Before the Hearing Commissioners
appointed by the Grey District
Council and West Coast Regional
Council

Under	the Resource Management Act 1991
In the matter of	Resource consent applications by TiGa Minerals and Metals Ltd to establish and operate a mineral sands mine on State Highway 6, Barrytown (RC-2023-0046; LUN3154/23)

Statement of evidence of Jens Haaye Rekker

19 January 2023

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QUALIFICATIONS AND EXPERIENCE

1 My full name is Jens Haaye Rekker.

2 I hold the qualifications of Bachelor of Science and Postgraduate Diploma in Science (with Credit) within the science of geology, from the University of Otago. I have 31 years of experience primarily as a hydrogeologist (or groundwater scientist) in a range of consulting, regional council and research institute roles.

3 I am currently employed as a Principal Hydrogeologist by Kōmanawa Solutions Ltd and have held that position since January 2022.

4 My previous work experience includes five years at Otago Regional Council as Resource Scientist – Groundwater and a further year as Senior Catchment Modelling Scientist. I was tasked with groundwater basin sustainable yield assessments, water quality studies, assistance to water policy development and providing expert testimony for hearings, District Court or Environment Court.

5 Between 1992 and 2008 I worked in engineering and environmental companies on mining, water supply and hydrological impact studies. My project work over this time has included relevant groundwater desktop studies, feasibility studies, drilling & aquifer test supervision, aquifer test analysis, water monitoring design & operations, groundwater flow / contaminant transport modelling and the preparation of assessment of effect documents to inform the consenting process.

6 In consulting roles for mineral enterprises, I have undertaken integrated hydrological assessments of coal, alluvial gold, hard-rock gold, base metals and coastal mineral sand deposits. I have been involved in the hydrological assessments of the Barrytown mineral sands proposals since late 2019, and the current Application proposal in the Application Site since March 2022. I have attended most of the hydrological fieldwork undertaken in and around the Application Site since then.

7 My role in relation to TiGa Minerals and Metals Limited's (**TiGa MM**) application to establish and operate a mineral sands mine at SH6 Barrytown (**Application** and **Application Site**) has been to provide advice in relation to undertaking field investigations, develop a hydrological monitoring programme, prepare a conceptual model of Application Site hydrology and hydro chemistry, and carry out environmental assessment with the assistance of predictive groundwater computer modelling.

8 My assessment is based upon the proposal description attached to the evidence of Ms Katherine McKenzie.

9 In preparing this statement of evidence I have considered the following documents:

(a) the **AEE** accompanying the Application; “Barrytown Mineral Sands Mine Hydrological Impact Assessment.” Kōmanawa Solutions technical report prepared for TiGa Minerals & Metals Pty Ltd, Report No: Z22004_1-Rev3, Christchurch, NZ, and

(b) the **Water Management Plan** titled “Water Management, Monitoring and Mitigation Plan” Kōmanawa Solutions technical report prepared for TiGa Minerals & Metals Pty Ltd, Report No: Z22004_2-Rev2, 17 April 2023. This report is appended as **Appendix 1**.

(c) review of TiGa resource consent application – Barrytown Mine, hydrological and hydrogeological aspects of the application by Brett Sinclair, WGA NZ Ltd for WCRC and GDC, and responses made by KSL on 27 July 2023.

(d) reporting of **additional assessments** undertaken since the submission of consent applications by TiGa MM, including a memorandum titled “Barrytown, Coates Block Hydrological Revision: Injection and Infiltration Trials, Conceptual & Groundwater Model Re-Model,” by Jens Rekker of KSL, Draft, 17 November 2023, and a memorandum titled ”Hand Augering 29 – 30 November 2023”, by Zeb Etheridge of KSL, dated 17 January 2024. This report is attached as **Appendix 2**.

(e) reporting of **additional information** relating to the above additional assessments, including the memorandum titled Revision of Assessed Pit Seepage Rates and pumped Groundwater Metals Concentrations in the light of recent Injection & Infiltration Trials, dated 13 October 2023 and prepared by myself. This report is appended as **Appendix 3**.

