Table 6 summarises low-flow, median and mean annual hydrology for the main Barrytown Flats creeks. The catchment areas differ in places to those listed in Table 5 due to the estimation point being differently placed. Estimation nodes do not necessarily coincide with each creek's crossing of SH6, often placed at the nearest confluence of different branches of the creek network. In the cases of Maher Creek, Granite Creek and Fagan Creek the estimation node was measured at Maher Wetlands, coastal lagoon and coast, respectively. To this extent the creek catchments listed in Table 5 and Table 6 are not always comparable.

It can be expected that the values contained within Table 6 would be internally consistent and broadly reflective of the long-term hydrological patterns. Table 6 and Figure 9 cover the creek catchments as formulated within the River Environmental Classification version 2 (REC2).

Table 6: Summary of hydrological data from NZ River Maps and MfE River Flows for Barrytown Flats creek catchments

Creek	Catchment and measuring point	Catchment Area (km^2)	1:5 year Low Flow (m^3/s)	$MALF_{7d}$ (m^3/s)	Median Flow (m^3/s)	Mean Flow (m^3/s)
12 Waiwhero* Ck	@SH6	9.46	0.0964	0.124	0.488	0.877
10 Maher Creek	@ Maher Swamp	3.7	0.0239	0.0336	0.104	0.184
9b Unnamed Ck	@Lagoon	1.46	0.00647	0.00926	0.032	0.0584
9 Deverys Creek	@ Upstream of SH6	2.36	0.0241	0.0308	0.12	0.213
8 Collins Creek	@SH6	1.91	0.011	0.016	0.047	0.094
3 Canoe Creek	@ Downstream of SH6	23.4	0.517	0.63	1.8	3.08
4 Granite Creek	@ Coast	7.6	0.074	0.0958	0.4	0.751
2 Fagan Creek	@ SH6	8.08	0.179	0.215	0.637	1.1

Note: Creek numbering consistent with Table 5 and Figure 9; * Waiwhero Creek is the same as Lawson Creek in Figure 8, Table 5, Figure 9 and Table 6.

The Barrytown Flats creek catchments in terms the River Environmental Classification system version 2 (REC2) is also shown in Figure 9. Creek catchments are however labelled in consistency with the numbering adopted by Coffey Partners (1991). The surrounding catchment, including the Punakaiki River, Moonlight Creek and Ten Mile

(Waianiwaniwa) River are shown for orientation. Only the larger Canoe Creek backs onto the Grey River catchment tributaries, Moonlight and Blackball creeks at the crest of the Paparoa Range.

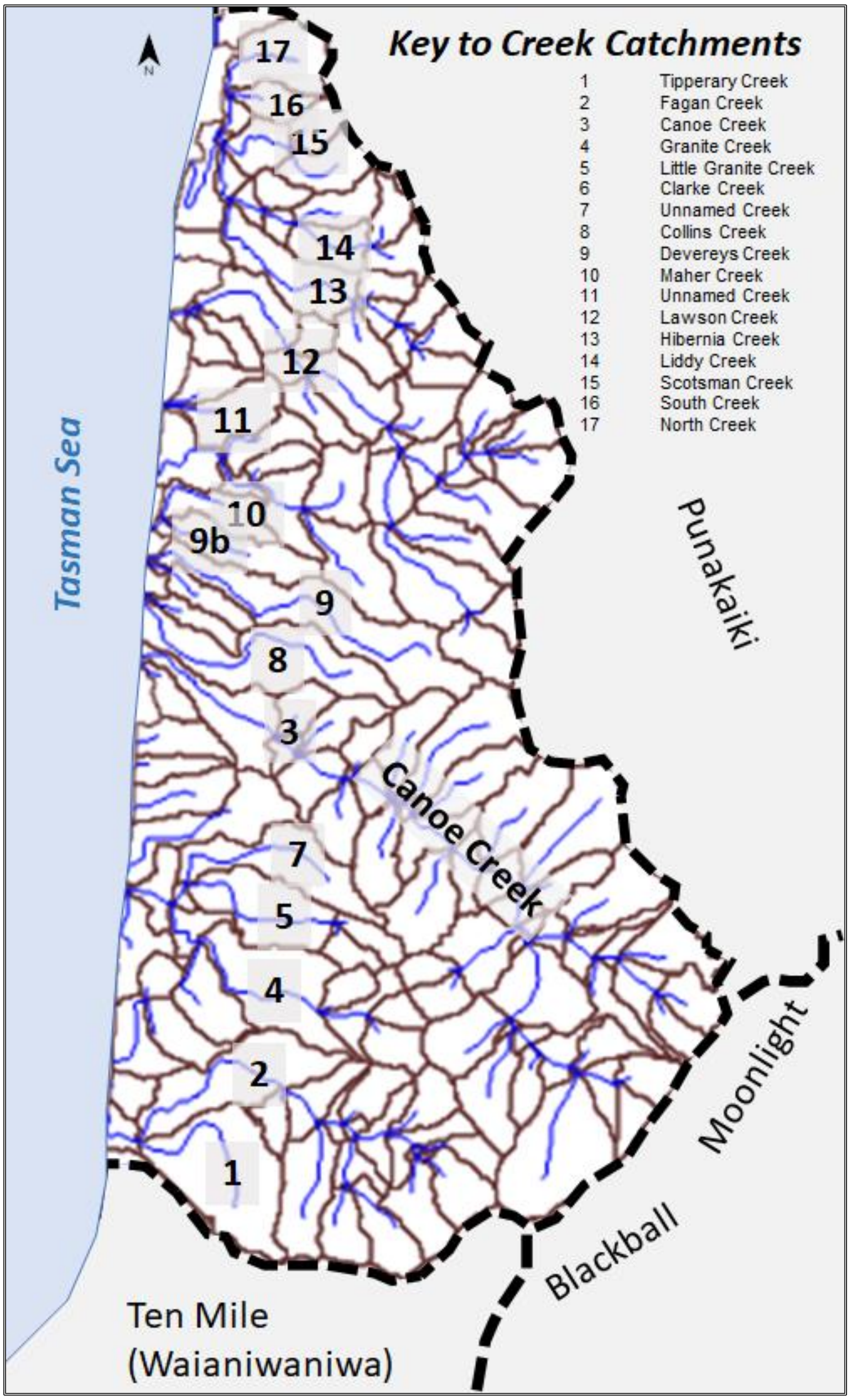

Figure 9: Barrytown creek catchment boundaries[3]

2.5.4 Recent Hydrological Studies

No further hydrological investigation had been undertaken in the Barrytown Flats until 2022, when two gauging and flow monitoring sites were established on Collins Creek. Collins Creek is the principal creek drainage of the

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[3] According to the River Environmental Classification version 2 (REC2)

upstream hill catchment and farmland associated with the Cowan Block. Table 7 lists the two Collins Creek sites, while Figure 10 and Figure 11 provide setting photographs of the upstream and downstream hydrological sites, respectively.

Table 7: Summary of hydrological sites established and monitored in 2022.

2022 Hydrological Site	Location of Site	Approximate Catchment (km^2)	Intervening Landcover
Collins Creek Upstream	U/S State Highway 6	1.4	Regenerating bush
Collins Creek Downstream	Cowan Block farm ford	2.1	Pasture (drained)

Figure 10: Photograph of Collins Creek Upstream hydrological site

Figure 11: Photograph of Collins Creek Downstream hydrological site looking south, section line to left (upstream)

Flow gaugings and stage monitoring were undertaken at both hydrological sites. Ultimately sufficient flow gaugings were obtained in separate field visits to allow the plotting of rating curves. High flows were experienced in 2022. However, it was assessed that re-rating was not require at either site.

2.5.4.1 Upstream Hydrological Site

The upstream hydrological site had a shallow profile and coarse creek bed that complicated flow gaugings with the FlowTracker2 velocity meter. From 4 March 2022 an INW LevelScout with 5 m resolution and absolute (non-vented) operation was fitted at the staff gauge installed at the flow gauging site (see Figure 10). The pressure transducer was consistently placed at the base of the creek channel at the staff gauge, suspended on a steel wire. Initial difficulties were experienced with sand and grit entering the 20 mm OD conduit holding the transducer – data logger. The sand / grit around the transducer body prevented it from being withdrawn from the conduit. In response, the base of the conduit pipe was wrapped in a robust gauze that permitted the transmission of water and level changes but prevented the ingress of sand or grit.

Regular downloads of the data logger were carried out coinciding with flow gaugings, although the pressure poling set at 1 hour intervals was not reset, merely allowed to continue accumulating. A barometric pressure transducer and data logger was maintained at a piezometer housing (PZ-01) on the Cowan Block, which allowed direct subtraction of atmospheric pressure from the gauge pressure at the submerged hydrological site pressure records. With subtraction of the barometric component of gauge pressure, the resulting pressure values were converted to equivalent metres of water height above the transducer base.

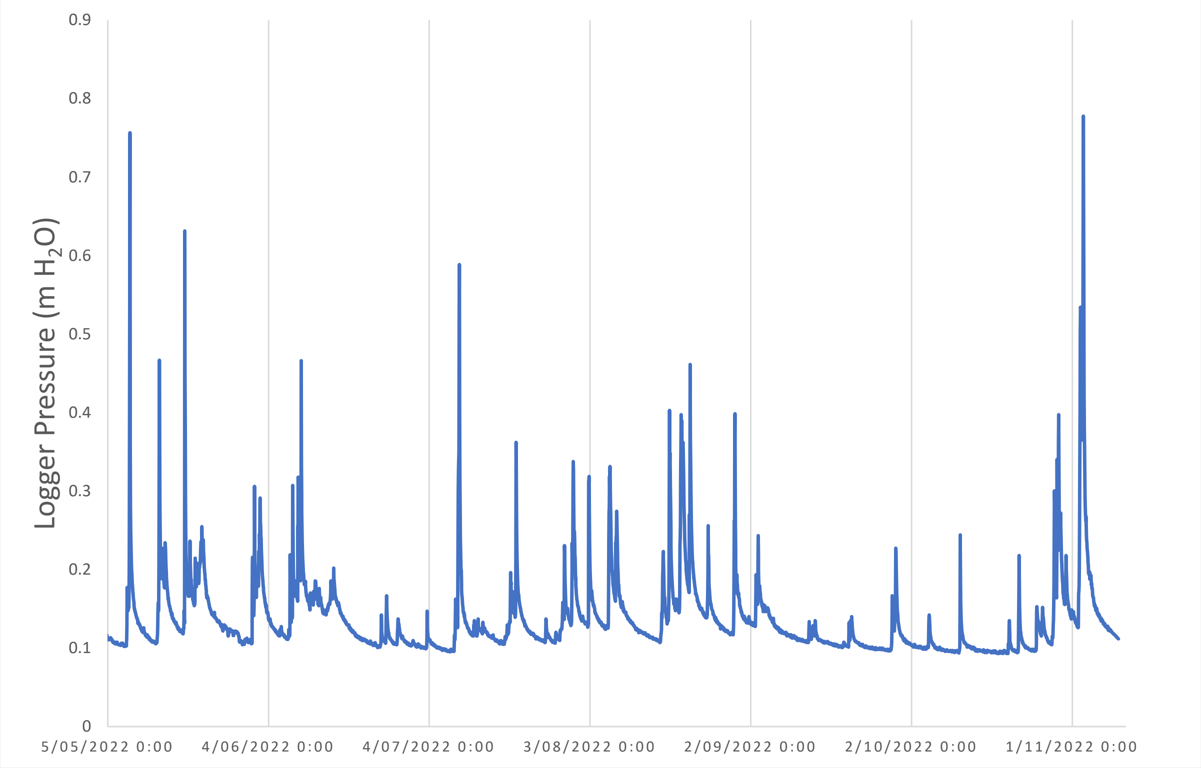


Figure 12: Logger water pressure above transducer at Upstream hydrological site from early May to November 2022

Figure 12 displays the recorded tendency of measured logger water level to rest at approximately 0.1 m (10 cm) above the transducer base. From this base, flooding during the 4 May to 8 November 2022 period could result in peak water level approaching 0.8 m (80 cm), hence a total range in level of 0.7 m. The range of creek water level from the lowest (41 L/s) and highest (111 L/s) gaugings was 0.05 m. The rating curve was used to convert the logger water pressure hydrograph to flow rate.

Figure 13 shows the measured flow rate from the logger record conversion from logger pressure to creek flow rate. Gauged flow rates determined with the Flowtracker2 are also plotted in Figure 13. In all instances, the measured spot rate falls on or close to the hydrograph modelled from the rating curve. The flow monitoring period was 190 days, and the mean and median flow rates during this time were recorded as 73 L/s and 56 L/s, respectively. These statistics are broadly in consistency with the respective 83 L/s and 47 L/s long-term statistics indicated for the same location on Collins Creek in the NZ Rivers model. The highest flow during the monitored period was 768 L/s (3 November) and lowest was 25 L/s (18 October).

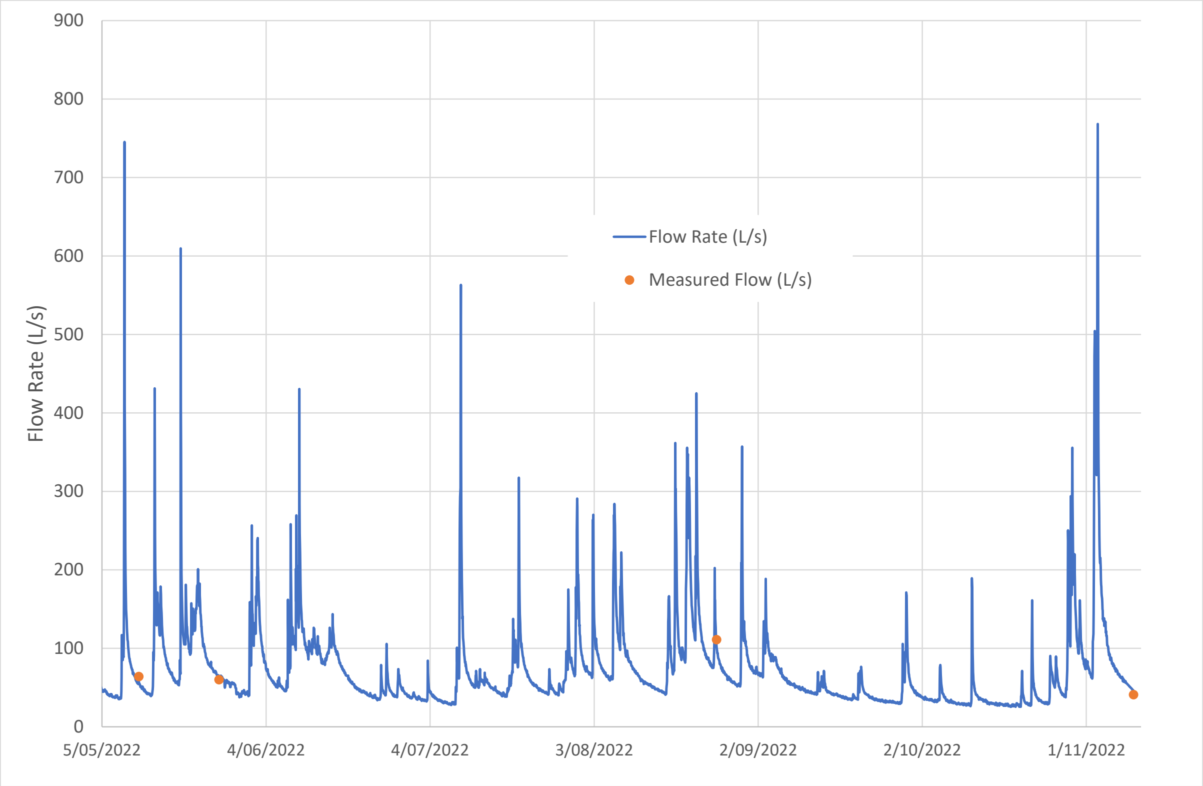


Figure 13: Measured Collins Creek flow rate from 4 May to 8 November 2022 at Upstream hydrological site at SH6

The creek hydrograph in Figure 13 is punctuated by flow peaks relating to heavy rainfalls. The only identifiable low flow period extended from early September to mid-October, and even this period of overall declining flows was interrupted by six rainfall events, albeit apparently smaller than most other rainfall events occurring outside the period.

2.5.4.2 Downstream Hydrological Site

The downstream hydrological flow site on Collins Creek coincides with the main ford across the creek. The downstream wheel ruts of the ford is armoured with coarse cobbles and provides the main natural control on creek stage measured at the staff gauge. The flow gauging site lies downstream of the confluences of small creeks with Collins Creek that rise from spring outflows on the neighbouring property. The Cowan block farmland tends to drain via internal farm drains into the coastal wetlands and the Northern Boundary Drain rather than Collins Creek. Accordingly, the flow recruitment between SH6 and the Downstream hydrological site is predominantly groundwater discharges from the springs.

Figure 14 shows the measured flow rate from the logger record conversion from logger pressure to creek flow rate. The flow monitoring period was 190 days, and the mean and median flow rates during this time was recorded as 63 L/s and 52 L/s, respectively. These statistics are broadly in consistency with the respective 94 L/s and 53 L/s long-term statistics indicated for the same location on Collins Creek in the NZ Rivers model. The highest flow during the monitored period was 900 L/s (9 May).

Conceptual modelling suggests that the middle reaches of Collins Creek, where it passes onto the Holocene elevated terraces and transgressive beach deposits with increased permeability and downward vertical groundwater gradients, has the potential for water to be lost from the creek into the ground. Figure 34 illustrates the main reaches of Collins Creek where a vertical gradient exists for loss and subsequent gain of water between creek and groundwater system.

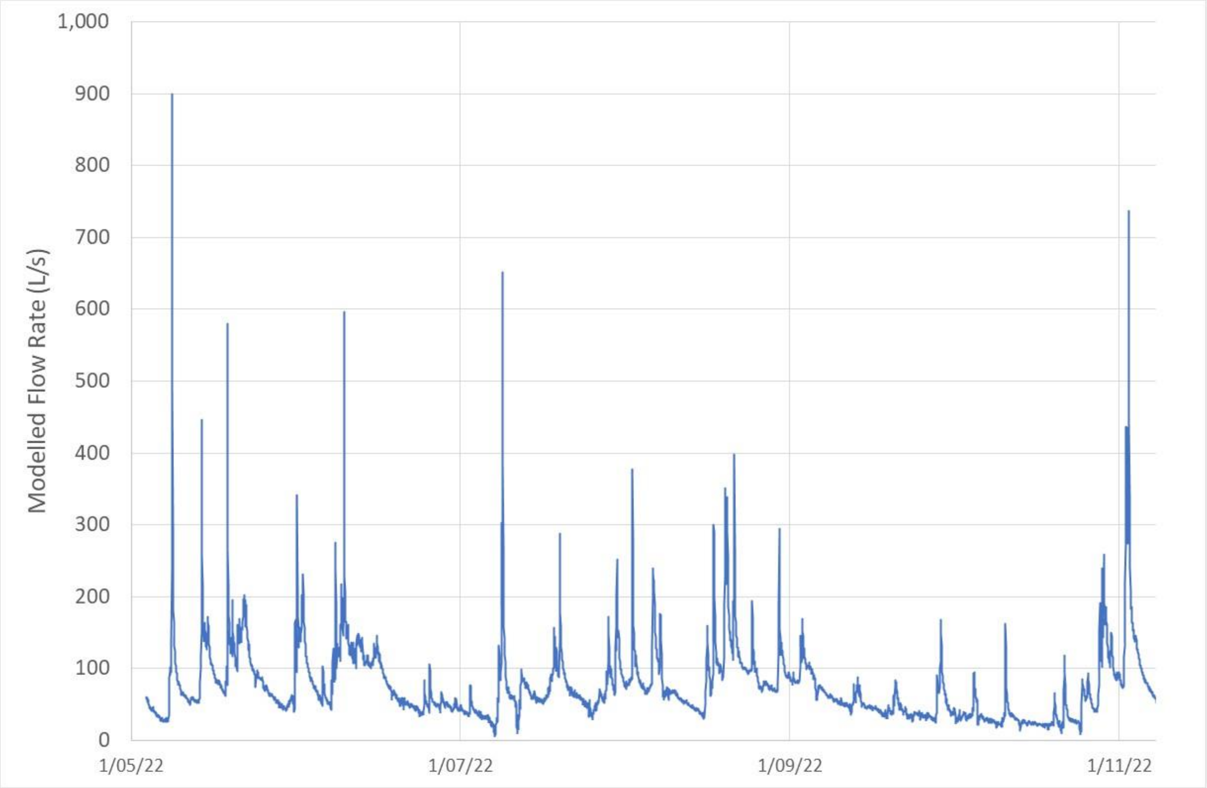


Figure 14: Measured Collins Creek flow rate from 4 May to 8 November 2022 at Downstream hydrological site at farm ford

2.5.5 Northern Boundary Drain

The Northern Boundary Drain is a constructed open drainage channel running just inside the Cowan Block north-eastern boundary from near SH6 to the upstream side of Rusty's Lagoon. Figure 2 maps the course of the drain. The upstream end is ephemeral, being essentially a water line for flood water to collect and enter the incised upstream end of the artificial drain alignment. There have been signs that storm-generated runoff from the SH6 roadway crosses the eastern property boundary and has periodically eroded a set of storm channels in the most upstream end of the drain.

A field inspection of the course of the Northern Boundary Drain in early February 2023 found that the drain was largely non-flowing until the most downstream third of its course. Some visible ponding of possible groundwater was evident in distinct pockets of the drain's upper two-thirds of its course. Figure 15 shows the slight ponding of tannin-stained water in the base of the drain, without displaying any joined-up flow in the drain. Figure 16 shows the point adjacent to piezometer PZ-10 on the Northern Boundary Drain where sustained flow, albeit minor, became visible in the longitudinal inspection on 7 February 2023 (see Figure 17 for locations of photographs). An inspection in late winter on 24 August 2022 noted the Northern Boundary Drain sustained flow from piezometer PZ-13, downstream. It was observed that runoff from the remnant Kahikatea forest on the north side of the property boundary was the main source of surface flow.

These observations are largely consistent with the overlay of piezometer-derived groundwater level profile and the LiDAR-derived drain invert level profile. This longitudinal overlay of hydraulic gradients, displayed in Figure 35, showed that the groundwater level did not rise above the bed of the drain upstream of the point at which sustained flow was noted. The most reasonable conclusion is that the Northern Boundary Drain conducts flood waters following heavy rain in the upper catchment, forest runoff during extended wet periods in the middle reaches, and only groundwater seepage in the lower reaches during summer periods. No further hydrological assessments were undertaken on the Northern Boundary Drain.

Figure 15: Photograph of the Northern Boundary drain in the middle reaches on 7/02/2023

Figure 16: Photograph of a gathering trickle of water near piezometer PZ-10 on 7/02/2023

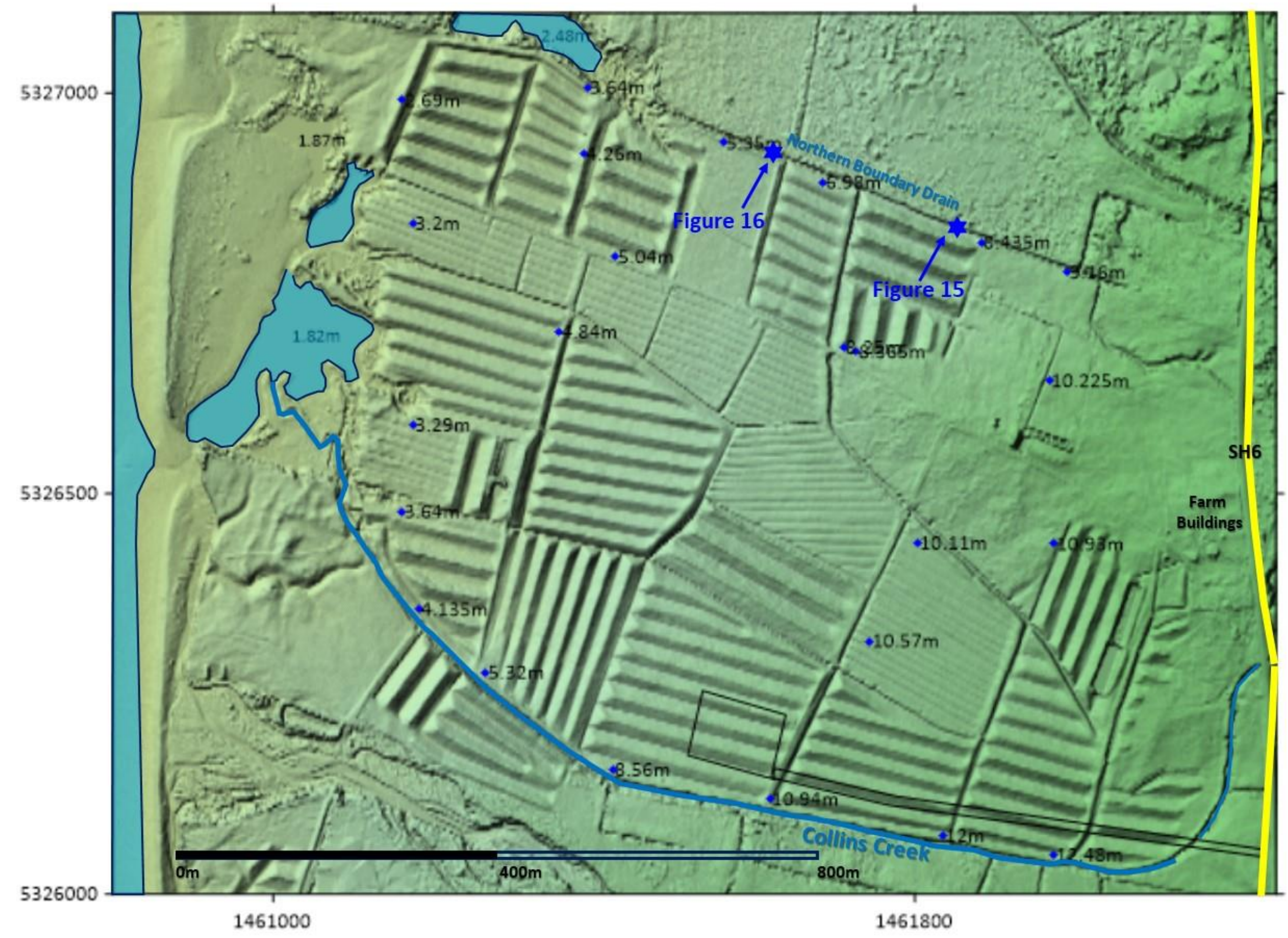


Figure 17: Location of photographs taken on 7/02/2023 along the Northern Boundary Drain

2.6 Groundwater Hydrology

2.6.1 Previous Studies

The Rekker (2020) analysis of groundwater information drew on existing data and reports, particularly:

- Coffey Partners (1991) and
- Vidanovich (2008)

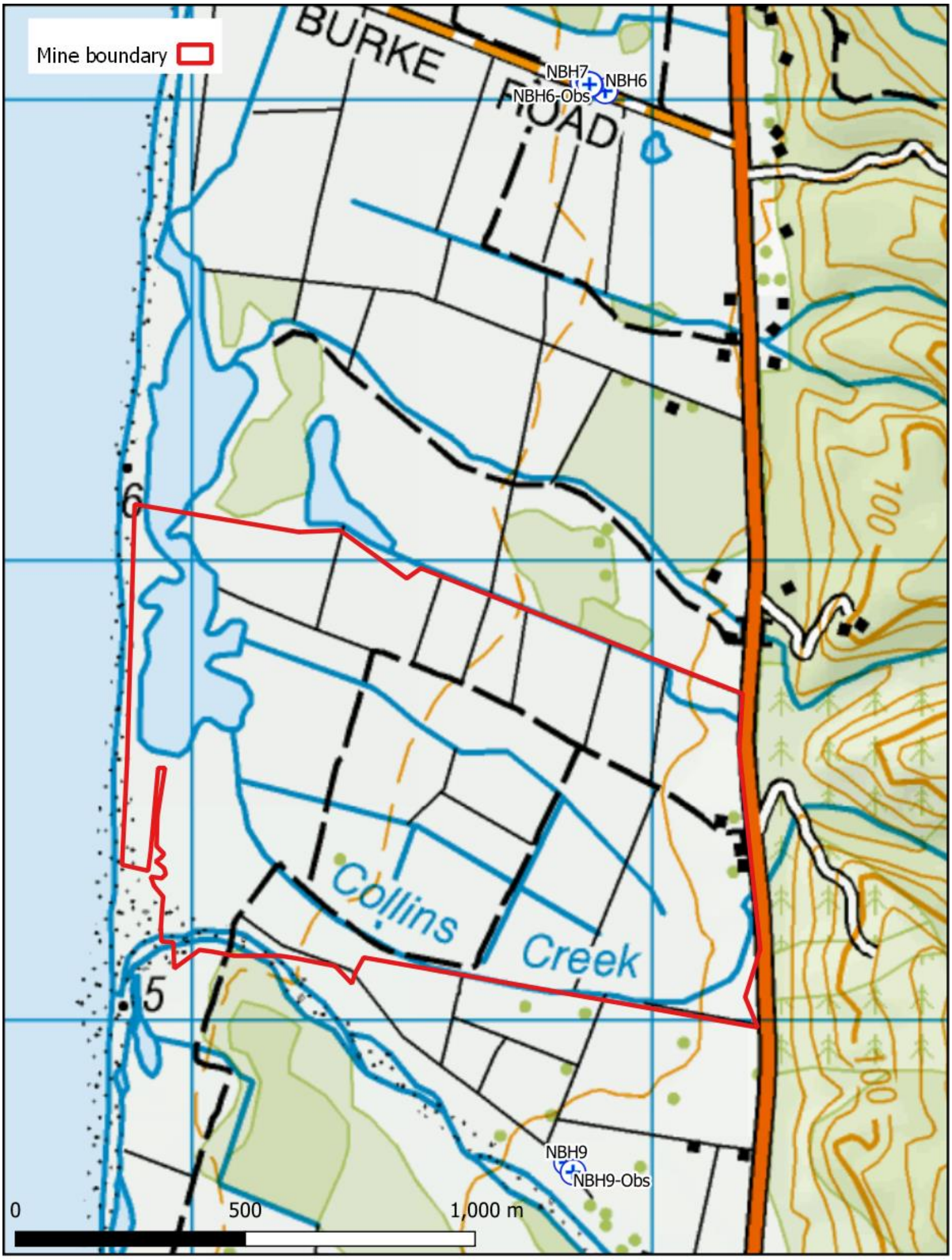
The Coffey Partners (1991) report and appendices reported the installation of ten pumping test bores with paired observation bores at distances averaging 16.5 m apart. Test bores NBH6 to NBH9 were installed adjacent Burke Road (see Table 8 and Figure 15 for details and locations) and are therefore highlighted in the table below. The drilling investigations at Burke Road and Canoe Creek included eight bores of different depths, primarily bracketing 'shallow'(not far below the water table) and 'deep'(towards the base of the saturated coastal sediments).

Bores NBH6 and NBH7 were adjacent to each other as shallow and deep screened bores within the portion of the Holocene mineral sands termed 'elevated terraces'. By locating NBH6 and NBH7 adjacent to each other but at different depths it is possible to examine contrasts in static water level and groundwater hydraulic properties. Each of the test bores from NBH6 to NBH9 displayed in Figure 18 were test pumped at rates ranging between 0.2 and 2.3 L/s for durations ranging between 1 hour and 3¼ hours to determine aquifer properties using standard pumping test analysis methodologies such as the Theis Recovery Method or Boulton Method. Coffey Partners also conducted 43 separate pneumatic slug tests on each available piezometer. These tests included eight pneumatic slug tests conducted on deep bores placed towards the base of the mineral sands and alluvial fans. The slug testing included 15 piezometers located adjacent to the proposed mining area. Pneumatic slug tests were also conducted in each of the pumping test observation bores (marked ending in 'Obs' in Figure 18) to allow comparison of the results in pumping tests and pneumatic slug tests. If the two methods were equivalent, it was more likely results would coincide.

Table 8: Coffey Partners (1991) Groundwater Investigation bores along Burke Road and Canoe Creek

Bore #	NZTM_E	NZTM_N	Total Depth (m)	RL Collar (M AMSL)	SWL (m TOC)	SWL (m AMSL)
NBH6	1461897	5328021	8.5	8.92	2.83	6.09
NBH6-Obs	1461865	5328034	9.34	8.61	2.97	5.64
NBH7	1461849	5328040	24.7	8.43	3.27	5.16
NBH7-Obs	1461863	5328034	26.95	8.62	3.02	5.6
NBH8	1461053	5328353	9.5	4.06	1.74	2.32
NBH8-Obs	1461053	5328331	9.3	4.57	2.56	2.01
NBH9	1461813	5325690	28.8	20.61	4.9	15.71
NBH9-Obs	1461827	5325669	31	20.62	4.75	15.87

Note: NBH# = New Bore Hole (Number) for pumping and observation bores; Bore NBH1 was not tested by pumping test; Obs = observation bore; NZTM = New Zealand Transverse Mercator (Easting / Northing); RL = Reference Level, essentially reference elevation; AMSL = Above Mean Sea Level; SWL = Static Water Level measured two days apart on 30 August and 1 September 1990; and blue shading indicates adjacent to proposed mining area.



KSL Kōmanawa Solutions Ltd	Project name:	Barrytown JV Mineral Sands Extraction
	Date:	Date: 3/12/2020
	Title	Piezometer and well locations

Figure 18: Location of Coffey Partners' nearby test and observation bores adjacent Burke Road and Canoe Creek

Coffey Partners' drilling programme installed logged boreholes along two East – West section lines north and south of the proposed mining area (see Figure 19). The section line to the north crossed the wetland area called

Maher Swamp, including elevated terraces and transgressive beach deposits. The southern section line crossed the lower Canoe Creek course, including the large creek alluvial fan and transgressive beach deposits. Essentially, Coffey Partners included dense collection of hydrogeological data in the form of bore logs, pumping tests, pneumatic slug tests and corrected water level measurements.

Figure 19: Location of pneumatic testing piezometers adjacent to proposed mining area

2.6.2 Aquifer Properties Determined in 1989

2.6.2.1 Pumping tests

Coffey Partners (1991) undertook three aquifer tests in the vicinity of the Cowan Block, then conducted graphical (i.e. graph paper) semi-logarithmic fitting of data to type curves, which was the standard practice in the early 1990s. Residual drawdown from the recovery phase of the test was fitted to the Theis type curve and the resulting transmissivity or storage coefficient is also recorded in the Recovery column of Table 9.

Table 9: Interpreted pumping test results for five Barrytown Flats test bores along Burke Road and Canoe Creek

Bore #	Duration (min)	Rate (m^3/d)	T (m^2/d)		K (m/d)			
			Dd	R	Dd	R	S_y	Formation Code (A-D)
NBH6-Obs	-------------	---------	325	680	16.3	34.5	_	B
NBH7	150	206	7.1 – 6.3	62.8	0.2 - 0.3	2.1	_	B (Deep)
NBH7-Obs	-------------	---------	_	337	_	11.2	_	B (Deep)
NBH8	120	1.5	_	1.5	_	0.08	_	A
NBH8-Obs	-------------	---------	_	29	_	1.5	_	A

Note: T = transmissivity, K = hydraulic conductivity, S_y = specific yield, Dd = drawdown test, R = recovery test, NBH# = New Bore Hole (Number) for pumping and observation bores; Obs = observation bore; (Deep) in the Formation Code indicates bore screen was not shallow and was set at depth near base of deposit; Specific yield values reported in instances where late curve fits were feasible; and blue shading indicates within or immediately adjacent to proposed mining area. Formation Codes: A = Transgressive Beach Deposit; B = Elevated Terrace.

2.6.2.2 Pneumatic Slug Tests

Forty-three pneumatic slug tests in total were conducted on piezometers or observation bores with nominal casing diameters between 32 mm and 50 mm. Nineteen tests were conducted along the two closest transects to the Cowan Block. The method of testing involved using a bore-head assembly to seal the bore into a pressure manifold with pressure gauge and pressure transducer – data logger suspended below the bore water level. The results of the above methodology and interpretation using the Hvorslev (1951) for the nineteen slug test analyses are listed in Table 10, which focuses on the piezometers closest to the proposed mining area.

Table 10: Summary of pneumatic slug test results closest to proposed sand extraction area

Piezometer / Obs. Bore No.	Depth (m BGL)	Diameter (mm)	SWL (m ToC)	Basic Time Lag t_o(seconds)	K (m/d)	Strata Code
VA_2600	9.6	32	1.43	5.57	0.5	A
VA_3000	9.7	32	0.55	8.59	0.9	A
VA_4100S	9.7	32	0.99	13.95	1.0	C
VA_4100D	18.7	32	1.52	13.55	1.3	C
VA_4900	6.5	32	2.86	16.88	4.5	C
VA_5700D	30.9	50	6.72	17.5	2.6	C
VA_5700S	9.7	32	6.05	18.31	1.1	C
VA_6600	15.6	32	6.55	21.07	1.2	C
WS_3200D	30.5	32	1.71	2.85	2.0	A
WS_3200S	9.6	50	0.9	3.16	2.2	F
WS_5000	8.95	50	1.65	4.93	7.0	B
WS_5500	9.3	50	2.19	5.16	3.1	B
WS_6000	6.6	32	2.11	7.69	2.3	B

Piezometer / Obs. Bore No.	Depth (m BGL)	Diameter (mm)	SWL (m ToC)	Basic Time Lag t_o(seconds)	K (m/d)	Strata Code
WS_6300D	16.7	32	7.6	5.38	4.2	B
WS_6300S	6.65	32	2.91	10.04	1.1	B
NBH6-Obs	9.34	50	2.97	5.64	2.5	B
NBH7-Obs	26.95	50	3.02	5.6	2.4	B
NBH8-Obs	9.3	50	2.56	2.01	0.2	A
NBH9-Obs	31	50	4.75	15.87	7.0	C

Note: SWL = Static Water Level measured two days apart on 30 August and 1 September 1990 and in terms of depth to water from Top of Casing (ToC); refer to notes of Table 9 for Formation or Strata codes. A = Transgressive Beach Deposit; B = Elevated Terrace; C = Alluvial Fan; D = Previously Mined; and F = Recent Foredune.

A comparison of pumping test and pneumatic slug test results is possible by contrasting the pumping test observation bore results for both testing systems. Table 11 provides a comparison of ranges of hydraulic conductivity results within the separate drawdown and recovery phase-interpreted results, plus the singular slug test results. Coffey Partners (1991) also aggregated aquifer and slug test data to advance a single value of horizontal hydraulic conductivity in

Table 12.

Table 11: Comparison of pumping test and pneumatic slug test results (all Barrytown results)

Pumping Test Hydraulic Conductivity (m/d)			Slug Test Hydraulic Conductivity (m/d)	
Bore #	**Drawdown Phase**	**Recovery Phase**		**Strata Code**
NBH2-Obs	9	12.3	4.1	B
NBH3-Obs	0.7 – 0.8	4.9	0.9	B (Deep)
NBH4-Obs	2.6	7.1	8.8	A
NBH6-Obs	16.3	34.5	2.5	B
NBH7-Obs	–	2.1 - 11.2	2.4	B (Deep)
NBH8-Obs	–	1.5	0.2	A
NBH9-Obs	–	1.9 – 2.4	7	C (Deep)
NBH10-Obs	–	8.1 – 9.3	3	D

Note: NBH# = New Bore Hole (Number) for pumping and observation bores; Obs = observation bore; Strata or formation codes noted in Table 9; and green shading indicates within or immediately adjacent to proposed mining area.

Table 12: Interpretative assignment of hydraulic conductivities per formation/strata[4]

Code	Formation / Strata	Hydraulic Conductivity (m/d)	Testing Bore & Comments
A	Transgressive Beach	3	Relatively consistent results (1.5 – 7.1 m/d) throughout the transgressive beach deposits approximating 3 m/d.
B	Elevated Terrace	14	The mean of results was 16.4 m/d for shallow and 7.4 m/d for deep screened bores. The value of 14 m/d is a synthesis assuming that most flow occurs at shallow depths.
C	Alluvial Fan	3	Alluvial deposits are highly variable. A value of 3 m/d is consistent with the result for the Canoe Creek alluvial fan measured in test bore NBH9. Clay fraction and poorly sorting most likely limit on permeability.
D	Previously Mined	9	Based on a single set of results from NBH10 near Barrytown settlement. More emphasis on the pumping test results (8.1 – 9.3 m/d).
F	Recent Foredune	6	Based on slug test results in piezometers CAR1 and WS3200S. Nominated value reflects range of mean and median values.

The above formation or deposit singular hydraulic conductivities are interpretive and consider the wider Barrytown coastal flats' post-glacial to Holocene deposits.

2.6.3 Water Table and Surrounding Water Levels

2.6.3.1 Horizontal Water Level Patterns

The Coffey Partners (1991) piezometer and test bore programme allowed the snap-shot and periodic measurement of groundwater levels within installed bores. On the whole, the contouring showed water table contours arranged sub-parallel to the coastline, with finer scale influences from wetlands and creeks on the coastal flats. However, the wide spacing of the transects used in the water table contour map covering the entirety of the Barrytown coastal flats, including that none of the transection fell within the Cowan Block diminishes the relevance of derived lateral water level patterns.

2.6.3.2 Vertical Water Level Patterns

As mentioned previously, several paired shallow and deep piezometers or bores were installed within the Westland Ilmenite hydrology programme. This positioning allowed the estimation of vertical head difference and calculation of vertical hydraulic gradients.

Table 13 lists the paired piezometers and observation bores, some of which were aligned along cross-section lines north and south of the proposed mining area. The lowest difference in water level was 0 m or negligible in piezometers YK6000, and largest level difference was 4.66 m for piezometer WS6300 indicating a negative vertical gradient of -0.463 metre per metre (m/m), i.e. strongly downwards. No positive (upward) vertical hydraulic gradients were observed, although the mildly flowing artesian pressure at NBH10 would suggest that upward gradients could exist in the Barrytown settlement area.

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[4] Taken from Coffey Partners (1991)

Table 13: Summary of calculated vertical hydraulic gradients between paired shallow and deep piezometers or bores

Piezo or NBH No.	Easting	Northing	Depth (m BGL)	SWL (m_AMSL)	Strata Code	Vertical Difference£ (m)	Vertical Gradient (m/m)
YK_4300S	1461534	5332293	10.1	2.04	F		
YK_4300D	1461546	5332287	27	1.96	A	-0.08	-0.0047
YK_6000S	1462081	5332236	9.05	3.09	B		
YK_6000D	1462082	5332239	19.8	3.09	B	0	0
VA_4100S*	1461441	5325585	9.7	13.95	C		
VA_4100D*	1461444	5325585	18.7	13.55	C	-0.40	-0.044
VA_5700S*	1461910	5325562	9.7	18.31	C		
VA_5700D*	1461907	5325566	30.9	17.5	C	-0.81	-0.038
WS_3200S¥	1461197	5328929	9.6	3.16	F		
WS_3200D¥	1461186	5328931	30.5	2.85	A	-0.31	-0.029
NBH6-Obs¥	1461865	5328034	9.34	5.64	B		
NBH7-Obs¥	1461863	5328034	26.95	5.6	B	-0.04	-0.0023
WS_6300S¥	1462144	5328960	6.65	10.04	B		
WS_6300D¥	1462144	5328964	16.7	5.38	B	-4.66	-0.463

Note: * Along cross-section 713550 south of Canoe Creek; ¥ Along cross-section 716900 north of Burke Road; £ Positive (+) difference equals upward, Negative (-) difference equals downward. Strata Codes: A = Transgressive Beach Deposit, B = Elevated Terrace, C = Alluvial Fan, F = Recent Foredune

The predominance of downward vertical gradients potentially indicates a pattern of shallow groundwater being recharged by soil drainage (i.e. land surface recharge) and surface water infiltration coupled with outflow of the post-glacial / Holocene aquifer's water at depth along the coastal boundary in the west. Such patterns of inflow and outflow alongside observed vertical gradients are common among unconfined coastal aquifers in moderate to high rainfall regions. Elsewhere, upward vertical groundwater gradients in a coastal setting are more commonly associated with low permeability layers such pervasive silt, clay or peat beds between the shallow and deeper parts of the groundwater system. The balance of evidence would suggest that the vertical level differences measured in the Barrytown Flats area are the result of boundary effects and mild vertical stratification of an otherwise unconfined, stratified aquifer between water table and silty sandstone basement.

2.6.4 Recent Groundwater Investigations

2022 groundwater investigations have included the following –

- 26 piezometers for manual dipping and levelling,
- 6 continuous level loggers in selected piezometers,
- 18 groundwater samples taken for analysis in two campaigns (May and November), and
- One multi-observation bore pumping aquifer test (PB-1), and
- Slug testing of lower permeability sediments.

2.6.4.1 Piezometers

Perimeter Piezometers

Nineteen (19) perimeter piezometers were installed to depths between 9 and 12 m below ground level, which coincides with the depth limit of the economic mineral sand excavation. The eastern extent of the perimeter was also set at the NZ Transverse Mercator easting of 1,462,000 m, while the more likely eastern limit of sand extraction would be 1,461,700 m, approximately 300 m further west. Other perimeter bores were placed so that they were less likely to be affected by proposed sand extraction and they can therefore have a long-term role in measuring the baseline groundwater level or groundwater quality, followed by operational groundwater conditions during sand extraction, and ultimately the recovery of groundwater conditions back to post-extraction state following the completion of sand extraction with rehabilitation. The perimeter piezometers have a nominal diameter of 32 mm with a consistent screen length of 3 m.

Internal TAC Piezometers

Seven (7) piezometers were placed opportunistically during mineral sand resource drilling. The locations of the seven TAC piezometers were selected to provide indications of groundwater levels within the proposed sand extraction area, and also to provide groundwater level indications along the 1,461,700 m easting line, The hole labelling used the "TAC" prefix and the TAC numbering carried over the associated TAC number. The piezometer diameter this time was 15 mm, precluded the ability to install continuous level loggers or groundwater sampling.

Aquifer Test Observation Bores

At the PB-1 testing site, three bores were left in place following testing –

- 150 mm diameter steel cased bore PB-1 that was used to pump up to 4.5 L/s of groundwater,
- 50 m diameter PVC observation bore TB-1 with a depth of 10.5 m BGL, and
- 50 m diameter PVC observation bore TB-2 with a depth of 4.6 m BGL.

The pre-existing TAC-157 piezometer also at the aquifer test site was also used in response observation and left in place following testing.

Figure 20 maps the perimeter and TAC piezometers installed in late autumn and winter (April – June) of 2022.

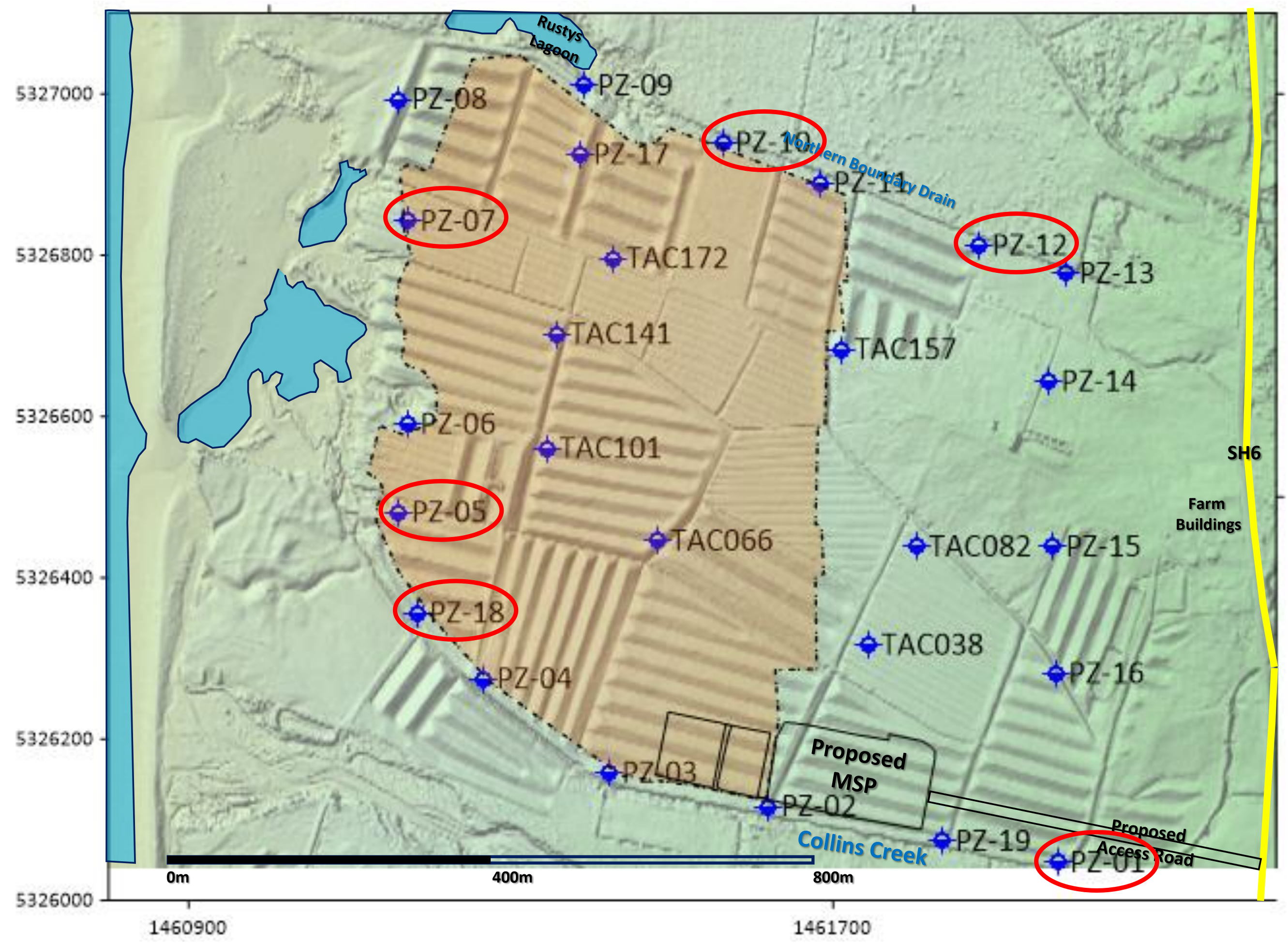

Figure 20: Location of perimeter (PZ-#) and internal (TAC-#) piezometers (continuous level loggers marked in red ellipse)

2.6.4.2 Groundwater Level Continuous Monitoring in 2022

The location of six level loggers placed in perimeter piezometers on 4 May 2022 are shown in Figure 20 and marked by a red ellipse around the piezometer number. The approximate placement rationale for the six level loggers in characterising baseline conditions can be approximated as follows –

- PZ-05 and PZ-07 for proximity to coastal lagoons and coastline,
- PZ-10 and PZ-12 for proximity to Northern Boundary Drain and Kahikitea wetlands,
- PZ-18 for proximity to Collins Creek, and
- PZ-01 for proximity to Collins Creek and Langridge springs.

The influences on groundwater level fluctuation were thought to be as follow –

- Creek flow/level fluctuations in Collins Creek and Northern Boundary Drain (rainfall influenced),
- Soil drainage through pasture and the fluctuations due to the balance of rainfall and evapotranspiration (also rainfall influenced),
- Coastal lagoon water level fluctuations,
- Tasman Sea tidal and ocean surge fluctuations, and
- Atmospheric / barometric pressure fluctuations.

Not all the sources of influences on groundwater fluctuation would be independent, such as creek flow/level and soil drainage that would be initiated by the same increase in rainfall intensity. Higher intensity rainfall events are also often associated with low pressure systems.

Figure 21 shows a series of groundwater hydrographs in terms of groundwater elevation at all six sites.

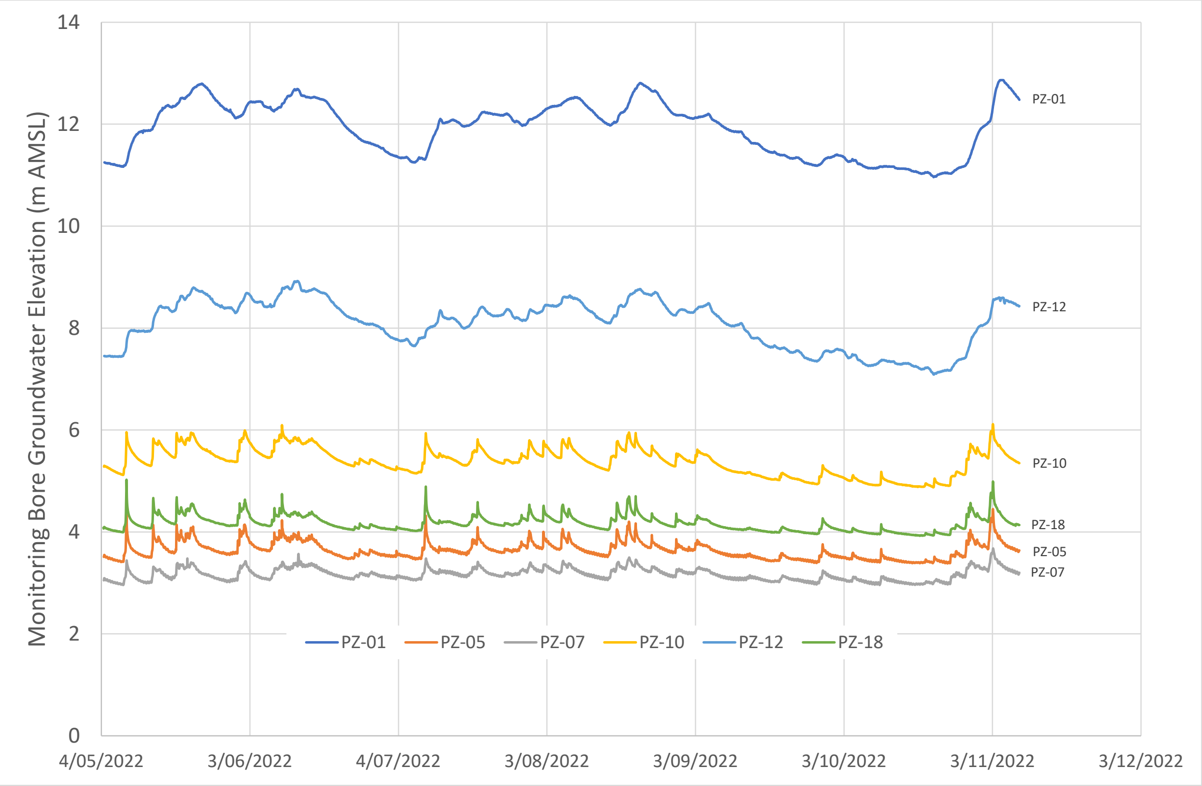

Figure 21: Composite groundwater elevation plot of six continuous level hydrographs in the Cowan Block

Conveniently by using the elevations reference, Figure 21 displays a tiered presentation of the associated hydrographs without any one obscuring the adjoining hydrographs. The tiering is due to the overall groundwater hydraulic gradient from east-south-east to west-north-west and the tendency of the lower-lying monitoring piezometers to fluctuate under the same set of influences.

- PZ-01 and PZ-12 can be grouped as fluctuating distinctly from the lower piezometers,
- PZ-10 is transitional in its pattern of level fluctuation, and
- PZ-18, PZ-05 and PZ-07 share a very similar pattern of fluctuation.

Indeed, the higher level piezometers (PZ -01 and -12) appear to respond wholly to rainfall or barometric stimuli. The shape of the hydrographs in this group are softer and less sharply punctuated by arcuate rises and falls in the hydrograph that are a feature of the lower group (e.g. PZ -18, -05 and -07). Figure 22 implies that groundwater and creek water levels can be correlated between creek or flow.

As correlation is not the same as indicating a definitive cause of the apparent response, the groundwater levels may be influenced by events of higher rainfall that in turn increases creek flow and the drainage of excess moisture through the soil profile to the water table. Indeed, the higher magnitude of groundwater level change in the order of 1.5 m are substantially higher than the largest creek level increases of 0.7 m. Soil drainage related groundwater recharge in response to saturated soils would be likely to correlate temporally with high creek flow and would produce a water table rise related to the specific yield of the groundwater system. For instance, where a singular slug of recharge in the order of say 100 mm accumulates at the water table, the initial rise in groundwater level under a 0.35 specific yield would approximately 0.3 m of increase to peak. The accumulation of several such pulses of recharge in a short period, faster than could be shed in discharge, could result in water table increases of the magnitude recorded in 2022.

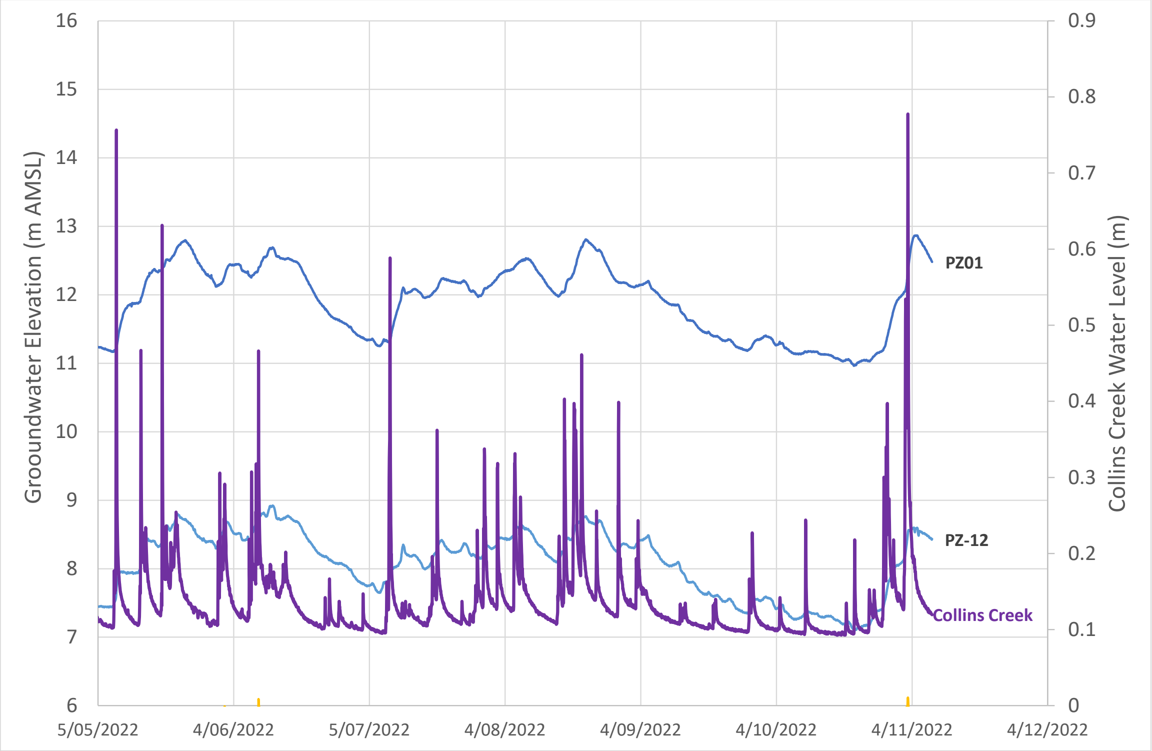

Figure 22: Groundwater elevation of PZ-12 and PZ-01 plotted against Collins Creek water level on a secondary axis

The groundwater accruing at higher level can be expected to flow down-gradient to the lower level part of the Cowan Block on the way to the coastal lagoon where it discharges. Fluctuations of lower groundwater level magnitude close to the coastal lagoons would be more visibly influenced by creek level fluctuations, as indicated in Figure 23.

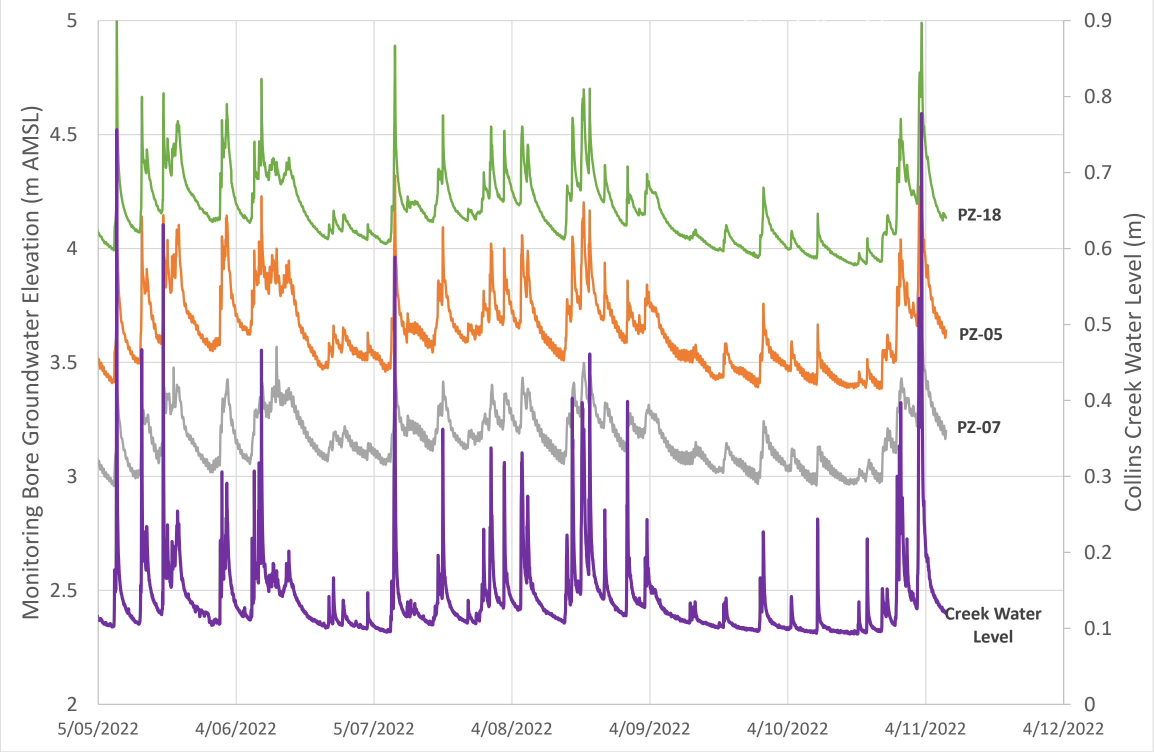

Figure 23: Groundwater Elevation of PZ -05, -07 and -18 plotted against Collins Creek water level on a secondary axis

Collins Creek flow rate had a relatively quiet period in the first three weeks of September 2022, as discernible in Figure 23. A blow-up of the hydrographs of PZ-05 and PZ-07 that are located adjacent to the coastal lagoons displays indications of a tidal influence in the period 8 to 13 September overlain on an ambient groundwater decline. This pattern is shown in Figure 24, including a trend line representing the average of the groundwater level delineating the ambient trend.

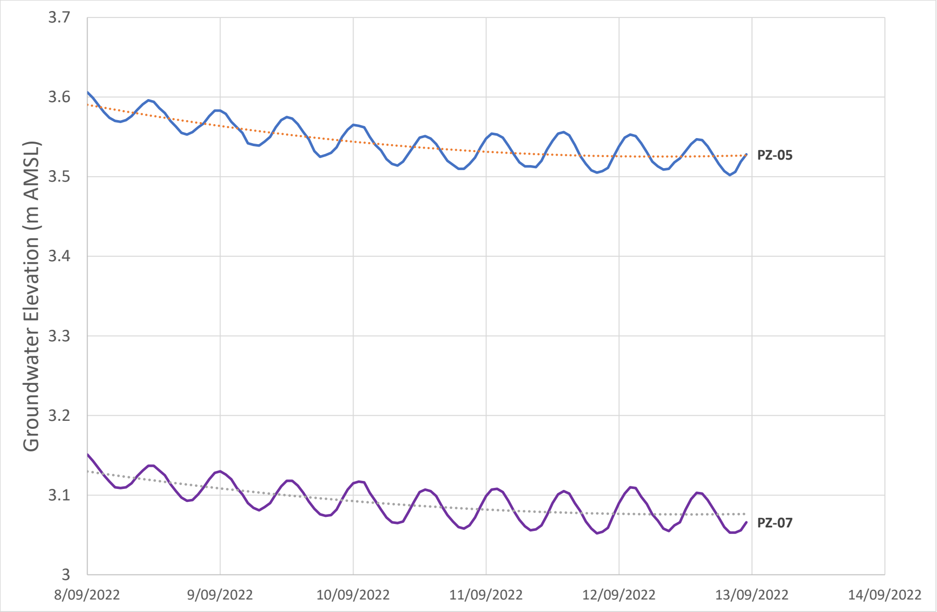

Figure 24: PZ-05 and PZ-07 groundwater between 8 and 13 September 2022 showing tidal signature

It is feasible to model and subtract the longer term ambient trend and thereby plot the groundwater tidal fluctuation alongside the groundwater influence. The National Institute of Water & Atmosphere (NIWA) provides a database of tidal time series for any point on the New Zealand coastline. Specifying the coastline at the Cowan Block, plus the date range (8 to 13 September) and temporal resolution (hourly) allows tidal hydrographs to be generated.

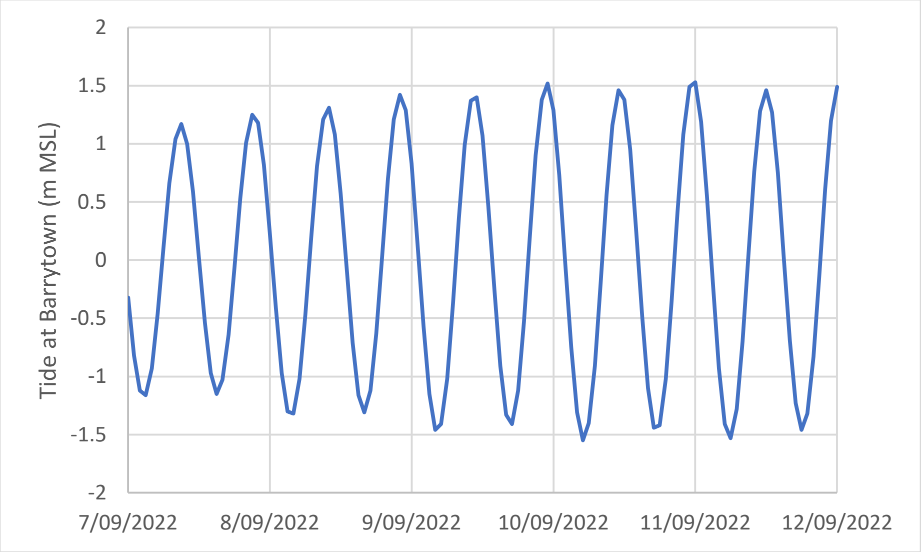

Figure 25: Tide at Barrytown from NIWA Tide Forecasts (tides.niwa.co.nz)

The tide and filtered groundwater levels for the coincident period are plotted on dual axes in Figure 26. The plot shows that the groundwater fluctuation lags the sea tide by approximately 1 hour and tidal efficiency (TE) is as little as 1.75%.

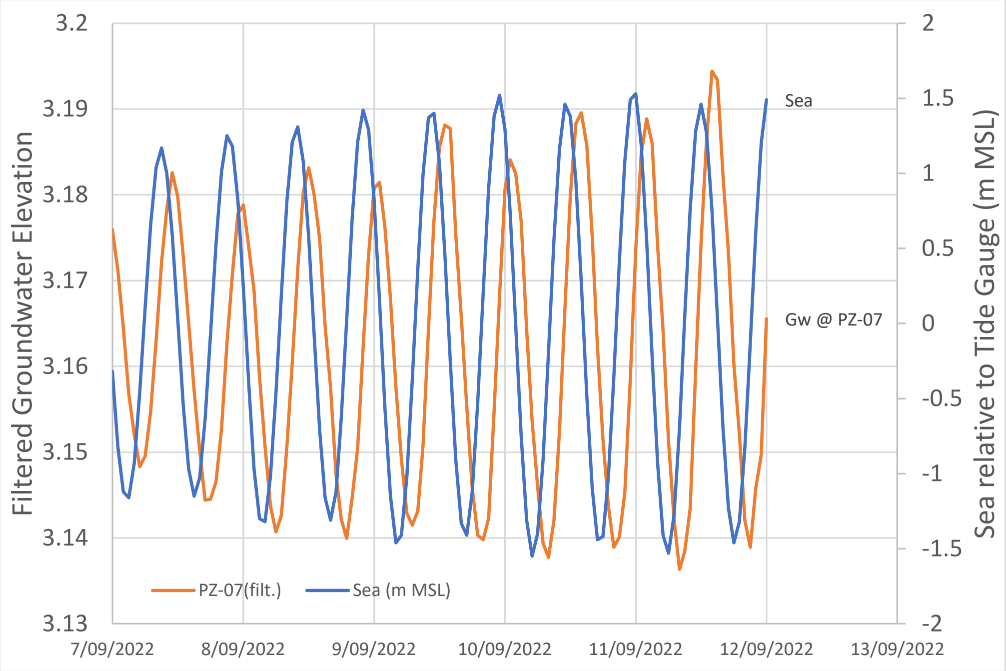

Figure 26: Dual axis hydrographs of the sea at Barrytown and PZ-07 filtered to remove the ambient trend

There is uncertainty whether the coastal lagoons have a tidal fluctuation pattern or whether the lagoons are effectively static, and the tidal signature is transmitted through the groundwater system directly from the Tasman Sea coastline. Either way the effect of tide on the groundwater system is minor and does not tangibly extend any further than 300 m from the landward edge of the coastal lagoons.

2.6.5 *Recent Aquifer Testing*

2.6.5.1 *Outline Methodology*

A multiple observation bore aquifer test was conducted inside the Cowan Block at the “PB-1” site marked in Figure 3. The test site with pumped bore PB-1 encountered mixed sands and sandy gravels plus a shallow gravel overburden layer. PB-1 was developed with compressed air surging over 10 hours and two further observations bores were installed at different distances and depths. The PB-1 site also had a flowing farm drain at 33 m distance NW from the pumped bore. The test site configuration can be summarised as follows -

- TAC-157 was already present prior to installing PB-1,
- TB-1 was drilled and installed to 11.2 m BGL, it lay 5 m to the southeast,
- TB-2 was drilled and installed to a depth of 6 m BGL, it lay 9 m to the east, and
- PB-1 was drilled and installed to a depth of 11.3 m BGL, the casing diameter was 0.15 m (150 mm).

The TB-1 and 2 observation bores were 50 mm diameter with a 1.0 m long section of slotting at each base. The pumped bore, PB-1 was constructed by telescoping the 150 mm diameter casing to expose a 1.2 m long section of 2 mm slot stainless steel screen with 125 mm diameter. The location plan is provided in Figure 27, while the depth related configuration is shown in Figure 28 as a cross-section from NW to SE through most of the bores used in the aquifer testing.

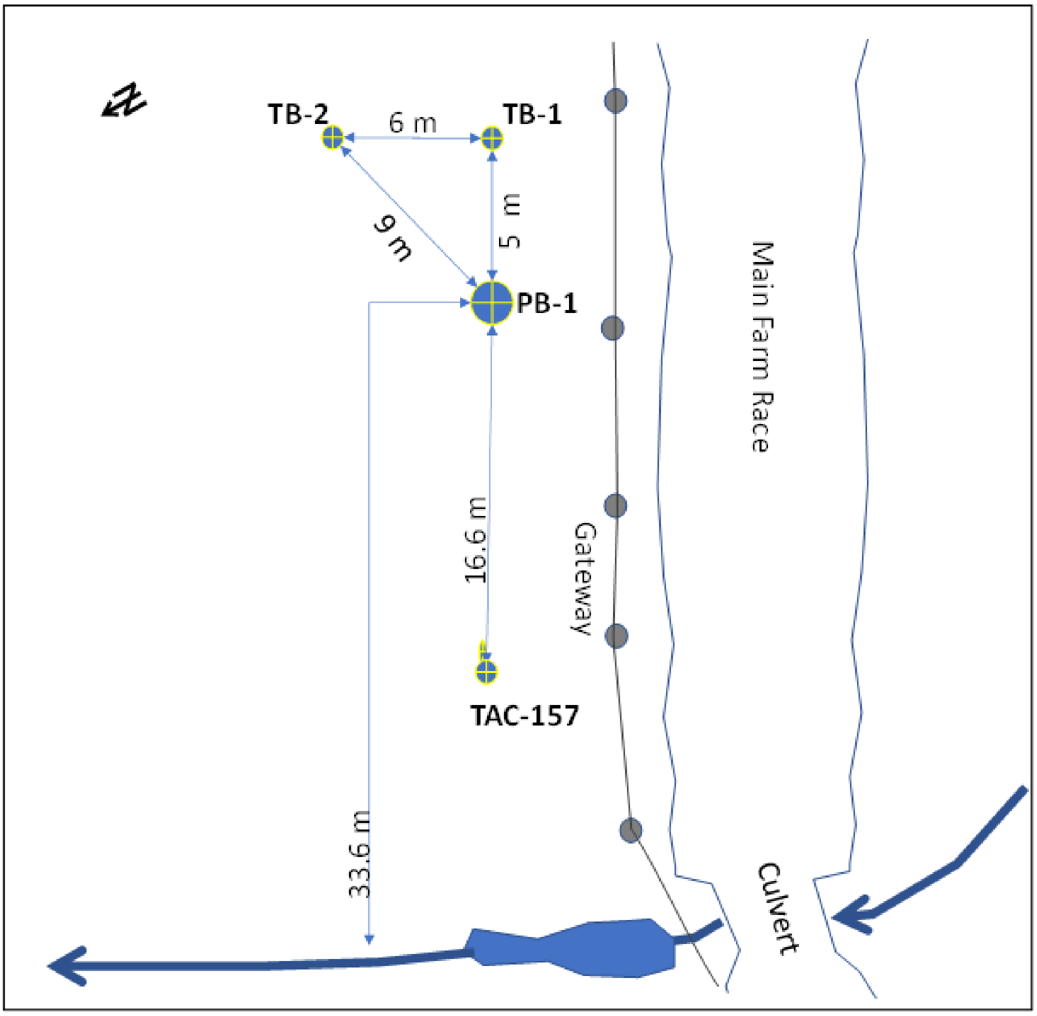

Figure 27: Schematic PB-1 site layout plan showing location of pumped bore, observation bores and farm creek

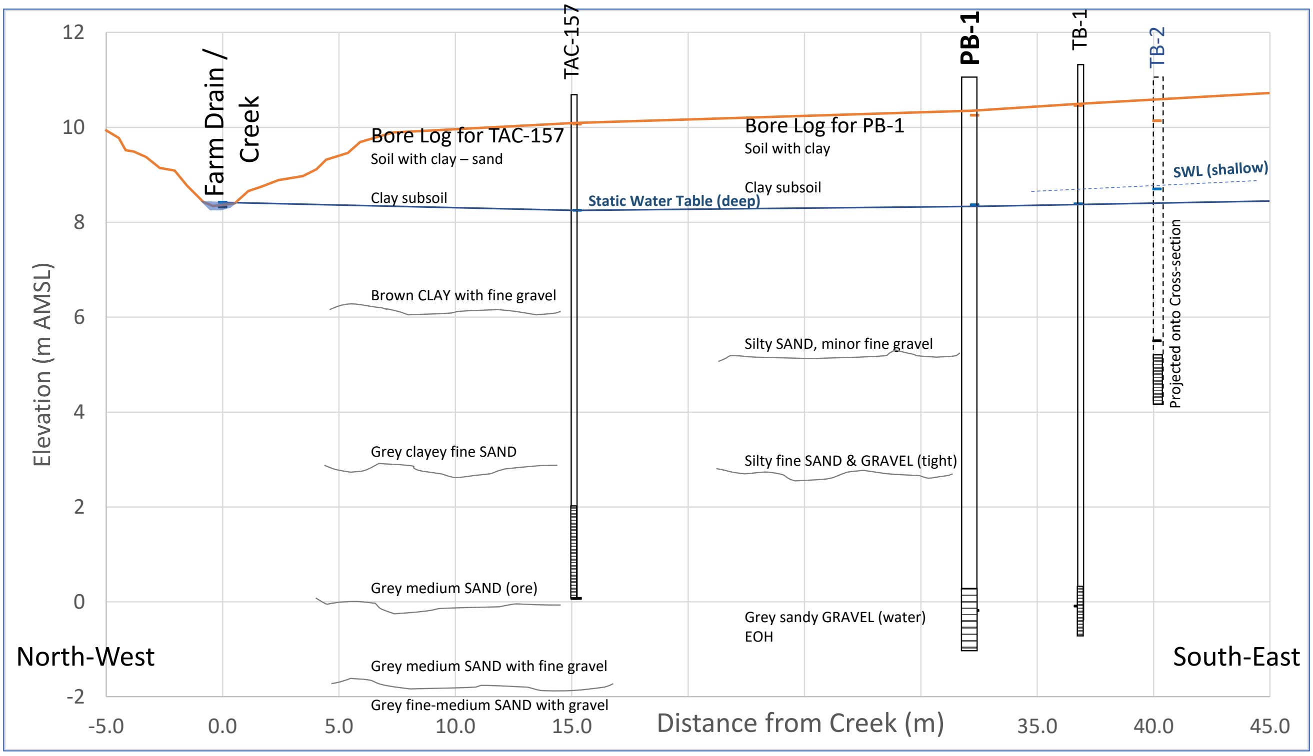

Figure 28: Composite cross-section of PB-1 test site showing depths of bores, static water tables and two bore logs

A degree of hydrogeological stratification was noted in drilling the test site. A gravelly shallow water-bearing layer from 8.8 m to approximately 5.0 m AMSL with a perched water level was noted and separated shallow monitoring bore (TB-2) from the deeper installations. This is interpretated as being a western-most lobe of the Eastern Gravel Overburden or Canoe Creek alluvial fan deposits present across the Cowan Block and overlying the main coastal mineral sands deposits. The aquifer test was an opportunity to observe the interaction between the shallow alluvium and underlying coastal deposits. The testing at site PB-1 used the step rate (drawdown) test (SRT) and constant rate test (CRT) at pump rates between 2.1 L/s and 4.5 L/s. The six and a half (6½) hour constant rate test was run at 4.0 L/s.

The second aquifer testing site (PB-2) was undertaken in the southwest of the Cowan Block, adjacent to Collins Creek at a farm race junction as shown in Figure 3. Despite that gravelly materials were found at 11 m BGL in drill hole PB-2, a screen could not be placed or developed in a manner allowing a pumping test to be undertaken. Consequently the well screen was removed, and a section of open hole was jetted out using a water pump and developing tool below the end of the bore casing. Figure 29 shows a profile of the test bore and surrounds. The testing carried out used the falling head slug test methodology whereby the bore casing was filled to overflowing, external pump turned off and the drop in bore water level monitored manually until the ambient water level was reached.

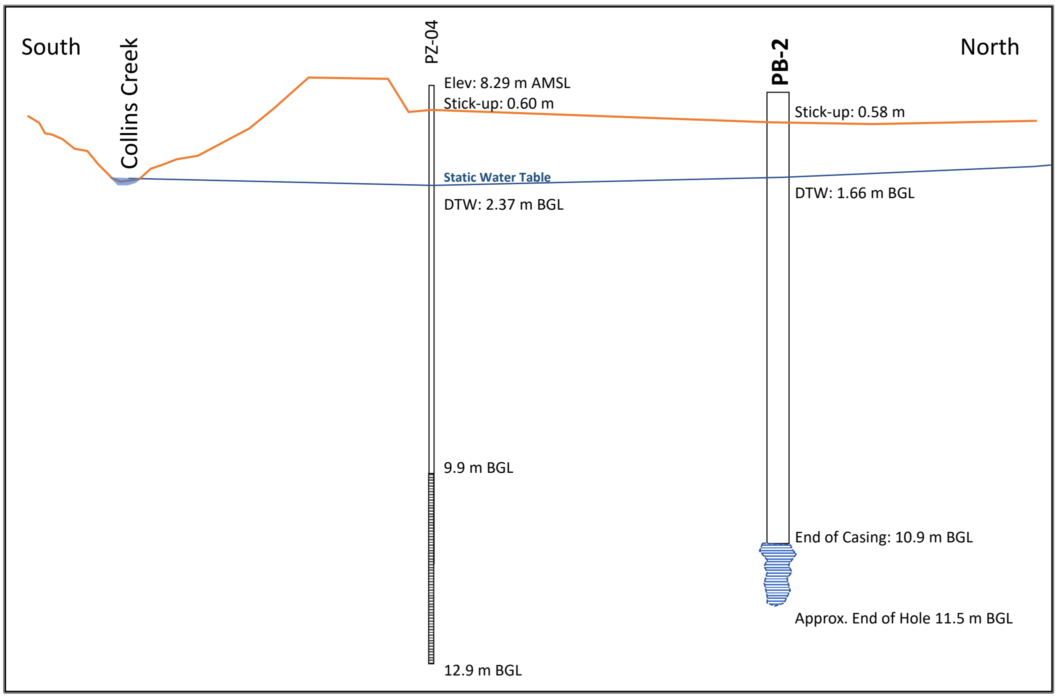

Figure 29: Cross-section through PB-2 testing site from south to north

The project also had the ability to carry out an empirical conversion of particle size distribution analysis obtained from a bulk sample taken on 5 May 2020 from mineral sand in the west of the Cowan Block. The PSD conversion to equivalent hydraulic conductivity followed the detailed methodology of six applicable methods.

Both test bores were also tested for their ability to accept farm drain or creek water by pumping surface water into each bore in turn. Test bore PB-1 was injected with 4.2 L/s of water from the nearby farm drain following airlift development. The bore casing water level rose to approximate ground level but did not overflow due to the additional stick-up of bore case above ground surface. The injected water level was held for an hour and reached quasi-steady state. The slug test bore was injected with 0.9 L/s of creek water and held at the injection rate for an hour (60 minutes) until the pump injection was stopped.

2.6.5.2 Results of Testing

The results of testing at the Cowan Block in November 2022 was separated into results for “gravel with minor sand” and “sand with minor gravel” for the sake of clarity and convenience. These classes of lithology for which hydraulic property results were obtained in a testing or PSD conversion are listed in Table 15. This lists ranges for transmissivity taken from test analysis with associated ranges in hydraulic conductivity for each of the two specified lithologies. While presenting the transmissivities is helpful to the reader, the hydraulic conductivity values have more universality in being unique to the lithology independent of saturated thickness, etc.

Table 14: Hydraulic properties estimated during aquifer testing and PSD conversion at the Cowan Block in November 2022

	Lithology in terms of broad Grain Size Distribution	
Property	**Gravel with minor sand** (leaky, semi-confined properties)	**Mineral Sand with minor gravel** (unconfined or indeterminate pressure state)
Transmissivity (m^2/d)	290 - 388	15.5 - 85
Estimated Mean Hydraulic Conductivity (m/d)	58 - 78	3 - 17
PSD Correlated Hydraulic Conductivity (m/d)	_	11
Storativity	1 x 10^{-3} to 6.2 x 10^{-4}	*2.2 x 10^{-2}*
Specific Yield	_	0.35
Radius/Leakage Ratio, r/B	0.024 to 0.046	_
Leakage Coefficient, B (m)	208 to 361	_

Note: Values in italics are thought to be questionable and potentially subject to analysis artefacts; unconfined aquifer settings' storage coefficients are better defined by Specific Yield (comparable to drainable or effect porosity); semi-confined / leaky aquifer settings provided a range of leakage coefficients, of which the Leakage Coefficient (B) is the more universal and insensitive to the radius between pumping bore and observation bore.

The results present in Table 15 indicate a contrast in hydraulic conductivity between "gravel with minor sand" and "sand with minor gravel" lithologies measured in aquifer testing and confirmed in PSD conversion in the case of sand with minor gravel. A specific yield value was obtained for sand with minor gravel in the unconfined Eastern Gravel Overburden material. This value of 0.35 (35%) is towards the upper end of values we might expect for alluvial sand. A relatively tight range in leakage coefficient was obtained for the deeper semi-confined gravel with minor sand at the PB-1 site was obtained. A storativity value range was obtained for the deeper semi-confined gravel with minor sand at the PB-1 site. However, leakage and storativity coefficients are unlikely to be particularly relevant as the leaky compartments are relatively shallow, potentially disjointed and are proposed to be unroofed by overburden stripping as part of the mining process prior to disturbance in the extraction of mineral sand.

A more detailed account of the recent aquifer testing, including raw test data, environmental corrections and numerical analyses, is available within Appendix 1.

2.6.6 Estimated Distribution of Hydraulic Conductivity

The Aircore exploration drilling from April to June 2022 provided three-dimensional data on the distribution of grain size, or Particle Size Distribution (PSD) across the Cowan Block wherever drilled and recorded in TAC# bore logs. The bore logs resolved the composition of each 1 metre length of drill hole cuttings into a main component and a secondary component. The main associations of sediment composition are listed as follow in Table 15.

Table 15: Main associations of Sediments in Aircore Bore Logs

Main Component	Secondary Component
Gravel, coarse	Sand
Gravel, medium	Sand or Silt
Gravel, fine	Sand or Silt
Sand, coarse	Minor gravel
Sand, medium	Minor Gravel
Sand, fine	Minor Gravel
Silt	Sand
Clay	Silt

The translation from main component estimated hydraulic conductivity was undertaken using the upper and lower ranges within Bouwer (1978) plus expert judgement obtained from the November 2022 aquifer testing results.

Table 16: Translation of Sedimentary Main Component into Estimated Hydraulic Conductivity

Main Component	Lower Estimate (m/d)	Upper Estimate (m/d)	Mean Hydraulic Conductivity (m/d)
Gravel, coarse	100	1000	200
Gravel, medium	1	100	50.5
Gravel, fine	–	–	20
Sand, coarse	20	100	15
Sand, medium	5	20	12.5
Sand, fine	1	5	3
Silt	–	–	0.7
Clay	1.0×10^{-8}	1.0×10^{-2}	5.0×10^{-3}

Note: Correlation from grain size or PSD utilised the ranges of hydraulic conductivity for grain size from Bouwer (1978), and expert judgement.

The mean hydraulic conductivity was assigned to the bore log of each TAC drill in 1 metre increments. The sum of hydraulic conductivities were calculated and assigned as a drill hole transmissivity. Subsequently, each drill hole transmissivity was divided by its depth to provide a hole-average hydraulic conductivity. As each TAC Drill hole had a grid coordinate, the mean hydraulic conductivity could be contoured across the investigated part of the Cowan Block. The kriging interpolation and contouring methods were selected to provide as close to realistic presentation of the state of hydraulic conductivity.

Figure 30 maps the distribution of sediment hydraulic conductivity to the base of the depth of drilling for the TAC# drill holes. The median and maximum depths of the TAC# drill holes was 11 m and 17 m BGL, respectively. So, the estimation of hydraulic conductivity needs to be viewed in light of the depth of investigation not extending to the full depth of the freshwater aquifer within the coastal sediments. The following observations or interpretations of Figure 30 can be ventured –

- The 10 m contour approximately delineates the extent of the Eastern Gravel Overburden,
- The highest hydraulic conductivities are limited to the Eastern Gravel Overburden, and
- Low and moderate hydraulic conductivity mineral sands area found within the sand extraction area,

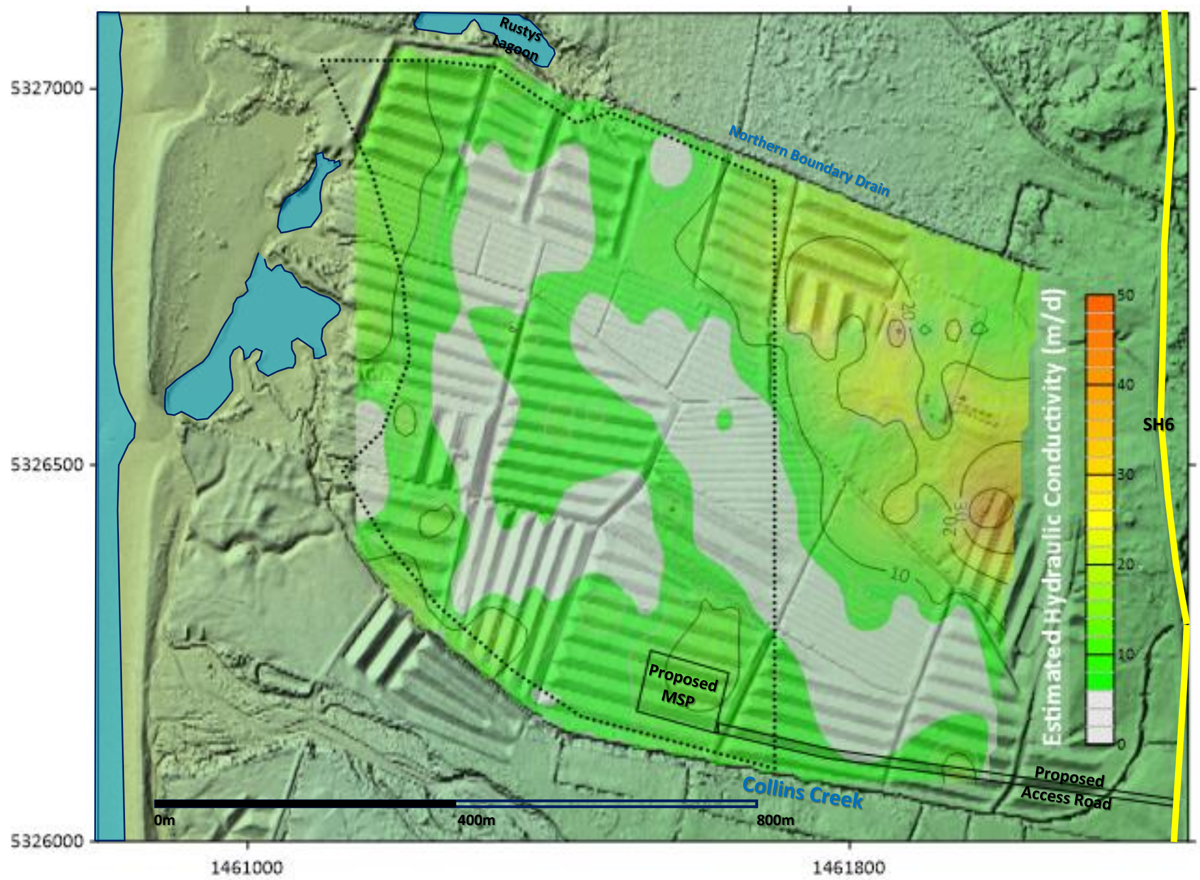

Figure 30: Contour colour-flood map of estimated mean hydraulic conductivity for alluvial and coastal sediments

The mean hydraulic conductivities as interpolated at the aquifer test sites, came close to indicating the mean hydraulic conductivity measured in aquifer tests, which is a form of confirmation albeit to be considered with caution. The Eastern Gravel Overburden has a strong influence in elevating the estimate of mean hydraulic conductivity within its footprint. The results of the PB-1 aquifer test could not be compared against the shallow Eastern Gravel Overburden estimation since the pumped bore was within the deeper “gravel with minor sand” lithology rather than the overburden.

2.6.7 Static Groundwater Level Contour Map

A survey of groundwater heights across the Cowan Block was conducted from 7 to 11 November 2022. The survey included perimeter piezometers, TAC# drill holes fitted with piezometers and an aquifer test observation bore (TB-1). The tops of plastic piezometer tubes had previously been surveyed to Mean Sea Level reference datum. Water levels were extracted from LiDAR survey data at Rusty Lagoon and the coastal lagoons. As capture dates of the LiDAR survey were widely separated 2019 to 2021, a date of the water level cannot be put on the elevations noted in the LiDAR Digital Elevation Model.

Figure 31 maps the corrected water levels dipped from 7 to 11 November 2022. The levels are expressed as elevations, i.e., metres above mean sea level. LiDAR based water levels in Rusty Lagoon and the coastal lagoons adjoining the Cowan Block are also noted on the map. Rusty Lagoon has water level elevation of 2.48 m, No. 1 Lagoon 1.87 m and No. 2 Lagoon 1.82 m AMSL. The overall trend in groundwater elevation in Figure 32 displays a west-north-west hydraulic gradient orientation that would be broadly coincident with the average groundwater flow direction. The preliminary groundwater flow pattern would suggest that water infiltrates through the bed of Collins Creek downstream of the SH6 crossing and percolates in a west-north-west direction before terminating at the lower Collins Creek and coastal lagoons.

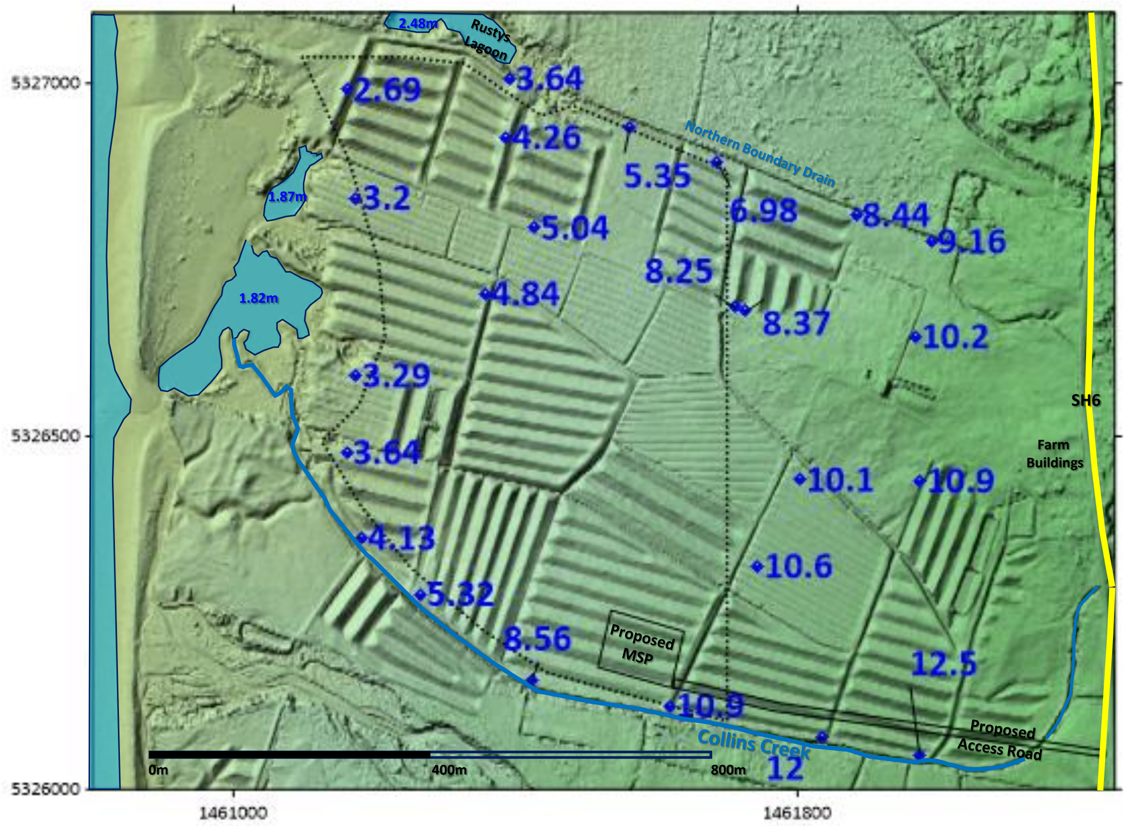

Figure 31: Corrected groundwater levels across the Cowan Block as level elevation w.r.t. Mean Sea Level

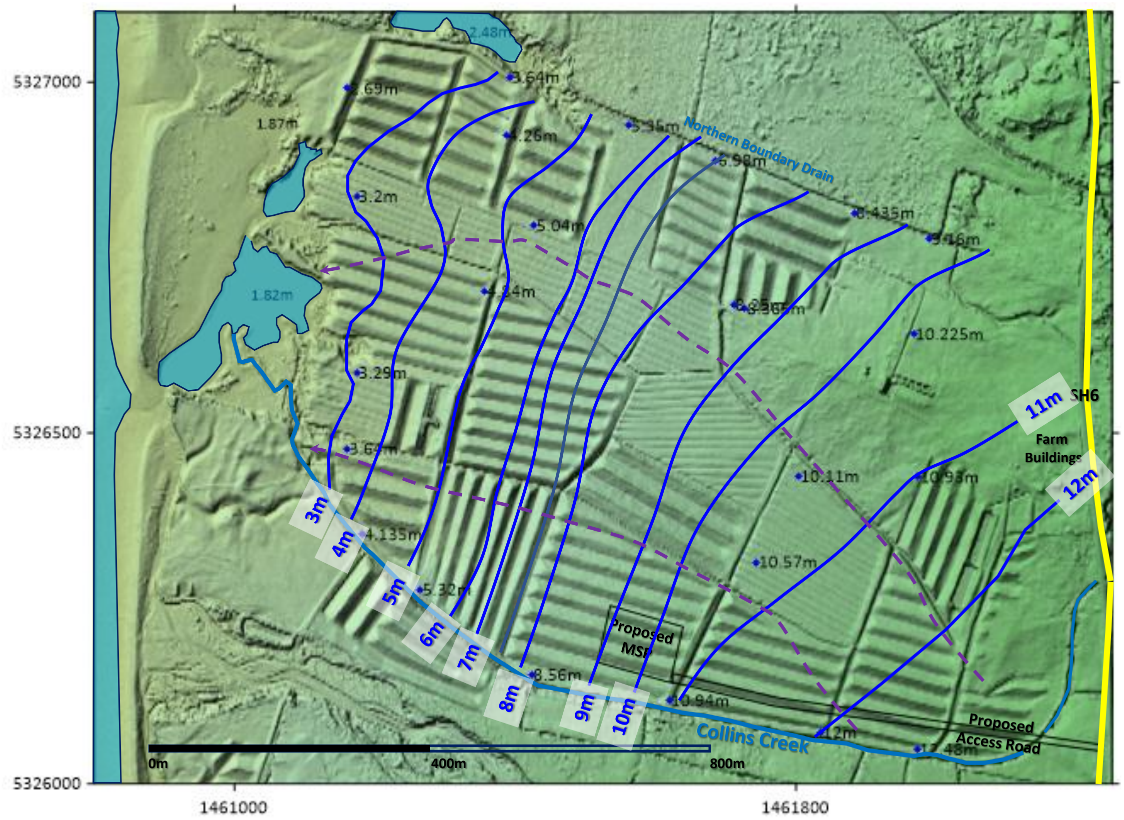

Figure 32: Groundwater level contours drawn from groundwater elevations mapped across the Cowan Block

2.6.7.1 *Groundwater Hydraulic Gradients*

The mean groundwater hydraulic gradient across the Cowan Block could be estimated by dividing the decline in groundwater level (Δh) by the measured mean flow path length (Δl), as expressed in the following equation:

$$\begin{aligned} \text{Gradient} &= \Delta h/\Delta l \\ &= (12.7\ \text{m} - 1.8\ \text{m}) / 1{,}310\ \text{m} \\ &= 0.0083\ \text{m/m} \\ &= 0.83\ \% \\ &= 1{:}120 \end{aligned}$$

Such a gradient is relatively steep slope for groundwater flow in alluvial or coastal sediments, albeit not as steep as the mean land surface gradient over the same traverse, which was estimated from the LiDAR DEM at 0.012 (1.2 %). Figure 33 profiles the land surface and groundwater level surfaces along the principal groundwater flow path through the Cowan Block, illustrating the diminishing separation between the two surface as the coastline is approached.