(f) submissions relevant to my area of expertise;

  (i) the statement of evidence on mineral process development prepared by Tom Lawson for TiGa MM;

  (ii) the statement of evidence on geotechnical aspects of mining activities prepared by Cam Wylie for TiGA MM;

  (iii) the statement of evidence on coastal processes by Gary Teear for TiGa MM;

  (iv) the statement of evidence on ecology by Gary Bramley for TiGa MM;

  (v) the statement of evidence on water quality and metallic contaminants by Mike Fitzpatrick for TiGa MM;

  (vi) the statement of evidence on aquatic ecology by Mark Roper for TiGa MM;

(g) Section 42A reports prepared for this Proposal; specifically, the West Coast Regional Council commissioned Section 42A Officer's Report dated 15 January 2024, and the Grey District Council commissioned Section 42A Officer's Report dated 22 December 2023;

(h) key directive policies relating to hydrology for the NPS-FM and NES-F, namely;

  (i) National Policy Statement - Freshwater Management (2020),

  (ii) New Zealand Coastal Policy Statement,

  (iii) West Coast Regional Policy Statement, and

  (iv) West Coast Land and Water Regional Plan.

10 I was first invited to contribute to the evaluation of hydrological matters connected to a previous mineral sand proposal at Barrytown between Burke Road and Canoe Creek for Barrytown Joint Venture Ltd in December 2019. I ceased involvement in that project in late 2020 to take up a local government role and I returned to private practice for my current consulting role in January 2022. I began to work on the current TiGa MM proposals over the Application Site in March 2022.

11 I have visited the Application Site on 11 April, 3-4 May, 27-28 June, 18-19 July, 23-25 August, 31 October – 10 November 2022; 27 February 2023, 28 March 2023, and 11-22 September 2023 in the course of establishing or maintaining hydrological monitoring, water sampling, specialised groundwater testing or trials, and site meetings. During these visits spanning a year and a half, the Application Site has exhibited a wide range of weather and climate states, including consequential soil saturation and hydrological conditions.

12 I have undertaken hydrological and water quality assessment in collaboration with my Kōmanawa colleagues, Zeb Etheridge and Evelyn Charlesworth. These colleagues have been active in the TiGa Minerals and Metal's Application, including undertaking fieldwork, managing laboratory requests, Application Site mapping and assessment report preparation.

CODE OF CONDUCT FOR EXPERT WITNESSES

13 While this is not a hearing before the Environment Court, I confirm that I have read the Code of Conduct for expert witnesses contained in the Environment Court of New Zealand Practice Note 2023 and that I have complied with it when preparing my evidence. Other than when I state I am relying on the advice of another person, this evidence is within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

SCOPE OF EVIDENCE

14 I have prepared evidence in relation to:

(a) the existing environment of the Application Site covering surface water, groundwater and hydro chemical aspects of the Application;

(b) the key findings of my assessment of effects covering the Site and adjacent properties and on surface water quality, including sediment discharges;

(c) the draft Water Management Plan (“Water Management, Monitoring and Mitigation Plan”) prepared by Zeb Etheridge and myself, included as **Appendix 1**, which sets out how information on baseline conditions will continued to be collected before mining operations start, the ongoing monitoring that will occur during mining and the actions that will be undertaken to avoid and manage hydrological effects;

(d) Additional fieldwork and hydrological analysis (“Barrytown, Coates Block Hydrological Revision: Injection and Infiltration Trials, Conceptual & Groundwater Model Re-Model”, KSL Report No: Z22004-4-Rev0. Draft report dated 17 November 2023, and labelled “Revised assessment and model development to supplement the KSL report Z22004_1-Rev3”).

(e) matters raised by submitters to the Application;

(f) matters raised in the West Coast Regional Council’s (**WCRC**) and Grey District Council’s (**GDC**) staff reports (reports issued under s42A of the RMA); and

(g) proposed conditions of consent.

15 I conclude the proposed mining activities, combined with measures that avoid, minimise and monitor for water-related effects on the environment are consistent with the policies and objectives set out above and would have water-related environmental effects less than minor in nature.

EXECUTIVE SUMMARY

16 The existing environment at the Application Site entails a pastoral farming operation (dairy support) at 3261 Coast Road on the Barrytown Flats between Canoe Creek Lagon in the west and Coast Road or State Highway 6 in the east.