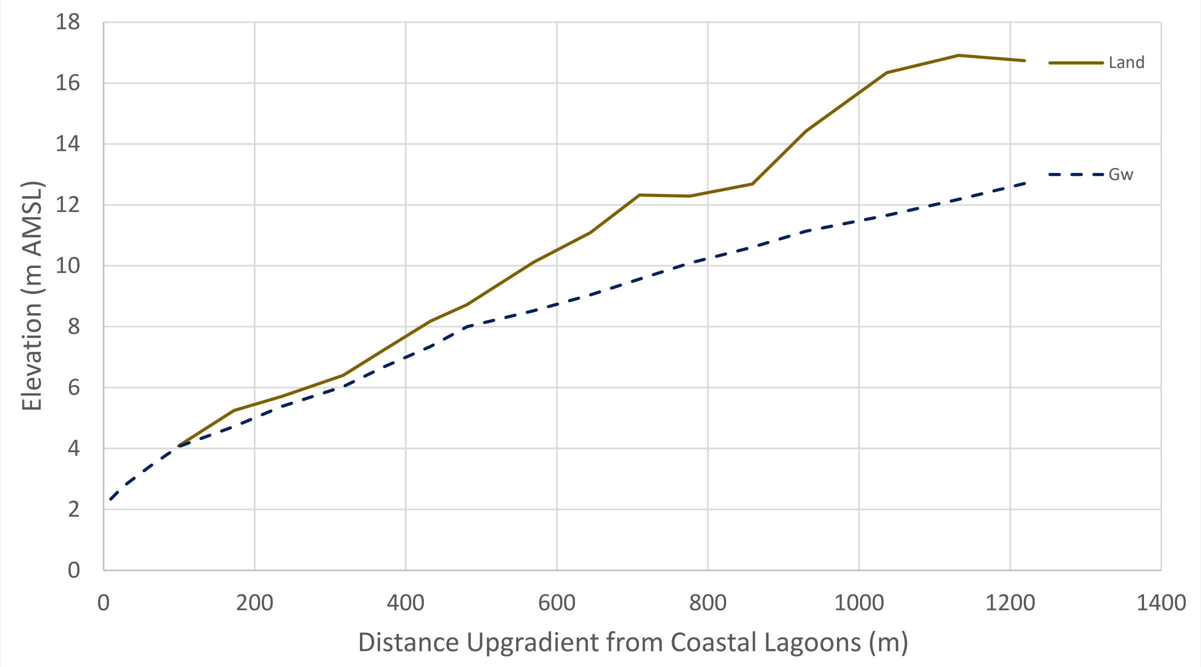

Figure 33: Profile of land surface and approximate groundwater level in underlying coastal sediments

Figure 33 suggests potential for groundwater recharge in the east and groundwater discharge as diffuse or discrete seepage in the west. It was also feasible to determine the Collins Creek invert (bed) level from the LiDAR DEM, however the accuracy and precision of the creek invert profile would not be as high as for land surface due to rising creek banks reducing the point cloud reaching the bed of the creek. Figure 34 plots the LiDAR-derived creek invert elevation alongside the measured groundwater levels at perimeter piezometers adjacent to Collins Creek. This profile also indicates the potential for surface recharge of groundwater in the eastern (upstream) reaches of the creek and seepage discharge to the creek in the western (downstream) reaches approaching the coastal lagoons.

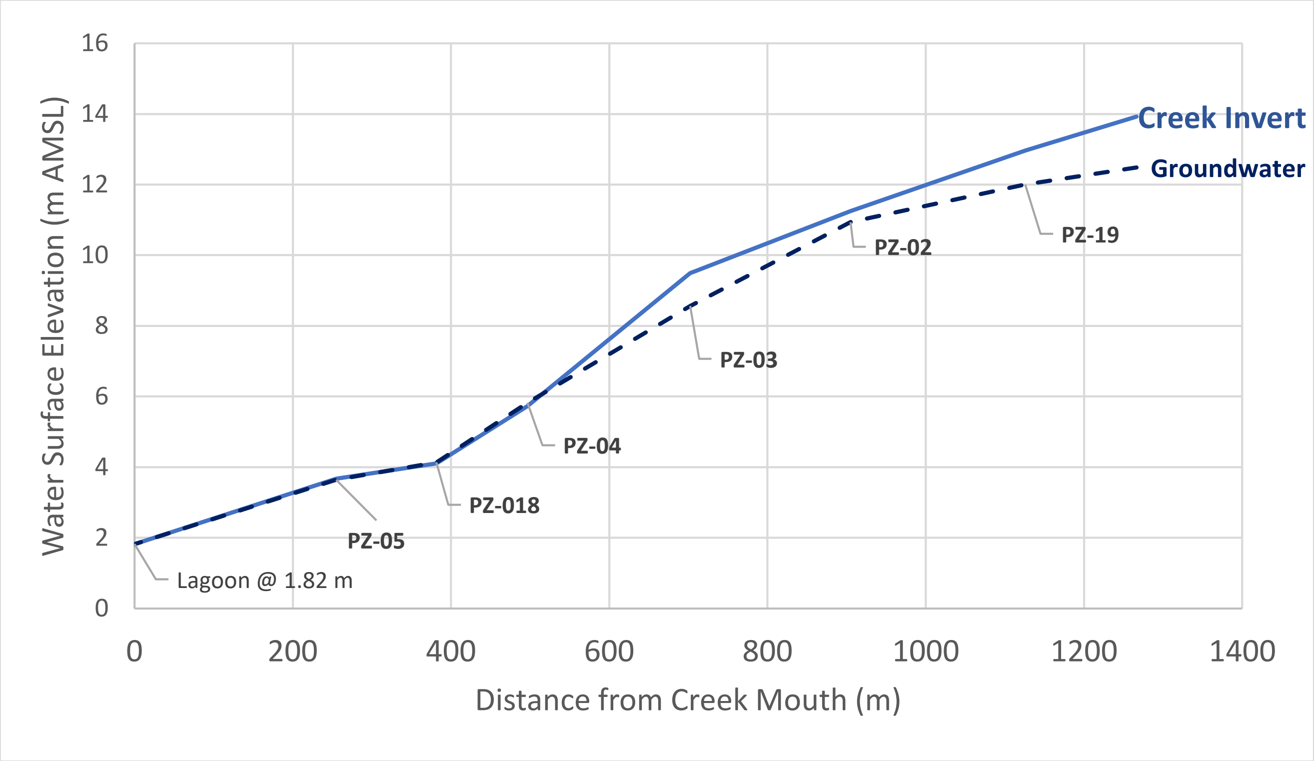

Figure 34: Dual water level profile of Collins Creek invert (bed) and the adjacent measured groundwater elevation

A similar but more accentuated pattern of separations between the Northern Boundary Drain and groundwater is evident along the northern property boundary of the Cowan Block. In the vicinity of piezometer PZ-11 the below ground separation between land surface and water table flips to being above-ground groundwater levels in the direction of Rusty Lagoon.

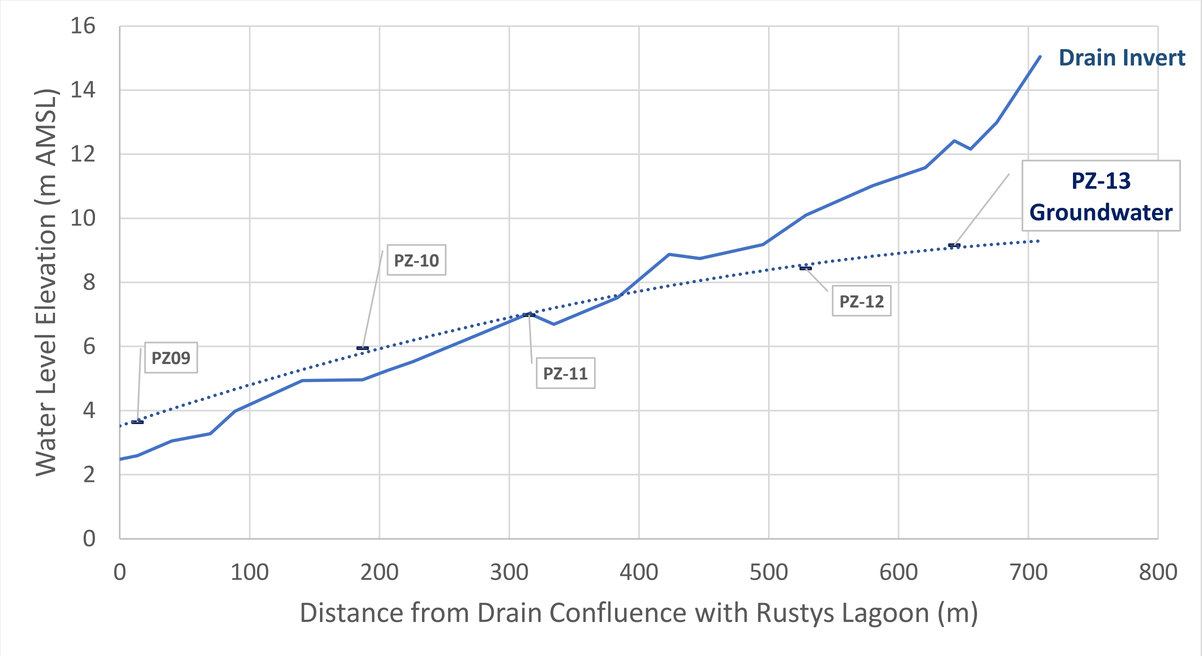

Figure 35: Dual water level profile of the Northern Boundary Drain and adjacent measured groundwater elevation.

The polarity of groundwater level and drain invert downstream of PZ-11 implies that groundwater seeps into the adjacent drain between the position of PZ-11 and Rusty Lagoon. However, lower drain seepage conductance related to the thickness and permeability of the drain bed may limit the quantities of groundwater leaving the coastal sediments' groundwater to infiltrate the Northern Boundary Drain or Rusty Lagoon.

2.6.7.2 Estimated Groundwater Through Flow & Velocity Rates

Groundwater through flow can estimated approximately wherever there is a predominant groundwater flow direction and independent estimates of the following parameters –

- Mean hydraulic conductivity,
- Mean saturated thickness, and
- Mean groundwater hydraulic gradient.

These parameter values were obtained from the following sources. The hydraulic conductivity was average along the main groundwater flow path by taking a profile through interpolated horizontal hydraulic conductivity in Figure 30, the mean saturated thickness was estimated from hydrological setting discussion in Section 2.4 Geology with Figure 7, Section 2.6.1, and Section 2.6.5, while the mean hydraulic gradient was obtained from an extract from Figure 32 based on corrected November groundwater elevations. The flow from perpendicular to the Cowan Block's principal boundaries (Collins Creek and the Northern Boundary Drain) is approximately 800 m. However, due to geometric factors and the converging flow geometry, the estimated flow front was reduced to 600 m.

The basic equation for the calculation of through flow is as follows –

$$
\begin{aligned}
Q &= (K\, b)\, i\, W \\
&= (9.14\ \text{m/d} \times 15\ \text{m}) \times 0.0083 \times 800 \\
&= 910\ \text{m}^3\text{/d (or 10.5 L/s)}
\end{aligned}
$$

Where:

K = Mean horizontal hydraulic conductivity
= 9.14 m/d

b = Mean saturated thickness
= 15 m

i = Mean groundwater hydraulic gradient
= 0.0083 m/m

W = Groundwater flow front
= 800 m

An estimate of mean groundwater velocity may also been made using a variation the Darcy Equation (Darcy, 1856).

$$
\begin{aligned}
\text{Velocity} &= (K\, i)/\, n_e \\
&= (9.14\ \text{m/d} \times 0.0083) \times 0.35 \\
&= 0.22\ \text{m/d (or 80 m/year)}
\end{aligned}
$$

Where:

K = Mean horizontal hydraulic conductivity
= 9.14 m/d

i = Mean groundwater hydraulic gradient

= 0.0083 m/m

n_e = Effective porosity (taken from specific yield in Section 2.6.5.2 Results of Testing)

= 0.35

The results of the groundwater through flow and velocity calculations are averaged across the complete flow path. The estimation also assumes that groundwater traverses a complete flow path beneath the Cowan Block along the principal flow path from Collins Creek immediately downstream of SH6 to the Coastal Lagoons. Intermediate groundwater paths from, for instance, soil drainage through pasture to seepage discharge at the medial farm drain would be shorter and differing transport parameters, and hence different groundwater flow velocities.

The through flow and velocity estimates indicates relatively slow groundwater transmission rates. Whereas the surface water drainages carried water at rates approximating 100 L/s and higher with mean open water velocities in range of 0.05 to 0.20 metres per second (m/s), the various estimated groundwater transmission rates from east to west across the Cowan Block were estimated to be in the order of 10 L/s and 80 m/year. This is a strong contrast in hydrological capacity, which suggests that the groundwater system beneath the Coates Block plays a significantly lesser role in effective land drainage.

2.7 Water Quality

2.7.1 Groundwater Quality

2.7.2 Field investigations

Field investigations in 2022 also included focused investigations of groundwater quality and groundwater composition. The Coffey Partners (1991) reporting of groundwater chemistry was limited, and the Barrytown area has not received attention from national, regional or local government groundwater investigations covering water quality in any way, i.e., NGMP[5], LAWA[6] or WINZ[7] water quality databases. Groundwater sampling with analysis had not previously been undertaken in the Cowan Block.

Following the drilling and installation of 19 perimeter piezometers in April 2022, a sampling round of eight selected piezometers was undertaken on 11 May 2022 (see Figure 36). This round as an initial survey of water quality used analysis of total elemental or compound concentrations. Samples were not filtered. The follow-up survey on 9 November 2022 repeated the same list of selected piezometers but was analysed for dissolved constituents rather than total constituents. The samples were sampled in the field to remove particles larger than 0.45 micron (μm), including larger bodied biota. Filtration assists with reducing in situ reactions or complexing in the sample bottles after sampling. All samples were chilled to maintain sample temperature below ambient between sampling and analysis.

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[5] National Groundwater Monitoring Programme is a database that provides a national perspective on Aotearoa New Zealand's groundwater quality through time run primarily by GNS Science with assistance from regional authorities.

[6] Land, Air, Water Aoteoroa (LAWA) shares environmental data and information from a variety of environmental monitoring sources across the country and presents it in a layperson compatible format.

[7] Water Information New Zealand (WINZ) is a national database developed by ESR for the Ministry of Health.

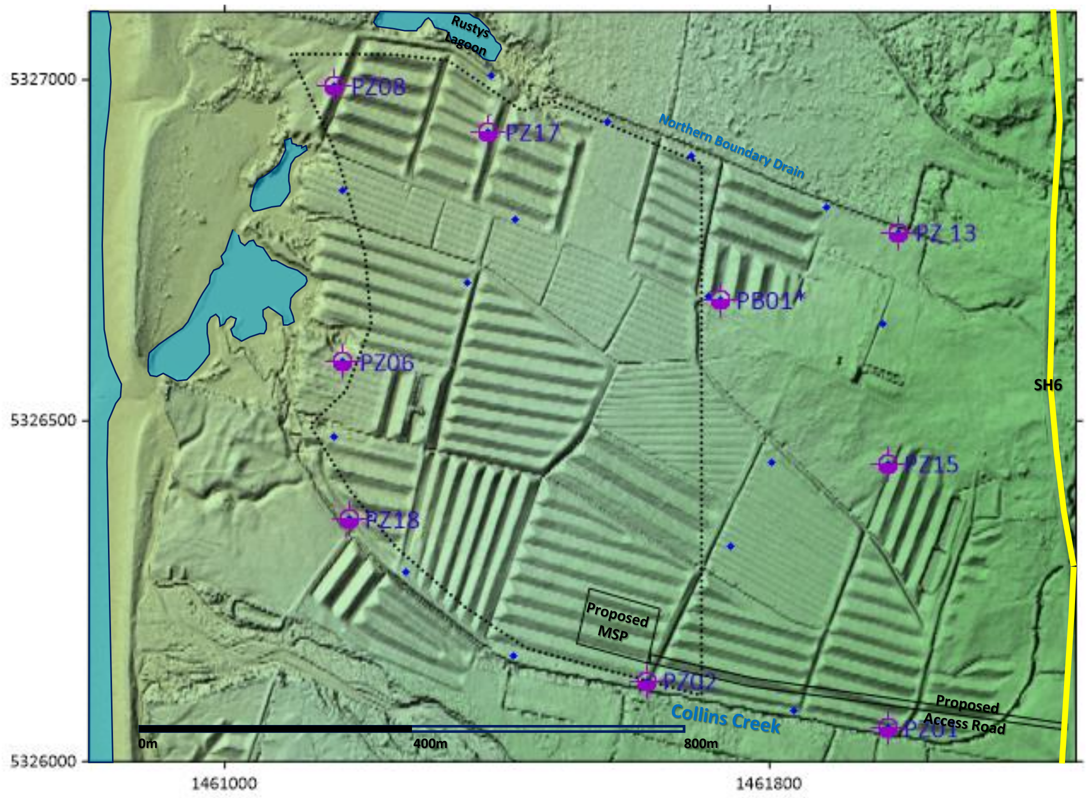


Figure 36: Location of selected perimeter piezometers used in groundwater sampling survey (note: * sampled in aquifer test only)

2.7.2.1 Groundwater quality results screening

Groundwater quality monitoring results from the nine groundwater sampling locations for dissolved constituents were compared to the Australian and New Zealand guidelines (ANZG) for fresh and marine water quality (2018 revision). The ANZG freshwater values are useful for preliminary screening for potential water quality issues because the receiving waters for discharges from the mine are fresh surface water bodies on and adjacent to the site. Drinking water standards are not relevant because the local groundwater resource on and downstream of the site is not used for drinking water supply.

The screening process identified the six parameters with concentrations above the ANZG 95% species protection values as per Table 17. Although nutrient concentrations are not included and are discussed in the Barrytown Sand Mine Stream Ecology Report (EcoLogical, 2023), we note that phosphorus concentrations are also elevated in groundwater beneath the site and that treatment may be required to avoid the potential for adverse effects in receiving waters. This is discussed further in Section 6.

Table 17: Groundwater quality screening assessment summary

Parameter	ANZG 95% value	Max recorded	No of samples > ANZG	Samples exceeding ANZG
Aluminium	0.055	0.1	1	PZ-15
Arsenic	0.013	0.036	1	PZ-02
Chromium	0.001	0.0035	1	PZ-15
Copper	0.0014	0.0055	6	PZ-15, PZ-17, PZ-13, PZ-18, PZ-02, PZ-01
Nickel	0.011	0.122	2	PZ-18, PZ-01

Parameter	ANZG 95% value	Max recorded	No of samples > ANZG	Samples exceeding ANZG
Zinc	0.008	0.104	8	PZ-15, PZ-08 PZ-17, PZ-13, PZ-18, PZ-02, PZ-01, PB-01,

It should be noted that this screening assessment does not account for the specific hydrochemistry of the local receiving environment and do not therefore provide an indication that adverse effects will occur. The preliminary screening assessment highlights the need for a more detailed site-specific assessment. This is provided in the Barrytown Sand Mine Stream Ecology Report (EcoLogical, 2023).

2.7.3 Process plant and backfill seepage water quality

Because the minerals processing is mechanical and does not involve the additional of chemicals to the process water, the potential for water quality changes in the water circulating through the processing plant (some of which will be discharged back to the mine excavation within the separated sand deposits) is limited. The likely quality of the process water and seepage from the backfill material (sometimes referred to as “ tails”) was evaluated by analysing a set of samples as follows:

1. Representative core samples from the site drilling programme were processed to create the following four samples: Run of Mine (ROM: unprocessed sand) Heavy Mineral Concentrate (HMC, i.e. the end product from the processing plant), Tails (sand with the HMC removed) and Slimes (the residual fine material after the HMC and Tails are removed).
2. The four samples were used to generate representative water quality samples using the “shake test” procedure which comprises:
    a. Each material sample was air dried (at 40°C) and ground (to less than 2 mm particles)
    b. The processed samples were mixed into suspension in a solution of one part material sample to five parts deionised water at 25°C.
    c. Samples were then shaken for one hour and allowed to settle for one hour. The solution was then extracted and sent to the laboratory for analysis.

The lab results for dissolved constituents were compared to the Australian and New Zealand guidelines (ANZG) for fresh and marine water quality (2018 revision) as an initial screening as per the groundwater quality samples (see Appendix 6). The results (Table 19) show that the concentration of three metals exceed the screening criteria. Aluminium exceeds the screening value in all four samples; chromium exceeds the screening value in the HMC sample and copper exceeds the value in the slimes and HMC samples; the remaining samples were below the limit of detection, which was higher than specified in the analysis request to the laboratory.

Table 18: Process water quality screening assessment summary

Parameter	ANZG 95% value	Slimes	Tails	ROM	HMC
Aluminium	0.055	0.12	0.2	0.12	0.39
Chromium	0.001	OK	OK	OK	0.0036
Copper	0.0014	0.012	<0.01	<0.01	0.0055

The potential effects of mobilisation of elevated metals in the HMC and backfill pore water are discussed in Section 4.2

2.7.4 Surface Water Quality

2.7.4.1 Field investigations

Field investigations in 2022 also included sampling of Collins Creek (upstream on SH6, and downstream at farm ford), the Northern Boundary Drain and one point on the coastal lagoon. The initial sampling on 11 November

2022 was analysed for total constituent concentrations, while the subsequent samplings from 28 July 2022 were analysed for dissolved concentrations and filtered in the field. Figure 37 maps the location of all four sampling sites of surface water.

Surface water is more volatile than groundwater since the groundwater flow velocities are typically in the order of metres per year versus metres per second for creeks. Surface water frequently reflects the inflow of upstream groundwater in terms of concentrations and proportions of constituent concentrations reflecting the contribution of seepage in base flow. Concentrations also shift in accordance with changes in creek flow rate. In the case of Collins Creek the upstream and downstream sampling sites coincide with flow gauging sites at SH6 and farm ford, respectively.

2.7.4.2 Results screening

Surface water quality monitoring results from the four surface sampling locations for dissolved constituents are compared to the Australian and New Zealand guidelines (ANZG) for fresh and marine water quality (2018 revision). The preliminary screening process identified the four parameters with concentrations above the ANZG 95% species protection values as per Table 19. Nutrient concentrations are not included and are discussed in the Barrytown Sand Mine Stream Ecology Report (EcoLogical, 2023).

Table 19: Surface water quality screening assessment summary

Parameter	ANZG 95% value	Max recorded	No of samples > ANZG	Samples exceeding ANZG
Aluminium	0.055	0.131	2	Northern Drain 23/8/22 and 1/11/22
Cobalt	0.0014	0.0016	1	Northern Drain 1/11/22
Copper	0.0014	0.0029	3	Northern Drain 23/8/22 and 1/11/22, Lagoon 21/9/22
Zinc	0.008	0.0168	2	Northern Drain 23/8/22 and 1/11/22

A detailed evaluation of current surface water quality and the potential effects of the proposed activity is provided in the Barrytown Sand Mine Stream Ecology Report (EcoLogical, 2023).

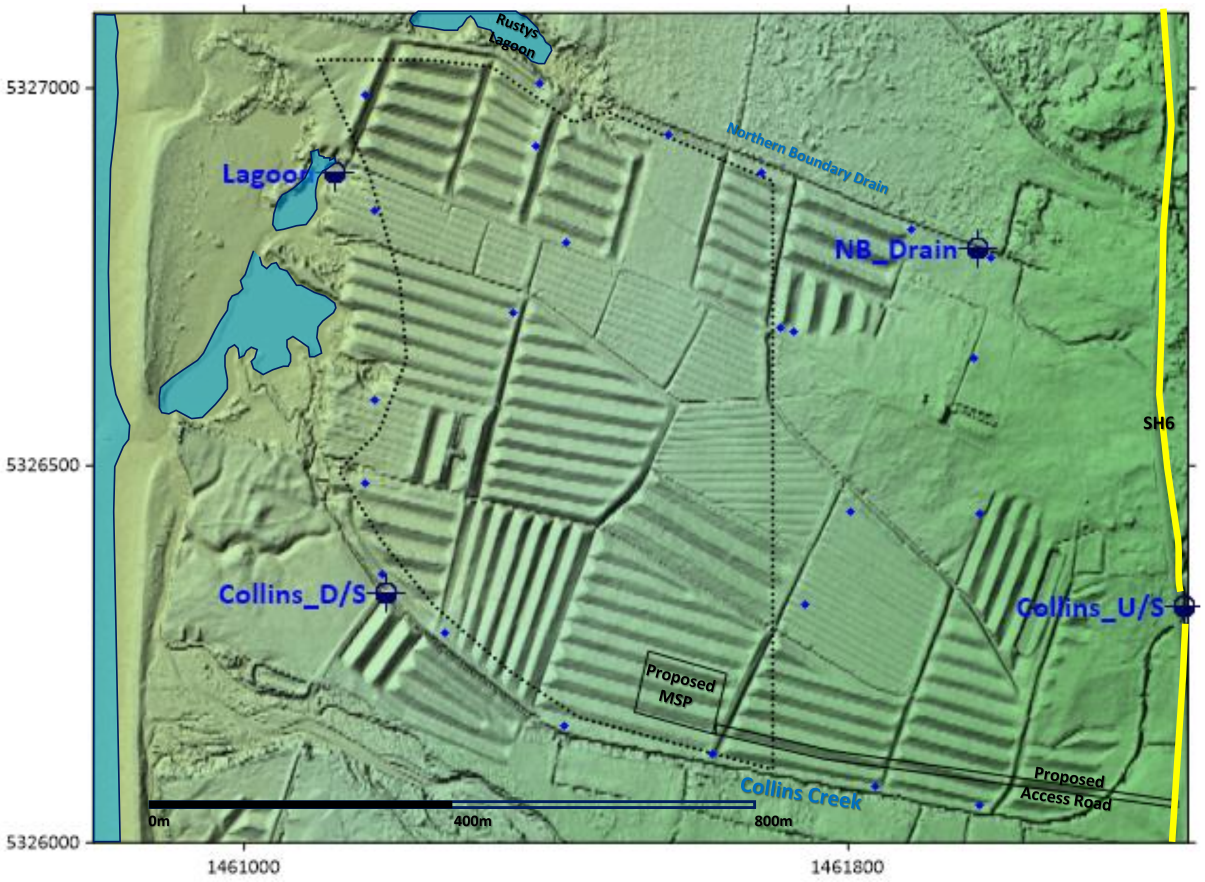


Figure 37: Location of surface water sampling sites used for analysis of waters surrounding the Cowan Block

3 Proposed Sand Extraction Activities

3.1 Summary of Proposal

The outline of activities relating to the proposed sand extraction within the Cowan Block can be advanced as follows –

- The target mineral ore comprises sediments with significant concentrations of garnet, ilmenite, Rare Earth Elements, gold and accessory heavy metals/minerals,
- The ground would be stripped of soil, subsoil and overburden to a depth of up to 2 m prior to sand extraction (pre-stripping) with stripped materials handled to facilitate land restoration / rehabilitation,
- Sand extraction would precede as a series of 80 m wide strips, moving from west to east until the strip terminates against the eastern margin of the extraction area,
- The exposed mineral-bearing sediments would be extracted and processed materials back-filled into the extraction void,
- The active sand extraction zone would progress generally from west to east in strips that would generally progress from south to north,
- Remaining within the sand extraction area, avoiding the Processing Plant plus laydown area and access road and avoiding the water treatment zone leaves a potential area for active sand extraction operations of 34 ha criss-crossed by strips,
- The active and operational pre-stripping, sand excavation and back-filling zone at any one time is likely to fit inside an 3 ha area, surrounded by Cowan Block land that has been mined and rehabilitated or yet is to be mined,
- The active sand extraction area will thus travel as the sand deposit is steadily worked, and

- Areas of active mining and the Processing Plant would be linked by slurry lines carrying water and sand material.

Plans show each mine strip or panel was either 100 m or 80 m with a 20 m wide ancillary strip. The distinction is that part of the 100 m width is a 20 m wide roading strip. The sand extraction paths would be nominally 100 m wide, while the pit would be 80 m. As each panel is mined the roading strip of the previous panel is mined out.

Figure 38 maps the proposed location of sand extraction paths, the Central Drain (which incorporates the existing drainage pathway) and terminal water treatment holding dam. The central drain is intended to conduct accumulated clean water to the water treatment ponds in the north western. This central drain would be partly original and partly re-aligned, especially in the lower half and into the water treatment ponds 3 and 4.

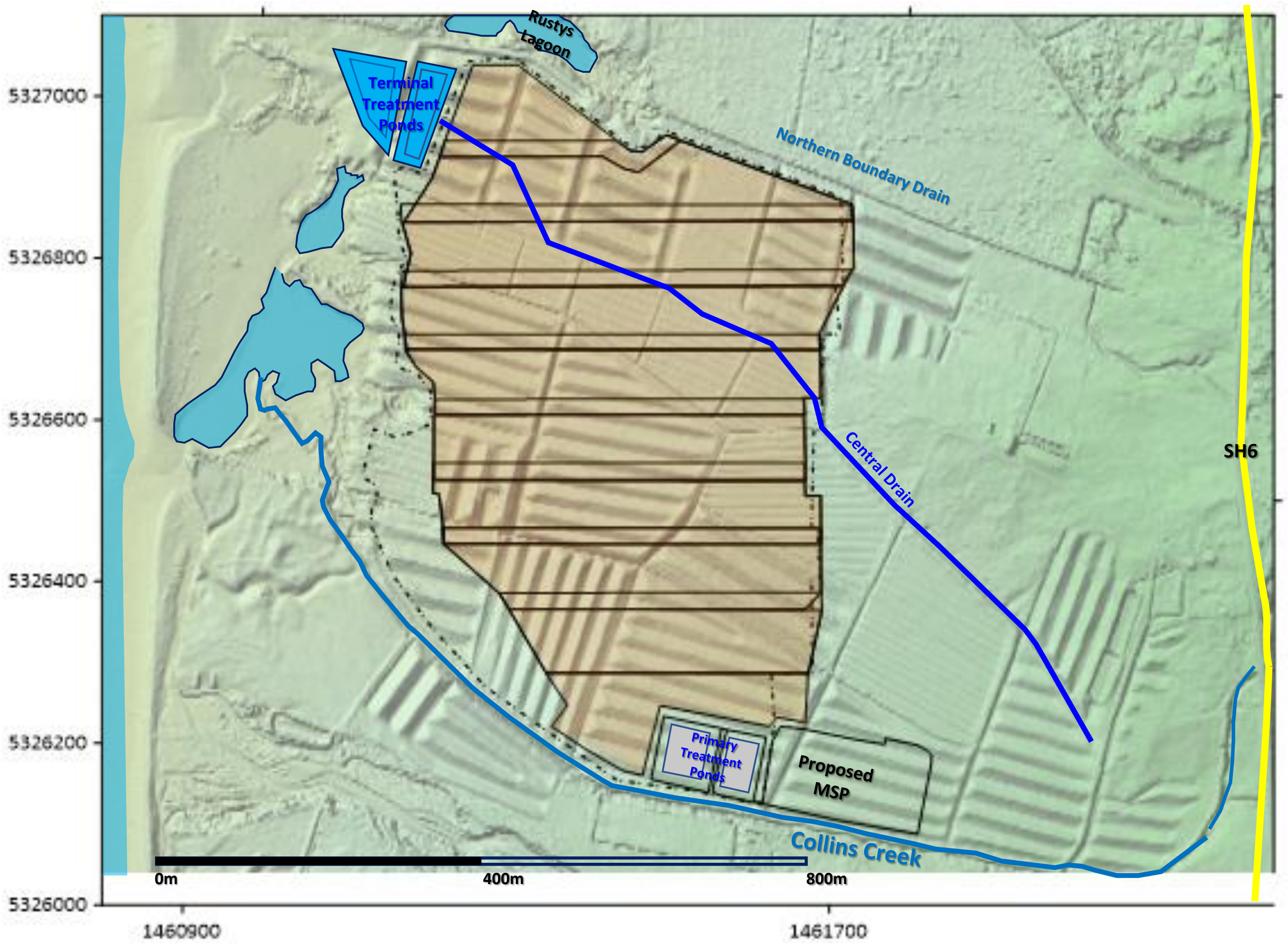


Figure 38: Schematic map of 80 m wide sand extraction paths within the boundaries of the provisional extraction area

3.2 Proposed Water Management

Water management has several dimensions –

- In-pit water management around the active sand extraction area,
  - To be covered by Kōmanawa Solutions
- Management of water-related impacts on external eco-hydrological systems, including creek, springs, wetlands and lagoons,
  - To be covered by Kōmanawa Solutions
- Slurry, Processing Plant and Tailings water management,
  - To be covered by IHC Robbins

- Land rehabilitation water management, including the formation of swales and restoration of drainage,
    - To be covered by Palaris
- Stormwater and ESCP water management, including diversions and water treatment structures,
    - To be covered by Ridley Dunphy Environmental,
- Tailings emplacement and associated water management,
    - To be covered by RDCL

This report covers the first two areas of water management; in-pit dewatering systems and off-site impacts.

3.2.1 In-Pit Water Management

The actively disturbed sand extraction area at any one time would be an area 100 m by 300 m with the long axis parallel to the mining strips. The 300 m length would be 75 m of tailings drying and rehabilitation, 75 m wet deposition of tailings and open pit to full depth, 100 m of progressive sand extraction, 25 m of stripping and 25 m of topsoil grading. Accordingly, a zone extending over 75 m by 80 m could be considered as the 'pit' and would be mostly subject to the full depth of excavation and require ongoing water level depression.

With the focus of sand extraction undulating along mine panels and in accordance with mineral sand grades down to ~10 m below ground level, in-pit water management would require suppression of the ambient water table. The ambient water table in most instances is expected to reside between the land surface and the excavator bench atop the ore sand. Accordingly, some form of in-pit water management to depress the excavation water level will be required for optimal materials handling, pit wall stability and site safety.

The in-pit water management method is sump pumping from the deepest part of the active excavation.

3.2.2 Wider Water Management

The Cowan Block undergoing the active phases of sand extraction and land restoration / rehabilitation would require management of water flows and levels in the wider areas outside of the active extraction zone. Proposals for water management include –

1. The construction of a terminal water treatment impoundment in the northwest of the Cowan Block (see Figure 38),
2. The re-alignment and deepening of the existing farm drain system to produce a central drain running from southeast to northwest, and
3. Tailored water management to account for the impacts of constructing the processing plant, primary treatment ponds and access roadway from SH6.

In addition, Erosion & Sediment Control Planning (ESCP) implementation would centre on the pre-stripping, active extraction and restoration zones of the travelling sand extraction features. These ESCP measures would be applied to the areas with disturbed or destabilised land cover prior to them going back into stable land cover, typically pasture. Additionally, heavy machinery would require access to different parts of the Cowan Block, so the tracking would need focused ESCP measures to minimise turbid water or sediment mobilisation.

Tailored ESCP measures such as porous sediment trapping barriers would be deployed to enhance sediment capture and downstream water clarity in clean water channels such as the central drain. Trapped sediment would be regularly or as required dug out and added to the sand extraction tailings for co-disposal. These matters are discussed in detail in the ESCP for the site. It is significant to note that diversions of Collins Creek or the Northern Boundary Drain are not part of mineral extraction at the Cowan Block. However, minor re-alignment and bypass of farm drains or significant 'hollows' would be necessary ahead of pre-stripping and managed within the auspices of the ESCP planning.

3.2.3 Potential effects on External Eco-Hydrological Systems

The primary potential hydrological effects of the proposed sand extraction can be grouped and defined as follows –

- Sub-Surface Hydrological Effects – Water Table Fluctuation
    - Water table lowering due to in-pit water level drawdown
        - Creek flow depletion
        - Wetland and lagoon water level lowering
    - Water Table mounding – artificial infiltration of water
        - Groundwater flooding
        - Effects on wetlands
- Surface Hydrological Effects – Interruption of Drainage Patterns
    - Diversion of existing drains and small creeks
    - Loss of floodway
    - Depletion of creek flow related to water table lowering (see above)
- Water Quality Effects – liberation of sediment or chemical compounds
    - Disturbance of soil and geologic material
        - Generation of turbidity and suspended sediments
        - Inflow or discharge of turbid water into more sensitive environments
    - Reversal of groundwater flow rates
        - Seawater (saline) intrusion of fresh groundwater
    - Discharge of groundwater into surface water,
        - Elevated oxygen demand release
        - Metals and metalloids, including flocculant coatings
    - Accidental discharge of fuels, oils or lubricants
        - Light phase fuels filming or floating with surface water
        - Light phase fuels in non-aqueous phase atop groundwater
        - Hydraulic oil or bulk lubricant leak (Dense Non-Aqueous Phase Liquids) entering surface water or the water table below ground

3.3 Groundwater Quantity – Excavation Water Pumping

The primary source of potential hydrological effects emanates from the need to maintain a managed water level in the active sand extraction excavation within the deepest part of the active sand extraction zone. Typically the active sand extraction zone comprises an approximate extent of 2.4 ha within a 3.0 ha strip, containing the following component zones grouped by the principal activity –

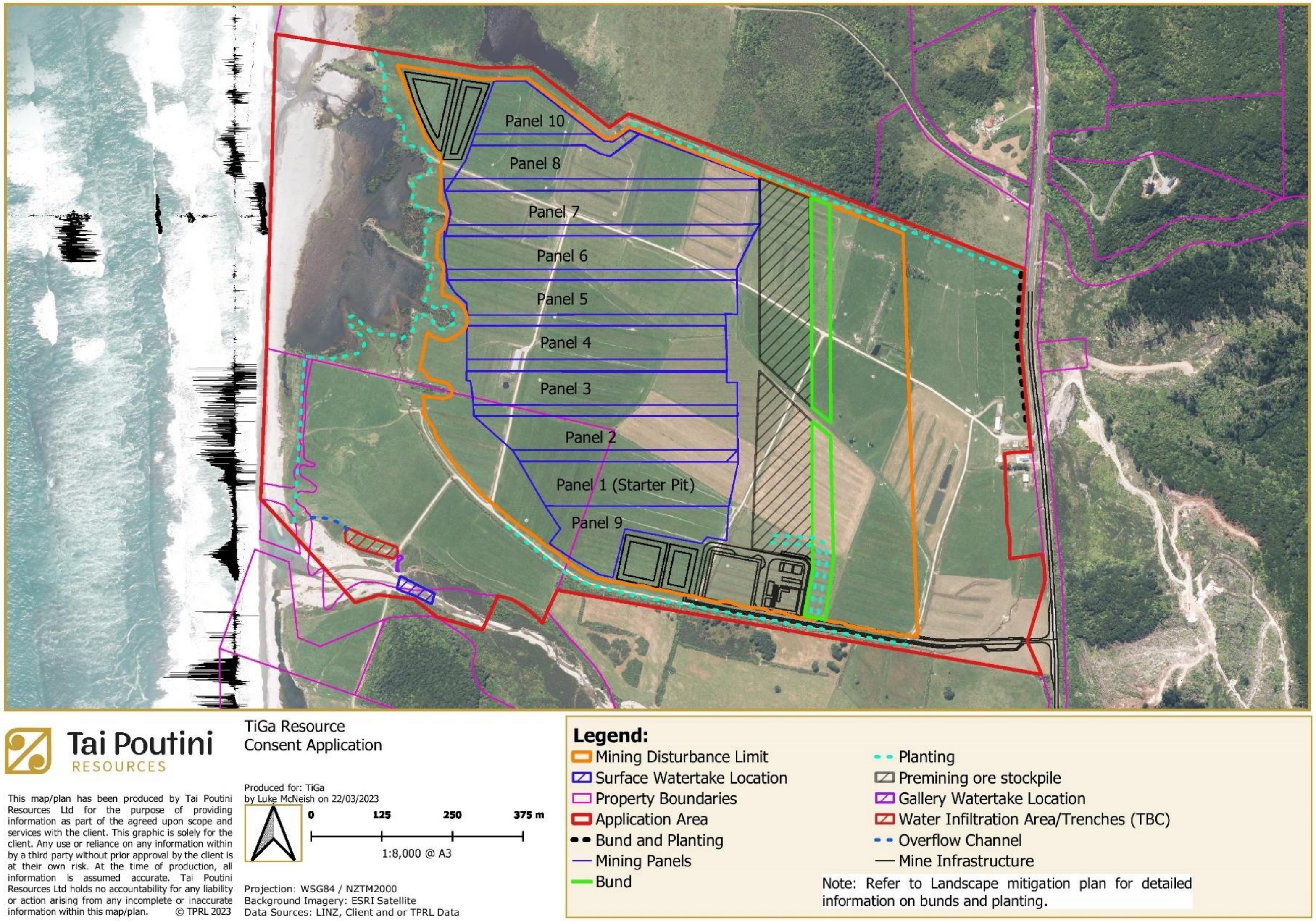
- **Topsoil grading zone** (pre-stripping soil for stockpiling) of 0.25 ha extent,
- **Stripping of overburden** (subsoils, clay-silt and silty gravel overburden) of 0.20 ha extent,
- **Ore extraction** (progressive extraction of mineral sands) of 0.8 ha extent,
- **Base – Backfill** (50:50 area of the base of the economic sand and wet backfill) of 0.6 ha extent,
- **Dry backfill** (mixed area of dried and draining wet sand backfill) of 0.20 ha extent,
- **Overburden over-backfill** (restoration of subsoil and overburden fines) of 0.20 ha extent,
- **Topsoil restoration** (restoration of topsoil from stockpile) of 0.20 ha extent, and
- **Running road** (outside berm of relatively undisturbed ground for vehicular & plant traffic) 0.55 ha.

Where the running road is left unexcavated by the previous mine strip, the subsequent mine strip would include the running road. The result is the effective individual mine strip width would be 80 m. The principal zones requiring water management, particularly water table suppression are the Base – Backfill, and Dry backfill.

The Base – Backfill zone is generally the deepest and requires water table suppression. Water table lowering is usually facilitated by pumping groundwater at increasing rates of flow until an equilibrium is achieved that maintains the excavation at the required state of saturation. The pumping of water also needs to be conveyed away from the excavation to prevent immediate recirculation.

The dry / drying backfill and ore extraction can tolerate shallower depths of water table suppression than the Base – Backfill zone. Variable depths of water table suppression are expected. In general, the depth of economically extractable mineral sand places the base of the excavation at approximately 7 m below the ambient water table or about 9 m below the land surface.

The approximate sand extraction block layout is shown in Figure 39.



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Projection: WSG84 / NZTM2000
Background Imagery: ESRI Satellite
Data Sources: LINZ, Client and or TPRL Data

Note: Refer to Landscape mitigation plan for detailed information on bunds and planting.

Figure 39: Approximate sand extraction layout

Figure 39 shows the proposed sand extraction arrangement, comprising –

- 10 mine strips of variable length from the south to the north,
- The total length of all strips would be 4 km,
- The total mass of ore extracted would be approximately 5 million tonnes (Mt),
- The sand extraction would progress at a maximum rate of 1.1 million tonnes per year (Mt/a),
- The active lifetime of the operation would be about 5-7 years[8].

4 Assessment of Water Quality Effects

4.1 Suspended sediment and turbidity

Water pumped from the mine excavation will contain suspended sediment and turbidity associated with plant operation and localised erosion of the pit walls by rainfall and groundwater seepages. The presence of clay material in the overburden in some areas of the mine site may give rise to high levels of turbidity for part of the mine life. Careful water management is required to avoid potential adverse effects associated with the discharge of water with high suspended sediment and/or turbidity levels.

The ESCP describes a water treatment train to remove as much sediment as practicably possible from the influent water. The turbidity of the Pond 4 water will be dependent on the exposure to clay materials in the mine excavation and the settling properties of the clay when subjected to treatment. It is not possible to reliably predict the turbidity of the treated water and hence it is possible that turbidity could be significantly elevated above the low levels of background turbidity in Canoe Creek Lagoon, Collins Creek and to a lesser extent the Northern Boundary Drain during some periods of the mining operation. The water management strategy which has been developed to manage this issue and avoid effects is described in Section 6.3.

4.2 Metals and metalloids

4.2.1 Groundwater

The screening assessment presented in Section 2.7.2.1 identified six parameters with concentrations above the ANZG 95% species protection values: aluminium, arsenic, chromium, copper, nickel and zinc. Of these, aluminium, copper, and zinc were recorded in one of the surface water bodies (the Northern Boundary Drain) on one or more occasions. The maximum aluminium concentration in surface water was slightly higher than the maximum groundwater concentration; the maximum copper and zinc concentrations in surface water were lower than the maximum groundwater concentrations.

Discharge of influent groundwater from the mine pit to surface water has the potential to result in concentrations of aluminium, arsenic, chromium, copper, nickel and zinc to exceed the ANZG 95% species protection values. Bramley (2023) provides a detailed assessment of the potential for adverse effects associated with this proposed discharge.

4.2.2 HMC and backfill material

The screening assessment presented in Section 2.7.3 identified three parameters with concentrations above the ANZG 95% species protection values: aluminium (in HMC, Tails, Slimes and ROM), chromium (in HMC only) and copper (confirmed in Slimes, possibly in other samples).

4.2.2.1 HMC

HMC will be stored on a covered area of hardstanding adjacent to the processing plant. The moisture content of the processed HMC will be low (around 10%), in order to minimise the weight (and hence the cost) of shipping. The volume of water seeping from the HMC will be very low. Any seepage water will be conveyed to the water

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[8] Note that groundwater modelling encompasses 6 years due to an initialising 365 day period added to the front end of the transient simulation.

treatment system, where it will mix with groundwater pumped from the mine pit. The contribution of HMC seepage to the overall metals load entering the water treatment system will therefore be negligible, and no further assessment is considered necessary.

4.2.2.2 Tails

Aluminium is naturally elevated in groundwater beneath the site, with a maximum concentration of 0.1 mg/L recorded (compared to the tails concentration of 0.2 mg/L), and hence the potential for a significant increase in aluminium concentrations in the lagoon is very limited.

The Tails will be pumped back to the mine excavation and will comprise the bulk of the backfill material. As the mine excavation moves forward and groundwater levels recover from in-pit pumping, the tails material will become saturated. Groundwater flowing through the backfill material will then mobilise pore water entrained in the tails. Part of this water is likely to be drawn back onto the pit by pumping in the adjacent active excavation area and part will likely flow downgradient, following the natural flow path to the coast. A proportion of the seepage may discharge into the coastal lagoon, but most of the influx to the lagoon comprises inflows from Collins Creek and hence any seepage from backfilled material to the lagoon would be diluted significantly. The estimated groundwater throughflow rate at the site is 10 L/s (see Section 2.6.7.2). The mean flow of Collins Creek is estimated to be ~ 50 L/s (Section 2.5). Assuming that all groundwater throughflow beneath the site discharges to the lagoon (which is unlikely to be the case, a significant proportion is likely to flow underneath the lagoon and discharge at the coast), the rate of dilution with Collins Creek water will be at least fivefold, giving a maximum concentration of 0.04 mg/L. This is below the ANZG screening value of 0.055 mg/L.

4.2.2.3 Slimes

Slimes, which are expected to comprise 14% of the mass of material excavated from the pit, will be separated from the mineral sand in the pit and immediately discharged to the backfill area. The concentration of aluminium in the Slimes seepage is expected to be lower than that of the Tails based in the data in Table 19 above and hence the water quality assessment for the Tails material above is also applicable to the Slimes.

The copper concentration in the bulk backfill material pore water (comprising 86% Tails and 14% Slimes) can be estimated as a weighted average as follows: Tails Cu = <0.01 mg/L; assume actual concentration = 0.5x detection limit = 0.005 mg/L; Slimes 0.012 mg/L Cu. Weighted average = (0.005 x 0.86) + (0.012 x 0.14) = 0.006 mg/L. Applying a conservative fivefold dilution factor to account for mixing with Collins Creek water gives a copper concentration of 0.0012 mg/L which is less than the NZG screening value of 0.0014 mg/L. This calculation assumes that the copper concentration in all of the groundwater flowing through the backfill material is equal to the initial porewater concentration in the backfill after it is deposited and becomes saturated. In reality the release of backfill porewater into the groundwater system will happen more slowly, as each mine strip is excavated and backfilled. Furthermore, the rate of groundwater flow through the Slimes, being fine grained, will also be significantly less than that of the tails. Elevated copper concentrations in the Slimes pore water will be therefore released more slowly, and therefore subject to more dilution by groundwater inflows from upstream of the mine area, than the Tails. These two things mean that potential concentrations in the lagoon will be much lower than the assessment suggests. Natural attenuation processes may reduce copper concentrations further still, so even if the copper concentration in the Tails is at the detection limit (rather than at 0.5 x the detection limit as assumed above), adverse water quality effects are unlikely.

It is important to note that the backfill material will not constitute an ongoing source of unnaturally elevated metals concentrations because the mineralogy will not be altered, other than removal of HMC. Removal of HMC will reduce the mass of metals present in the saturated material beneath the site and is therefore more likely to cause an overall reduction in dissolved metals concentrations in groundwater and the surface water bodies to which groundwater discharges after the site is rehabilitated.

4.3 Saline intrusion

The Nine Mile Formation sediments across the Cowan Block are coastal deposits and the coastal margin is bathed in saline seawater. Saline intrusion is a consequence of disturbance of the freshwater – saline water interface along the coastline or at depth below fresh groundwater. Unconfined groundwater systems in humid climates, such as the Barrytown Flats, there tends to be a net surplus of freshwater outflowing to the coast. Coffey Partners' electro-magnetic surveys (Coffey Partners, 1991) along the foredune and beach zones of the Barrytown coastline found no evidence of low resistivity (i.e., high electrical conductivity) indicative of saline groundwater. Similarly, deep bores (e.g., drill hole WS-3200-Deep reported in Coffey Partners, 1991) and shallow bores sampled in the foredune immediately inland of the beach encountered low electrical conductivity (plus low chloride when laboratory analyses were undertaken), also indicative of fresh groundwater at the coastline. Nonetheless, unconfined aquifers that experience saline intrusion become saline or brackish at the coastline do so as a process of seawater infiltrating landward across the coastline.

Low salinity electrical conductivity and low chloride concentration have been found in piezometers close to the Canoe Creek Lagoon and the lagoon itself; more recent monitoring has confirmed the outward polarity of groundwater flow. Continuous groundwater level monitoring has confirmed that there is a tidal cyclicity over-printed onto piezometers PZ-06 and PZ-07, but at a low magnitude of 0.05 m (5 cm) per cycle. The derived tidal efficiency of the tide forcing on monitored groundwater adjacent to the Canoe Creek Lagoon was approximately 1.75%.

The illustrative cross-section of a section line through the Cowan Block proposed sand extraction area from the coast to the western margin of the activity area is drawn in Figure 40.

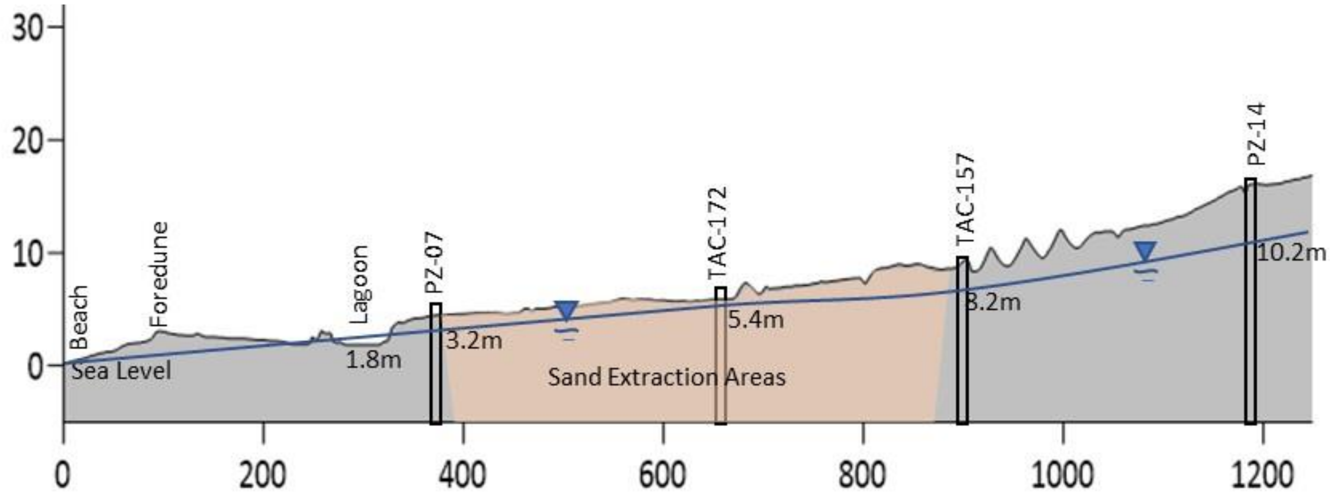

Figure 40: Cross-section from Tasman Sea to PZ-14 through sand extraction areas, including water levels

Evaluation of other aspects of such pre-conditions include the depth of fresh groundwater beneath the sand extraction area is required to ascertain the risk of saline up-coning[9] of a deeper saline groundwater body. The Ghyben-Herzberg Equation posits that there is 40 m of fresh groundwater beneath each 1 m head of water table above mean sea level. As the western margin of the sand extraction area has a November 2022 recorded head above mean sea level of 3.2 m, it is consistent with this equation that at least 128 m of freshwater rests beneath the sand extraction area. This places the fresh-saline water interface within the silty sandstone Blue Bottom Formation, which for the purposes of assessing short term saline up-coning is effectively impermeable, precluding any meaningful potential for saline intrusion in this manner.

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[9] Upconing is the process by which saline water underlying freshwater in an aquifer rises upward into the freshwater zone as a result of pumping water from the freshwater zone.

The chief preconditions of saline intrusion by lateral movement of the fresh – saline water interface are disruptions to the aquifer water balance tipping the freshwater outflow into the negative and the reversal of the previous seaward groundwater gradient. In a setting such as the West Coast, where outward groundwater flow into the sea is the norm, the theoretical reversal of groundwater outflow at the coastline would be as a result of an extractive disturbance to the prevailing groundwater flow pattern (i.e., groundwater abstraction). Large capacity well extraction or dewatering of coastal sediments would be required to induce a reversal of the normal coastwards flow pattern. Reduction of groundwater levels around such a well or dewatering site to significantly below mean sea level is a usual pre-condition to inducing saline intrusion.

The actions of the southwestern infiltration trench in particular, which are proposed to be operating in concert with sand extraction, would return pumped groundwater and re-balance the aquifer water balance to prevent a reversal in the external groundwater gradient. It is anticipated that infiltration trench injection would assist in precluding the potential for saline intrusion.

4.4 Operational materials

Potentially contaminating materials to be used on the site include fuel oils, lubricants and grease and flocculants used for water treatment. These substances will be managed in accordance with usual good practices which will be described under the Hazardous Substances Management Procedure for the site and are not evaluated further in this document.

5 Assessment of Groundwater Quantity-Related Effects

5.1 Groundwater Modelling for Predictions of Effects

Groundwater related effects of the sand extraction proposals comprise the diversion of groundwater gradients as the travelling active sand extraction pit moves across the deposit within the mining boundary. As has been outlined, the in-pit water management would involve supressing the ambient water table by continuous pumping of the excavation at sumps. The artificial hydraulic profile that water table suppression creates changes the previous ambient groundwater flow pattern and may reverse some pre-existing flow gradients.

A numerical model was developed to:

a) Examine hydrologic relationships between the area of sand extraction pit with water table suppression and the responses through the groundwater system, including groundwater level drawdown at a distance and depletion of groundwater connection surface water bodies; and
b) Provide a tool for evaluation of the effectiveness of water management actions to avoid adverse hydrological effects.

5.1.1 Model Implementation

The numerical model employed was MODFLOW (McDonald and Harbaugh, 1988) implemented via Groundwater Vistas (Rumbaugh & Rumbaugh, 2005), which is a pre-processing / post-processing model facilitation package. During the model calibration, the PEST (Doherty, 2003) parameter estimation package was also employed to find the optimal parameter set associated with the conceptual model, prior parameters and field measurements of groundwater levels.

5.1.2 MODFLOW Packages

The following MODFLOW package (subroutines) were employed for specific elements of the modelling process:

- RIV River boundaries were used to simulate the presence of the Canoe, Deverys and Maher creeks
- DRN Drain boundaries were used in a variety of roles, including the following –
    - Creek mouths of Canoe and Deverys creeks to simulate the gain in creek flow from groundwater seepage into the creeks

    - Wetland areas to simulate the 'day-lighting' of the water table and outflow of excess groundwater into the effluent creek, and
    - In the mining simulation, the excavation was simulated by drain boundaries imposing a target water level below the ambient water table.
- WELL boundary conditions were used to simulate the return of the dewatering abstraction to the aquifer via soakage pits or injection wells
- RCH Recharge boundaries across the surface of the active groundwater system, thus simulating land surface recharge to groundwater of excess soil moisture.
- CHD Constant Head boundaries simulating the position of the coastline in Layer 1 (Shallow) and Layer 2 (Deep) aquifer compartments.
- HNF Head No Flow boundaries simulating the presence of low permeability muddy sandstone, granite and greywacke basement rocks east of the Post-Glacial Cliff.

The type and set-up of MODFLOW boundary conditions was altered in the process of a finer scale Telescopic Mesh Refinement (TMR) high resolution simulation focused on the Cowan Block (see section 5.3) within the wider numerical context of the Barrytown Flats MODFLOW simulation described herein.

5.1.3 Ancillary Software

Groundwater Vistas has already been mentioned as a pre-processing / post-processing model facilitation package. Groundwater Vistas also facilitated the generation of model datasets (e.g. formulations of the modules listed above), diversion to PEST and receipt of PEST optimisation results back into the Groundwater Vista domain for post processing. The post-processing package allowed enhanced parameter optimisation and presentation of the water budget results following each model simulation.

PEST (Doherty, 2003) software encompasses a process of guiding MODFLOW through a series of theoretical parameter settings, stochastically comparing the results and progressively optimising independent parameters to the best model solution available from the model formulation. Such parameter optimisation approaches could be described as automated parameter optimisation processes since they reference the parameter optimisation data included in the model set-up.

5.2 Steady State Model Parameter Optimisation

Coffey Partners (1991) provided a snapshot of groundwater levels from early Spring 1990 that could be used as a parameter optimisation dataset for a steady-state model of the Barrytown Flats groundwater system. A total of 38 piezometer and observation bore measurements spread across the length and width of the Barrytown Flats were drawn from August 30th or 1st September 1990 surveys of project bores. Eight measurements related to deep piezometers or bores and were thus assigned to parameter optimisation of Layer 2. The remaining 30 measurements were classed as shallow and assigned to Layer 1.

Model parameter optimisation is essentially adjusting model parameters until model and measured groundwater phenomena, such water levels in bores, correlate to a degree judged suitable by the modeller, after considering data and model limitations and uncertainties. In this case, 38 groundwater measurements spanning the groundwater system were compared with groundwater levels predicted by the model in the same positions and layers. An initial parameter optimisation was undertaken of the Barrytown Flats model based on parameters drawn from the Coffey Partners reports.

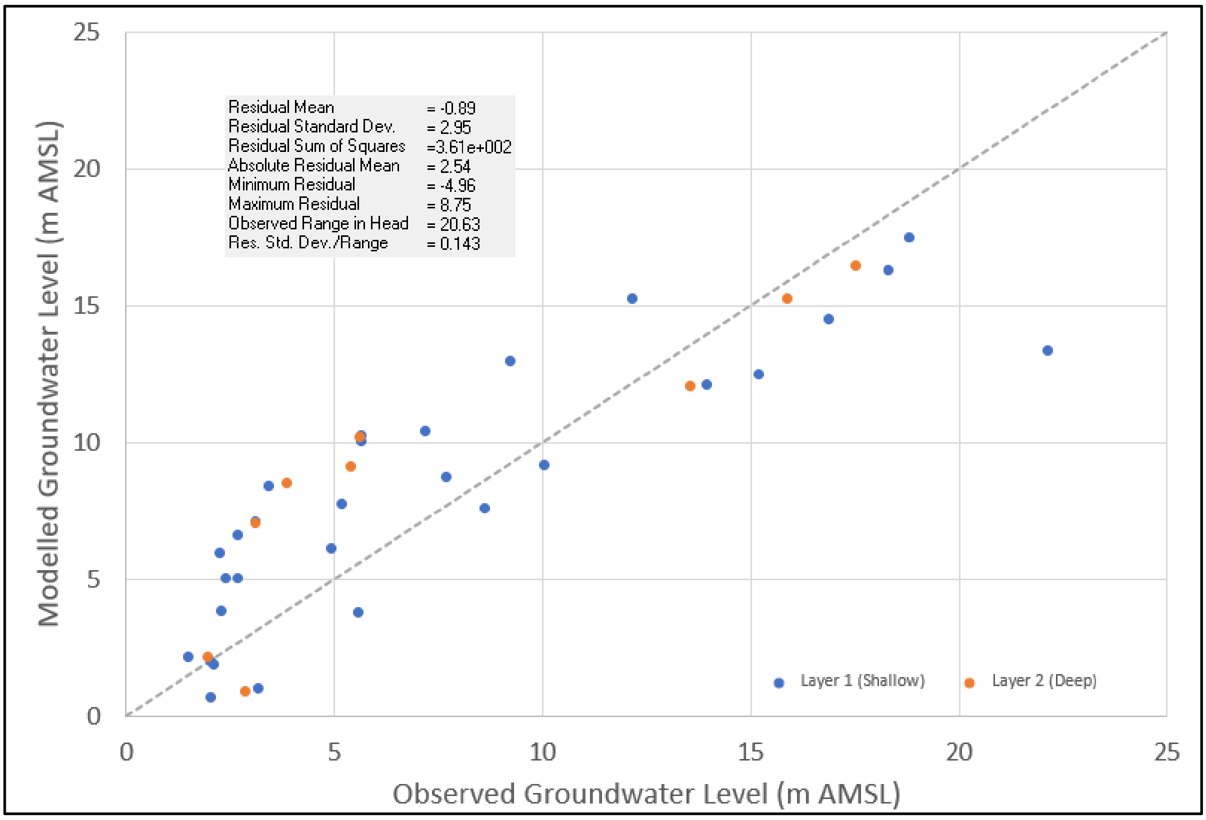

Figure 41: Parameter optimisation results based on initial model run

Figure 41 displays the parameter optimisation results for this initial model run. A caption includes statistical analysis of the results. Significantly, the residual standard deviation divided by the observed range in groundwater level (*Res. Std. Dev./Range*) amounts to 0.143 (or 14.3%). Visually, the plot in Figure 41 shows significant scatter of cross-plot points away from the dashed best fit line. Subsequent to the above initial parameter optimisation run, the model was subjected to lengthy parameter optimisation within PEST. Figure 42 shows the parameter optimisation result after final optimisation.

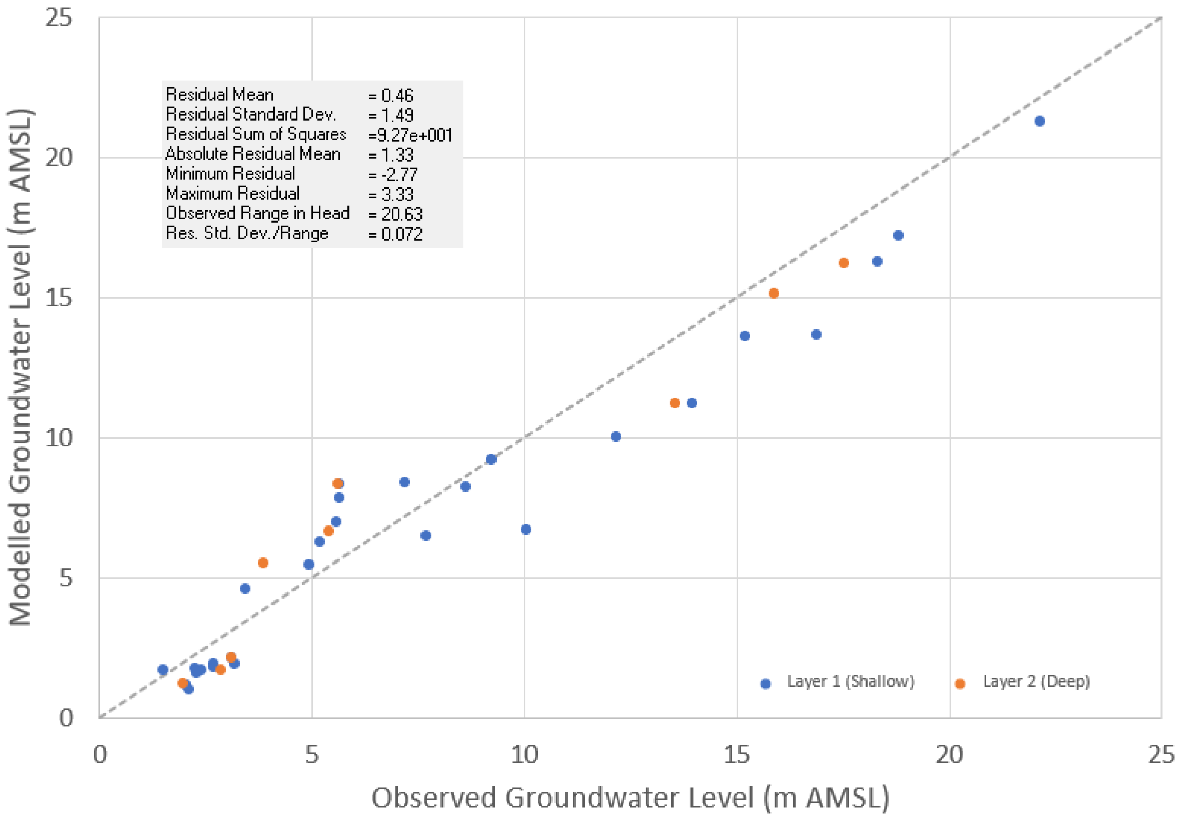

Figure 42: Parameter optimisation results after final parameter optimisation

Comparing Figure 41 and Figure 42 it should be clear that the result of parameter optimisation has been to bring cross-plot points closer to the best fit line and significantly reduce model-to-measurement misfit. The residual standard deviation divided by the observed range in groundwater level has been halved to 0.072 (or 7.2%). Table 20 outlines the impact of parameter optimisation on parameters in the groundwater model.

Table 20: Comparison of initial and final model simulation parameters

Formation / Strata	Coffey Partners' Hydraulic Conductivity (m/d)	Final Optimised Model Hydraulic Conductivity (m/d)	Initial LSR (mm/yr)	Optimised Model LSR (mm/yr)
Transgressive Beach (Shallow, Layer1)	3	6.01*		
Transgressive Beach (Deep, Layer 2)	1.7	0.13*		
Alluvial Fan	3	3.44		
Recent Foredune	6	0.72		
Land Surface Recharge			460	40

Note: * the combined transmissivity of Layer 1 and Layer 2 available to convey groundwater is 122 m^2/d, allowing for layer thicknesses at the modelled hydraulic conductivities for each layer.

The changes in hydraulic conductivity are not as great in their effect on groundwater flows as it appears in Table 20. When the optimised layer 1 and layer 2 hydraulic conductivities are multiplied by their respective saturated thickness and summed together, the resulting average transmissivity of 122 m^2/d can be compared with the combined transmissivity for both layers of 137 m^2/d used in the throughflow estimation (see section 2.6.7.2).

The estimated LSR recharge rate of 460 mm/year within the throughflow estimate assumed all recharge came through the land surface. In fact, recharge in the model environment is a mixture of creek and Land Surface

Recharge (LSR) as the three creeks closest to the proposed mining area are specifically modelled as MODFLOW river boundaries with specified water level and bed conductance parameters. Therefore, model parameter optimisation resulted in only 9% of recharge derived from vertical recharge through the top of Layer 1 (i.e. LSR), in favour of 91% of model recharge originating at river boundaries. It is understood, but more difficult to quantify, that a substantial portion of soil water excess that might otherwise form groundwater recharge is 'refused' by high saturation levels in subsoils or at the near-surface water table. Coffey Partners' report also found that measurement of soil infiltration indicated low rates of infiltration of water through topsoil, silt, clay and peat, being as little as 0.5 mm/hour. This may be consistent with the properties of orthic gley soils that cover the transgressive beach deposits (see section 2.3.3).

Overall, parameter optimisation with PEST has produced a model simulation of the Barrytown Flats groundwater system that replicates what is known of the system from existing data sources with reasonable accuracy. It was therefore concluded that the model provided a sufficiently useful approximation of reality to be suitable for forward modelling to assess the effect of proposed mining on the groundwater and surface water environments.

5.3 Telescopic Mesh Refinement & Re-Optimisation

Because the Barrytown Flats scale MODFLOW model was too coarse for the Cowan Block sand extraction modelling and since high resolution calibration data was available from 2022 monitoring, a refinement of the original December 2020 MODFLOW simulation was conceived and undertaken. The refinement used a method within the United States Geological Survey MODFLOW packages (Leake & Claar, 1999) termed Telescopic Mesh Refinement (TMR) and involves defining a smaller subset of the regional scale model at higher resolution.

A subset of the main model was delineated surrounding the Cowan Block. The new TMR model encompassed the Barrytown Flats groundwater system within the Holocene deposits from the basement contact to the Tasman Sea, plus northern and southern perimeter to either side of the Cowan Block.

Table 21 lists the features of the main model and TMR model. The minimum cell size reduces from 50 x 50 m to 10 m or 20 m (TMR cells are rectangular with a 2:1 ratio of length versus height). The new TMR model has a cell size of 210 m^2, while the main model had a cell size of 2,500 m^2 underlining the increase in model grid resolution available through TMR. The number of active cells correspondingly increases from 6,937 to 14,445 in the refinement process. The TMR model retains a two-layer configuration, and the model grid remains rotated -21.4 degrees from horizontal, as illustrated in Figure 43.

As part of the automated mesh refinement process, the far-field or regional flow patterns are replicated in the TMR version of the model as constant head cell boundaries along the periphery, particularly to the north and south. To this extent the main model calibration and optimisation is retained. However, due to the 2022 acquisition of groundwater parameters (hydraulic conductivity), calibration data (groundwater elevations) and higher resolution boundary elevations from the recent LiDAR survey, the TMR model was re-optimised.

Table 21: Comparison of the Main Model (2020) and refined TMR Model (2023)

Details	Main Model	Telescopic Mesh Refined Model
Number of Rows	167	100
Number of Columns	68	100
Number of Layers	2	2
Total Number of Active Cells	6,937	14,445
Approximate Active Area (ha)	1,700	302

Details	Main Model	Telescopic Mesh Refined Model
Maximum Row Spacing (m)	168	10.1
Minimum Row Spacing (m)	50	10.1
Maximum Column Spacing (m)	168	20.7
Minimum Column Spacing (m)	50	20.7

Note: Both models' grids are rotated -21.4 degrees from horizontal to optimise grid to principal boundaries (e.g. Northern Boundary Drain)

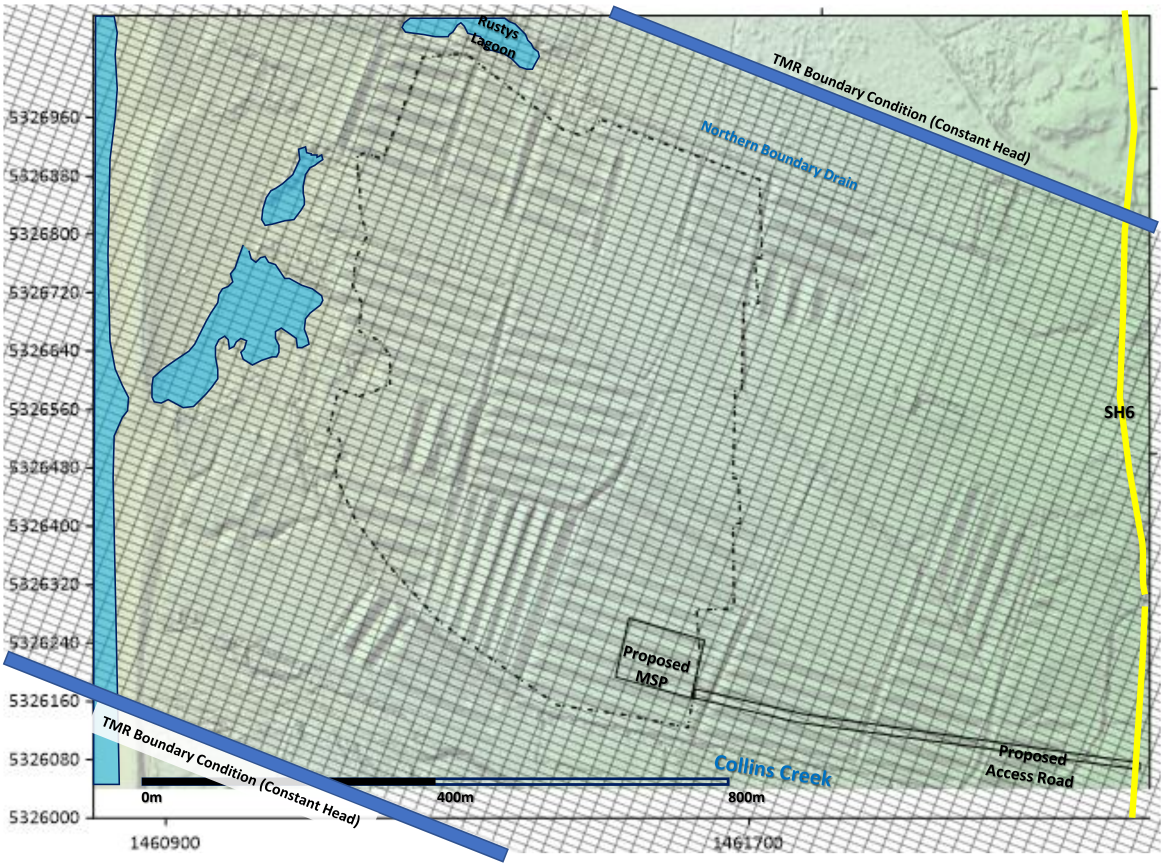

Figure 43: Illustration of mesh refinement and boundary condition assignment in the Telescopic Mesh Refinement process

5.3.1 Re-Assignment of Properties and Boundary Conditions

The re-optimisation process was preceded by a re-assignment of model settings in line with information generated by 2020 field determinations and recent LiDAR digital elevation modelling of the Cowan Block and environs. The re-assignment fall into two main categories –

- Assignment of Layer 1 (i.e., shallow layer) hydraulic conductivity based on the estimated distribution of the parameter arising from field investigations (see section 2.6.7.2 and Figure 30), and
- Assignment and re-alignment of boundary conditions on the basis of better information –
    - Collins Creek as River (RIV) and Drain (DRN) mixed boundary conditions (see Figure 34,

- Northern Boundary Drain as River (RIV) and Drain (DRN) mixed boundary conditions (see Figure 35),
- Mahers Wetland Lagoon as a River (RIV) boundary condition (1.87 m AMSL elevation)
- Rusty Lagoon as a River (RIV) boundary condition (2.48 m AMSL elevation), and
- Coastal lagoons as a DRN (DRN) boundary condition (1.85 m AMSL elevation)

Boundary condition conductance values were specified to high values (typically 10,000 metres per day) since these parameters could not be determined from 2022 field investigations and it would be a conservative stance to employ higher values.

5.3.2 Optimisation

PEST optimisation manipulated hydraulic conductivity in the main hydraulic conductivity zones (see Figure 30) and groundwater recharge. The optimisation ran 5 iterations and 37 model calls, ending in a final phi value of 17.98 and correlation coefficient of 0.97. Assessing the performance of optimised calibration results, the Root Mean Squared Standard Error to measurement range rate (RMSE/Range or Res. Std. Dev/Range) equalled 0.065 (or 6.5%), which is similar to the RMSE/Range ratio achieved in the main model optimisation. The cross-plot of observe / modelled heads and summary calibration statistics are shown in Figure 44. Table 22 lists the recharge and horizontal hydraulic conductivity of the Holocene deposits grouped into zones according to the broad distribution indicated in Figure 30.

Table 22: Optimisation parameter results for groundwater recharge and horizontal hydraulic conductivity.

Parameter	Optimised Value	Unit	Description of Zone or Comment
Global Recharge	36.5	mm/a	Presumably low due to refused recharge
Zone 1 K_h	2.86	m/d	Main fine mineral sand (i.e., “transgressive beach deposits”)
Zone 3 K_h	5.4	m/d	Eastern Gravel Overburden and associated silty sandy gravel (i.e., “elevated terraces”)
Zone 5 K_h	80*	m/d	Sandy gravels peripheral to mineral sand area, sometimes adjoining Zone 3.
Zone 6 K_h	1.9	m/d	Buried strandlines, mostly fine mineral sand (i.e., “transgressive beach deposits”)

Note: * the value of 80 m/d is consistent with the values indicated for ‘gravel with minor sand’ from Table 14.

Table 14 of 2022 aquifer testing results; K_h = horizontal hydraulic conductivity

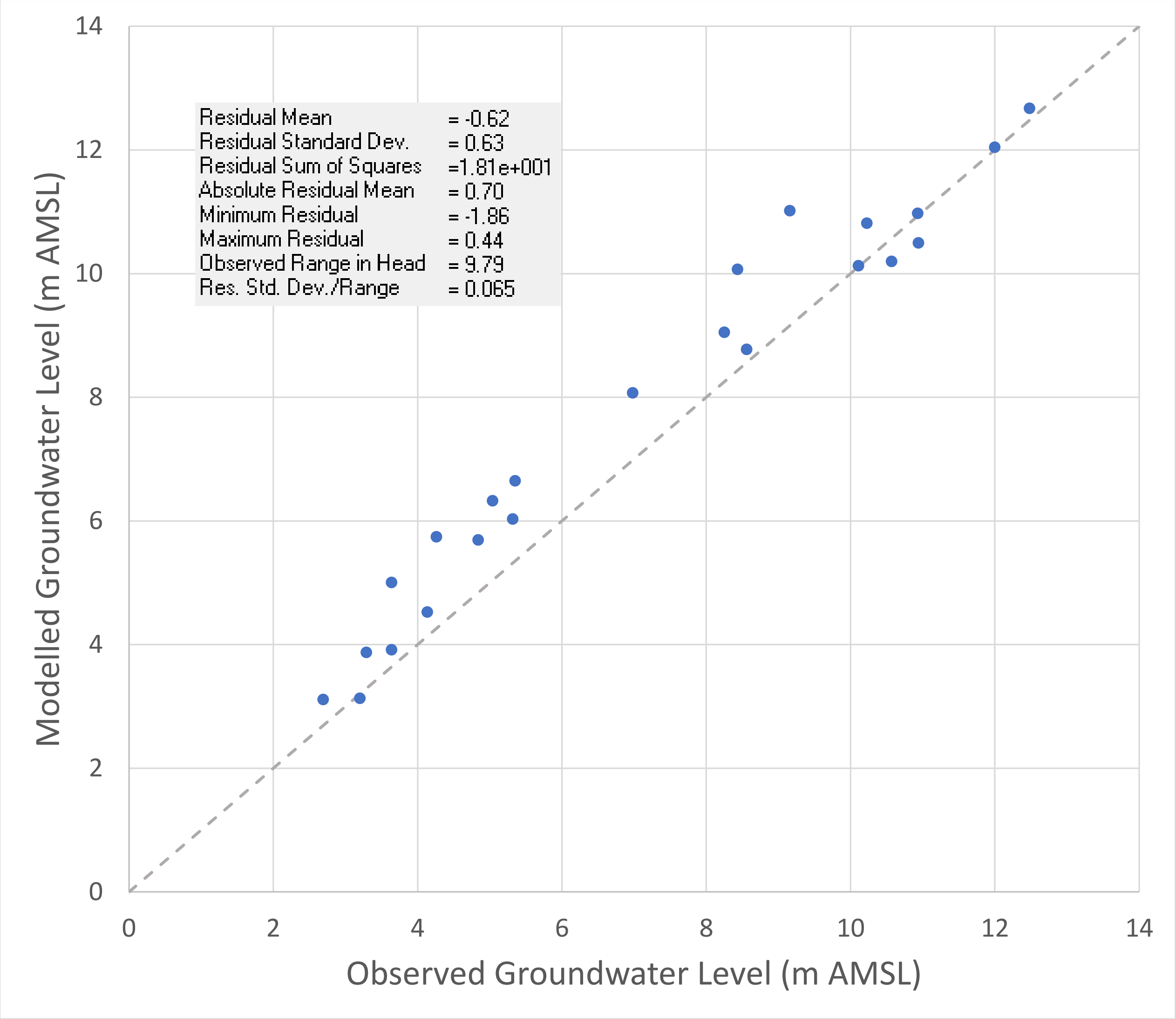

Figure 44: Post-optimisation calibration results of observed versus modelled Layer 1 groundwater levels.

The optimisation process used a steady state simulation and compared model run heads against a snap-shot water table survey.

The underlying Layer 2 horizontal hydraulic conductivity was not altered from the original 75 m/d derived in the main model optimisation. The value of 75 m/d is also consistent with the value accepted for 'gravel with minor sand' that indicated a range in hydraulic conductivity of 58 to 78 m/d on the basis of aquifer testing.

RSC Geological Consultants delineated a 'basal gravel' deposit beneath the mineral sands. The RSC Geological Consultants modelling of Cowan Block was based on drill holes with a mean depth of 11 m (averaging about -3 m MSL) and maximum depth of 17 m BGL. Accordingly, the geological modelling of the top of the basal gravel is based on a relatively small number of drill holes beneath the Cowan Block. The main model and TMR model both simulate a 15 m thickness of Layer 2 basal gravel layer from -5 m to -20 MSL.

The re-optimisation achieved similar performance to the previous optimisation of the main model, while allowing the parameter distributions indicated in field determinations to be tested against site-specific groundwater levels observed in early November 2022. The optimisation process largely maintained hydraulic conductivity at values close to the magnitudes measured in 2022 aquifer testing. The main area of poorer calibration with residuals between 1.0 m and 2.0 m was in the north of the Cowan Block, especially piezometers

PZ-09 to 13 and PZ-17. It is considered that higher errors may be the result of vertical stratification in this area that are not well enough understood to be incorporated in the model formulation. Calibration residuals in the south, east and west of the Cowan Block lie between +0.37 m and -0.85 m, while the mean absolute residual was calculated as 0.7 m.

5.3.3 Discussion

The spatially refined, re-calibrated and optimised model focused on the Cowan Block includes as much reliable new information available from the more recent LiDAR DEM surveys of land surface and water body invert heights and 2022 field investigations or monitoring of surface and groundwater. As such it incorporates significant fresh data and information, plus fresh interpretations of the conceptual model.

Substantial conservatism is built into the groundwater model formulation. The uniform 15 m saturated thickness of gravelly material in Layer 2 is not likely to be so thick nor permeable (80 m/d) with the high model transmissivity implied by those settings. However, these defaults were retained in the interests of groundwater modelling retaining conservativism.

The aquifer testing (see Appendix 1), particularly in test site PB-1 noted the presence of vertical stratification in permeability to groundwater flow between shallow overburden and mineral sand-bearing gravels. Vertical stratification is also presumed be present between ore and proposed to be mined and underlying basal gravels. Such stratification and the vertical flow resistance that this would impart is not included in the final MODFLOW model, which is a further source of intentional conservativism included in the model assessment framework.

6 Management of effects

6.1 Primary effects of In-Pit Pumping

The primary impact of in-pit pumping during the proposed and modelled 5.1 years of sand extraction would be the extraction of volumes of groundwater from the ground to balance the requirement to maintain the in-pit water level required for sand extraction. The rates of groundwater pumping through time were modelled using transient progression of active mining zones across the proposed sand extraction area from mine strip /panel 1 to 10. The rate change as the sand extraction area moves in strips from south to north is shown in Figure 45.

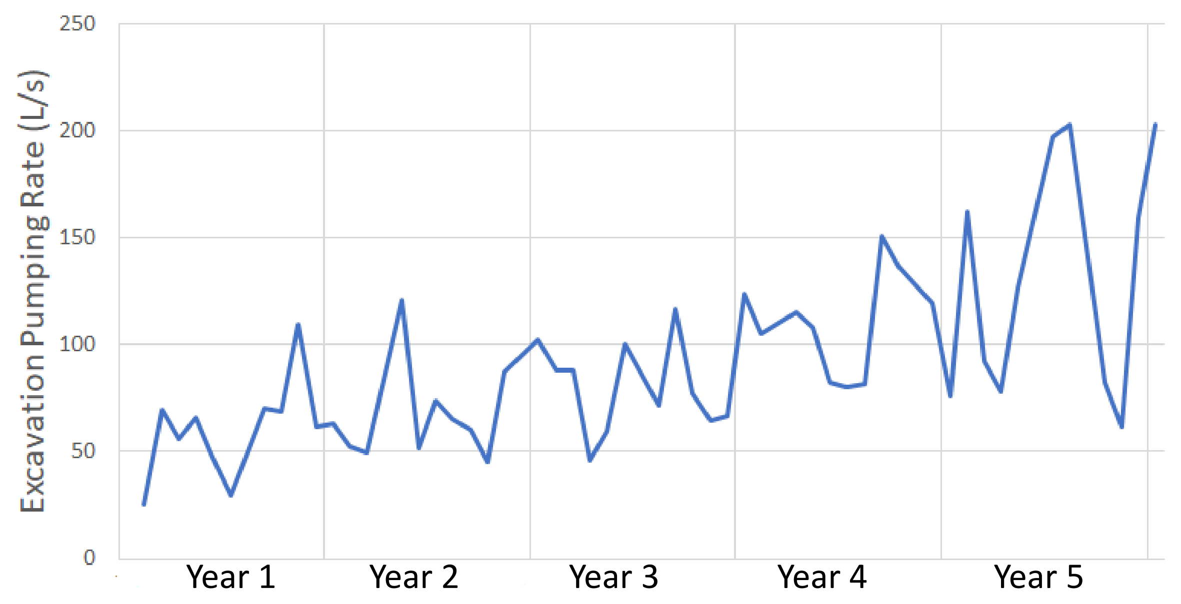

Figure 45: Progression in modelled in-pit pumping rate from start to conclusion of sand extraction over 5 years

The knock-on effects on groundwater levels and distant depletion effects are proportional to the following chief factors –

- The magnitude of in-pit pumping rate,
- The intervening permeability of the groundwater system between the site of the pit and the site of impact, and
- The distance between these sites.

These factors are integral to groundwater model settings and are used to predict the levels of environmental effects arising.

6.2 Water management requirements

Management is required to address the potential water quantity and quality effects listed in Section 3.2.3 and evaluated in the preceding sections of this report. The primary potential water quantity effects of unmanaged sand extraction operation and in-pit pumping are as follow –

- Drawdown and water table suppression extending beyond the limits of the active mining area, and
- Depletion of surface water bodies: the effect of drawdown and re-arranged hydraulic gradient would be to divert groundwater into the sand extraction excavations at the expense of **creeks, drains, springs, wetlands or lagoons** previously receiving groundwater seepage.

Of these two types of effects, drawdown by itself would not require mitigation due to the absence of water bores. However, the effect of altered hydraulic gradients within the groundwater system produces a potential water body depletion effect requiring management intervention. The most readily available means of avoiding depletion for flowing water bodies are groundwater recharge and direct flow augmentation.

The potential water quality effects which require management and fall within the scope of this report are:

a) reduced visual clarity in receiving surface waters due to discharge of potentially turbid water from the sediment treatment system (see ESCP for details);
b) enhanced mobilisation of metals, metalloids and nutrients to surface water bodies associated with discharge of groundwater inflows from the mine excavation; and
c) saline intrusion related to water table decline around the mine excavation near the coast.

6.3 Water management system goals

A water management system has been developed to manage water on the site such that adverse hydrological impacts can be avoided with a high level of certainty.

Water quantity management goals are as follows:

Priority 1: Minimise potential surface water depletion and avoid a reduction in wetland extent and values by minimising the net rate of groundwater pumping from the mine excavation. This will be achieved by design of the mine operation to minimise the area of open excavation below the static water table at any given time, as far as practically possible.

Priority 2: Minimise surface water depletion and avoid a reduction in wetland extent and values by returning groundwater pumped from the mine excavation to the aquifer at the mine boundary. This approach maintains the pre-mining groundwater level in key areas and hence does not result in an increase in the rate of water loss from key water bodies or a reduction in the rate of groundwater seepage to surface water bodies outside of the site boundary.

Priority 3: Minimise surface water depletion and avoid a reduction in wetland extent and values by returning water pumped from the mine excavation via the treatment system to the water bodies that might otherwise be depleted.

Priority 4: Minimise surface water depletion and avoid a reduction in wetland extent and values by augmenting the water bodies that might otherwise be depleted with water from Canoe Creek.

Water quality management goals are:

Priority 1: Minimise water quality changes by minimising the disturbance/alteration of existing water flow paths and the land surface.

Priority 2: Minimise the potential for turbidity, phosphorus and suspended sediment changes in the receiving environment by installing a water treatment system and avoid adverse effects on receiving water clarity and suspended sediment by discharging water from the treatment system to ground. Minimise the potential for adverse ecological effects from naturally elevated metals and metalloids in groundwater pumped from the mine excavation by increasing the hardness in the discharge water, if required.

Priority 3: Minimise potential for changes in visual clarity by discharging any treated water which does not meet the water quality thresholds for Canoe Creek Lagoon/Collins Creek/Northern Boundary Drain to an alternative location, particularly the Canoe Creek Infiltration Basin.

The Priority 2 - 4 water management actions are described below, with comprehensive details provided in the Barrytown Mineral Sand Operation Water Management - Monitoring and Mitigation Plan by Kōmanawa Solutions; and the Erosion & Sediment Control Plan by Ridley Dunphy Environmental.

6.4 Summary of Proposed Water Management

In summary, the proposed water flow and water quality management arising from sand extraction activities comprise the following broad classes of actions –

- Minimising the areas of land disturbance and area of excavation open at any given time.
- Clarifying mine-affected water by settling and iron precipitation coupled with alum addition and hardness adjustment where required to reduce turbidity, dissolved iron and phosphorus concentrations and the potential toxicity of dissolved metal/metalloid elements at the following sites:
    - Primary treatment ponds 1 & 2,
    - Limestone drains/lime dosing in the central drain/Pond 1-3, and
    - Terminal treatment ponds 3 & 4.
- Augmenting groundwater by injection of treated or Canoe Creek water via a mine perimeter infiltration system as follows:
    - Northern boundary by infiltration trenches supplemented with recharge barrier wells if required,
    - Collins Creek and coastal lagoon by infiltration trenches supplemented with recharge barrier wells if required.
- Direct augmentation by clean water discharge at the following sites:
    - Collins Creek upstream of the farm ford,
    - Northern Boundary Drain.
- Discharge of excess system water at the Canoe Creek infiltration basin, where the outflow would discharge to land by groundwater seepage or overland flow across farmland to the Canoe Creek riverbed at the mouth,
- Abstraction of Canoe Creek using a bank infiltration gallery on the edge of the river or a direct river intake. A gallery intake would draw clean water even when Canoe Creek was turbid due to the filtration effect of water passage through river gravels.

A schematic flow chart of the water exchanges within the hydrological and water treatment mitigations is shown in Figure 46; a map of the proposed water management and monitoring system is provided in Figure 47.

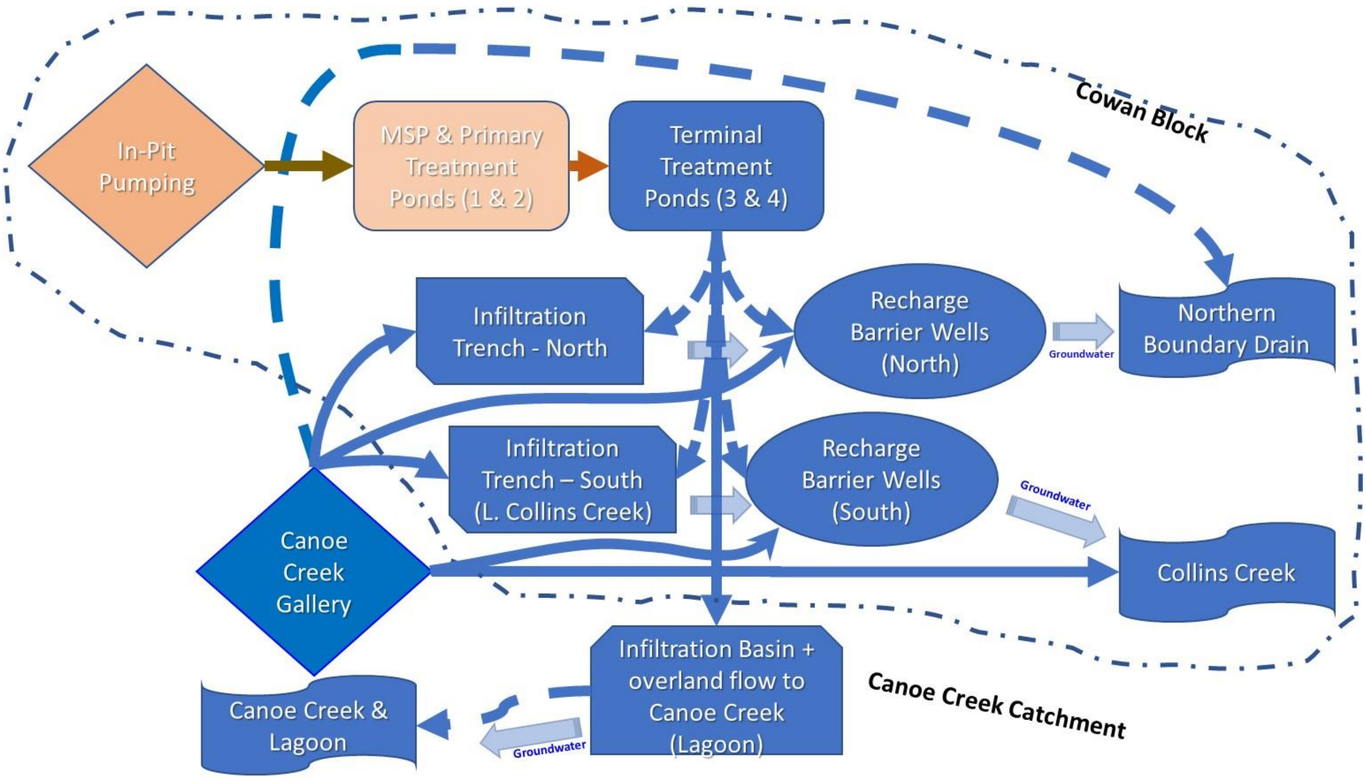

Figure 46: Schematic flow chart of the proposed hydrological and water treatment mitigations[10].