17 The Applicant proposes to excavate and process 4.8 million tonnes of sand from beneath a 34 hectare area (within the 63ha mining disturbance area) of the farm. The sand ore would be conveyed to a wet processing plant where the Heavy Mineral Concentrate would be extracted and dispatched to market. Rejected sand

and slime (fine grained) materials following mineral processing (i.e., ‘tailings’) would be returned to the re-filling mine void for utilisation in land restoration.

18 The sand and occasional gravel deposits making up the Barrytown Flats host a groundwater system and the deposits area saturated by a water table found between 0.5 m and 4 m below the land surface. The deposits have been found to have a wide range in permeability to water (also termed hydraulic conductivity or transmissivity) from low to high permeability. Such variability in permeability is characteristic of coastal and terrestrial water-lain deposits.

19 Drilling and groundwater property testing of the Application Site subsurface has highlighted some vertical stratification in groundwater properties related to deposit grain sizes compositions, including –

(a) Superficial clay-rich overburden (low permeability) and partial confining layer,

(b) Mineral and other sands (low – moderate permeability),

(c) Gravels towards the base of the sands (moderate - high permeability),

(d) Sands with minor gravels to great depth (low – moderate permeability),

20 At odds with the general stratification of materials and groundwater properties, the margins and beds of Collins Creek and Northern Boundary Drain were found to be associated with pronounced thickening of the clay-rich, low permeability overburden covering. This partially isolates the water courses hydrologically from the underlying groundwater system, as confirmed in drilling and groundwater property testing investigations.

21 The Barrytown Flats have a humid climate with nationally elevated rainfall generating high flows in the hill catchments but also falling on the coastal flats. The area’s hydrology displays adaptation to these factors in terms of shedding and absorbing accumulating rainfall surpluses, including episodes of high intensity rainfall. These factors are reflected in the area’s vegetation and fluviatile geomorphology, as it also is in the formation of wetlands and coastal lagoons formed behind gravel barrier beaches.

22 The Barrytown Flats’ water balance is most often in surplus with the resulting shedding of catchment water as indicated above. Rarely, the monthly soil water balance might fall into deficit in response to ‘dry spells’. The longest recorded dry spell from 1981 to 2010 along the Grey – Buller coast was only 40 days in duration, in 2013.

23 Of hydrological significance, the active mining void would necessarily be managed with an artificially lowered target water level, achieved by sand - water slurry

extraction in slurry lines to the plant plus sump pumping to achieve the temporary target water level.

24 The sand extraction (mining) methodology involves the active mine void or pit progressing steady from west to east along ten Mine Panels (1 – 10) with the first mined panel in the south of the Application Site adjacent to the mineral separation plant.

25 Thus, the centre of groundwater pumping disturbance would move with the active pit from west to east, south to north, and finally south for Mine Panel 9 adjoining the plant site, through the life of the mine. The ground disturbance would be restored in the wake of the active mining areas by a process of restoration and land rehabilitation.

26 The assessment of scale of mining related effects on the area’s hydrology has undergone material revision since the lodging of consent application in April 2023, primarily due to greater understanding of the subsurface and groundwater conditions gained in the course of carrying trials for infiltration mitigation systems.

27 In a nutshell, the thick, highly permeable ‘basal sandy gravels’ inferred from shallow drill holes was found to be a flawed and unjustifiably conservative concept applying to the subsurface beneath the mineral sands. Deeper drilling and testing of groundwater conditions indicated that the April 2023 AEE hydrological projections of groundwater pumping required to manage pit water levels were overly conservative and significantly over estimated both pumping rates and the degree of depletion effect on surrounding water bodies.

28 The amount of surface water depletion and groundwater level lowering exerted beyond the pit walls is directly proportional to the net rate of pumping from the mine pit. Rates as high as 200 litres per second were estimated and submitted in April 2023.

29 Revised calculations of the net rates of pit pond pumping indicated a peak of 68 litres per second, averaging 30 L/s across the 5-7 year life of the sand mining. It is also proposed that the treated mine water is handled as a resource in mitigating any lowered groundwater levels or in augmentation of surface water flows.