Water management will be tied to monitoring of the mine processing, water treatment and hydrological stations as follows –

- Monitoring of treatment ponds and forebays will inform batch exchange rates in the respective treatment stream, use of flocculants, aeration and other water quality amendments,
- Monitoring of the Processing Plant water and solids balances will inform the management of deficits and surpluses of water,
- Monitoring of Collins Creek upstream and downstream of the mining area will identify the requirement for augmentation by either infiltration or direct discharge,
- Monitoring of perimeter piezometers for groundwater levels will inform the planning for infiltration trenches or recharge barrier wells and discharge to the Northern Boundary Drain (to maintain water levels in the Northern Boundary Drain, the Rusty Lagoon and connected wetland water levels) and monitoring of the infiltration structures such as infiltration trenches, recharge barrier wells or infiltration basins in terms of operating water levels, acceptance rates and any overflows or indications of the need for maintenance.

Sensor technology and automation of pumping with variable speed drives and valve actuation will link the monitoring system with tailored mitigation responses.

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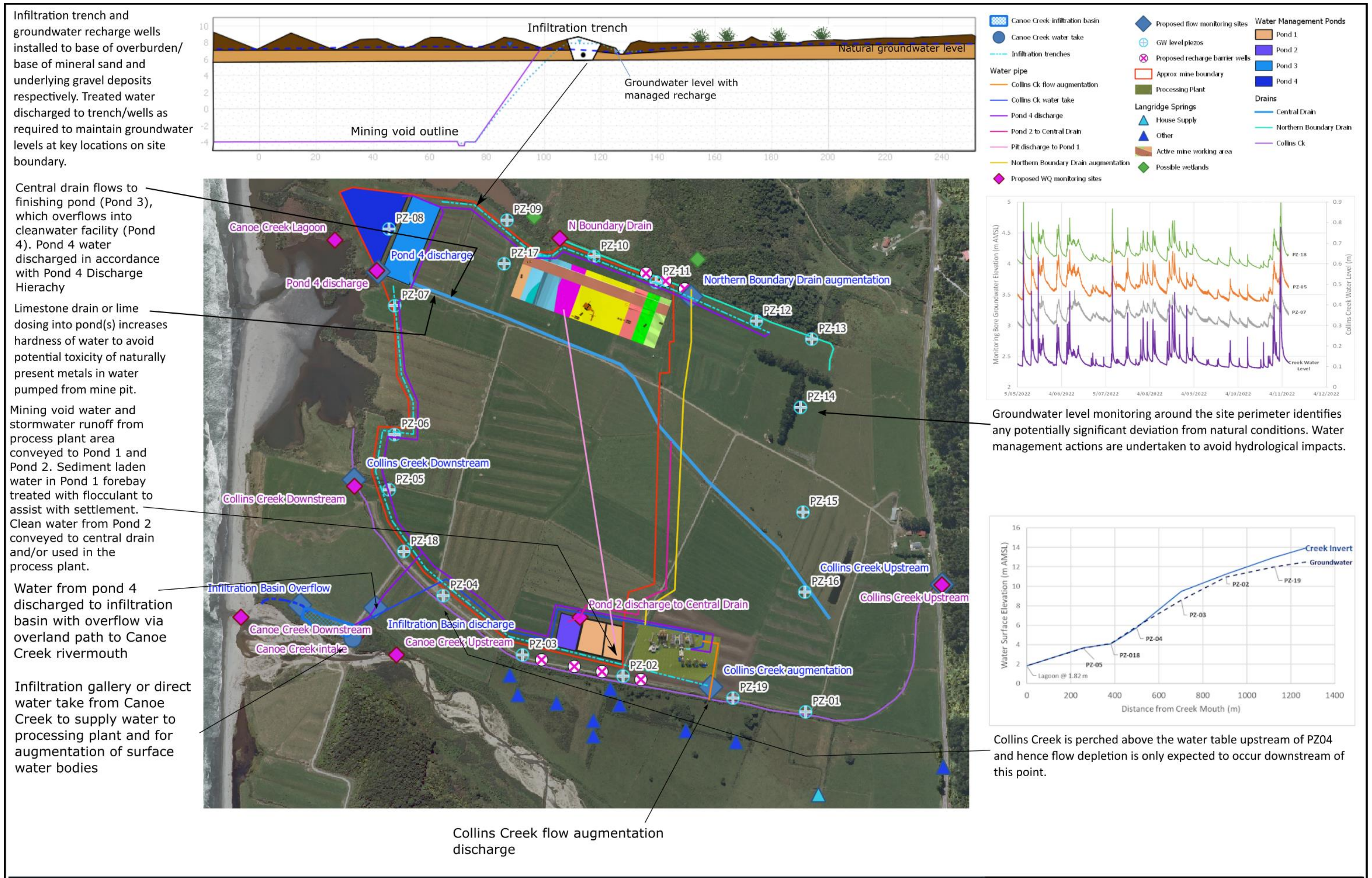
[10] Note: Solid transfer lines indicate the usual or preferred transfer pathway, while less usual or less preferred transfer path.



Infiltration trench and groundwater recharge wells installed to base of overburden/ base of mineral sand and underlying gravel deposits respectively. Treated water discharged to trench/wells as required to maintain groundwater levels at key locations on site boundary.

Central drain flows to finishing pond (Pond 3), which overflows into cleanwater facility (Pond 4). Pond 4 water discharged in accordance with Pond 4 Discharge Hierachy

Limestone drain or lime dosing into pond(s) increases hardness of water to avoid potential toxicity of naturally present metals in water pumped from mine pit.

Mining void water and stormwater runoff from process plant area conveyed to Pond 1 and Pond 2. Sediment laden water in Pond 1 forebay treated with flocculant to assist with settlement. Clean water from Pond 2 conveyed to central drain and/or used in the process plant.

Water from pond 4 discharged to infiltration basin with overflow via overland path to Canoe Creek rivermouth

Infiltration gallery or direct water take from Canoe Creek to supply water to processing plant and for augmentation of surface water bodies

Groundwater level monitoring around the site perimeter identifies any potentially significant deviation from natural conditions. Water management actions are undertaken to avoid hydrological impacts.

Collins Creek is perched above the water table upstream of PZ04 and hence flow depletion is only expected to occur downstream of this point.

Collins Creek flow augmentation discharge

KSL
Kōmanawa Solutions Ltd

Project: Barrytown Mineral Sands
Title: Water Management Concept 1a
Date: 07/03/2023

Figure 47: Indicative water management and monitoring system (see Figure 50 for Canoe Creek detail)

6.5 Water Transfer and Augmentation Structures

6.5.1 Perimeter Infiltration System

The proposed means of mitigating this groundwater lowering effect is to install an infiltration trench system combined with four deeper recharge barrier wells along the southern boundary in the land between the sand extraction margin and Collins Creek. The dual mitigation objectives can be explained as follows:

- Infiltration trenches installed along the Cowan Block boundaries to bolster the groundwater levels and creek or drain flow rates, which in turn
- reduce any tendency of springs, Collins Creek or wetlands across the northern boundary to be subjected to water levels declines.

6.5.1.1 Infiltration Trenches

The infiltration galleries or trenches are expected to extend for approximately 700 m and 1,300 m lengths along the northern and south - western boundaries respectively. The infiltration systems for groundwater and creek or wetland augmentation are designed to mitigate groundwater level decline and/or surface water depletion exerted by in-pit pumping at the sand extraction zones.

In simplest terms the gallery is proposed as a buried perforated pipe in gravel trench backfill overlain by a sand filter for downward infiltration from the trench surface, as shown in Figure 48. The trench would be taken to a depth appropriate to enable optimal contact between the injection structures and the groundwater system. A full description of the infiltration trench system operation and maintenance is provided in the Water Management, Monitoring and Mitigation Plan.

The discharge would cause water table mounding beneath and adjacent to the trench and a more general groundwater raising over a wider area.

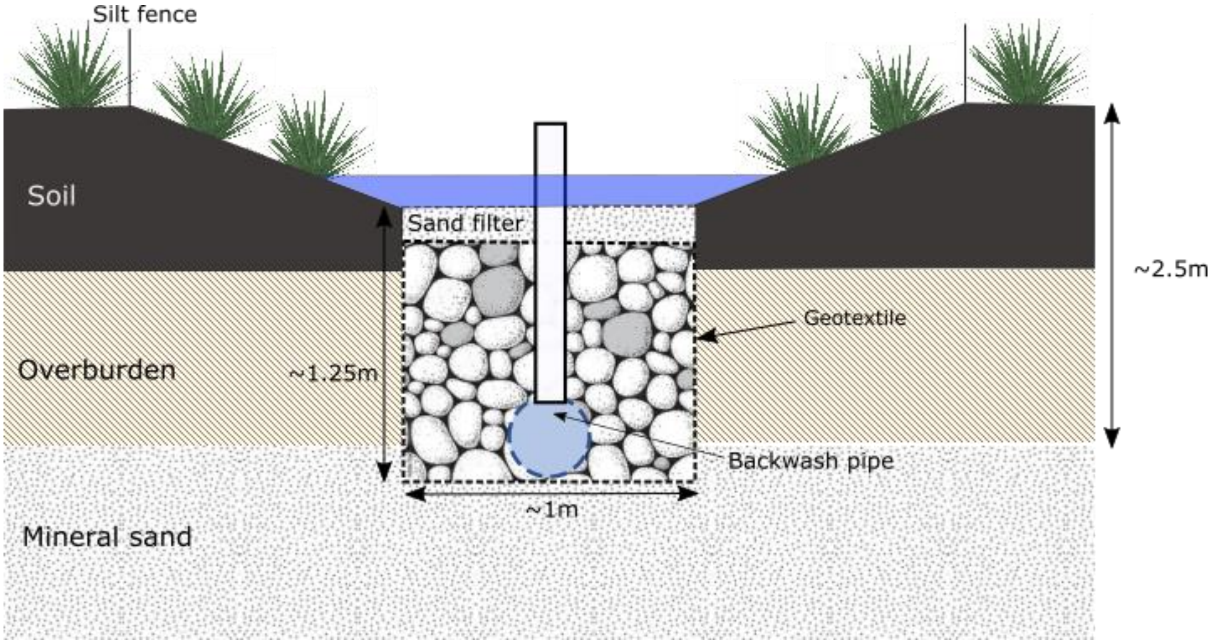


Figure 48: Schematic of infiltration trench showing trench void, gravel backfill and perforated PVC pipe

6.5.1.2 Recharge wells

The principal of an array of recharge barrier wells is to infiltrate water into the groundwater system at a site conducive to offsetting any declines in groundwater level arising from sand extraction activities in a specific location. The vertical tube well nature of injection wells is such that the depth of injection is typically greater than infiltration trenches, which are for a number of reasons shallower and even above the water table. Recharge barrier wells can supply water to the groundwater system at the base of the ore sand zone or the basal gravel depths while still serving to raise groundwater levels locally.

The proposed recharge barrier infiltration wells are individual vertical wells drilled and constructed with blank casings and screen intervals in much the same manner as groundwater production wells. In hydrogeological settings such as the Barrytown flats the performance of a well in pumping (extracting) water is much the same as performance in injecting water, provided sedimented sediment content is sufficiently low to prevent clogging of the contact zone with the groundwater system. In other words, if a well can be pumped at unit rate for unit drawdown, then the same well injected with water at the same unit rate would manifest the same groundwater level mounding. This was proven via the injection well trial undertaken at the site during field investigations in 2022 (see Section 2.6.5). Figure 49 illustrates in profile the relative equivalence of the drawdown and mounding of the groundwater system water table.

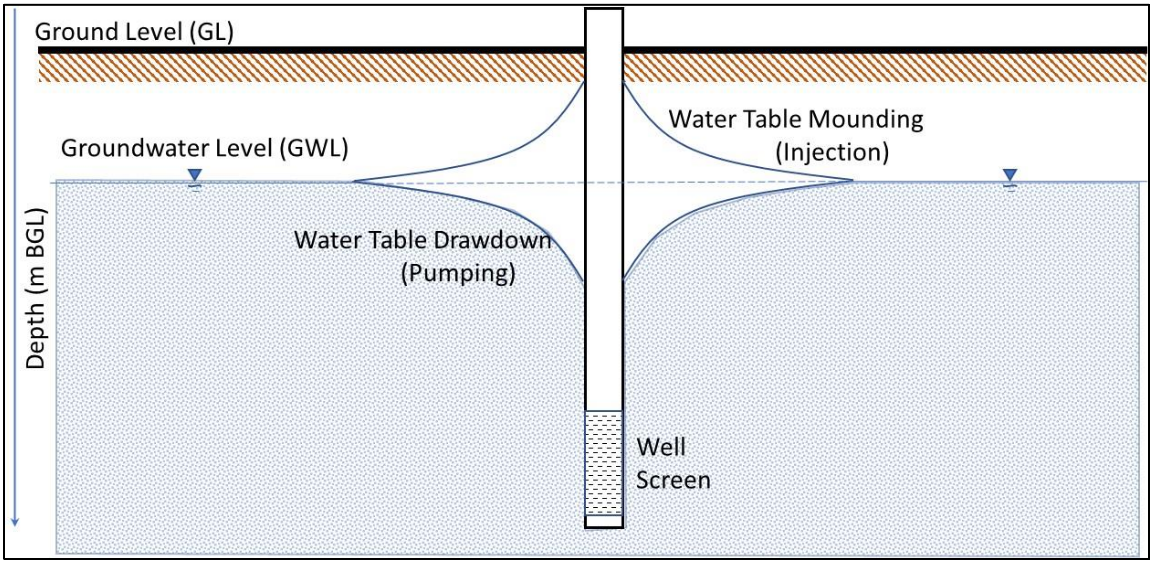


Figure 49: Schematic representation of mirroring of pumping drawdown and water table mounding under water injection.

Since pumped drawdown and injection mounding are calculable by the same hydraulic properties and equations, mounding heights above the water table can be calculated. The depth from ground level in the vicinity of the proposed recharge barrier well is measured as approximately 1.2 m below ground level (BGL). The land surface is projected to be raised in a berm and the well head can be raised about 1 m above the new ground level. Placing these dimensions together, the most probable freeboard for injection mounding would be 3.0 m. Estimates of capacity indicate that for an injection well screen entirely within the following lithologies the maximum injection rates would be –

- Ore sand with minor gravel, injection = 1.5 L/s
- Gravel in ore sand matrix, injection = 5 L/s
- Sandy gravels (i.e., transmissivity > 300 m^2/d), injection = 15 L/s

In practice, the recharge barrier injection wells would be selected for the higher injection rates such 5 L/s for shallow screen setting and 15 L/s for deeper screen installations.

Recharge barrier wells have the advantage of being possible to regularly flush and remediate for the effects of clogging. The remediation methods available for wells are as follow –

1. Air lift flushing with agitation,
2. Over-pumping and surge block, or
3. Jetting lance.

6.5.2 Canoe Creek Infiltration Basin

Figure 51 below (taken from the Barrytown Mineral Sand Operation Water Management - Monitoring and Mitigation Plan) shows the location and general geometry of the basin to be established on the north bank of Canoe Creek. It shows an existing landform somewhat suitable for use as a basin, albeit benefitting from minor re-profiling to optimise the landform. The infiltration basin with a base elevation between 5.2 m and 4.8 m AMSL is located on the terrace above Canoe Creek riverbed, the riverbed has an elevation of approximately 3.8 m AMSL as it passes alongside the basin. The basin is 1,400 square metres in extent and would be reprofiled as shown in Figure 51 to receive excess water piped to the basin for infiltration into the underlying sandy gravel alluvium.

The recharge capacity of the infiltration basin is somewhat uncertain at present, but experience with infiltration trenches installed in clean river channel and over bank deposits[11] has shown that infiltration of 80 L/s to ground over is possible over a 300 m² area, subject to periodic maintenance to remove clogging material.

The Canoe Creek basin could be expected to have a similar water acceptance rate initially but would likely decline over time until maintenance is undertaken to restore the original capacity. Accordingly, basin would include an overflow structure so that elevated basin water levels would be discharged through a control structure onto an existing drainage pathway (see Figure 50). Either the excess basin water would be infiltrated through soils or take the existing overland path to the Canoe Creek Lagoon / Mouth area. Further details are provided in the Water Management, Monitoring and Mitigation Plan.

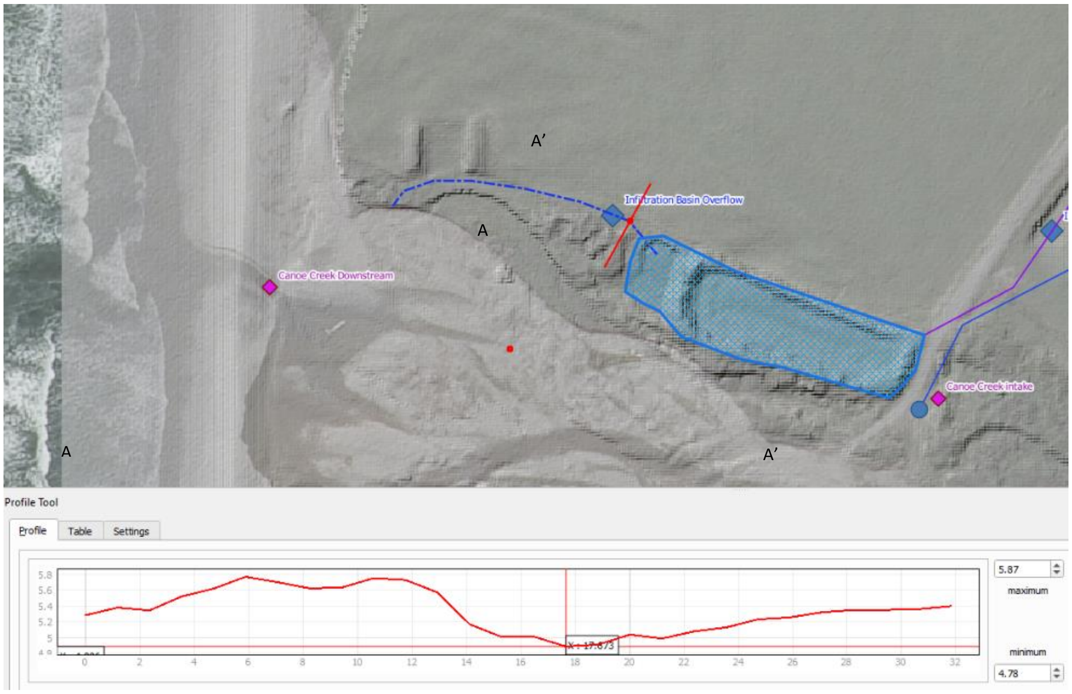


Figure 50 **Existing drainage pathway downstream of proposed infiltration basin**

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[11] See https://www.stuff.co.nz/the-press/news/north-canterbury/108015251/work-continues-to-reduce-nitrate-levels-at-silverstream-near-kaiapoi for example of 150 m x 2 m trench recharging 80 L/s to ground

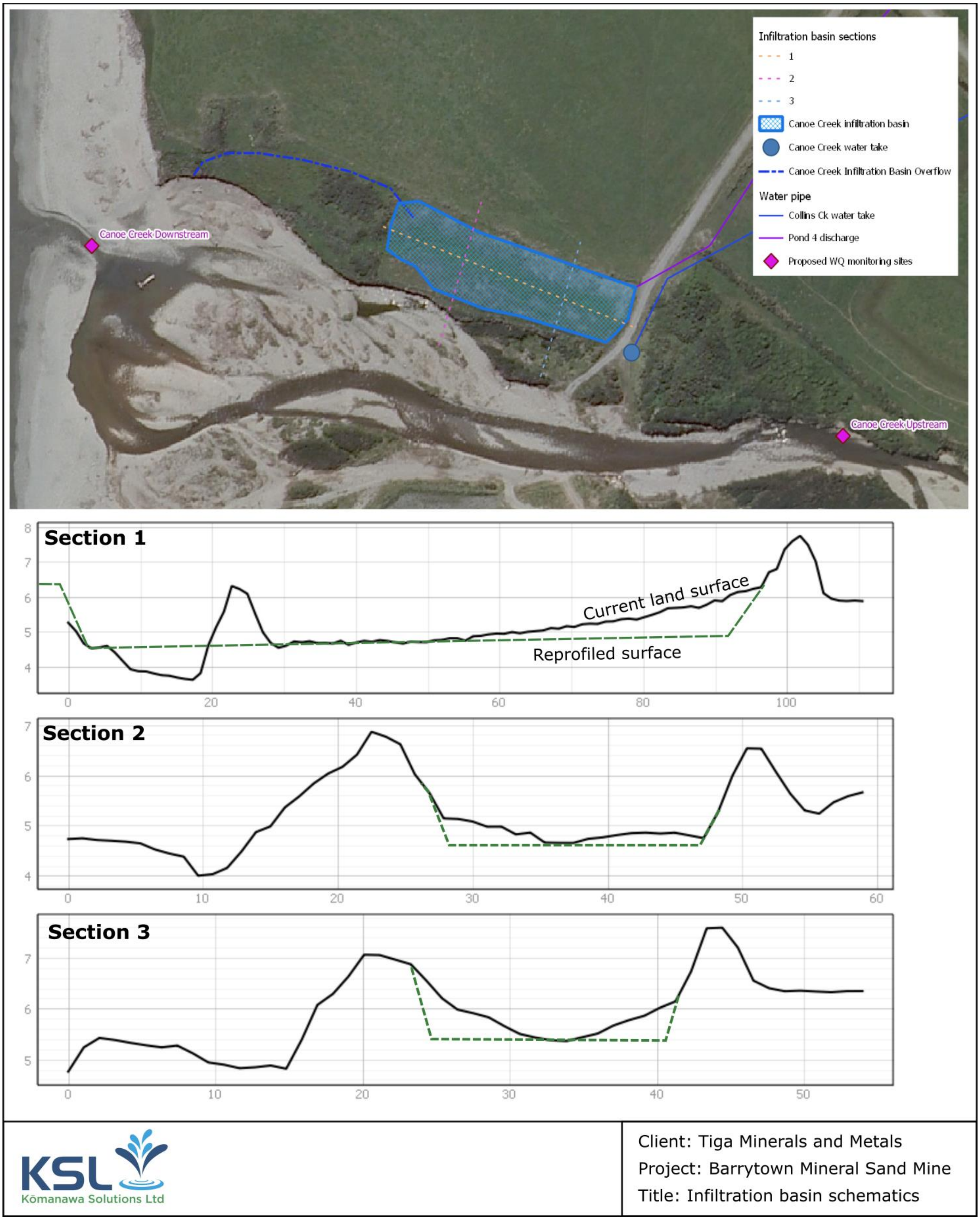

Figure 51: Location, setting and proposed reprofiling of the land surface to provide a 0.15 ha infiltration basin.

6.5.3 Canoe Creek Direct Take or Bank Infiltration Gallery

A direct surface water take or, more likely, a bank infiltration gallery would be established in the north bank / bed of Canoe Creek adjacent to the farm track terminus in the creek bed and to the immediate east of the infiltration basin as shown in the map portion of Figure 47 (labelled “Canoe Creek water intake”). The maximum rate of take would be 63 L/s, which is 10% of the MALF. The infiltration gallery option would encompass a horizontal slotted pipe lain in a trench and backfilled with coarse graded gravel to maximise entry rates for groundwater as shown in Figure 52. Being installed in the Canoe Creek gravel fan in proximity to the active creek channel(s), the gallery would draw in creek water. The chief benefits in using this approach would be relative invulnerability to flood damage by being buried and outside of the active creek bed and the treatment of water moving through creek bed gravel in removing suspended sediments or turbidity.

Figure 52: Example of infiltration gallery construction [photo credits to Butt Drilling Ltd (buttdrilling.co.nz)]

6.5.3.1 Water Treatment Infrastructure

The requirements for mitigation of turbidity, iron and toxic metal content in waters circulating within the managed mine water systems would require the construction and commissioning of ponds and associated plant to allow for settling, aeration and hardness adjustment. These processes fall into the following categories –

- Settling ponds, including
    - Initial forebays for the collection of readily settleable sediments, and
    - Programmed cleaning of settling ponds to remove solid sediment for co-disposal in mine tailing areas,
- Floating aerators in settling ponds and/or drop structures designed to maximise aeration effect,
- Limestone drains, such as limestone-lined sections of the central drain to provide hardness adjustment and facilitate dissolved metals removal or direct lime dosing into the treatment train, and
- Targeted flocculant dosing to enhance phosphorus removal, settling and clarification of settling pond water; both alum and iron-based flocculants are proven treatment agents.

Further details of the sediment treatment infrastructure are provided in the ESCP.

The main aim of the water treatment infrastructure is to produce an appropriate standard of terminal pond water quality for either discharge via the Canoe Creek Infiltration Basin or use in augmentation structures (infiltration trenches, recharge infiltration wells, or Collins Creek direct discharge). The interface surfaces of subsurface structures such as the slotting / screens of infiltration trenches or recharge infiltration wells are susceptible to clogging by suspended sediment particles. Clogging using higher suspended solids containing augmentation water would have the effect of reducing the infiltration capacity of the structures until remediation could be undertaken.

6.6 Operation of Water Management System

The interaction of the onset of water-related effects and deployment of mitigation measures sets up several dependencies, such as –

- Establish the guiding monitoring network for decision-making as to the timing of water transfers, treatment and discharges to the ground or surface water for augmentation,
- Constructing and commissioning water transfer and augmentation structures ahead of the need to provide mitigation of depletion effects,
- Constructing, operating and maintaining water treatment systems (settling ponds, aeration, hardness adjustment, etc.) for the provision of water at appropriate water quality for discharge or augmentation,
- Establishing a supplemental water supply intake adjacent to Canoe Creek for make-up water to be used in augmentation,
- Establishing a supplemental water discharge system at the Canoe Creek Infiltration Basin to allow balancing discharges of treated water.

Figure 53 shows the operational process that will be implemented to determine where treated water from Pond 4 (the final element of the treatment train) will be discharged to in accordance with the prioritised goals in 6.3 above. Excess water is defined as flows greater than the infiltration capacity of the mine boundary perimeter infiltration trenches and recharge wells.

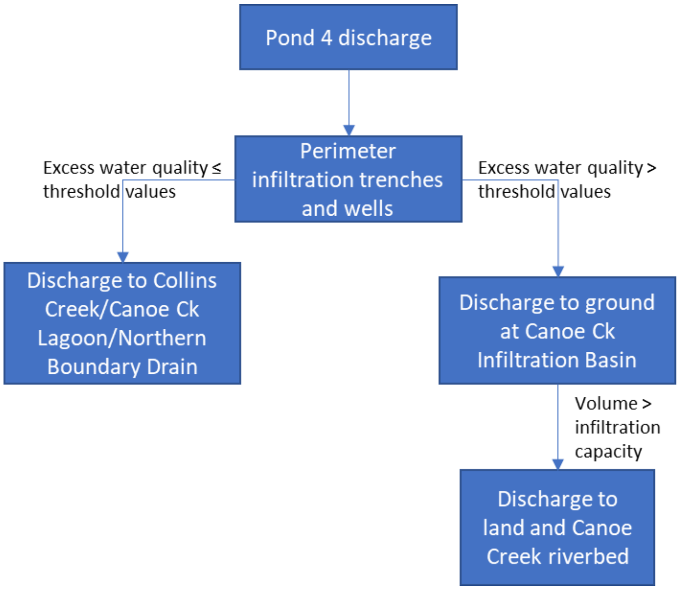

Figure 53: Pond 4 discharge hierarchy

The planning for the timing and augmentation rates would be guided by groundwater modelling, the hydrological monitoring system already mentioned, and other data sources such as short-term mine planning or weather forecasts. The rationale for utilising groundwater modelling is that depletion effects on creeks, drains, lagoons and wetlands is in practice difficult to predict or measure without modelling tools. In addition, by combining the use of modelling, monitoring and measuring augmentation it is feasible to develop an improved conceptual model of the effectiveness and benefit of augmentation over time.

It is likely that the rate of groundwater inflow to the mine excavation will be less that the infiltration capacity of the mine perimeter groundwater recharge system for some periods of the mine life. The groundwater model described in Section 5 was deployed to determine the priority locations for managed groundwater recharge during the various stages of the mine life as described below. Model results provided below indicate that depletion of boundary groundwater levels and water levels in nearby surface water bodies will be minimised by discharging treated water from the mine excavation to the perimeter infiltration system as follows:

- To the South western trench when mining strips 1 – 4,
- To the Northern trench when mining strips 5 – 8, plus the strip adjacent to Ponds 1 & 2.

6.7 Simulation of Perimeter Infiltration System

Flux boundaries, primarily well (WEL) cells were employed within MODFLOW to simulate the lineation of injection trenches and recharge barrier well fields. The northern boundary utilised the modelled groundwater lowering effect to assign requisite infiltration rates to maintain groundwater levels at the boundary within the median groundwater level band. The well alignments simulating proposed infiltration trenches were operated in transient mode, meaning transient infiltration rates were specified based on modelled level lowering effect along segments of the respective project boundaries.

6.7.1 Northern Boundary – Maintenance of Groundwater Levels

6.7.1.1 Northern boundary values for protection & mitigations

The sand extraction area and the Cowan Block has a northern boundary generally defined by the Northern Boundary Drain.

The principal hydrological and associated values for which avoidance or mitigation measures would be sought include the Northern Boundary Drain, the wetlands on the other side of the property boundary, including the flax wetlands on the upstream side of Rusty Lagoon and the area of kahikatea in the vicinity of PZ-12. The lagoon comprises a former mining excavation below the natural water table and is therefore considered to be in direct hydraulic continuity with the surrounding water table aquifer. Groundwater level monitoring in well PZ-09, located approximately 10 m from the edge of the lagoon, is therefore a suitable proxy for the water level in the lagoon and any surrounding wetland vegetation. Prevention of mining related groundwater level declines below the pre-mining median groundwater level in the site boundary monitoring wells would therefore avoid adverse hydrological impacts on these water features. Discharge of water of appropriate quality to the Northern Boundary Drain would also maintain water levels in Rusty Lagoon and surrounding wetland vegetation.

6.7.1.2 Monitoring results

Perimeter monitoring bores were installed in April 2022, including five along the northern boundary given this flank's significant wetlands values on the opposite side of the Northern Boundary Drain and fringing Rusty Lagoon. The sand extraction areas pass within 50 m of the property boundary. Within the transient groundwater model and analysing the simulated mining period, it is evident that later stage (Year 4 to 5) sand extraction would result in lowering in the groundwater levels, affecting groundwater – surface water interactions such as the seepage of groundwater into Northern Boundary drain, wetlands to the north of the property boundary and Rusty Lagoon.

The time trends of two of the northern boundary piezometers fitted with automated dataloggers show similarities with each other that extend over the other four groundwater level records in the Cowan Block. A pattern of a wider range of groundwater level fluctuations in the furthest east piezometers is evident. Median and mean statistics lie close together in each case. Piezometer PZ-10 is perhaps more influenced by variation in the lower Northern

Boundary Drain or Rusty Lagoon than PZ-12, which may be more influenced by overlying soil drainage. Figure 54 and Table 23 provide context and information on the groundwater level time series and associated hydrological statistics.

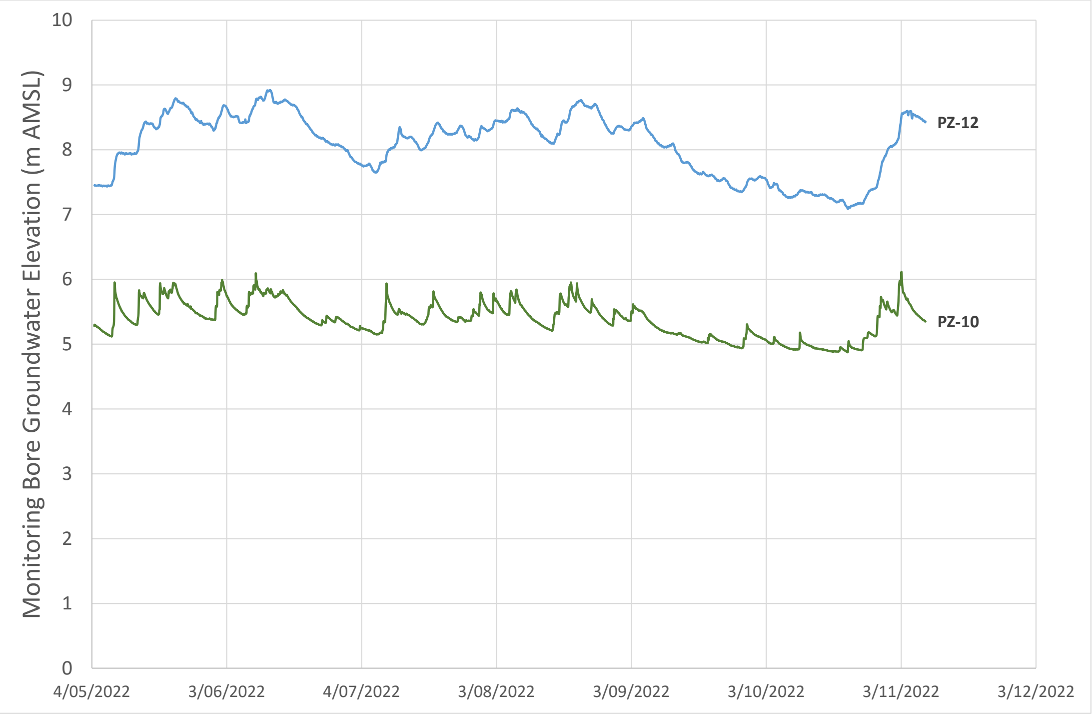

Figure 54: Measured groundwater levels along the northern boundary at PZ-10 and PZ-12 as elevation

Table 23: List of groundwater level statistics along northern boundary

	Monitoring Piezometer	
	PZ-10	**PZ-12**
Position	East	West
Duration (May – November)	6.2 months	6.2 months
Minimum (m)	4.88	7.09
Maximum(m)	6.12	8.92
Range of Measurements (m)	1.24	1.84
Median (m)	5.40	8.20
Mean (m)	5.38	8.09

6.7.1.3 Northern Perimeter infiltration system

Infiltration trench

The implementation of an infiltration trench system was undertaken in the TMR groundwater model as set of well boundary reaches from the west near Maher Swamp and to the east in the upper sections of the Northern Boundary Drain. Water was simulated to be injected into the well boundaries in proportion to the depletion rates estimated from model simulations without mitigation measures included. Groundwater model analysis of the proposed mitigation using infiltration trenches indicated that following estimated parameters –

- Mean injection rate = 7.5 L/s
- Peak injection rate = 29 L/s
- Length of gallery injection = 900 m (albeit, most concentrated over westernmost 500 m)
- Unit length injection rate = 2.8 m^3/d/m

Figure 55 illustrates the time trend of groundwater monitoring bores approximating perimeter monitoring piezometers extracted from the TMR model transient simulation over six years (5.1 years with sand extraction active). This time series plot indicates the maintenance of circum-median groundwater levels, with deviations being limited to short transient spikes and declines in one particular case for PZ-11. Monitored groundwater levels for the May - November monitoring period[12] have been overlaid on the plot as a repeating sequence to illustrate the potential change in natural variability. Although declines below the median groundwater level will generally be avoided, water level spikes above the median will still occur following rainfall events. Seasonal low flows in the Northern Boundary Drain and groundwater levels further north (e.g., in the wetlands north of the site boundary) are likely to be maintained at a higher level than they would normally be by the proposed water management system, but natural variability would still occur in response to weather and seasonal climate patterns.

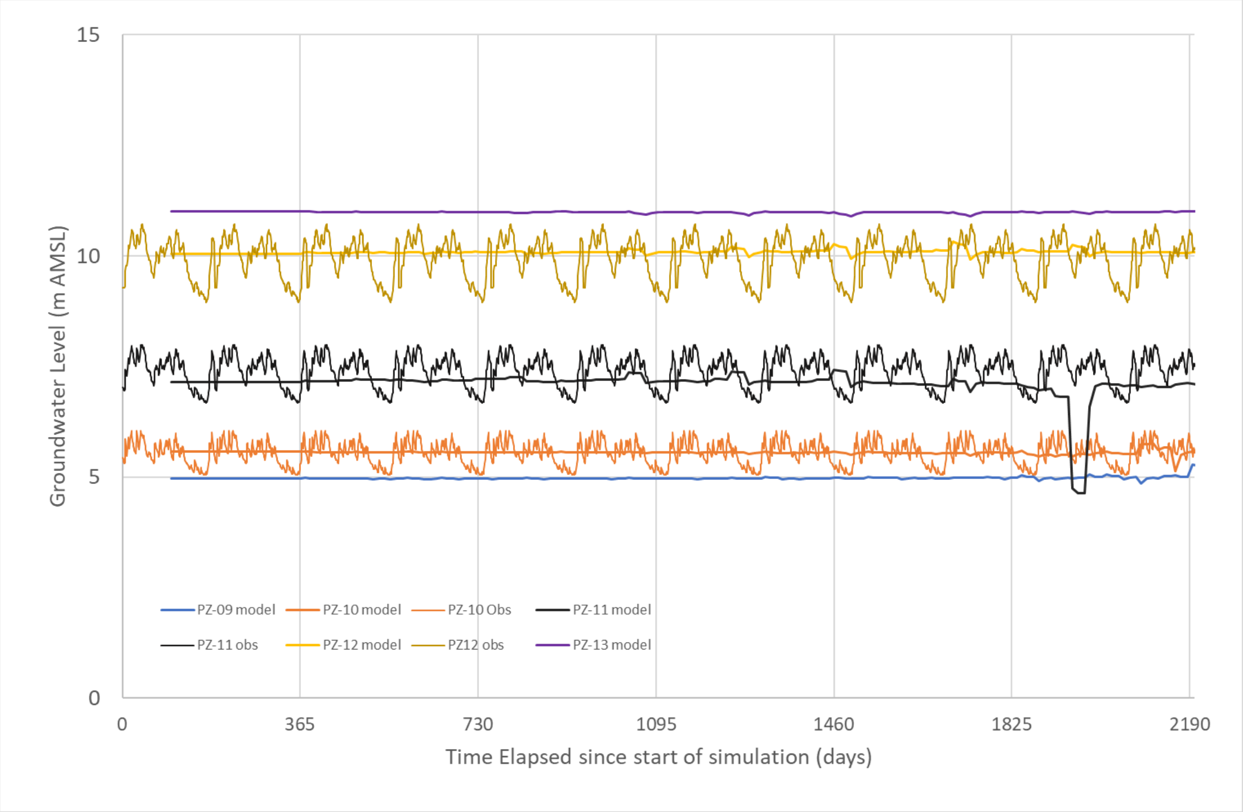

Figure 55: Modelled and observed groundwater levels along the northern boundary

Recharge Barrier Wells

Mitigation of the northern boundary with recharge barrier wells may establish wells at the transition from losing to gaining drain flow in the Northern Boundary Drain to supplement recharge form the infiltration trench system. Up to four recharge barrier wells with a mix of shallow and deeper injection depths of injection may be deployed.

The likely capacity of a recharge barrier well-field with four wells can be summarised as follows –

- 2 shallow wells into ore sands with minor gravels with 5 L/s capacity (i.e., 10 L/s), and
- 2 deeper wells into basal gravel with 15 L/s capacity (i.e., 30 L/s).

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[12] These being the only downloaded data available at the time of writing.

Requirement for Injection

The variable gallery injection rate through time derived from groundwater modelling is reproduced in Figure 56. Predictably, the effect of in-pit pumping is least when the sand extraction activity is in the south of the deposit and most distant from the northern boundary. The requirement for injection increases steadily as the latter panels from panel 4 to 9 are traversed closer to the northern boundary.

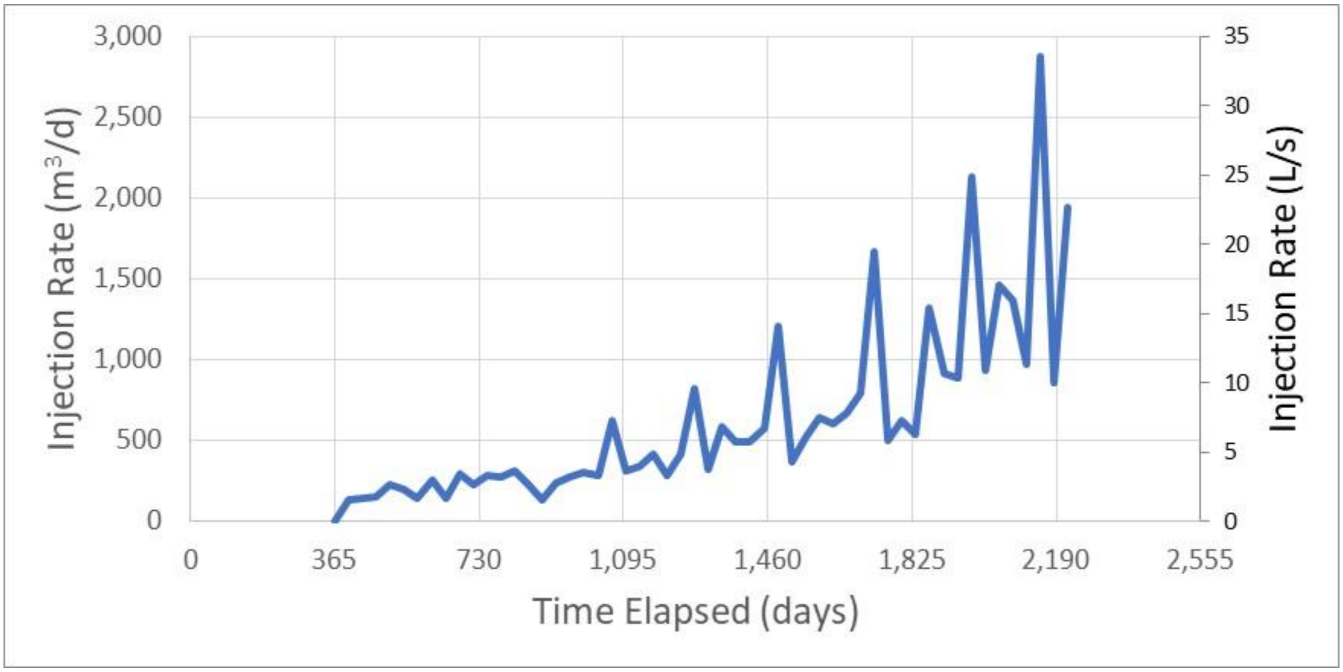

Figure 56: Required infiltration gallery injection rates through time to achieve groundwater level mitigation indicated above.

Although the modelling results presented above indicate that the capacity of the infiltration system is expected to be sufficient to recharge water at rates which maintain groundwater levels at the perimeter monitoring piezometers within the natural range of variability, and above the pre-mining median groundwater level, the performance of the infiltration gallery system will be checked with commissioning and pumping tests aligned with its construction. Additional measurements of performance in the period of active sand extraction would involve monitoring of the perimeter piezometers (PZ-09 to -13) for indications of significant deflection from the median groundwater defined in ongoing monitoring of levels from 5 May 2022 when monitoring began. Full details of the proposed monitoring, trigger and action system are provided in the Water Management, Monitoring and Mitigation Plan.

6.7.2 Southern Boundary – Maintenance of Water Levels and Flows

6.7.2.1 Southern boundary values for protection & mitigations

The sand extraction area and the Cowan Block has a southern boundary generally defined by Colins Creek. The presence of the proposed processing plant and water quality management areas west of the processing plant separates the southern boundary from the areas of active sand extraction by a more significant margin.

The principal hydrological and associated values for which isolation or mitigation measures would be sought, include Collins Creek for its fish habitat and fish passage values and the Langdridge's springs on the south bank of the creek but connected by the shared groundwater system. The coastal lagoon system being slow flowing is less sensitivity to depletion than Collins Creek for instance. Nonetheless, the lagoons may go through periods naturally when shifts in the coastal discharge across the beach barrier and/or extended dry climate intervals lead to lower lagoon water levels that affect associated natural values. Mitigation of mining related depletion effects during such periods would assist to reduce the impacts of the above.

6.7.2.2 *Monitoring results*

The southern boundary has a string of perimeter groundwater level monitoring bores from PZ-18, PZ-04 to -01 and PZ-19, as shown in the plot and table of Figure 57 and Table 24, respectively.

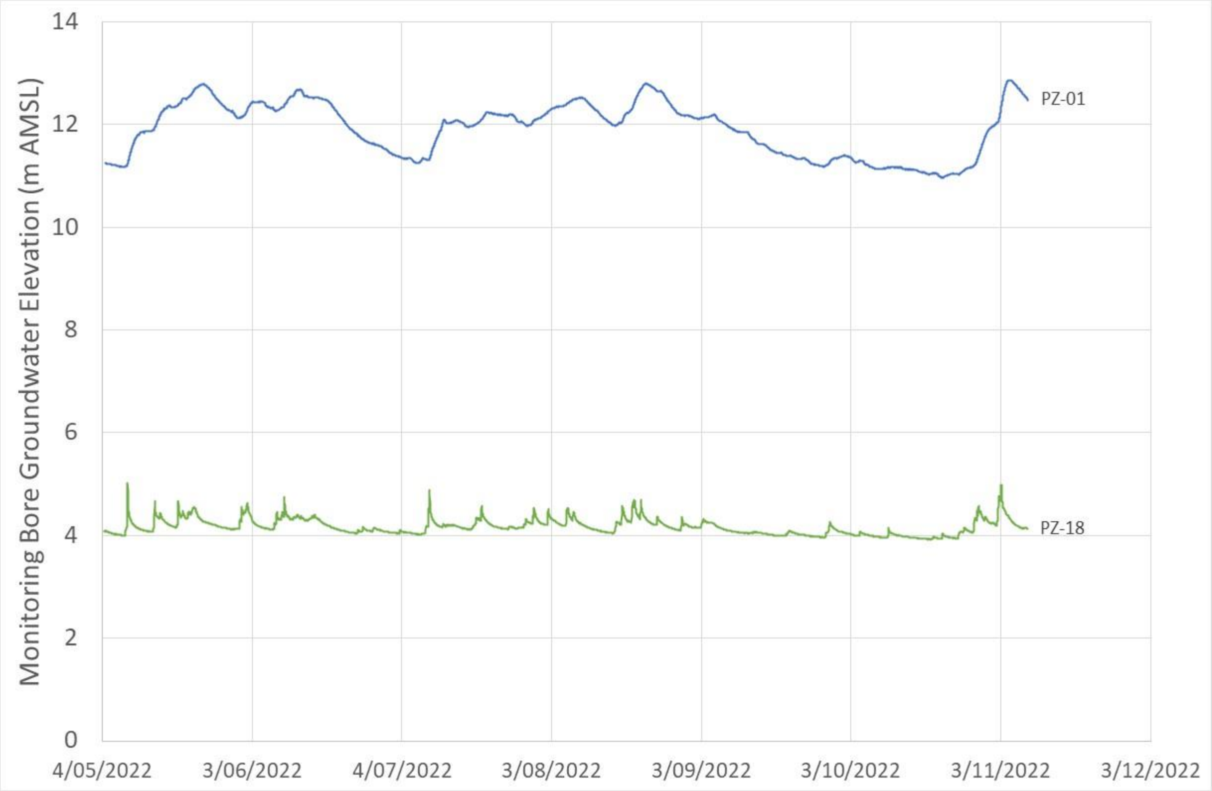

Figure 57: Measured groundwater levels along the southern boundary at PZ-18 and PZ-01 as elevation

Table 24: List of groundwater level statistics along southern boundary

	Monitoring Piezometer	
	PZ-01	**PZ-18**
Duration (May – November)	6.2 months	6.2 months
Minimum (m)	10.96	3.93
Maximum(m)	12.87	5.03
Range of Measurements (m)	1.91	1.10
Median (m)	12.04	4.14
Mean (m)	11.91	4.17

The background groundwater level variability followed the pattern observed in the other four monitoring piezometers installed and equipped with pressure transducer – dataloggers in 2022: the water table in the west has a narrower range of variability than further to the east. Being peripheral monitoring sites, the southern boundary piezometers tends to reflect the flow or stage variability of Collins Creek, to which the piezometers are closely located.

6.7.2.3 *Proposed Mitigation Approach*

The proposed means of mitigating this groundwater lowering effect is to install an infiltration trench system, potentially supplemented with four deeper recharge barrier wells along the southern boundary in the land between the sand extraction margin and Collins Creek. The dual mitigation objectives can be explained as follows:

- Infiltration trenches installed along the Cowan Block boundaries to bolster the groundwater levels and creek or drain flow rates, which in turn
- Minimise the potential for springs, Collins Creek and any wetlands across the southern boundary to be subjected to water level declines.

Infiltration Trenches

Infiltration trenches tend to produce shallow subsurface water level rises in sometimes previously unsaturated ground and may lead to shallow seepage into Lower Collins Creek. The infiltration trench system would flank the Canoe Creek (coastal) Lagoon and lower Collins Creek, extending over a length of 1,300 m. The specification and expected performance of the infiltration trench would be similar to that of the northern boundary, thus a total injection capacity up to 42 L/s could be anticipated. Figure 58 displays the time series graph of infiltration trench injection required to mitigate in-pit pumping depletion effects on lower Collins Creek and the coastal lagoon.

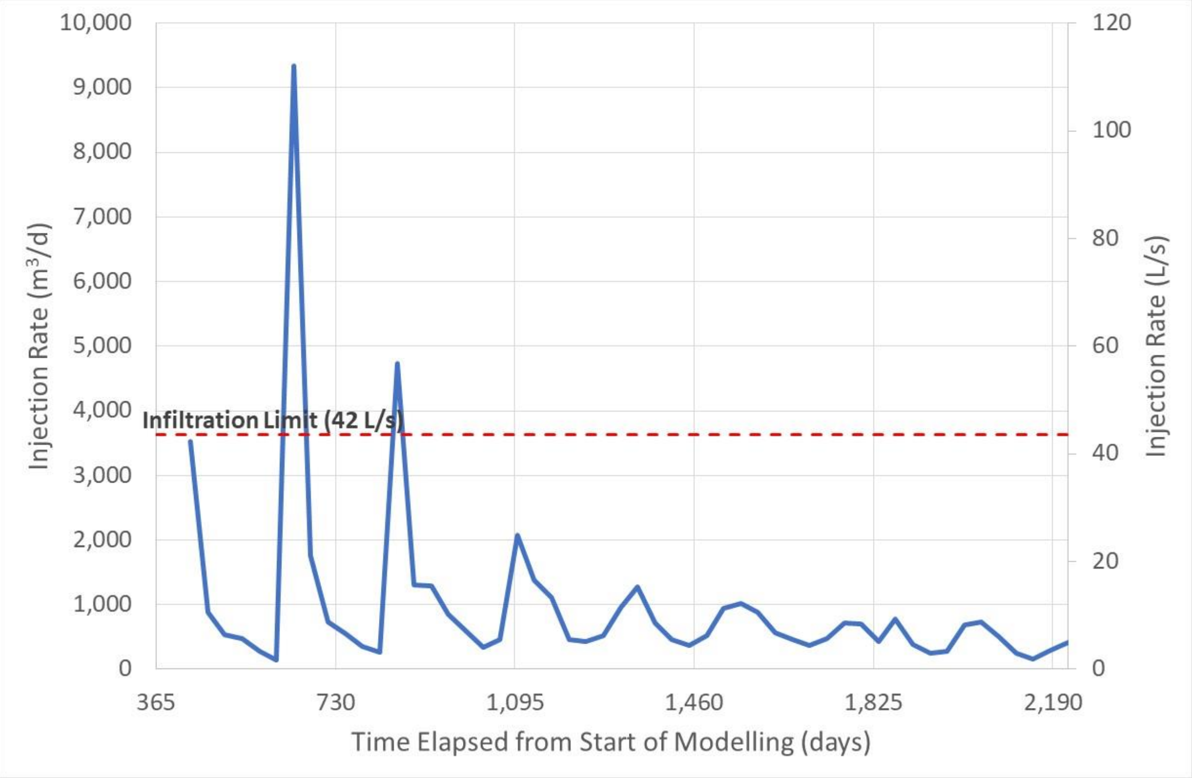

Figure 58: Modelled injection to southern infiltration trench system to mitigate effect on lower Collins Creek and coastal lagoon.

Figure 58 indicates that the 42 L/s infiltration capacity of the infiltration trench would be exceeded on two occasions as the sand extraction panels resume in-pit pumping proximal to the lower creek. On these occasions the monitoring network would anticipate the requirement for additional flow augmentation by discharging treated water from Pond 4 (if water quality is adequate) or utilising the abstraction capacity in the Canoe Creek bank infiltration gallery (or direct water take from the river, subject to confirmation of turbidity levels) and pumping the additional augmentation requirement from Canoe Creek to Collins Creek. As in-pit pumping would also be peaking at these times, any outstripping of the ability to discharge excess water within the Cowan Block could be provided by using the Canoe Creek Infiltration Basin as an additional discharge site.

It should also be noted that flow augmentation to mitigate for Collins Creek depletion also has the positive effect of maintaining natural levels of groundwater discharge and creek outflow into the coastal lagoon since the ultimate receiver of groundwater and Collins Creek flows are the coastal lagoon.

Recharge Barrier Wells

Recharge barrier wells could bypass the shallow subsurface and contribute water directly into fully saturated, deeper levels of the mineral sand or sand with minor gravel deposits. The basal gravels are an additional potential injection target using recharge barrier wells. By providing direct recharge to the groundwater system, the array of wells could induce a recharge barrier as a mound or groundwater flow divide along the southern boundary.

6.7.2.4 Effectiveness of proposed water management at southern boundary

Groundwater levels at southern site boundary

As the modelled southern boundary groundwater level declines due to sand extraction in-pit pumping in the absence of managed groundwater recharge is projected to be relatively small (see Figure 59 for modelled declines), the volume and frequency requirement for recharge barrier well injection may be limited to periods when groundwater levels fall below their pre-mining medians and/or the difference between flows in Collins Creek upstream and downstream of the site fall outside of their pre-mining range.

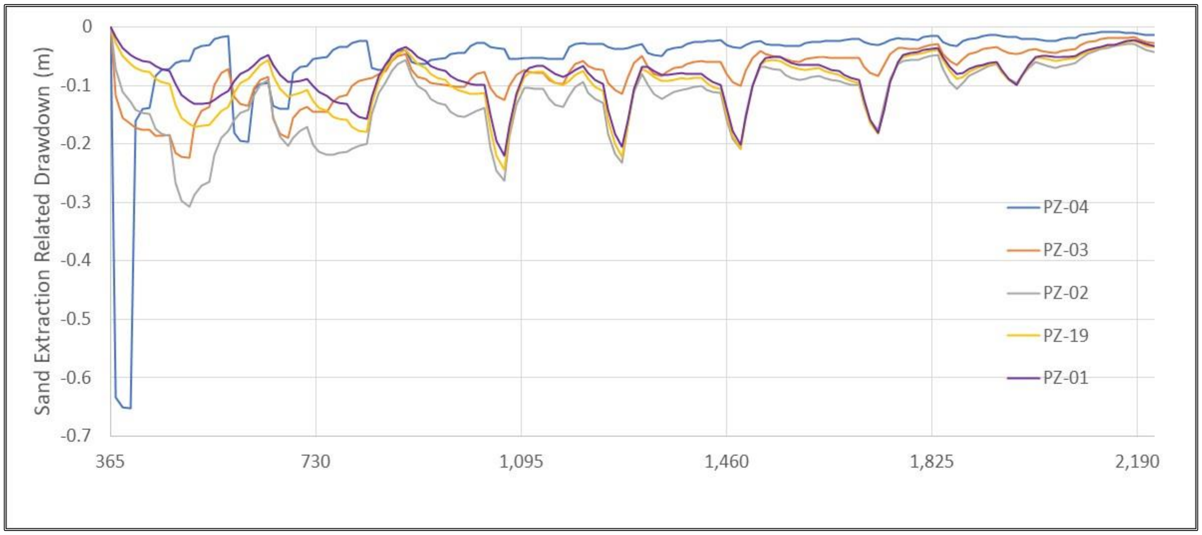

Figure 59: Groundwater level declines modelled to occur at five southern boundary monitoring piezometers.

Figure 60 illustrates the time trend of groundwater monitoring bores approximating perimeter monitoring piezometers extracted from the TMR model transient simulation over six years (5.1 years with sand extraction active) for the southern boundary with the proposed groundwater recharge in operation. Monitored groundwater levels for the May - November monitoring period[13] have again been overlaid on the plot as a repeating sequence to illustrate the potential change in natural variability[14]. The model results indicate that seasonal variability will is likely to be muted by the proposed water management system, although the modelling approach is likely to exaggerate this somewhat: although declines below the median groundwater level will generally be avoided, water level spikes above the median will still occur following rainfall events. Seasonal low groundwater levels further south (e.g. at the springs to the south of the site boundary) may be maintained at a slightly higher level than they would normally be

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[13] These being the only downloaded data available at the time of writing.

[14] Note that where logger data for a given piezometer were not collected the groundwater level variability was interpolated from adjacent piezometers.

by the proposed water management system, but natural variability would still occur in response to weather and seasonal climate patterns.

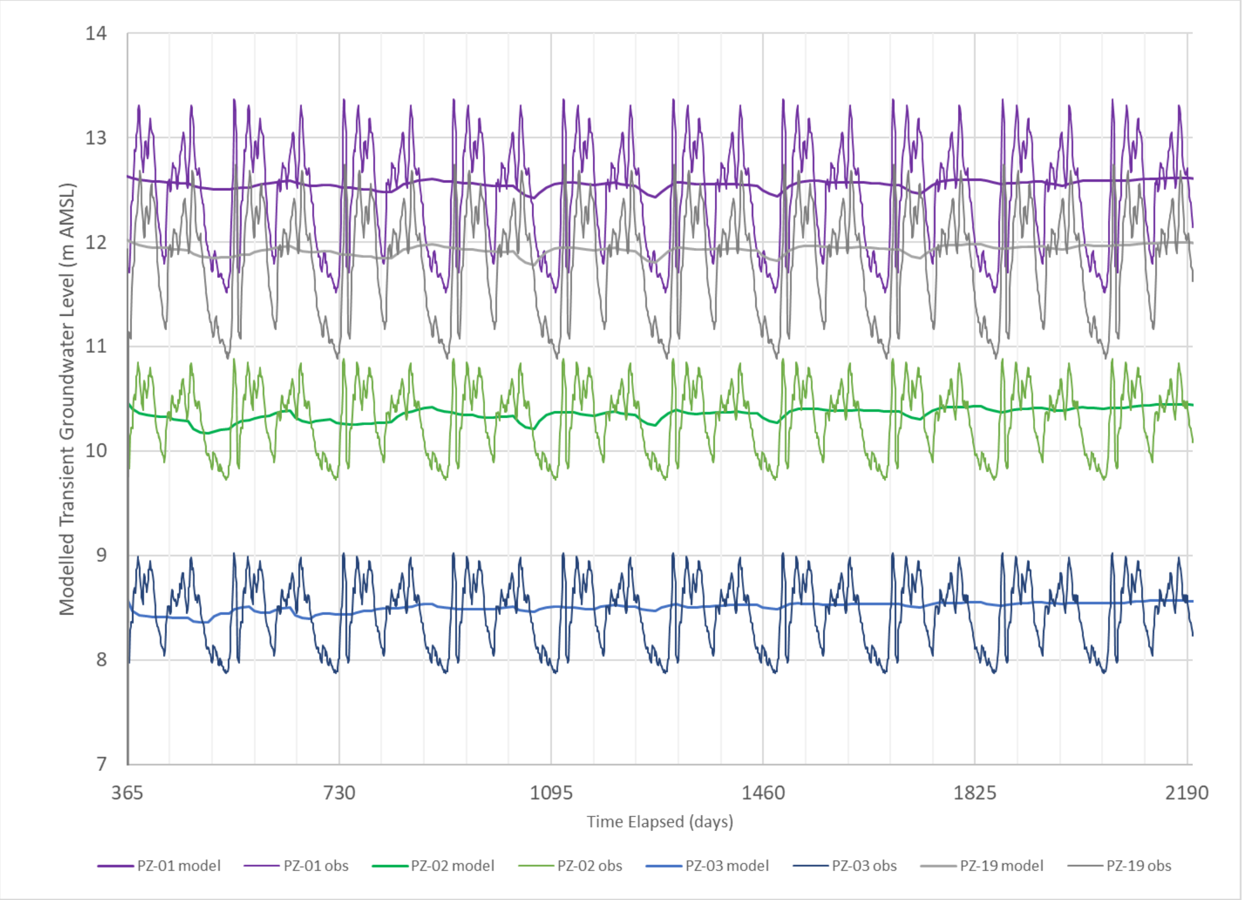

Figure 60: Modelled and observed groundwater levels on southern site boundary

The primary mechanism for maintaining Lower Collins Creek in good hydrological condition would be the augmentation provided by the infiltration trench along lower Collins Creek followed by the ability to directly augment the creek from the Canoe Creek water take. However, the location of the potential recharge wells adjacent to the processing plant, approximately 600 m upstream of the creek augmentation from Canoe Creek means that any seepage from recharge barrier wells into Collins Creek would provide additional beneficial augmentation of creek flow. Recharge wells could also assist with supporting groundwater levels and screen the springs beyond the southern boundary from artificially lowered groundwater levels if required, especially during the first three years of sand extraction when mine panels closest to the area are operational. As such, the use of the wells would be determined early on in the mine development process but maintained on an as-required standby for low groundwater levels or middle Collins Creek flow, triggered by the flow and level monitoring networks.

The likely capacity of a recharge barrier well-field with four wells can be summarised as follows –

- 2 shallow wells into ore sands with minor gravels with 5 L/s capacity (i.e., 10 L/s), and
- 2 deeper wells into basal gravel with 15 L/s capacity (i.e., 30 L/s).

The 40 L/s combined maximum injection capacity would be consistent with peak depletion effects seen in model files for the middle reaches of Collins Creek coincident with the closest approaches of the active sand extraction pit. The source of water for injection would be the terminal treatment pond, possibly the Canoe Creek take, and so doing avoid the introduction of turbid water to injection bore screens.

Augmentation of Collins Creek flows

The Barrytown Sand Mine Stream Ecology Report (EcoLogical, 2023) explains that a reduction in stream or river low flows of up to 10% of the MALF is widely accepted as being very unlikely to adversely affect the health of the waterbody. The $MALF_{7d}$ in Collins Creek is taken to be 16 L/s as per Table 6. The maximum rate of depletion of Collins Creek under low flow conditions based on the 10% threshold is therefore 2 L/s (rounding to the nearest L/s in recognition of flow measurement accuracy limitations).

The Water Management, Monitoring and Mitigation Plan proposes that the rate of augmentation of Collins Creek will be equal to the trailing 24-hour average flow in the Collins Creek upstream flow site minus the trailing 24-hour average flow in the Collins Creek downstream flow monitoring site +/- the average difference between these sites defined during a minimum 12 month monitoring period prior to the start of mineral sand excavations minus 2 L/s.

Taking a hypothetical example:

- The average pre-mining upstream flow is calculated to be 60 L/s and the average downstream flow is 70 L/s. The upstream/downstream flow gain is therefore +10 L/s.
- During mining operations near Collins Creek, the trailing 24-hour average flow in the Collins Creek upstream flow site is found to be 100 L/s and the trailing 24-hour average flow in the Collins Creek downstream flow monitoring site is 60 L/s.
- The augmentation rate in this example is therefore 100 - 60 +10 - 2 = 48 L/s.

Figure 55 shows that an additional ~60 L/s (~5000 m^3/d) of water may need to be discharged directly to Collins Creek to maintain flows in the creek and/or stage Canoe Creek Lagoon during the peak period of depletion. If this occurred during a period of average or below average flows, it is possible that under the most conservative scenario most of the flow in the creek downstream of the augmentation discharge site would comprise treated groundwater from the mine excavation and/or water transferred from Canoe Creek, with minimal dilution from water already present in the creek. In reality this is unlikely to be the case because the proposed flow augmentation discharge site is located adjacent to the processing plant. This is upstream of the potential stream depletion zone and hence natural flows would be present in the creek which would mix with Collins Creek flows from the upper catchment.

The proposed water take from Canoe Creek (with a maximum rate of take of 63 L/s) is capable of supplying the entire augmentation rate required, if excess Pond 4 water cannot be used.

6.8 Water quantity effects assessment summary

The key findings of the water quantity effects assessment can be summarised as follows:

- The main potential for hydrological effects relates to the need to maintain a managed water level in the active sand extraction excavation. Groundwater pumping from one or more sumps will be required for this.
- Field investigations coupled with a precautious groundwater modelling-based assessment of potential pumping rate requirements indicate that up to 200 L/s of groundwater might need to be pumped from the excavation when mining the deepest part of formation.
- Water table depression associated with this pumping has the potential to:
    - Reduce flows in Collins Creek and the Northern Boundary Drain. The latter contributes to the water budget of Rusty Lagoon and a wetland located on the edge of the lagoon around the Northern Boundary Drain inflow.
    - Reduce groundwater levels at Rusty Lagoon and hence the stage of the lagoon, which is a manifestation of the water table at the surface in this historic mining depression.
    - Reduce groundwater levels in the wetlands to the north of the site.

  - Reduce groundwater inflows to and the stage of the Canoe Creek Lagoon to the west of the excavation area.
  - Reduce the rate of discharge from the springs to the south of Collins Creek.
- A water management system has been designed to avoid all of the above by returning water pumped from the excavation to a mine perimeter infiltration system and by augmenting flows in Collins Creek and Northern Boundary Drain as required.
- Modelling results show that the mine perimeter infiltration system is expected to maintain groundwater levels in the network of mine boundary piezometers at or above the pre-mining median groundwater level and therefore avoid groundwater level declines in sensitive water bodies beyond the site boundary.
- The augmentation will also both maintain pre-mining flows in Collins Creek and maintain the pre-mining water balance of Canoe Creek Lagoon and Rusty Lagoon.
- The water management system includes a water take from Canoe Creek to provide additional water for augmentation and groundwater level maintenance at the site boundary should it be required.
- The water management system will therefore avoid any significant changes in groundwater levels beyond the site boundary, avoid potentially significant flow changes in Collins Creek and stage changes in Canoe Creek Lagoon and Rusty Lagoon.
- The water management system includes an infiltration basin and discharge to land which may overflow to the Canoe Creek riverbed. This facility will manage water under a scenario where a) mine-affected water volumes exceed the capacity of the mine perimeter infiltration system; and b) the quality of the treated water from the excavation and/or stormwater runoff from the site do not meet the standards required for discharge to Collins Creek/Canoe Creek Lagoon/Northern Boundary Drain.

6.9 Water quality effects assessment under proposed water management system

The scope of this report with respect to metals and metalloids is to provide an initial screening of the discharge water quality relative to the default toxicity values provided in the Australian & New Zealand Guidelines for Fresh & Marine Water Quality. The initial screening identified several exceedances of this threshold. The Barrytown Sand Mine Stream Ecology Report (EcoLogical Solutions Ltd, 2023) provides a set of site-specific thresholds and describes the management that will be undertaken to manage water quality. Estimates of dilution rates in receiving water bodies are required to support assessment of the extent to which these limits can be met. These have been provided in Table 25.

Table 25: Worst case receiving water dilution ratios

Receiving water	Dilution ratio	Notes
Collins Creek	2	The maximum expected depletion (and hence augmentation) rate (ex. recharge to the infiltration system) is 60 L/s. If the upstream flow in the creek at this time was 60 L/s, 60 L/s of augmentation water would need to be discharged to the creek upstream of the highest point of depletion to maintain normal flows, giving a twofold dilution in the discharge water.
Canoe Creek Lagoon	2	Assumed to be equal to Collins Creek. In reality the dilution ratio is likely to be higher because the lagoon receives groundwater seepages and some runoff from the Cowan Block.

Receiving water	Dilution ratio	Notes
Northern Boundary Drain	0	Flow in the Northern Boundary Drain upstream of the proposed augmentation discharge location reduces to a trickle or zero flows during dry periods.
Canoe Creek	5.3 - 15	See detailed explanation below. 5.3 is applicable to the MALF and hence acute toxicity effects/95th percentile concentration limits. 15 is applicable to the median flow and hence chronic toxicity effects/median concentration limits. These ratios are highly conservative for sediment and turbidity, which are likely to be reduced significantly by filtration through the infiltration basin bed, filtration through sediment on the subsurface flow path between the basin and the river, and filtration and settling along any overland flow paths to the river.

The water quality at the Pond 4 outlet may not meet the turbidity and/or dissolved reactive phosphorus requirements for the surface water receiving environments immediately adjacent to the site boundaries for all of the mine life. It is also possible that the treated water may not meet the metal and metalloid thresholds on some occasions. If this occurs and:

a) The volume of water requiring discharge at that time exceeds the requirements of the perimeter infiltration system; and
b) Any additional assessment and investigation undertaken, where appropriate[15], in response to a trigger level exceedance identifies the potential for adverse ecological impacts in local receiving surface water bodies; and
c) The quality of the water is suitable for discharge to the Canoe Creek infiltration basin; then
d) The excess water will be discharged to the Canoe Creek infiltration basin where it may also flow to the bed of the river near the river mouth via an overland flow path.

If the quality of the water does not meet the appropriate standard for discharge to the Canoe Creek infiltration basin then pumping of water from the mine excavation will cease until additional actions have been undertaken to address the issue.

Assuming that the capacity of the infiltration trenches and recharge wells is 80 L/s (i.e. 50% of the estimated capacity described in Section 6.7) under a conservative/precautious scenario and the peak rate of groundwater inflow to the pit is 200 L/s as per Section 6.1, the maximum seven-day discharge of groundwater to the Canoe Creek riverbank is likely to be no more than 120 L/s. The Canoe Creek MALF_{7d} of 633 L/s will provide a minimum 5.3 x dilution, assuming that all of the infiltrated water and basin overflows seep into the creek with no attenuation of potential contaminants. It is much more likely that much of this water will discharge to ground and discharge at the coast as seepages/groundwater outflows to sea and/or follow an overland flow path to the beach and discharge to the ocea, and hence the dilution ratio is likely to be much higher. Furthermore, the proposed metal and metalloid thresholds relate to potential chronic exposure effects rather than acute effects and hence it is appropriate to use the median

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[15] Additional investigation would not be appropriate in the case of a visual clarity exceedance, for instance, or any exceedance which could impact the attribute state of the receding water body.

Canoe Creek flow of 1,800 L/s for assessment of effects. The minimum dilution ratio is therefore 15 times. The potential effects of metal/metalloid discharges of this concentration are discussed in the Barrytown Sand Mine Stream Ecology Report (EcoLogical Solutions Ltd, 2023). It is worth noting that toxicants and turbidity entering the lower Canoe Creek catchment would also be attenuated by passage through either the ground or by passing over a grassed swale. Both instances would introduce factors conducive to amelioration of contaminant ecological exposure effects.

7 Rehabilitation concept

Details of the proposed rehabilitation concept are provided in the Water Management, Monitoring and Mitigation Plan but are reproduced below for ease of reference.

Mapping of current drainage patterns (Figure 61) shows that ~6.5 ha of the proposed mine area drains to the Northern Boundary Drain with the remainder draining to Canoe Creek Lagoon via farm drains, or via the lowest reach of Collins Creek. Drainage patterns from part of the Northern Boundary Drain catchment outside of the mine area but within the disturbed area footprint could also be affected by the proposed activity. The final landform will be contoured to re-establish the existing distribution of drainage such that the catchment area draining to the Northern Boundary Drain does not change by more than 15% (i.e. 1 ha). This recontouring will ensure that the runoff rates to Rusty Lagoon and Canoe Creek Lagoon do not change because of mining.

The groundwater[16] and topography cross sections through the proposed mining area in Figure 62 below indicate that the average water table elevation is at or above the base of the hollows in the hump and hollow areas of the site. This suggests that the hump and hollow system could be draining the water table in some parts of the site, which reduces the potential for nutrient uptake in the soil profile in the hollows and hence increases the potential rate of nutrient transport to downstream receptors. The final land surface will be recontoured with much lower gradient hump and hollows, with the elevation of the base of the hollows being above the average groundwater level as far as practically possible. Material from above the water table to the east of the proposed excavation area, where the seasonal high water table is between 1 m and > 3 m deep, will be excavated and transferred to the mined area to replace the heavy mineral concentrate material removed from the site.

The modified land relief will improve pasture quality, reduce potential for nutrient discharge to waterways and help to maintain groundwater levels beneath the site at or slightly above the pre-mining elevation. Soil drainage will also be improved by mixing of more permeable sand deposits from the deeper profile with the heavy soil overburden currently present at the surface. This is expected to reduce runoff and increase infiltration rates and the storage of nutrients in the soil for plant uptake. Higher rates of nutrient infiltration into the potentially anoxic underlying groundwater may also result in increased attenuation of nitrate losses from future agricultural activity on the land. The proposed rehabilitation design is therefore likely to reduce nutrient concentrations in downstream receiving waters relative to the status quo.

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[16] Note that groundwater level data in areas with no piezometers were interpolated are therefore subject to local uncertainty. The groundwater elevations shown in some of the hollows in Figure 62 are higher than is likely to be the case.

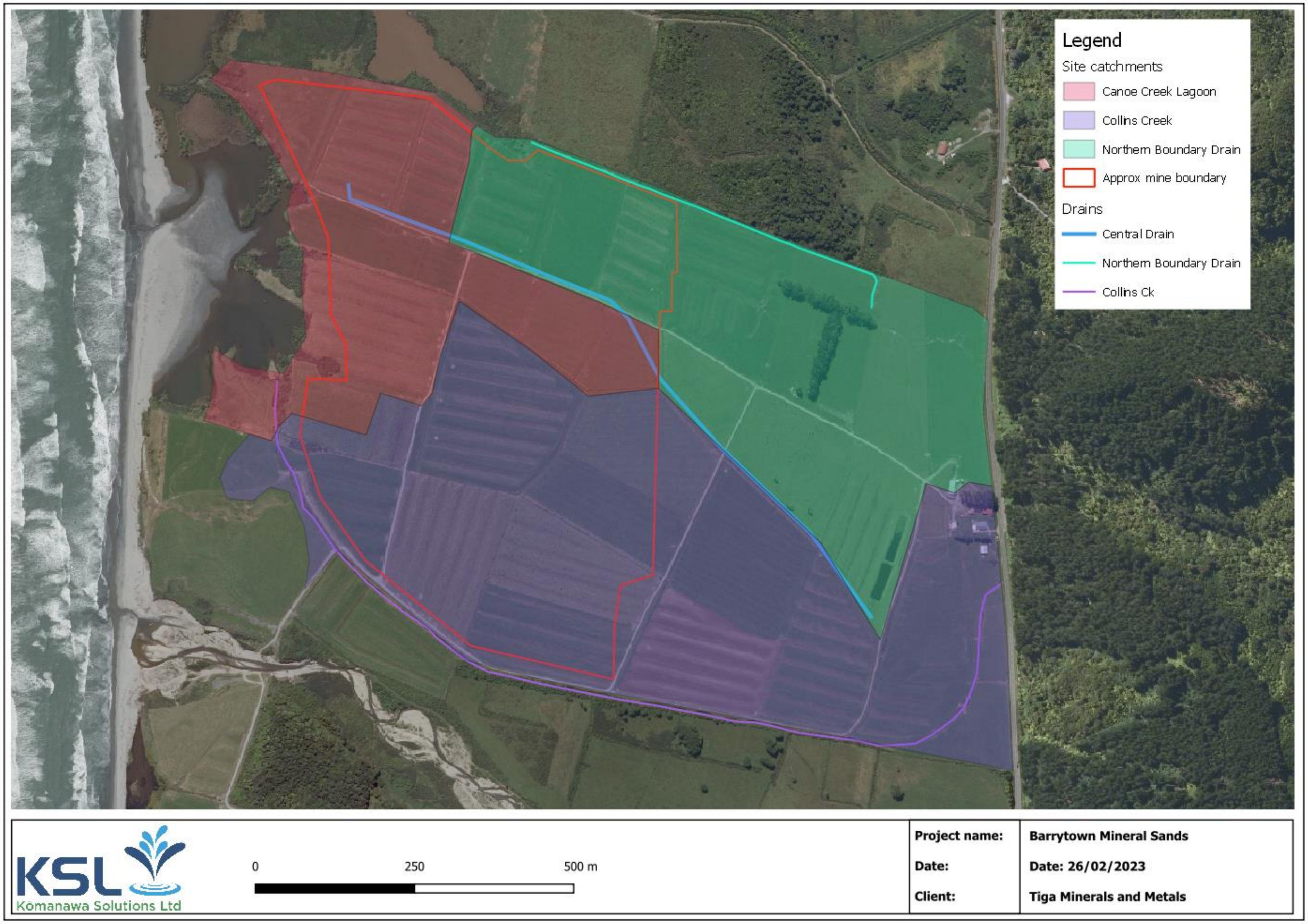

Figure 61: **Pre-mining surface water catchments**

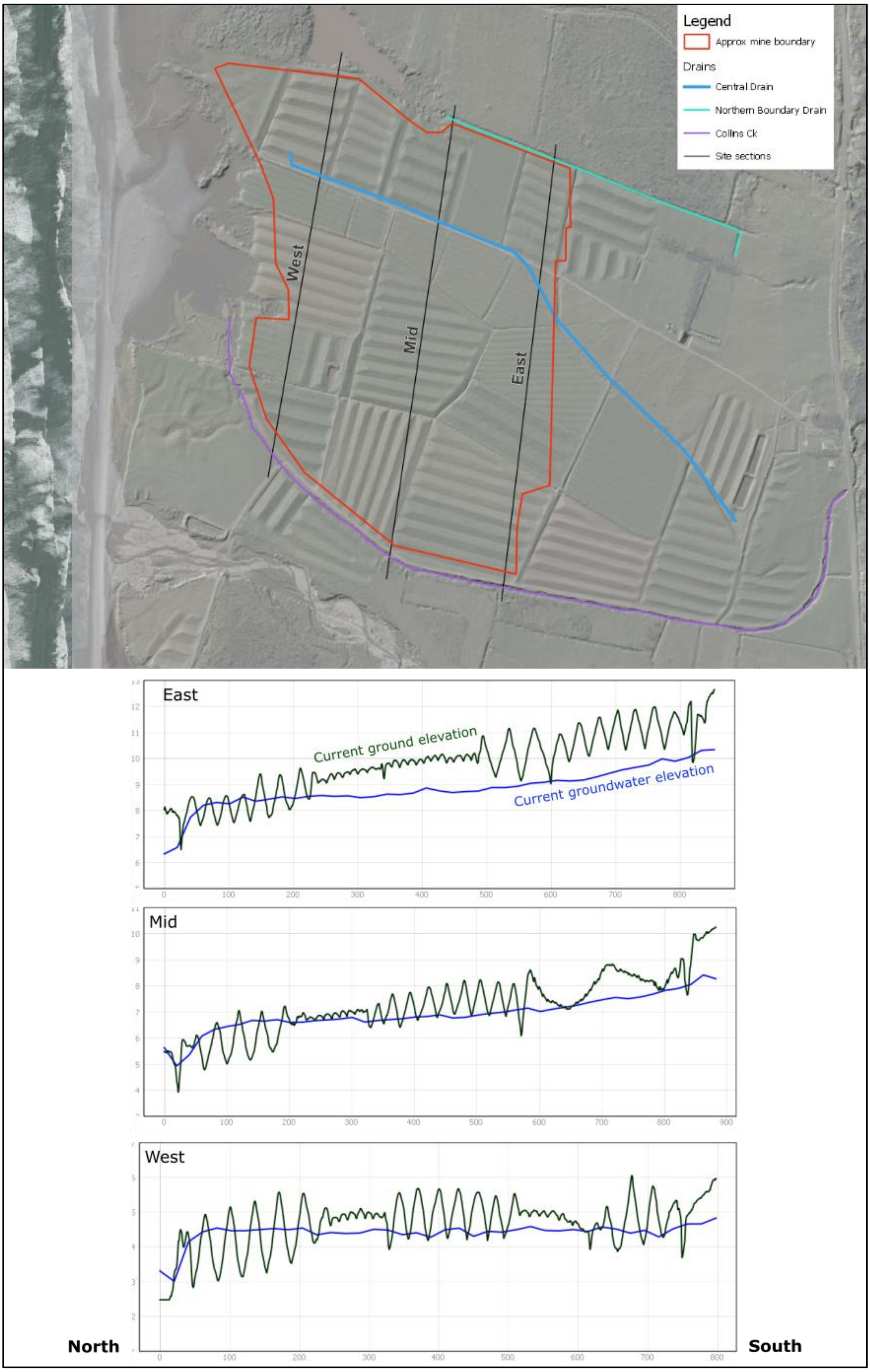

Figure 62: **North – south cross sections through mining area**

8 Conclusions

The following conclusions are drawn from the hydrological studies and assessments undertaken for the proposed Barrytown mineral sand project:

1. Resource consent is sought to undertake mineral sands mining and processing to obtain ilmenite, garnet and other minerals over an area of approximately 63ha (covered by Mining Permit MP 60785) at Nikau Deer Farm Ltd owned land on the Barrytown Flats, and to construct necessary infrastructure.
2. The site is currently used for dairy/dairy support and is a highly modified humped and hollowed parcel of farmland located adjacent to State Highway 6, with induced wetlands bordering the site to the south and west, a small unnamed man-made drainage channel on the northern boundary ("Northern Boundary Drain"), and Collins Creek on the southern boundary.
3. Sand extraction will progress in strips, with dimensions of 80 m to 100 m wide (strip width) and typically 300 m long. The mine pit area will be 3 ha, with 0.5 ha of stripping occurring ahead of the mine pit and 0.5 ha of active rehabilitation occurring behind the mine pit.
4. Sand extraction mining starts in the southwest of the area, and progressively moves eastwards. Each subsequent strip of mining is located north of the previous strip. Mining along each strip is always from the west to the east.
5. The proposed sand extraction area of approximately 34 ha is underlain by Nine Mile Formation sand with gravel and hosts a groundwater system that includes a basal sandy gravel deposit which is not part of the sand extraction mining project.
6. The project area is fringed by Collins Creek to the south, Canoe Creek Lagoon to the west and Northern Boundary Drain plus a water-filled historic mining void called Rusty Lagoon to the north. Collins Creek rises in a 1.9 km^2 hill catchment further east on the opposite side of State Highway 6.
7. Near Collins Creek mouth the mean, median and Mean Annual Low Flow (7 day) flow statistics are 94 L/s, 54 L/s and 16 L/s, respectively. At SH6, the mean, median and Mean Annual Low Flow (7 day) statistics are 83 L/s, 47 L/s and 9 L/s, respectively. Both sets of flow statistics are estimated and accessed via the New Zealand Rivers Maps repository (Booker & Whitehead, 2017).
8. Proposed sand extraction would entail the lowering of water table by up to 9 m below ground surface in the deepest active excavation zone using a sump pump to draw groundwater into the mine water system for conveyance to the processing plant and progressive treatment at settling ponds.
9. The groundwater pumping is modelled to range from 25 L/s to 200 L/s depending on local deposit permeability and depth of excavation. Surrounding groundwater levels, hydraulic gradients and hydrologically connected water bodies (creeks, wetlands and freshwater lagoons) could be affected by radiating water table lowering as a result of in-pit pumping in the absence of appropriate water management.
10. A water management system has been developed to manage water on the site such that adverse hydrological impacts can be avoided with a high level of certainty and therefore employs the effects management hierarchy. Key components of the system include:
    a. Treatment of water pumped from the mine excavation via a four-pond treatment train.
    b. Augmentation of the mining area northern boundary and southwestern boundary groundwater system using infiltration trenches to mitigate the groundwater pumping from the mine excavation.
    c. Recharge barrier wells strategically placed where required to supplement the infiltration trenches and bolster deeper groundwater levels.
    d. A flow and groundwater level monitoring network to be utilised in an integrated fashion to trigger augmentation and measure its effectiveness in maintaining flows and groundwater levels at the property perimeter within agreed standards.
    e. An infiltration gallery or direct water take from Canoe Creek and an infiltration basin on the banks of Canoe Creek to provide for balancing of treated water discharge, the needs for augmentation and variable groundwater in-pit pumping.
11. In addition to hydrological effects of proposed sand extraction related pumping, the *in situ* groundwater composition is known from sampling to be geochemically reduced (depleted with respect to dissolved oxygen), and as a consequence holds elevated concentrations of some naturally occurring metals,

including aluminium, arsenic, chromium, copper, nickel and zinc. It is understood that hardness adjustment and exposure of water to limestone channel linings, plus aeration would deal with much of the potential elevation of these metals prior to discharge back to the environment. Water treatment is beyond the scope of this report.

12. The material backfilled into the mine excavation may temporarily contain elevated concentrations of a limited number of metals, dissolved in the pore water as a result of the minerals processing, but the potential for this to cause adverse water quality effects in downstream receiving waters is very low, even on a temporary basis.
13. The volumes of water required to maintain groundwater levels at the site boundary and flows and water levels in sensitive local surface water bodies has been assessed with the help of a site-specific, calibrated groundwater model. Model results and the broader hydrological assessment indicate that the proposed water management system will avoid potentially adverse changes in the local hydrological system.
14. The final landform will be recontoured with a more gradual hump and hollow system, with the base elevation of the hollows being generally higher than the current landform, and the peaks of the humps also being lower. This will reduce the interception of shallow groundwater in the hollows and help to maintain groundwater levels at or above the pre-mining level. Soil infiltration rates are also expected to increase due to mixing of more permeable sand deposits from the deeper profile with the heavy soil overburden currently present at the surface. These two things together are likely to reduce the rate of nutrient runoff, increase the storage of nutrients in the soil for plant uptake and increase the rate of nutrient infiltration to groundwater, where natural attenuation of nitrate can occur.

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10 Limitations

Kōmanawa Solution Ltd (KSL) has prepared this Report in accordance with the usual care and thoroughness of the consulting profession for the use of Tiga Minerals and Metals Ltd.

This Report has been prepared in accordance with the scope of work and for the purpose outlined in our proposal dated 31/03/2022 and is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this Report.

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Appendix 1. Aquifer testing memo

Memo

To: John Berry, TiGaMM
From: Jens Rekker, KSL
CC: Zeb Etheridge, KSL
Date: 5 December 2022
Subject: Update on the Results of Aquifer Testing at Coates Block, Barrytown Mineral Sands Deposit

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1 Background

Kōmanawa Solutions is leading a series of hydrological investigations at Barrytown in support of existing environment description and hydrological effects assessments related to the proposed mineral sand extraction operations. As brief background the investigations can be summarised as follow –

- Piezometer manual and automated logger water level monitoring,
- Groundwater and surface water physio-chemical sampling and analysis,
- Hydrological flow measurement at two main sites on Collins Creek, the main property surface water drainage,
- Drilling by Alton Drilling, geological characterisation by RSC Consulting and hydrogeological characterisation by Kōmanawa Solutions of coastal sediments, and
- Aquifer testing.

Guidance had been received in the previous consent decision that the aquifer testing at Burke Road and Canoe Creek as reported in detail by Coffey & Partners would be insufficient to support an application for groundwater resource consent associated with environmental approvals yet to be made. The Coffey & Partners (1990) investigations in the late 1980s had included several aquifer testing bores and piezometers to the north and south of the Coates property as indicated in the map of Figure 1. Bore NBH-06 was installed in 1989 to a depth of 8 metres below ground in mixed mineral sand and gravel materials. This test bore was pumped for 3¼ hours at a rate of 2.4 litres per second (L/s) and derived a transmissivity of 325 square metres per day (m^2/d). Coffey Partners (1990) assumed that the water-bearing layer was 20 m thick and estimated the mean hydraulic conductivity at 16.3 m/d.

1.1 Test Setting

From extensive logging of 195 drill holes using the reverse-circulation Aircore method on the Coates' property, the lithological strata was known to be similar to that of bore NBH-06 on Burke Road. Plans were formed to undertake aquifer testing on the Coates' property using the normal-circulation rotary-pneumatic (Concentrix) drilling method. The same drilling system was used to install pumping bores and observation bores.

Figure 2 and Figure 3 show the two areas selected for aquifer testing. PB-2 in Figure 2 was found to be rich in mineral sands with extremely thin and possibility encapsuled gravel lenses, so could not be developed into a pumping bore that would readily sustain a continuous flow. This bore was converted for use in falling head testing. The test site with pumped bore PB-1 encountered mixed sands and sandy gravels similar to NBH-06, plus a shallow gravel overburden layer. PB-1 was developed with compressed air surging over 10 hours and two further observations bores were installed at different distances and depths. An existing piezometer installed at the PB-1 site by the Aircore method in June this year was also available for observation of pumping effect. The PB-1 site also had present a flowing creek or farm drain at 33 m distance from the pumped bore.

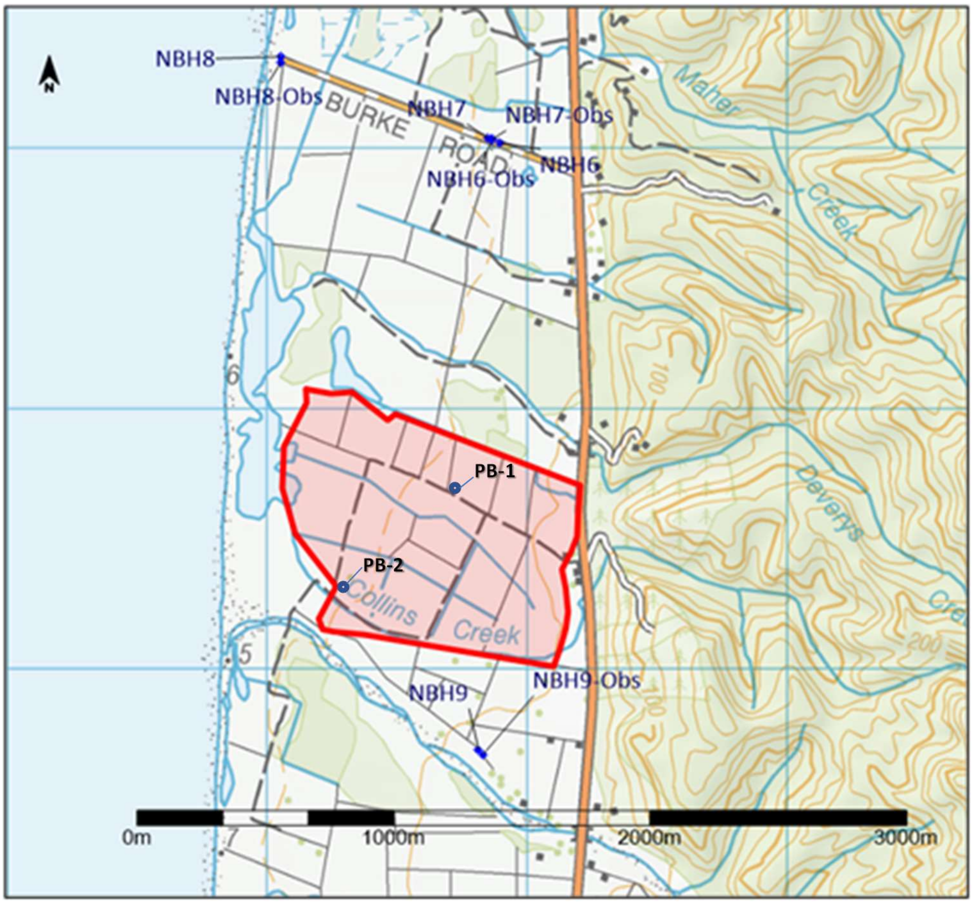

Figure 1: NBH test bores and associated observation bores on Burke Road and adjacent to Canoe Creek

2022 aquifer testing plans centred on the following two test sites in the south and north of the Coates' property.

Figure 2: PB-2 testing site adjacent Collins Creek and in an area with thick mineral sand deposits

Figure 3: PB-1 test sit, including three observation bores (piezometers) in an area with known alluvial sediments

1.2 Broad Scale Stratigraphy

Coffey & Partners (1990) saw the stratigraphy as a largely gravel-dominated sequence, as shown in the transect of drill holes along Burke Road.

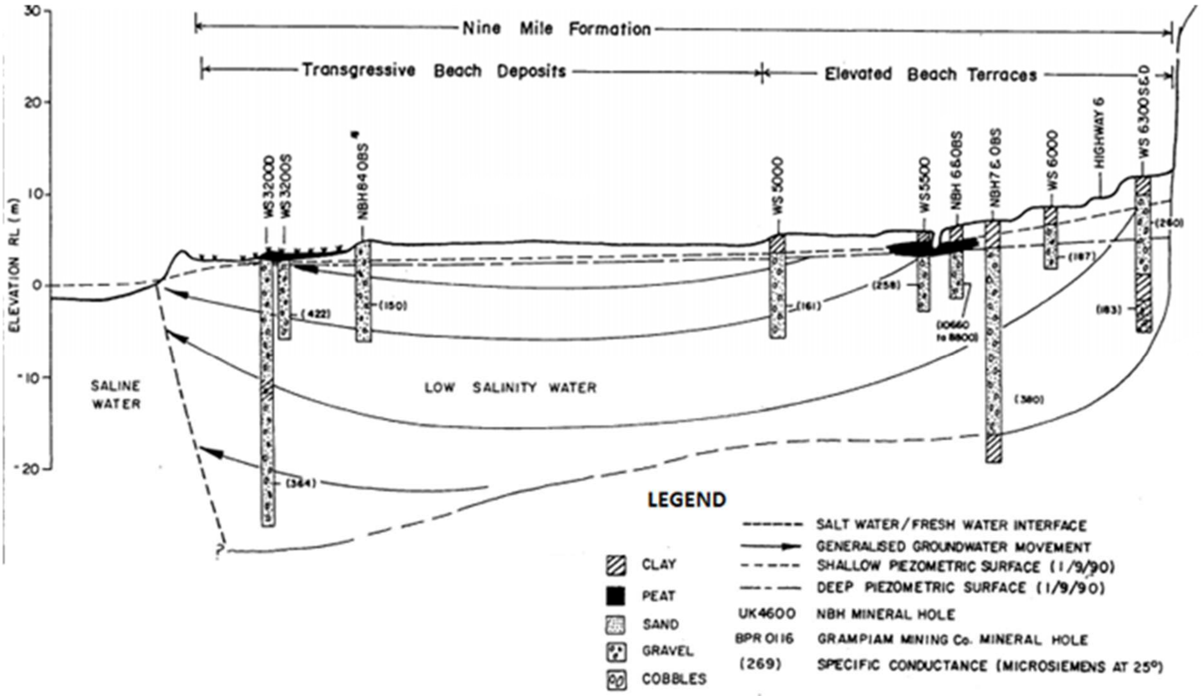

Figure 4: Coffey & Partners hydro-geological cross-section plot along Burke Road

Coffey & Partners included drill holes of up to 31 metres depth and dual depth paired piezometers to illustrate vertical relationships within the Holocene coastal sediments.

More recent drilling in 2022 has operated within a tighter depth range to 15 m, but typically 10 m to 12 m below ground level, focusing on the economically accessible mineral sand resource. A more relevant cross-section is scribed from west to east through the approximate mid-line of the Coates Block, including piezometers in the west and east.

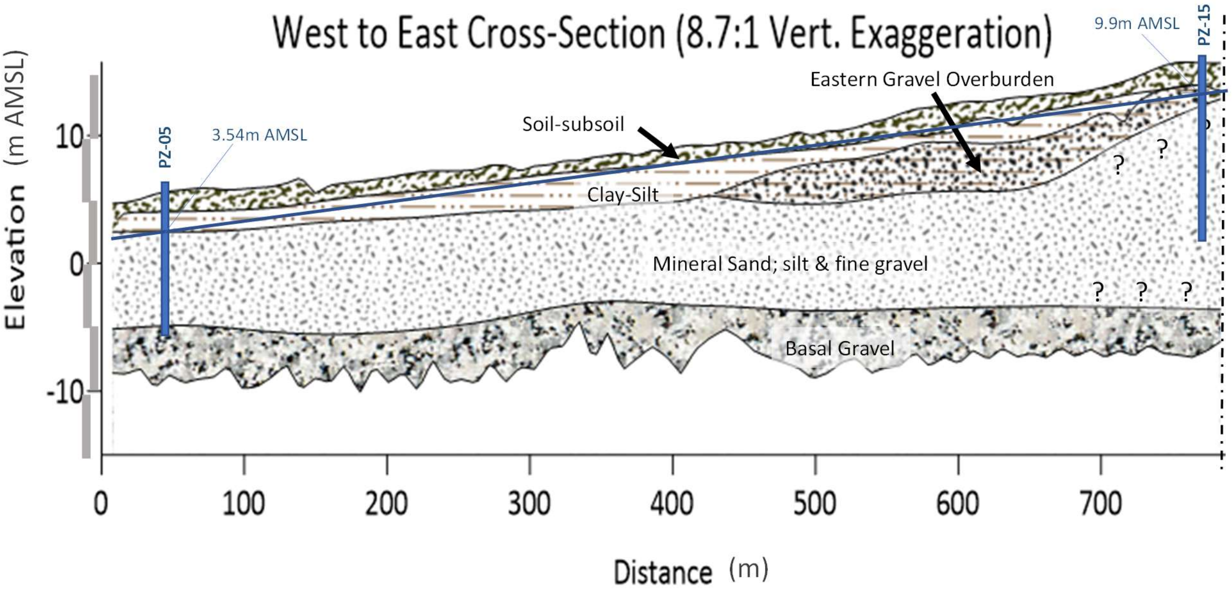

Figure 5: West to East cross-section through the Coates Block drawing on 192 Aircore drill hole logs

The above cross-section provides a stratigraphic scheme for the Holocene coastal – fluvial sediments down to approximately 12 m BGL. The mineral sands and associated fine gravels appear as a continuous feature, while the Eastern Gravel Overburden is attributed to the outer margin of a lobe of Canoe Creek alluvium / colluvium draped over the coastal mineral sand. These are generalisations as to lithological composition, emphasizing the dominant grain size. In practice, sand, gravel, silt and clay size grains are found mixed throughout the sequence. The PB-1 test site is located in an area with an over-drape of the Eastern Gravel Overburden and the hydrological stratification that results from this superposition. The PB-2 test site is located in a simpler, clay-silt-sand sequence more dominated by the medium – fine mineral sand, although gravels were still encountered in the drilling of the test bore.

1.3 Testing Objectives

The objectives set in the planning of the aquifer testing programme were as follows –

1. To derive hydraulic properties such as conductivity and storage for the lithologies at the Coates' property,
2. To assess the infiltration capacity of these materials using bores,
3. To take a groundwater sample following a period of flow testing, and
4. To evaluate the effect of adjacent surface water on groundwater response.

2 Test Methodology & Results

The test site with PB-1 was first drilled on 4/11/2022, the stainless steel screen installed in sandy gravel and developed by compressed air surging until lifted sand was minimal. The rig was shifted to the PB-2 test site and this bore drilled. The PB-2 bore screen was set to exploit a thin pocket of sandy gravel with medium mineral sand matrix, but once compressed air surging was attempted the screen section was pushed out of the open section of the borehole by heaving sand collapse. Consequently, no observation bores were drilled, instead the drill pipe was turned over for slug testing by the falling head method. The test sites are outlined in more detailed below.

2.1 Test Site PB-1

Conventional aquifer testing with a central pumped bore (PB-1) and radiating observation bores were installed at the PB-1 test site, as marked out in Figure 6 and Figure 7. The configuration can be summarised as

- TAC-157 was already present prior to installing PB-1, the TAC-157 casing diameter was 18 mm and it lay 16.7 m to the northwest of the pumped bore,
- TB-1 was drilled and installed to 11.2 m BGL, it lay 5 m to the southeast,
- TB-2 was drilled and installed to a depth of 6 m BGL, it lay 9 m to the east, and
- PB-1 was drilled and installed to a depth of 11.3 m BGL, the casing diameter was 0.15 m (150 mm).

The test site was relatively level with a slope to the northwest. A farm drain with visible flow lay 33 m to the northwest (downslope) of the bores. A farm lane lay to the south and hump & hollow terrain to the north. The main bore axis was parallel with the farmland and fence, although the shallow TB-2 bore was oriented of the axis at 20° to the north of the line.

The TB-1 and 2 bores were 50 mm diameter with a 1.0 m long section of slotting at the base. PB-1 was constructed by telescoping the 150 mm diameter casing to expose a 1.2 m long section of 2 mm slot stainless steel screen with 125 mm diameter. Figure 6 displays the test site layout in cross-section.

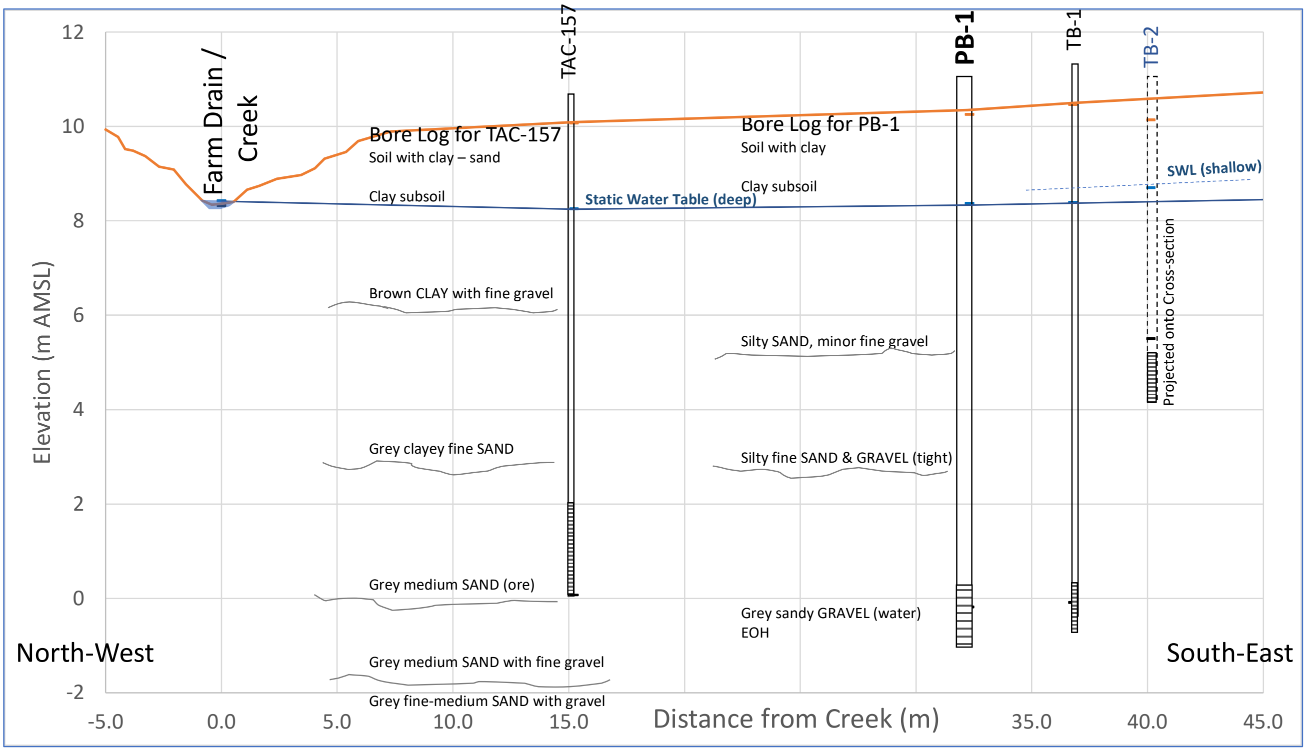

Figure 6: Composite cross-section of PB-1 test site showing depths of bores, static water tables and logged geology in bores

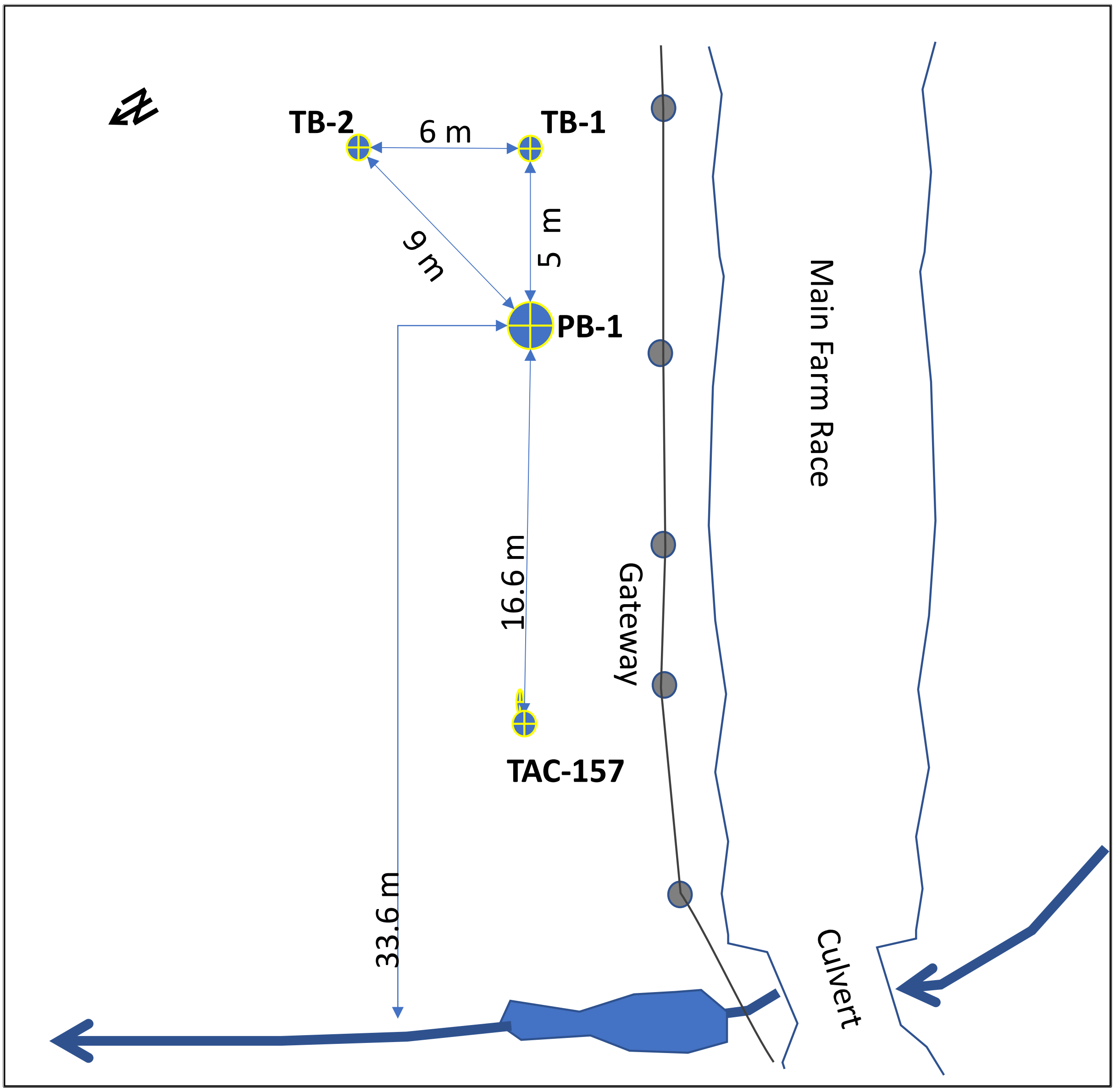

Figure 7: Schematic PB-1site layout plan showing location of pumped bore, observation bores and farm creek

2.2 Infiltration and Yield Testing

External water was pumped into bore PB-1 at a rate of 1.1 L/s for 110 minutes. The dynamic water level rose to within 1.5 m of the top of bore casing, a mounding effect of about 0.85 m. The mounding effect was generally consistent with the reverse polarity drawdown magnitudes at similar lower extraction rates during step drawdown testing.

An initial yield test at a rate of 2.1 L/s was undertaken using a surface pump and a 50 mm diameter suction line placed to 9.2 m depth in the pumped bore. A final 1.56 m of drawdown was recorded after 33 minutes of pumping. The yield test demonstrated stable pump rate would be achieved and indicated that pumping rates up to 5 L/s were feasible with the surface pumping configuration.

2.3 Step Drawdown Testing

2.3.1 PB-1 Test Data

Step testing was undertaken as four pumping steps of half an hour (30 minutes) duration of each step. The test was started at the same flow setting as the yield test with a measured flow of 2.12 L/s. Pumping steps were raised by increment each 30 minute period.

Table 1: Summary of Step Drawdown Test Measurements in PB-1 on Wednesday 9 November 2022

Step #	Clock Time HH:MM and (min elapsed)	Duration (min)	Measured Flow Rate (L/s)	Uncorrected, Final Drawdown at pump bore PB-1 (m)	Corrected, Final Drawdown at observation bore TB-2 (m)
Start	11:00 (0)	0	0	0	0
1	11:30 (30)	30	2.12	1.54	0.11
2	12:00 (60)	30	3.25	2.30	0.17
3	12:30 (90)	30	3.80	2.82	0.25
4	13:00 (120)	30	4.50	3.13	0.28

Note: PB-1 Depth To Water = 2.38 m with respect to (w.r.t.) Top of Casing, casing stick-up = 0.56 m AGL; TB-2 Depth To Water = 2.02 m w.r.t. Top of Casing, casing stick-up = 0.58 m AGL.

While monitoring of test observation bore TB-2 was eventually corrected for an antecedent trend, the pumped bore measurements of depth to water were not corrected due to lack of antecedent and/or post-pumping static water level measurements that could be used in correction. The magnitude of pumped bore drawdown was also large compared to the trend interference. Due to level logger failure in PB-1, pumped bore drawdown was manually measured as only final step drawdowns, as listed in Table 1 and presented graphically in Figure 8.

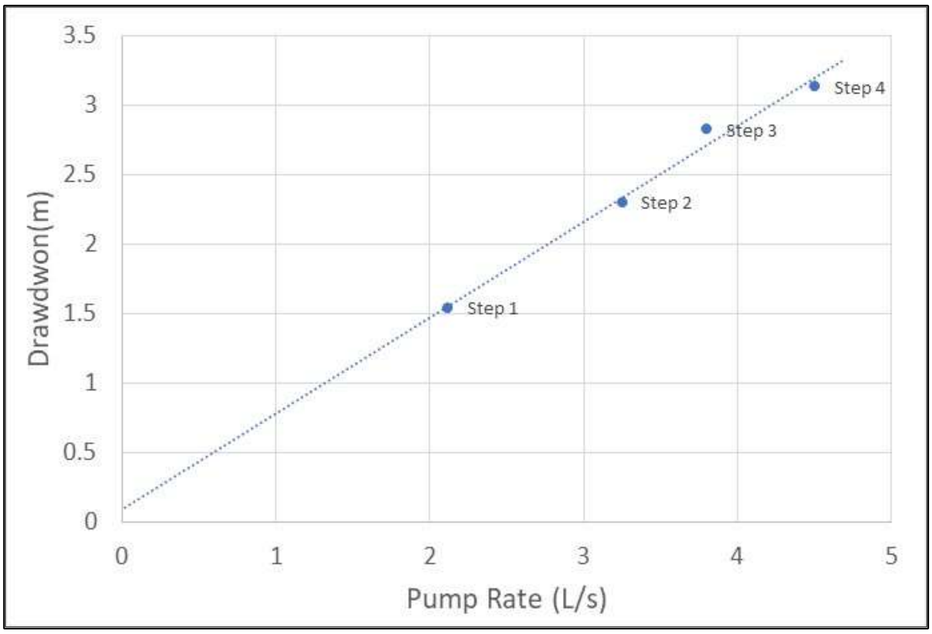

Figure 8: Final manual drawdowns in PB-1 during two-hour step drawdown test

Due to another logger failure, drawdown was not measured in the deeper test bore TB-1. Drawdown was however recorded during the step drawdown test in the shallow test monitoring bore TB-2. Filtering to remove the logger measurements that should have been unaffected by pumping, an antecedent level trend was discernible in static water levels of bore TB-1. This trend was modelled with a polynomial function and this function was used to remove the antecedent trend from TB-2 recorded water levels. Figure 9 illustrates the effect of removing the antecedent trend in the measured drawdown due to step testing of bore TB-2.

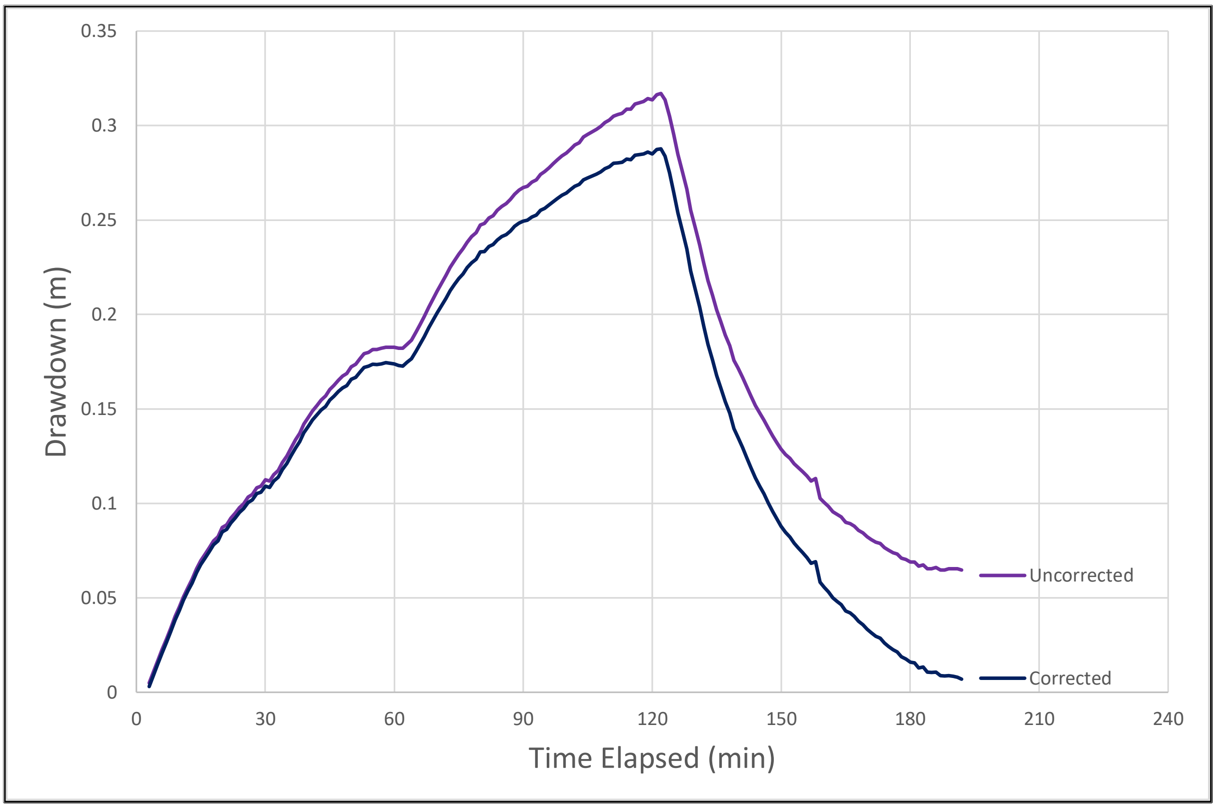

Figure 9: TB-2 Drawdown vs Time plot showing the effect of trend corrections

The recorded and corrected 1-minute frequency logging of bore TB-2 water level displays subtle inflections at the 30 minute step flow increases, particularly the second step from 2.12 L/s to 3.25 L/s. Recovery was almost complete at 72 minutes following the cessation of pumping. Final drawdown at 120 minutes was 0.28 m.

In addition to the horizontal separation radius of 9.0 m between PB-1 and TB-2, there is a vertical offset in the bore screens. The pumped bore has its bore screen set between 0.25 m and -0.95 m with respect to Mean Sea Level (MSL), while the screen for TB-2 is set between 4.1 and 5.1 m AMSL, equating to a 4.85 m vertical offset between the screens and no overlap. Bore PB-1 was screened in deeper sandy gravel, while bore TB-2 was screened in gravelly sand, a finer and probably less permeable material. The intervening material between the PB-1 and TB-2 bore screens was logged as “grey medium mineral sand” or “sand and fine gravel”. Broad scale lithological mapping indicates that the TB-2 was screened in eastern gravel overburden and pumped bore PB-1 was screened in mineral sands, or potentially also basal gravel deposits (see Figure 5). Consequently, the intervening mineral sand lithology (“Grey clayey fine SAND with gravel” to “Silty fine SAND & GRAVEL”) may act as a leaky semi-confining layer between the gravel overburden and the basal gravel deposits (see Figure 6 for vertical references).

Figure 10 and Figure 11 show the raw drawdown data plot of drawdown versus time, and interpretative curve matching of corrected drawdown versus time, respectively. The recovery phase of the test data is also included in the analysis. Figure 11 overlays the test drawdown data with the type-curve appropriate for the pumping rate and observation bore radius.

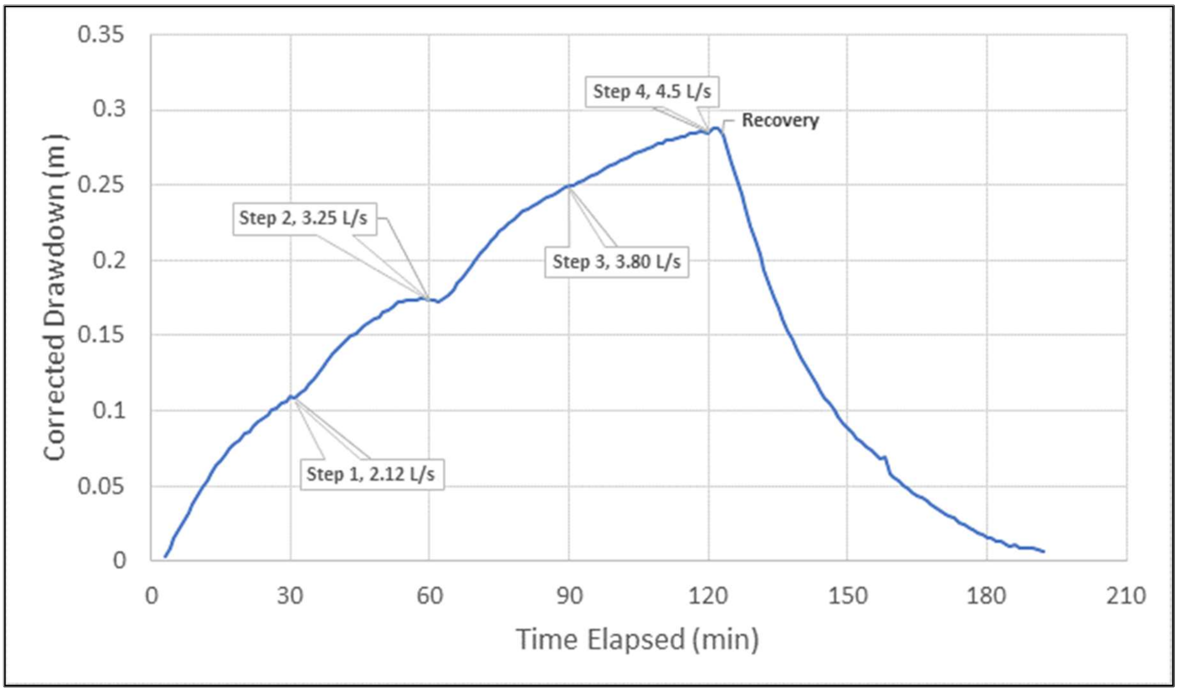

Figure 10: Time series plot of shallow bore TB-2 drawdown during step drawdown testing with final step pumping rate marked

2.3.2 Observed Step Testing Analysis & Results

Type curve fitting and analysis was undertaken using AQTeSolv software as displayed in Figure 11, below.

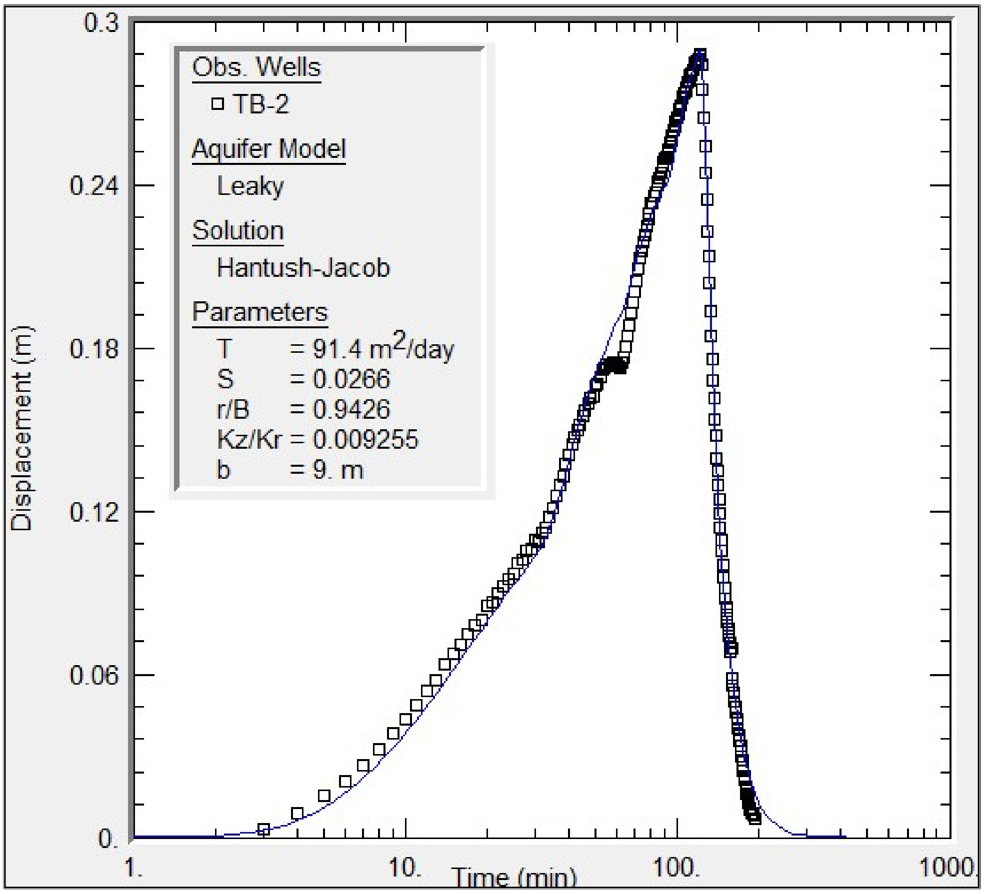

Figure 11: Interpretative drawdown measurement curve matching for observation bore TB-2

Figure 11 shows the test data on a semi-logarithmic scale with the Hantush-Jacob (1955) type curve, which is appropriate for leaky aquifer settings without aquitard storage. The AqTeSolv software carried out an automated optimisation of test data and type curve that resulted in the following best fit statistics –

- Mean residual (error) = -0.00024 m
- Variance = 0.000045 m
- Standard Error = 0.0067 m

This can be considered a relatively tight fit to the data having a higher possibility that the derived hydraulic properties in Figure 11 and Table 2 are valid.

Table 2: Summary of Derived Hydraulic Properties from Step Drawdown Test on PB-1, as observed at TB-1

Property	Derived Value	Comment
Transmissivity (m^2/d)	91.4	Likely correlated with the intervening materials between the pumped bore and the shallower TB-1
Storativity	0.026 (2.6×10^{-2})	High for a semi-confined water-bearing layer
Radius/Leakage Ratio, r/B	0.94	The leakage coefficient B is approximately 9.6 m

The derived properties relate to the properties pertaining to the material around the observation bore screen and the intervening materials between the pumped bore and observation bore. As discussed above, this includes the eastern gravel overburden, mineral sands & gravels, and basal sandy gravel deposits.

2.4 PB-1 Constant Rate Test

2.4.1 Test Methodology & Data

A constant rate test of 6½ hours was undertaken at the PB-1 test site on 10 November 2022, between 8:12 am and 1:42 pm. A fixed rate of 4.0 L/s was achieved for the full duration of testing and discharged into an area of farm drainage which displayed perennial saturation before drilling operations at the test site. Level loggers were deployed in the 50 mm diameter observation bores TB-1 and TB-2, while manual measurements were made at the 18 mm diameter observation piezometer, TAC-157.

Table 3: Basic Specifications of Constant Rate Test on 10 November 2022

Bore / Feature, and Depth	Radius (m) from Pump Centre	Pump Rate (L/s)	Monitoring: Levelling & Pump Rate Notes
PB-1, 10.5 m BGL	0.075	4.0	Minimally level monitored during pumping. Pump rate measured by duration for filling of a 140 L capacity barrel
TB-1, 10.6 m BGL (Deep)	5	_	Level logger and manual measurements
TB-2, 4.7 m BGL (Shallow)	9	_	Level logger and manual measurements
TAC-157, 10 m BGL	16.6	_	Manual measurements, PVC casing top surveyed to 10.79 m AMSL vertical datum
Farm Drain / Creek	33	_	Water level surveyed (dumpy level)

Automated level logger and manual depths to water were corrected for measured antecedent trends and calculated drawdown are plotted in Figure 12. Errors and imprecision in the correction and drawdown differencing process are the most probable source of the apparent drift in late-time logger and manual measurements, differences which were from 1 cm and up to 4 cm. The level logger in bore TB-2 also failed to provide accurate measurements after 120 minutes, although the manual drawdowns reveal the general trend of pumping phase drawdown and recovery in this observation bore.

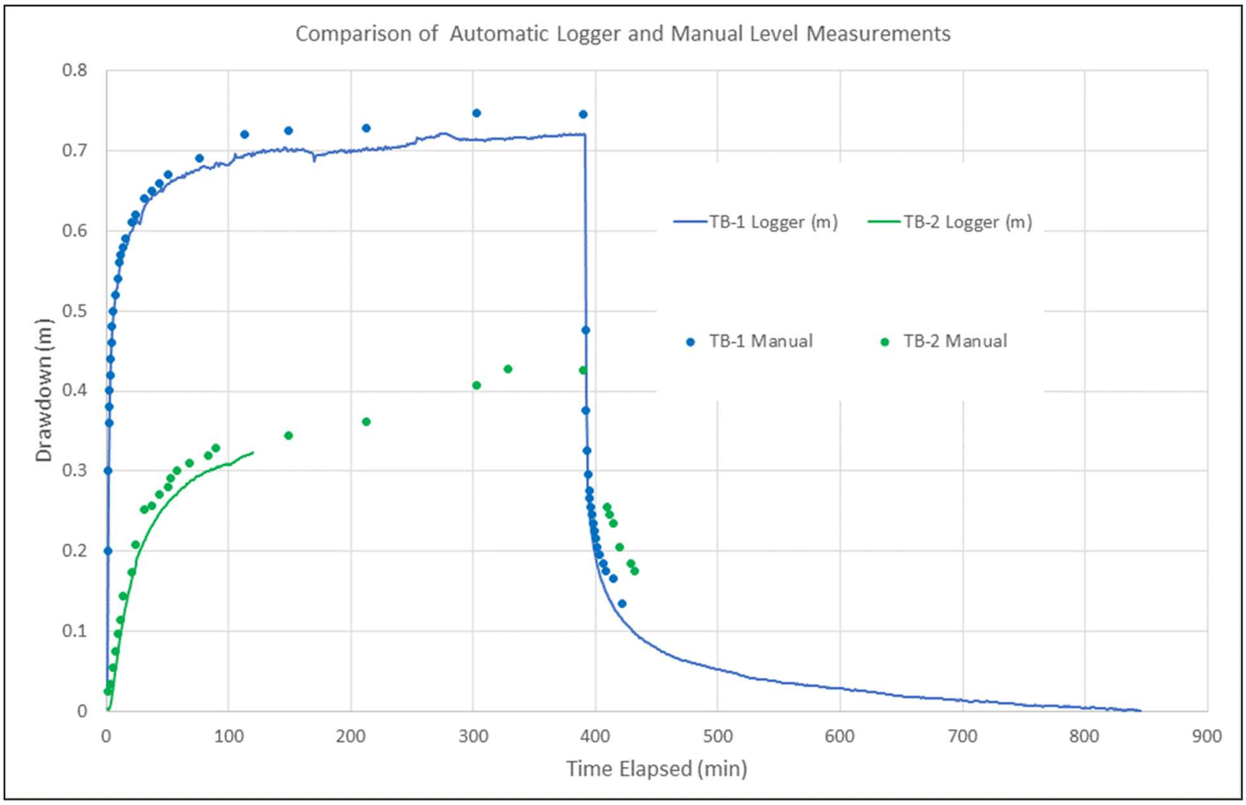

Figure 12: Level logger and manual level measurements recorded during constant rate test

Automated level logger could not be undertaken in bore TAC-157, so manual measurements were taken whenever opportunities for taking dips were available. Figure 13 shows the ten measurements as drawdowns in a linear plot. Final drawdown was 0.44 m in TAC-157, comparable to the final drawdown of 0.45 m at bore TB-2 despite TB-2 being much closer to the pumped bore than TAC-157. The comparability suggests that the materials between the pumped bore and TAC-157 screens are more permeable than between the pumped bure and TB-2.

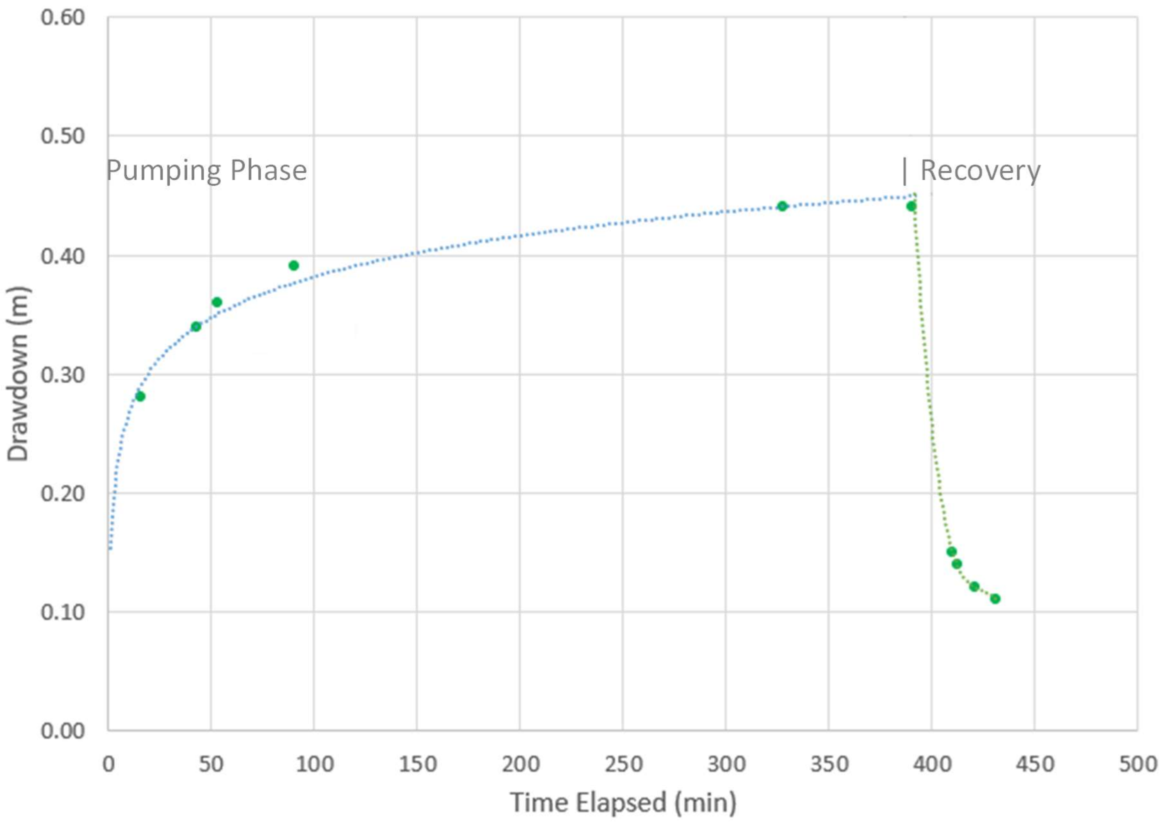

Figure 13: TAC-157 manual pumping phase and recovery measurements as drawdown

2.4.2 PB-1 Observed Constant Rate Testing Analysis & Results

Step testing suggest that there was a stronger interaction between the pumped bore and observation bores screened at the same depth. (i.e., PB-1 and TB-1 or TAC-157) than there was with the shallower observation bore TB-2.

Figure 14 illustrates the matching of the type-curves for pumping phase and recovery phase drawdown with the data points obtained in test pumping at constant rate in pumped bore, PB-1. The AqTeSolv software carried out an automated optimisation of test data and type curve that resulted in the following best fit statistics –

- Mean residual (error) = 0.0037 m
- Variance = 0.00033 m
- Standard Error = 0.018 m

Once more, the leaky or semi-confined Hantush-Jacob solution provided the better fit for the measured data, implying the drawdown curve was affected by leakage of groundwater from adjoining water-bearing layer(s). Figure 15 shows a similar type-curve match to a significantly smaller set of manually measured drawdown data points in the observation bore TAC-157 at a great distance form the pumped bore of 16.6 m. The AqTeSolv software carried out an automated optimisation of test data and type curve that resulted in the following best fit statistics –

- Mean residual (error) = 0.00018 m
- Variance = 0.000013 m
- Standard Error = 0.0036 m

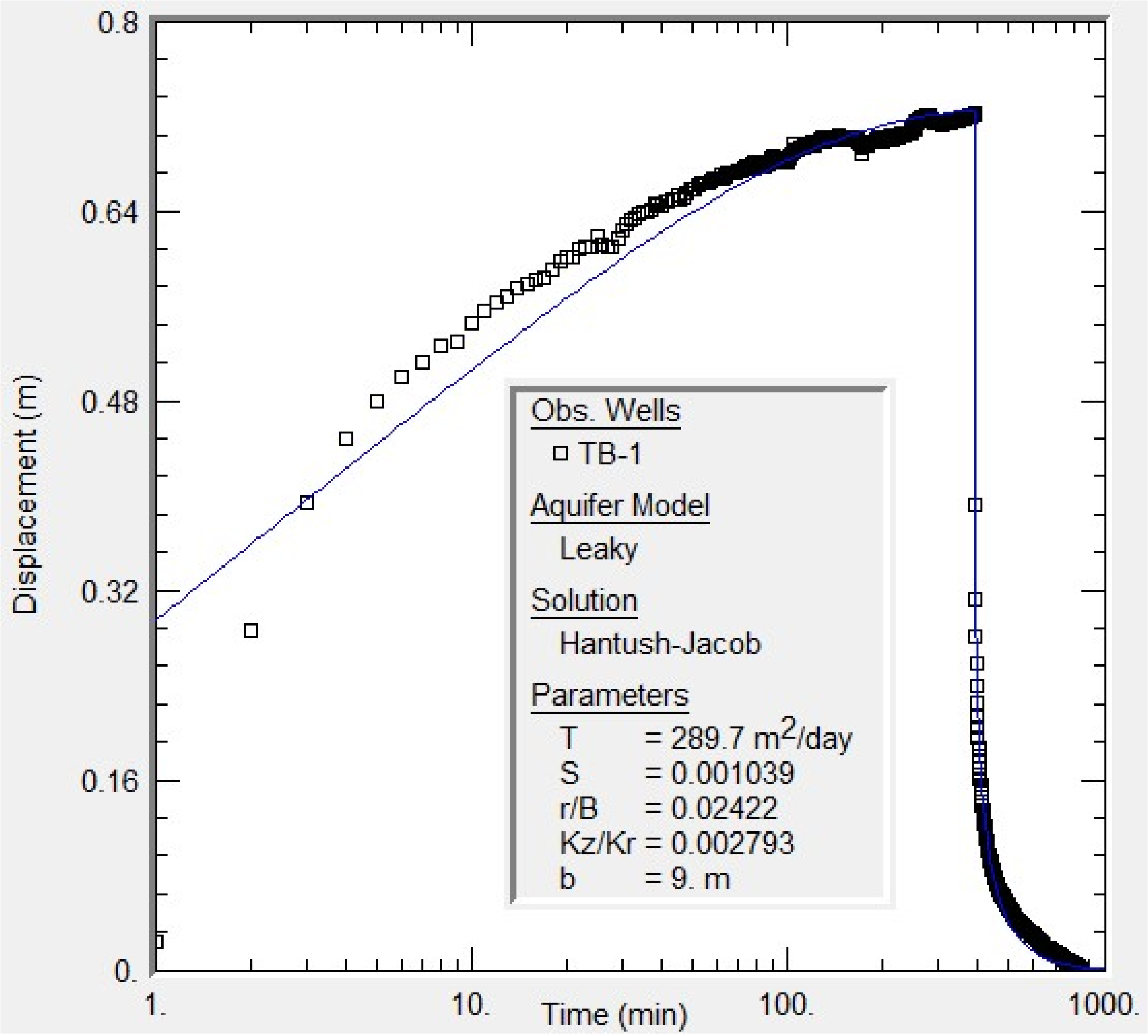

Figure 14: TB-1 drawdown AQTesSolv curve match with a Hantush-Jacob type-curve for a leaky aquifer setting

Drawdown in the shallower observation bore TB-2 was available as level logger data points at minute intervals to 120 minutes, followed by less frequent manual measurements to 390 minutes, plus recovery. Figure 16 displays the better type-curve fit with the composite high resolution / low resolution drawdown data. The Neuman (1974) type curve for unconfined aquifer settings indicated the following best fit statistics –

- Mean residual (error) = -0.00053 m
- Variance = 0.000025 m
- Standard Error = 0.005 m

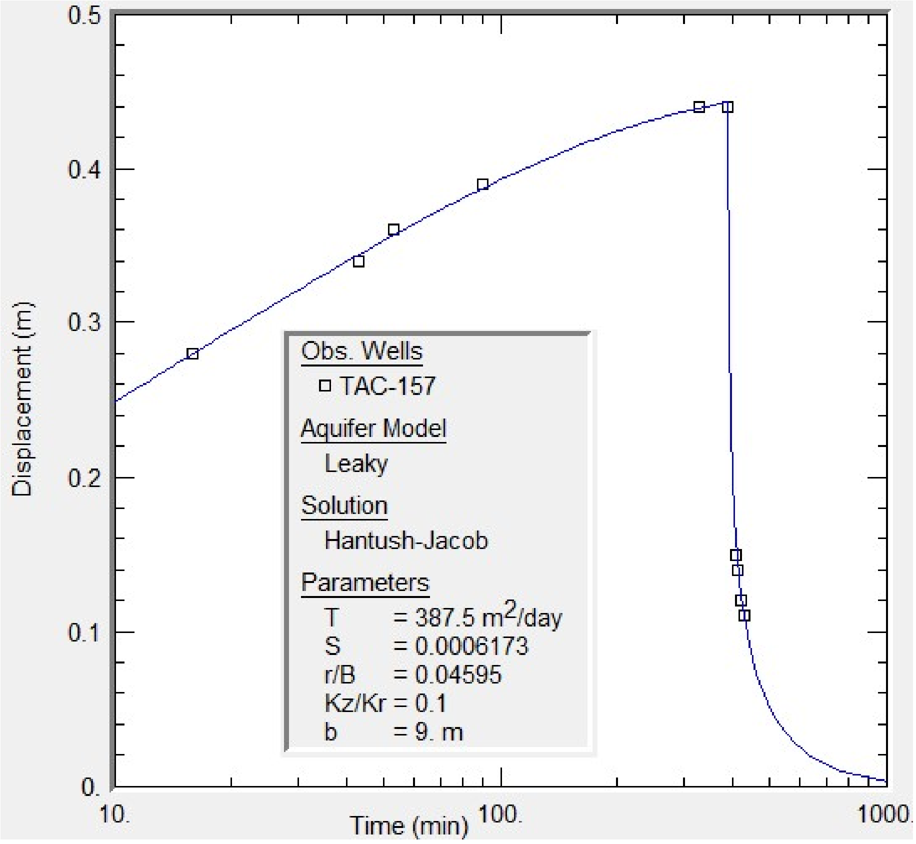

Figure 15: TAC-157 drawdown AQTeSolv curve match for this more distant observation bore with manually measured data points

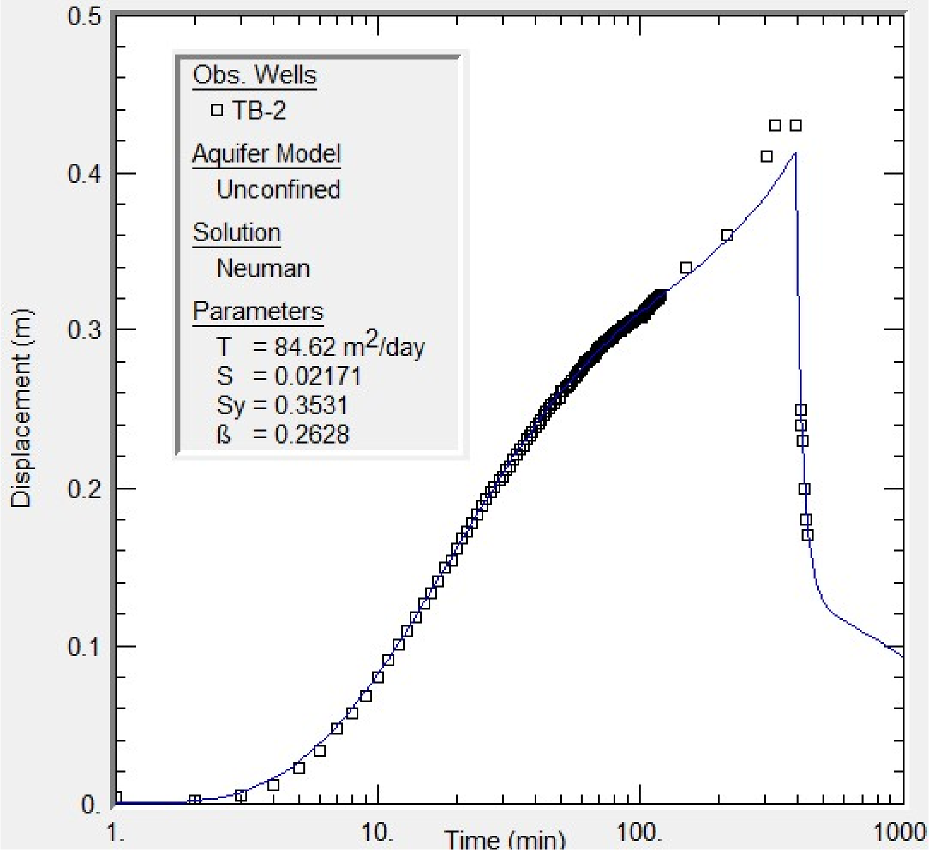

Figure 16: TB-2 shallower observation bore curve match with the Neuman (unconfined) aquifer setting

It was noteworthy that the specific yield falls into the range of specific yields (0.30 to 0.38) for unconsolidated fine to coarse fluvial, marine or dune sand (Morris & Johnston, 1967). The derived transmissivity falls close to the value derived in observing drawdown during the step drawdown test in TB-2. The interpreted results of all aquifer test analyses were listed in Table 4.

Table 4: Summary of derived hydraulic properties from Constant Rate Test at 4.0 litres per second over 6½ hours

Property	Observation Bore		
	TB-1 (same 11 m as PB-1) Sandy GRAVEL	**TAC-157** (10 m BGL) Sandy GRAVEL	**TB-2** (Shallow, 4.6 m) SAND with minor gravel
Offset or Radius (m)	5	16.6	9 (plus vertical offset)
Transmissivity, T (m^2/d)	290	388	85
Saturated Thickness, b (m)	5	5	5
Estimated Mean Hydraulic Conductivity, K_{est} (m/d)	58	78	17
Storativity, S_s	1×10^{-3}	6.2×10^{-4}	2.2×10^{-2}
Specific Yield, S_y	_	_	0.35
Radius/Leakage Ratio, r/B	0.024*	0.046*	_
Anisotropy Ratio, K_z/K_r	0.0028	0.1	_

Note: * r/B ratios consistent with leakage coefficient (b) values between 206 m and 360 m for TB-1 and TAC-157, respectively.

2.5 Falling Head Slug Testing on PB-2

Slug tests in the PB-2 test site utilised the 150 mm diameter steel casing and a 0.6 m open, water-filled void at the base of the casing to carry out falling head tests. In each instance, the casing was filled to the top of the steel casing and measurement were taken of the bore water level falling until it reached the original groundwater level approximately 2.29 m below ground level. Such tests are classed as slug tests, with the 'slug' being the volume of added water. Figure 17 displays an interpretative cross-section of the test site from north to south.

The slug testing was preceded by air-lift development of a stainless steel screen. The screen had been exposed by jacking back the temporary steel casing by approximately 0.7 m. An inferred combination of airlift disturbance and heaving sand led to the screen to being squeezed out of the exposed section (10.9 m to 11.5 m BGL). The screen was latched with a 'fishing' tool suspended on braided rope and removed from the bore hole by hand. In response, creek water was pumped from nearby Collins Creek for hydraulic development of the open bore hole. A hydraulic jetting tool on the end of the injection hose was extended beyond the end of casing to water-lift the intruded sand from the drilled section of open bore hole. Ultimately, a stable section of open hole was achieved of approximately 0.6 m length and an estimated 130 mm diameter. The depth to water stabilised to 1.66 m BGL following recovery from water injection.

Unlike the water injection at PB-1, the water injection of 0.9 L/s led to the bore hole overflowing with a similar quantity of water as was injected. It was drawn from these and other observations that the connected hydraulic conductivity was markedly lower at the PB-2 site.

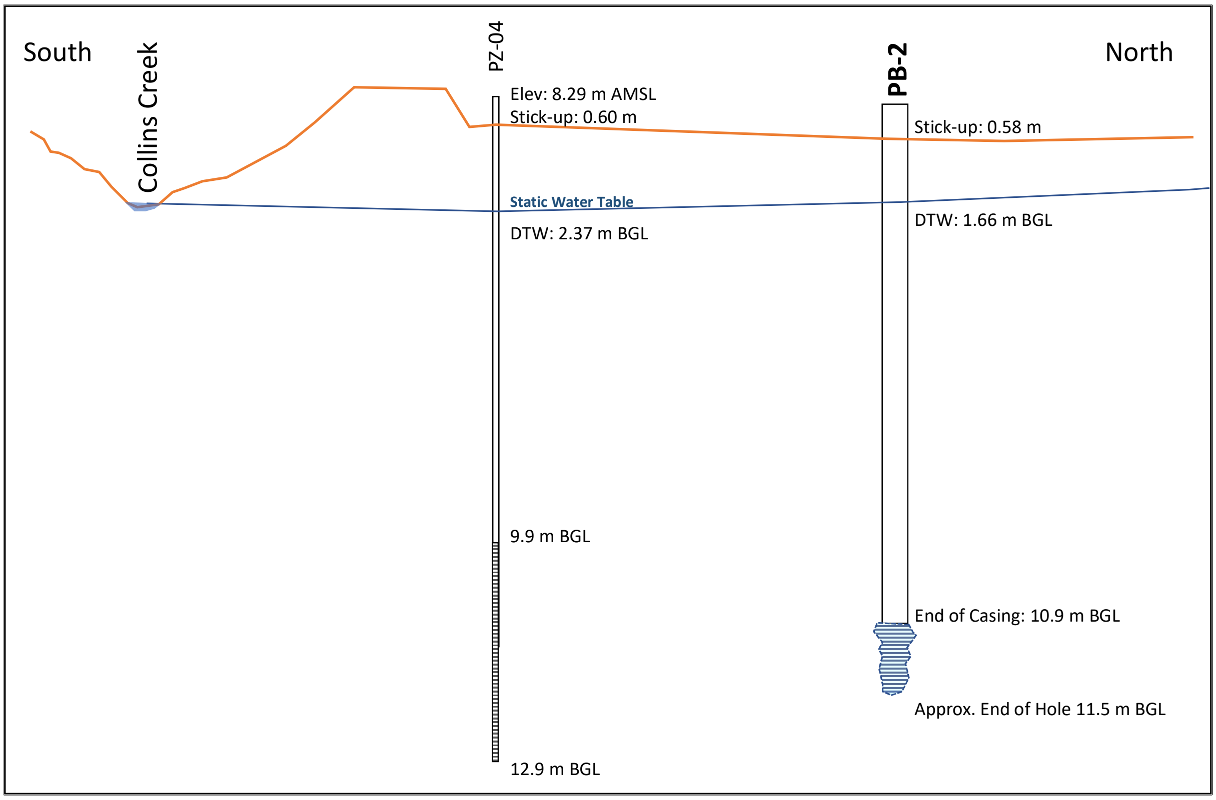

Figure 17: Sketch cross-section of PB-2 test site showing relative locations and depths from respective groundwater levels

2.5.1 Test Methodology & Data

Two consecutive falling head tests were undertaken. The falling head curves from initial displacement to stable static water level had the characteristic bimodal curve structures as shown in Figure 18 and Figure 19.

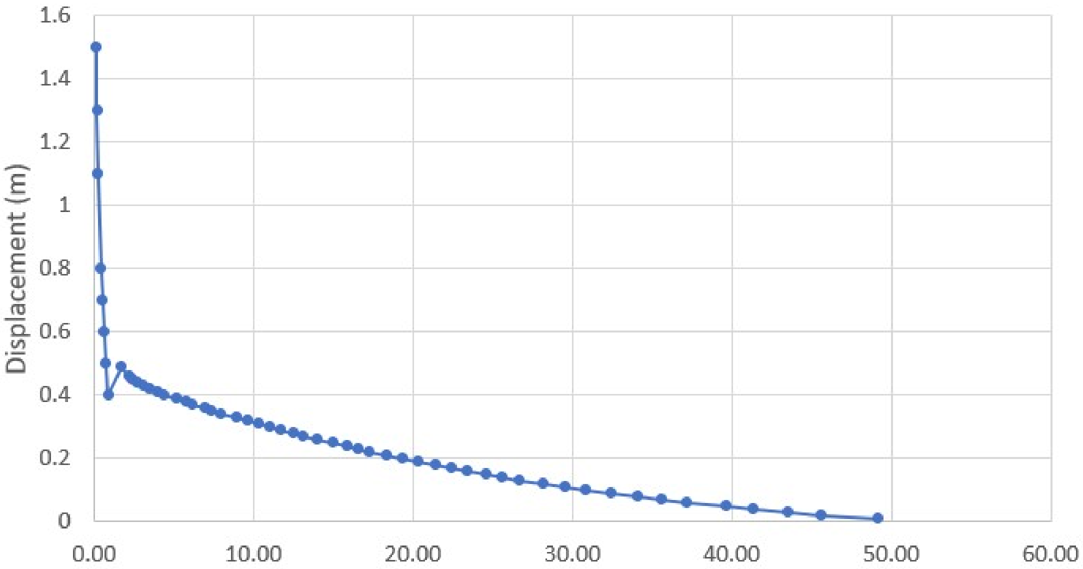

Figure 18: Measured falling head displacement in initial test

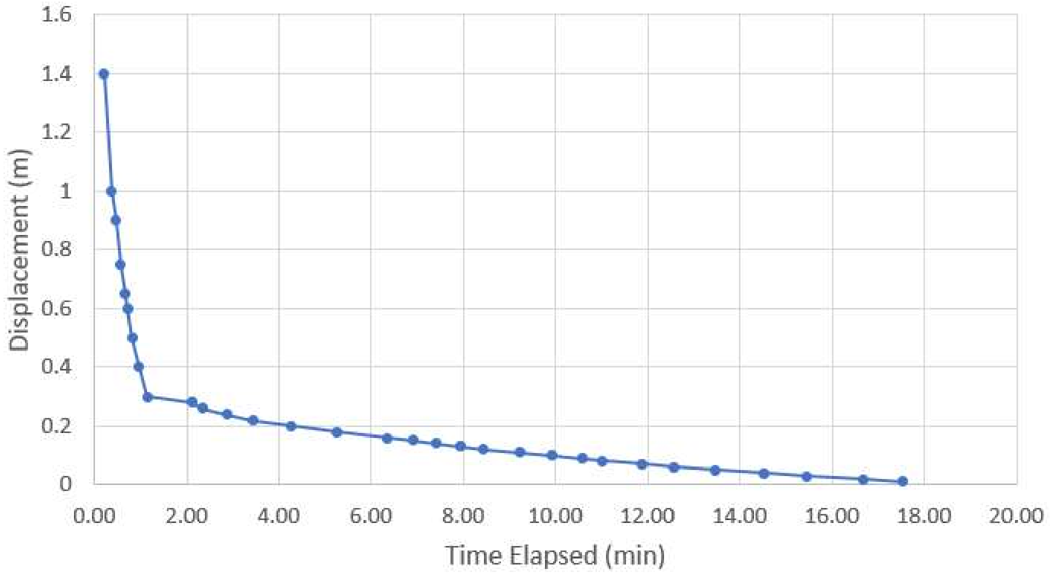

Figure 19: Measured falling head displacement in subsequent test

The initial test had a longer stabilisation period and more well defined response curves. Thus the initial test data was selected for slug test analysis. Figure 20 shows the slug test analysis using the Cooper-Bredehoeft-Papadopulos (1967) curve-match.

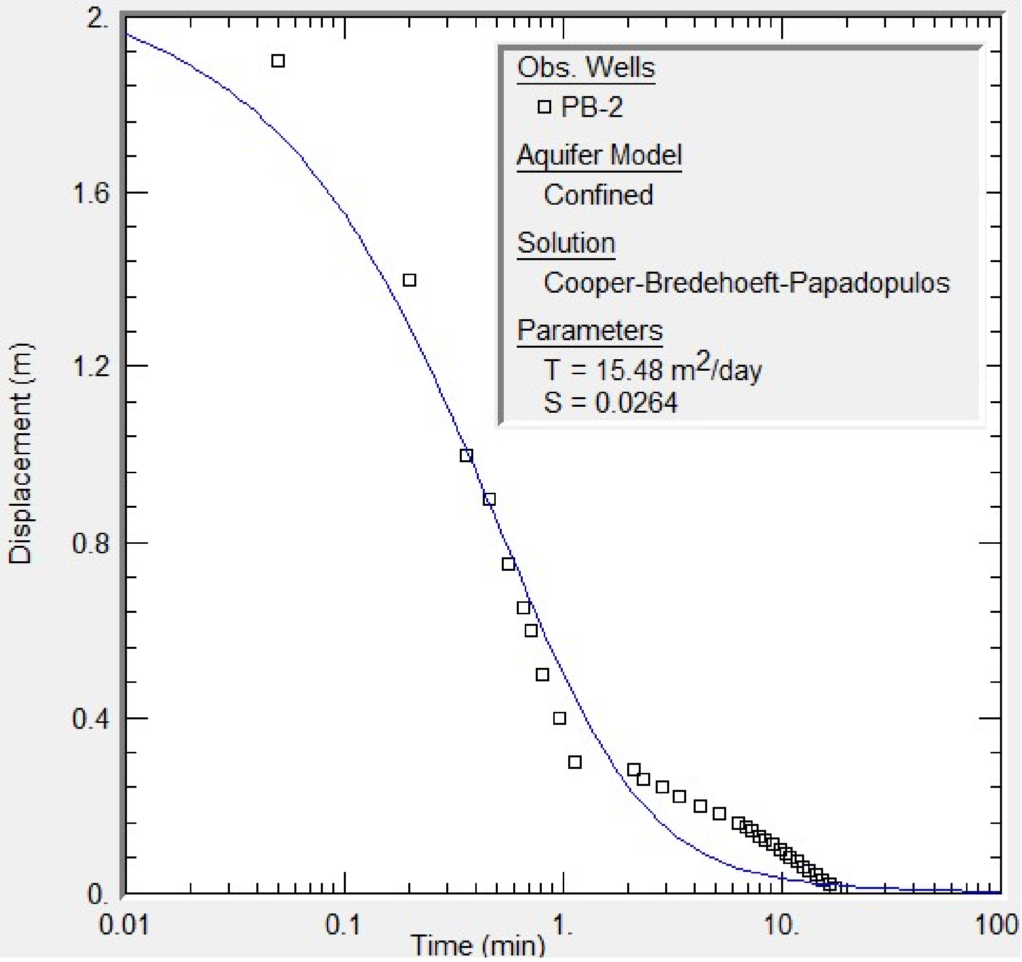

Figure 20: Cooper-Bredehoeft-Papadopulos curve match to initial falling head displacement data

The Cooper-Bredehoeft-Papadopulos type curve for confined aquifer settings indicated the following best fit statistics –

- Mean residual (error) = -0.037 m
- Variance = 0.0067 m
- Standard Error = 0.082 m

Slug test analysis methods commonly lack good curve-matches to all data-points in tests with bimodal displacements patterns. The Cooper-Bredehoeft-Papadopulos (1967) method is one of the better numerical approaches that allows fitting to the full bimodal data. Despite the use of the method, the best-fit statistics indicate a fair optimisation result.

Table 5: Summary of slug test hydraulic property results from initial falling head test on PB-2

Property	Derived Value	Comment
Transmissivity, T (m^2/d)	15.5	As determined in the Cooper-Bredehoeft-Papadopulos method
Saturated Thickness, b (m)	5	An assumption, made for consistency with Table 4
Estimated Mean Hydraulic Conductivity, K (m/d)	3.02	K = T/b
Storativity, S_s	0.026 (2.6 x 10^{-2})	Dimensionless

The derived storativity is unlikely to be valid due to the inability to match the full response curves. The derived storativity is also unrealistically high at 2.6 x 10^{-2} (dimensionless), when a more realistic value would have been 1 x 10^{-3} or 1 x 10^{-4} (dimensionless).

The lithologies encountered in the drilling of bore PB-2 included grey silty medium SAND with minor gravel between 8 m and 11 m BGL. Between 11.1 m and 11.6 m BGL, a thin sandy gravel layer was encountered in drilling cuttings. However, airlifting and infiltration testing indicated the 0.5 m section of sandy gravel results were at odds with the expected groundwater yield for this lithology. It was concluded as probable that the tested sandy gravel groundwater yield and therefore hydraulic properties were controlled by the encapsulating fine to medium sand. The results in Table 5 are therefore reflective of grey medium SAND with minor gravel. This inference is supported by the bore logs of TAC-15 and TAC-18, which were drilled near PB-2 (see Table 6) in the depth range of 6 m to 11 m BGL.

Table 6: Drilling log information for two Aircore holes adjacent to PB-2

Depth Range (m)	TAC-015	TAC-017
0 – 1	soil: clay to sand with organics	Clay
1 – 2	Medium sand	Clay
2 – 3	Silt (ore)	Clay
3 – 4	Medium sand (ore)	Clay
4 – 5	Medium sand (ore)	Silt with minor gravel (ore)
5 – 6	Silt with minor gravel (ore)	Silt with minor gravel (ore)
6 – 7	Medium sand with minor gravel (ore)	Fine sand with minor gravel (ore)
7 – 8	Medium sand (ore)	Medium sand (ore)
8 – 9	Medium sand (ore)	Medium sand (ore)
9 – 10	Medium sand	Medium sand (ore)
10 – 11	_ (not drilled below 10 m)	Medium sand with minor gravel (ore)

3 Bulk Sample Grain Size Analysis – Conversion to Hydraulic Conductivity

3.1 Bulk Sampling

A bulk sample of mineral sand was taken using a 20 tonne excavator on 5 May 2022 (see Figure 21). Two hundred litre drums of the bulk sample were shipped to IHC Brisbane for a range of analyses. Among these analyses was a Particle Size Distribution (PSD) of the Run Of Mine (ROM), i.e., unprocessed sample.

Figure 21: Bulk sampling on 5 May 2022, stockpile in foreground

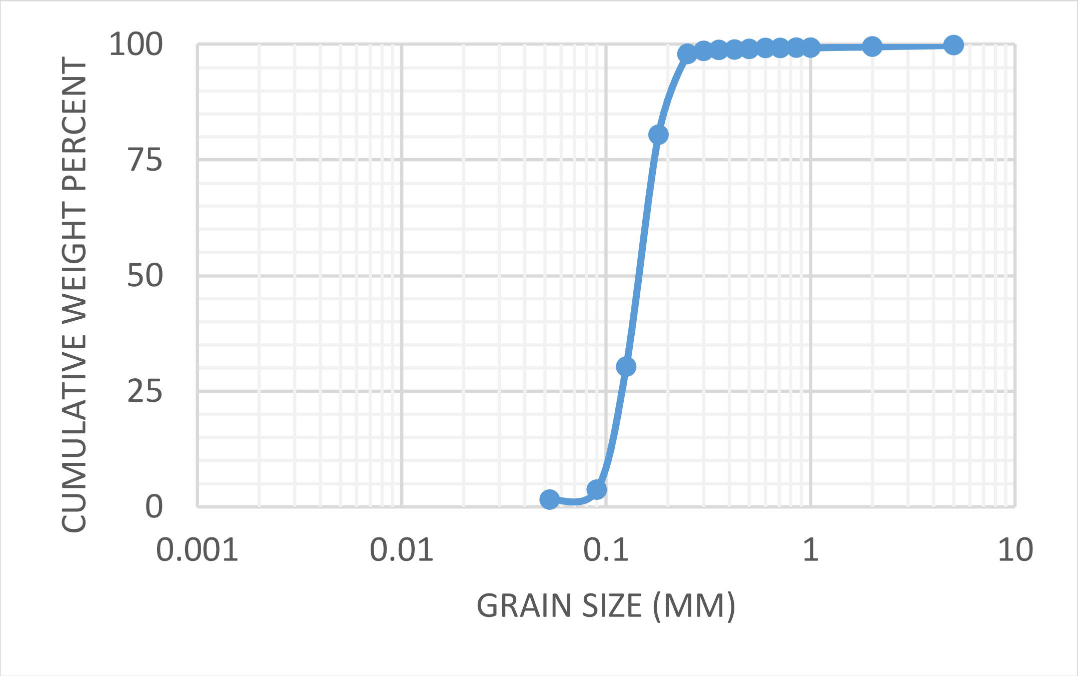

Figure 22: PSD plot of mineral sand bulk sample

The PSD indicated that the sample was a uniform SAND, low in fine fractions. This is illustrated in Figure 23, suggesting the sample is predominately fine SAND, with minor medium sand and coarse silt as minor grain size fractions.

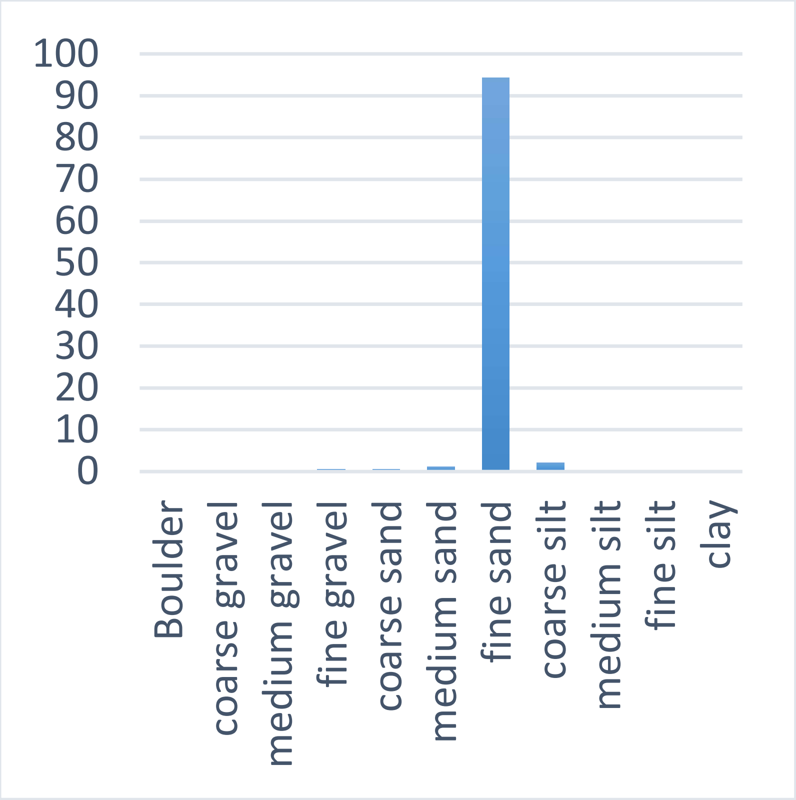

Figure 23: Grain size classification based on PSD

3.2 PSD Conversion to Hydraulic Conductivity

Particle Size Distribution correlation to hydraulic conductivity a primarily empirical approach first developed by Hazen (1892). The ROM sample subjected to PSD analysis provides a grain size analysis and associated distribution that can be used against 15 potential empirical correlation methods to estimate the sample's hydraulic conductivity. Of the 15 methods available for application, six methods passed the methodological and statistical criteria to be adopted, as listed in Table 7.

Table 7: Methods for estimation of Hydraulic Conductivity in various units and Results

Estimation of Hydraulic Conductivity	K in centimetres per second (cm/s)	K in metres per second (m/s)	K in metres per day (m/d)
Beyer (1964)	0.124E-01	0.124E-03	10.75
Sauerbrei (1932)	0.129E-01	0.129E-03	11.10
Zunker (1930)	0.197E-01	0.197E-03	17.05
Barr (2001)	0.109E-01	0.109E-03	9.45
Alyamani and Sen (1993)	0.115E-01	0.115E-03	9.93
Krumbein and Monk (1942)	0.982E-02	0.982E-04	8.48
Geometric mean	0.125E-01	0.125E-03	**10.84**
Arithmetic mean	0.129E-01	0.129E-03	**11.13**

The hydraulic conductivity indicated above lacks orientation, i.e., it does not specifically relate to either vertical or horizontal hydraulic conductivity). The results also related to a disturbed sample, the bulk sample is dug up, packed into barrels, transported, dried and analysed for particle size distribution as a disaggregated sample. Nonetheless, the mean PSD correlated hydraulic conductivity of 11 m/d is sufficiently close to the estimated hydraulic conductivity in Table 5 to provide a degree of confirmation of one of the hydraulic properties of the fine sand at the Coates Block.

4 Groundwater Chemistry of Pumping Test Sample

4.1 Methodology

A sample of groundwater was taken following 2.25 hours of pumping in bore PB-1 on 9 November 2022 from within sandy gravel deposits between 9.9 m to 11.1 m BGL. The mode of sampling was grab sample directly from the pump outlet. The test pumping was intended to provide full purging thereby drawing in fully mixed groundwater.

4.2 Analytical Results

The water chemistry results in terms of the pumped bore PB-1 has analysis results that plots within those of the ion chemistry of all other eight piezometers sampled on 9 November 2022. Of the piezometer results, the pumping test water chemistry displayed strongest affinities to that of piezometer PZ-15. Relative to the pumping test site, piezometer PZ-15 lies 360 m to the southeast and has topographic and hydrogeological similarities to the test bore PB-1.

The largest difference between the pumping test groundwater quality and those of the surrounding sampling piezometers relates to Reduction – Oxidation Potential (ORP) related constituents. The iron and manganese results for the pumping test groundwater (i.e., PB-1) were found to be the highest of all analytical results, by a long margin. The pumping test iron and manganese concentrations were 11.1 and 0.29 mg/L, respectively. This contrasts with the median iron and manganese concentrations for the other piezometers of 0.035 and 0.045 mg/L, respectively. Nitrate nitrogen was suppressed in PB-1, another indication of low ORP.

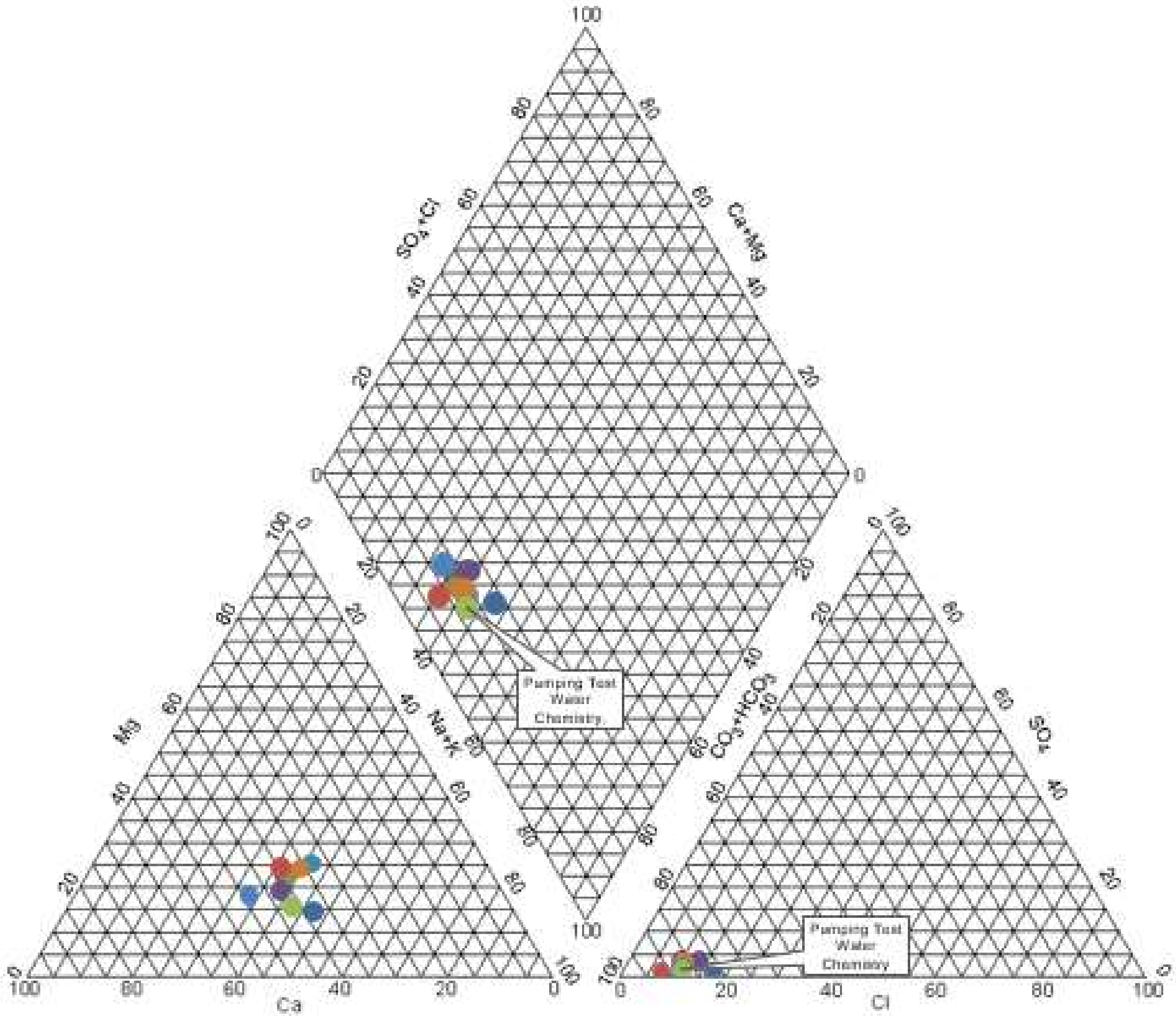

Figure 24: Pipe plot of ion chemistry for Coates Block groundwater samples taken on 9 November 2022, including from the pumping test site PB-1 (light green)

Previous analysis of piezometer groundwater sampled on 5 May 2022 had also indicated low dissolved oxygen (DO)and sub-oxic ORP status. The sampling of groundwater following vigorous pumping removing bore volumes in the thousands indicates that the groundwater sample taken during the pumping test remains low DO, and perhaps more so confirming the low DO status of Coates Block groundwater.

5 Conclusions

The following conclusions have been made with respect to the field investigations in line with study objectives:

- The following **hydraulic properties** were estimated during aquifer testing at the Coates Block in November 2022:

	Lithology in terms of broad Grain Size Distribution	
Property	**Gravel with minor sand** (leaky, semi-confined properties)	**Mineral Sand with minor gravel** (unconfined or indeterminate pressure state)
Transmissivity (m^2/d)	290 - 388	15.5 - 85
Estimated Mean Hydraulic Conductivity (m/d)	58 - 78	3 - 17
PSD Correlated Hydraulic Conductivity (m/d)	_	11
Storativity	1 x 10^{-3} to 6.2 x 10^{-4}	2.2 x 10^{-2}
Specific Yield	_	0.35
Radius/Leakage Ratio, r/B	0.024 to 0.046	_
Leakage Coefficient, B (m)	208 to 361	_

- The pumping test transmissivity range derived for gravel with mineral sand at bore PB-1 on the Coates Block (290 – 388 m^2/d) can be compared with the pumping test transmissivity result for similar lithology at NHB-06 on Burkes Road (325 m^2/d),

- The infiltration of external water poured into the test bores PB-1 and PB-2 was characterised by the infiltration rate being proportional to the respective transmissivities of the bore derived in pumping or falling head testing,

- The water chemistry of groundwater taken during the pumping test displayed broad affinities with groundwater sampled at piezometers (see Figure 24), with the following differences –
    - Iron and manganese concentrations were elevated in pumping test groundwater,
    - Nitrate concentration was suppressed in pumping test groundwater, and
    - Both relative differences are consistent with the groundwater taken following significant pumping manifesting more strongly post-oxic or reduced oxidation – reduction potential.

- There were few signs of interaction between pumping during tests in the adjacent creek were observed, aside from the coincidence of the water table height and creek level (see Figure 6).

6 References

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Appendix 2. Groundwater Results (09/11/2022)

	Sample Name:	**PZ-15**	**PZ-08**	**PZ-17**	**PZ-13**	**PZ-06**	**PZ-18**	**PZ-02**	**PZ-01**	**PB-01**
Sum of Anions	meq/L	1.86	0.98	0.99	1.15	0.89	0.94	0.87	1.43	1.41
Sum of Cations	meq/L	2	0.95	1	1.1	0.86	0.93	0.87	1.4	1.85
Turbidity	NTU	240	880	22	118	75	176	1.45	166	121
pH	pH Units	7.4	7.7	7.6	7.5	7.6	7.6	7.6	7.6	7.3
Total Alkalinity	g/m^3 as CaCO$_3$	55	34	35	36	31	33	31	57	51
Bicarbonate	g/m^3 at 25°C	67	41	42	43	38	40	38	70	62
Total Hardness	g/m^3 as CaCO$_3$	47	30	31	33	25	28	29	43	40
Electrical Conductivity (EC)	mS/m	20.6	10.7	11	12.3	9.5	10.2	9.7	14.8	14.9
Total Suspended Solids	g/m^3	610	1,440	112	183	880	640	60	310	19
Total Dissolved Solids (TDS)	g/m^3	131	64	63	71	56	62	58	85	106
Dissolved Aluminium	g/m^3	0.1	0.005	0.005	< 0.003	0.012	0.008	0.009	0.007	< 0.003
Dissolved Boron	g/m^3	0.014	0.008	0.007	0.009	0.006	0.006	0.006	0.009	0.011
Dissolved Calcium	g/m^3	13.7	7.6	7.7	9.2	5.7	6.7	8.4	10.6	11.7
Dissolved Cobalt	g/m^3	0.0011	< 0.0002	0.0002	0.0009	< 0.0002	0.0011	0.0002	0.0009	0.0006
Dissolved Iron	g/m^3	3.2	< 0.02	0.16	< 0.02	0.03	0.02	0.03	0.04	11.1
Dissolved Magnesium	g/m^3	3.1	2.6	2.7	2.5	2.6	2.7	1.87	3.9	2.6
Dissolved Manganese	g/m^3	0.29	0.0076	0.059	0.031	0.11	0.0183	0.0105	0.11	0.29
Dissolved Mercury	g/m^3	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008
Dissolved Molybdenum	g/m^3	0.0012	0.0004	0.0003	< 0.0002	0.0004	0.0153	0.002	0.003	0.0002
Dissolved Potassium	g/m^3	6.3	2.8	2.8	1.68	4.1	4.5	1.86	2	2
Dissolved Silver	g/m^3	< 0.00010	< 0.00010	< 0.00010	< 0.00010	< 0.00010	< 0.00010	< 0.00010	< 0.00010	< 0.00010
Dissolved Sodium	g/m^3	15.8	6.6	7.1	8.7	5.7	5.9	5.5	9.9	12.6
Chloride	g/m^3	22	7.6	8.1	10.9	7.2	7.8	7.4	9	12.5
Total Ammoniacal-N	g/m^3	1.17	< 0.010	< 0.010	0.106	< 0.010	0.022	0.087	0.73	0.72
Nitrite-N	g/m^3	0.24	< 0.002	< 0.002	0.004	< 0.002	< 0.002	0.017	0.004	< 0.02 #1
Nitrate-N	g/m^3	1.18	0.29	0.33	0.76	0.029	0.022	0.183	0.048	< 0.02
Nitrate-N + Nitrite-N	g/m^3	1.42	0.29	0.33	0.77	0.03	0.023	0.2	0.052	< 0.02 #1
Total Phosphorus	g/m^3	0.7	1.07	0.081	0.27	0.129	0.27	0.04	0.25	0.181
Sulphate	g/m^3	1.5	3.1	2.1	3.6	2.6	2.9	1.4	0.9	1.6
Total Organic Carbon (TOC)	g/m^3	6.7	2.4	0.8	1.1	2.2	1.2	1.4	3	4.7
Dissolved Arsenic	g/m^3	0.0091	0.0106	0.0021	0.0021	0.0017	< 0.0010	0.036	0.0025	0.0081
Dissolved Cadmium	g/m^3	< 0.00005	< 0.00005	< 0.00005	0.0001	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005
Dissolved Chromium	g/m^3	0.0035	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	0.0008	< 0.0005	< 0.0005
Dissolved Copper	g/m^3	0.0019	0.0014	0.0017	0.0018	< 0.0005	0.0055	0.0026	0.002	< 0.0005
Dissolved Lead	g/m^3	0.00113	< 0.00010	0.0003	< 0.00010	0.00038	0.00017	0.00023	0.00013	< 0.00010
Dissolved Nickel	g/m^3	0.0104	< 0.0005	0.0006	0.0019	< 0.0005	0.045	0.0053	0.122	0.0012
Dissolved Zinc	g/m^3	0.068	0.0151	0.039	0.074	0.0012	0.0198	0.104	0.046	0.0122

Appendix 3. Collins Creek (“CC”) Upstream (“US”) & Downstream (“DS”) Dissolved Analysis Results

Toxicant (dissolved)	Units	CC US 28/07/22	CC US 23/08/22	CC US 21/09/22	CC US 01/11/22	CC DS 28/07/22	CC DS 23/08/22	CC DS 21/09/22	CC DS 01/11/22	ANZG 95
Sum of Anions	meq/L	1.16	1.03	1.07	0.99	0.95	0.88	0.82	0.89	N/A
Sum of Cations	meq/L	1.16	1.06	1.14	1	0.94	0.9	0.88	0.92	N/A
Turbidity	NTU	0.95	0.6	1.19	0.82	3.7	6.6	1.07	1.35	N/A
pH	pH units	7.8	7.6	7.7	7.6	7.6	7.3	7.5	7.3	N/A
Total alkalinity	g/m^3 as	34	28	33	29	28	25	25	28	N/A
Bicarbonate	g/m^3 at	41	35	40	35	34	30	31	33	N/A
Total hardness	g/m^3 as	34	32	33	30	28	26	26	27	N/A
EC	mS/m	12.6	12	12.5	11.1	10.3	10.3	9.5	10	N/A
TSS				< 3	< 3			< 3	4	N/A
TDS	g/m^3	72	61	74	65	57	56	54	64	N/A
Aluminum	g/m^3	0.024	0.029	0.029	0.044	0.01	0.018	0.011	0.028	0.055
Boron	g/m^3	0.01	0.011	0.012	0.011	0.007	0.009	0.01	0.009	0.94
Calcium	g/m^3	9.9	9.2	9.4	8.3	7.9	7.3	7.1	7.3	N/A
Cobalt	g/m^3	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.0003	< 0.0002	< 0.0002	< 0.0002	0.0014
Iron	g/m^3	0.09	0.05	0.12	0.09	0.21	0.16	0.25	0.22	N/A
Magnesium	g/m^3	2.4	2.3	2.3	2.2	2.1	2	1.91	2.1	N/A

Toxicant	Units	CC US	CC US	CC US	CC US	CC DS	CC DS	CC DS	CC DS	ANZG 95
Manganese	g/m^3	0.0115	0.0049	0.0116	0.0073	0.034	0.0169	0.024	0.021	1.9
Mercury	g/m^3	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	0.0006
Molybdenum	g/m^3	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.034
Potassium	g/m^3	1.11	0.99	1.09	0.97	1.06	0.99	1	1.03	N/A
Silver	g/m^3	< 0.00010	< 0.00010	< 0.00010	< 0.00010	< 0.00010	< 0.00010	< 0.00010	< 0.00010	0.00005
Sodium	g/m^3	10	8.8	10.3	8.7	7.9	7.6	7.6	7.8	N/A
Chloride	g/m^3	14.4	14	12.5	12.5	12.2	11.7	9.7	10.5	N/A
Total Ammoniacal-N	g/m^3	< 0.010	< 0.010	< 0.010	0.016	0.04	0.026	< 0.010	0.065	0.9
Nitrite-N	g/m^3	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	N/A
Nitrate-N	g/m^3	0.036	0.036	0.023	0.025	0.147	0.149	0.058	0.092	N/A
Total phosphorus	g/m^3	0.008	0.005	0.081	0.006	0.008	0.007	0.008	0.009	N/A
Sulphate	g/m^3	3.5	3	3	2.7	2.2	2.4	1.8	1.9	N/A
Total organic carbon	g/m^3	2.6	1.9	2	3.3	1.6	1.5	2	3.3	N/A
Arsenic	g/m^3	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	0.013
Cadmium	g/m^3	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	0.0002
Chromium	g/m^3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	0.001
Copper	g/m^3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	0.0006	0.0014

Toxicant	**Units**	**CC US**	**CC US**	**CC US**	**CC US**	**CC DS**	**CC DS**	**CC DS**	**CC DS**	**ANZG 95**
Lead	g/m^3	< 0.00010	< 0.00010	< 0.00010	< 0.00010	< 0.00010	< 0.00010	0.00011	< 0.00010	0.0034
Nickel	g/m^3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	0.0005	0.011
Zinc	g/m^3	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	0.008

Note: ANZG 95 = Australia New Zealand (Default) Guideline value at 95% species protection

EC Electrical Conductivity

TDS Total Dissolved Solids

TSS Total Suspended Solids

Appendix 4. Canoe Creek Lagoon & Northern Boundary Drain Dissolved Analysis Results

Toxicant (dissolved)	Units	Lagoon 23/08/2022	Lagoon 21/09/2022	Northern Drain 23/08/2022	Northern Drain 21/09/2022	Northern Drain 1/11/2022	ANZG 95
Sum of Anions	meq/L	1	1.37	0.68	0.92	0.69	N/A
Sum of Cations	meq/L	1.09	1.54	0.7	1.03	0.73	N/A
Turbidity	NTU	10.1	7.6	6.2	4.4	2.7	N/A
pH	pH units	7.1	7.4	6.7	7.3	6.5	N/A
Total alkalinity	g/m^3 as $CaCO^3$	24	30	14.2	32	14	N/A
Bicarbonate	g/m^3 at 25°C	30	36	17.3	39	17.1	N/A
Total hardness	g/m^3 as $CaCO^3$	27	35	18.1	34	17.6	N/A
EC	mS/m	12	16.8	8.2	10.8	8.4	N/A
TSS			6		< 3	5	N/A
TDS	g/m^3	72	95	47	70	58	N/A
Aluminum	g/m^3	0.055	0.017	0.096	0.043	0.131	0.055
Boron	g/m^3	0.011	0.015	0.007	0.009	0.008	0.94
Calcium	g/m^3	7.1	8.6	4.7	10.2	4.2	N/A
Cobalt	g/m^3	< 0.0002	0.0004	0.0013	0.0005	0.0016	0.0014
Iron	g/m^3	1.15	0.88	0.12	1.01	0.29	N/A
Magnesium	g/m^3	2.3	3.2	1.55	1.96	1.76	N/A
Manganese	g/m^3	0.0071	0.097	0.031	0.046	0.043	1.9
Mercury	g/m^3	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	0.0006

Toxicant (dissolved)	Units	Lagoon	Lagoon	Northern Drain	Northern Drain	Northern Drain	ANZG 95
Molybdenum	g/m^3	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.034
Potassium	g/m^3	1.33	2	0.9	1.19	1.04	N/A
Silver	g/m^3	< 0.00010	< 0.00010	< 0.00010	< 0.00010	< 0.00010	0.00005
Sodium	g/m^3	10.5	17.2	6.9	6.6	7.5	N/A
Chloride	g/m^3	15.7	25	10.5	8.3	10.7	N/A
Total Ammoniacal-N	g/m^3	0.103	0.15	0.027	0.052	0.023	0.9
Nitrite-N	g/m^3	0.005	0.005	0.002	0.008	< 0.002	N/A
Nitrate-N	g/m^3	0.107	0.068	0.26	0.057	0.128	N/A
Total phosphorus	g/m^3	0.075	0.056	0.018	0.078	0.053	N/A
Sulphate	g/m^3	2.8	3.3	4.1	1.9	4.9	N/A
Total organic carbon	g/m^3	8.8	4.3	4.6	7.8	8.1	N/A
Arsenic	g/m^3	0.0012	< 0.0010	< 0.0010	< 0.0010	0.0011	0.013
Cadmium	g/m^3	< 0.00005	< 0.00005	0.00008	< 0.00005	0.00005	0.0002
Chromium	g/m^3	0.0008	< 0.0005	< 0.0005	< 0.0005	< 0.0005	0.001
Copper	g/m^3	0.0014	0.0018	0.0027	0.0014	0.0029	0.0014
Lead	g/m^3	0.00028	0.00012	0.00028	0.00019	0.0004	0.0034
Nickel	g/m^3	0.0013	0.0006	0.0021	0.0013	0.0025	0.011
Zinc	g/m^3	0.0019	0.0016	0.0151	0.0023	0.0168	0.008

Note: ANZG 95 = Australia New Zealand (Default) Guideline value at 95% species protection

EC Electrical Conductivity

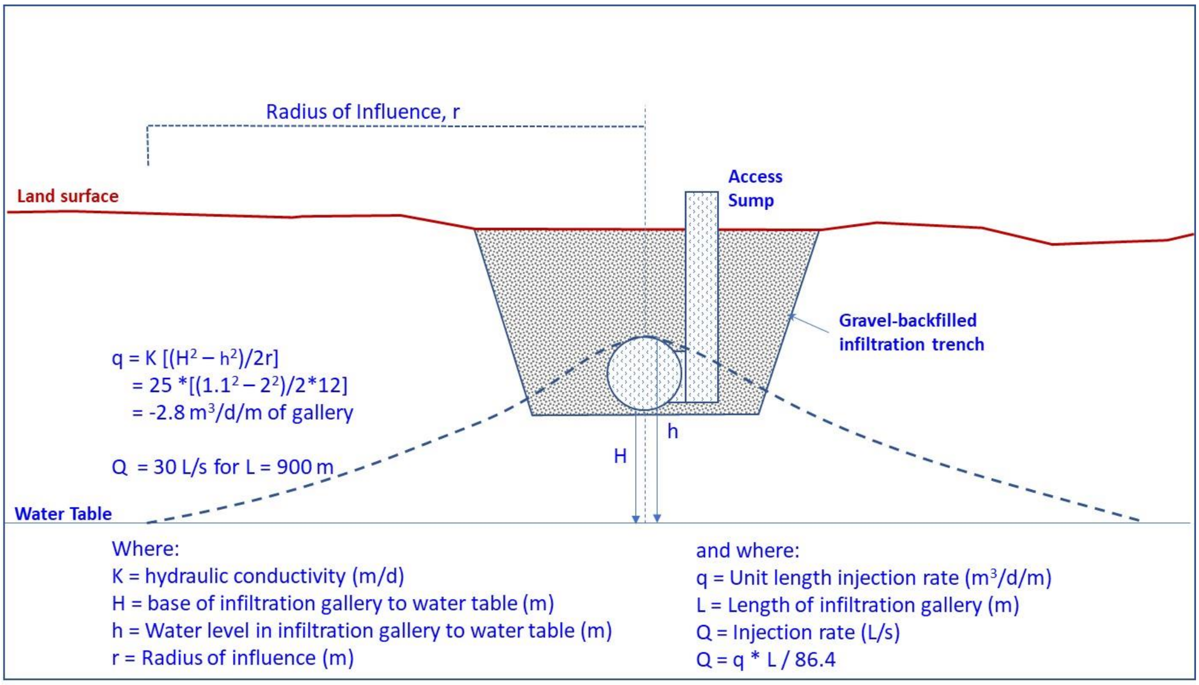
TDS Total Dissolved Solids

TSS Total Suspended Solids

0.0151 indicates that the ANZG 95 guideline is exceeded.

Appendix 5. Infiltration trench capacity assessment

An approximation of the representative parameters and conditions for the infiltration gallery at the above rates of injection is provided schematically, graphically and quantitatively in the schematic cross-section below. The associated equation used a variation of the steady state Dupuit (1863) Equation for groundwater flow in an unconfined aquifer. The figure and workings shows a cross-section of an infiltration gallery with graphical labelling of parameters used in estimating acceptance rates.



$q = K\,[(H^2 - h^2)/2r]$
$\quad = 25 * [(1.1^2 - 2^2)/2*12]$
$\quad = -2.8\ m^3/d/m$ of gallery

$Q = 30\ L/s$ for $L = 900\ m$

Where:
K = hydraulic conductivity (m/d)
H = base of infiltration gallery to water table (m)
h = Water level in infiltration gallery to water table (m)
r = Radius of influence (m)

and where:
q = Unit length injection rate ($m^3/d/m$)
L = Length of infiltration gallery (m)
Q = Injection rate (L/s)
$Q = q * L / 86.4$

Appendix 6. HMC, Tails, Slimes and ROM water quality results

Toxicant (dissolved)	Units	Slimes	Tails	ROM	HMC	ANZG 95
pH	pH units	6.9	6.9	6.9	6.8	N/A
Total alkalinity	g/m^3 as $CaCO^3$	134	29	31	5.8	N/A
Bicarbonate	g/m^3 at 25°C	163	35	38	7.1	N/A
Total hardness	g/m^3 as $CaCO^3$	3800	39	310	3.7	N/A
EC	mS/m	8.7	2.3	2.5	1	N/A
TDS	g/m^3				35	N/A
Aluminium	g/m^3	**0.12**	**0.2**	**0.12**	**0.39**	0.055
Arsenic	g/m^3	< 0.02	< 0.02	< 0.02	< 0.0010	0.013
Boron	g/m^3	< 0.10	< 0.10	< 0.10	0.008	0.94
Cadmium	g/m^3	< 0.0010	< 0.0010	< 0.0010	< 0.00005	0.0002
Calcium	g/m^3	310	4.6	23	1.13	N/A
Chloride	g/m^3				< 0.5	N/A
Chromium	g/m^3	< 0.0010	<0.0010	< 0.0010	0.0036	0.001
Cobalt	g/m^3	< 0.004	< 0.004	< 0.004	0.0004	0.0014
Copper	g/m^3	**0.012**	< 0.010	< 0.010	0.0055	0.0014
Iron	g/m^3	< 0.4	< 0.4	< 0.4	0.5	N/A
Lead	g/m^3	< 0.002	< 0.002	< 0.002	0.00148	0.0034
Magnesium	g/m^3				0.2	N/A
Manganese	g/m^3	0.12	< 0.010	0.026	0.0199	1.9
Mercury (inorganic)	g/m^3	< 0.00008	< 0.00008	< 0.00008	< 0.00008	0.0006
Molybdenum	g/m^3	< 0.004	< 0.004	< 0.004	0.0008	0.034
Nickel	g/m^3	< 0.010	< 0.010	< 0.010	0.0016	0.011
Nitrate-N	g/m^3				0.042	N/A
Nitrite-N	g/m^3				0.005	N/A
Potassium	g/m^3	2	< 1.0	1.6	0.64	N/A
Silver	g/m^3	< 0.002	< 0.002	< 0.002	< 0.00010	0.00005
Sodium	g/m^3	4.9	1.8	1.4	0.74	N/A
Sulphate	g/m^3				< 0.5	N/A
Total Ammoniacal-N	g/m^3				< 0.010	0.9
Total organic carbon	g/m^3	45	3.6	9.6	3.4	N/A
Total phosphorus	g/m^3	60	< 0.42	3.9	0.22	N/A
Zinc	g/m^3	< 0.02	< 0.02	< 0.02	0.006	0.008