30 Water related infrastructure required for mine include the following:

(a) A buried gallery intake in the Canoe Creek alluvium for filling the wet processing plant with water,

(b) A mobile sump pump in the active mine void or pit low point,

(c) Tailings management structures for emplacing rejected sand and restoring the land,

(d) Water treatment plants, including settling ponds and clarifier, at the main processing plant (Pond 1 and 2),

(e) Central Drain, including permeable limestone rock weirs, and

(f) Water treatment, including settling and coagulation, at the Clean Water Facility (Pond 3 and 4), and

Water Effects Mitigation Structures

(g) Southwest and northern peripheral infiltration trenches,

(h) Injection wells near the north and south property boundaries,

(i) Direct surface water augmentation outfalls at Collins Creek and Northern Boundary Drain,

(j) Canoe Creek Infiltration Basin for managing the infiltration of treated water not utilised in infiltration / injection / augmentation of water bodies, or otherwise not released at the tail of Pond 4.

31 The water related infrastructure, particularly the mitigation related structures, would be operated to avoid and mitigate effects on water quantity or quality.

32 In instances where water management infrastructures, such as mitigation wells and trenches and Ponds 3 and 4 (see Project description for location and extent), would fall within 100 metres of a wetland. There is a functional need for the infrastructural elements to be so placed due to the geometry of the Mine Panels and the requirement to be in a location for catching the mine water flows not otherwise utilised in active mitigation.

33 The starter mine pit would be located in the west of Mine Panel 1 and adjacent the sand stockpile reserved area that separates the starter pit from Lower Colins Creek. The excavation would be slow due to the need to lay out the full mine footprint. The mine water piping and processing circuits would require topping up from the Canoe Creek intake as the initial mine groundwater ‘make’ would be insufficient.

34 The taking of water via a buried gallery in the Canoe Creek alluvium would be intermittent and always less than 10% of the estimated Men Annual Low Flow, and thus consistent with the maintenance of ecological values for Canoe Creek.

35 The principal effects of the mining activities on the groundwater system are water table lowering, which is greatest at the site of active mining and decays in impact exponentially with distance from that site. Nonetheless, water table lowering may

extend to water bodies within the Application Site and beyond the Site boundaries unless mitigation measures are deployed.

36 Seawater intrusion of coastal groundwater is a rare occurrence in situations where artificial groundwater extraction substantially outstrips the natural outflow of groundwater causing a reversal in exchange between the sea and aquifer.

37 The high rainfall, high runoff setting of the Barrytown Flats, plus the presence of fresh groundwater right up to the coastline and at depth, plus significant slope on groundwater gradients into the freshwater coastal lagoon or sea, plus the relatively modest pit management pumping rates, contribute to a high certainty that seawater intrusion would not result from mining activities as proposed.

38 The risk of seawater intrusion was also assessed with the assistance of computer groundwater modelling which integrated all of the above risk factors as reported in the hydrological AEE assessments and responses to peer review. The risk was found to be very low.

39 Water table disturbance due to mining may have the knock-on effect of 'depleting' the flow of affected reaches of the water bodies unless the effect is mitigated. Minor to moderate depletion effects are predicted to correspond to the timing of the closest approach(es) of the active mine pit to the water bodies of –

(a) Collins Creek and adjoining Langridge South springs,

(b) Canoe Creek Lagoon and adjoining wetlands,

(c) Northern Boundary Drain and adjoining wetlands, and

(d) Rusty's Lagoon and adjoining wetlands.

40 All but 4% of groundwater taken in the process of mining as evaporative and adherent moisture losses is available for utilisation in mitigation structures, particularly the peripheral infiltration trenches bolstering shallow groundwater levels and injection wells bolstering deeper groundwater pressures. If unused in mitigation, mine waters are further treated and released at the tail of Pond 4, into Canoe Creek Lagoon.

41 Mitigation would be guided by water level and flow monitoring (perhaps 4 years of data defining seasonal patterns) and prior computer groundwater modelling. This data would be employed to apply the infiltration water in locations for most benefit in minimising water table lowering or surface water depletion.

42 The Application Site is not located in a semi-arid climate setting. Therefore, the risk of adverse effects of depleting surrounding water bodies in the Barrytown Flats' context is inherently minimised by the temporal predominance of hydrological

surpluses traversing the Deverys and Collins Creek catchments that are available to 'top-up' temporarily depleted groundwater, surface flows or water levels. Such dry spells that occur are rare, of short duration and readily identifiable from measurements of rainfall, water level and surface flow, which enables the triggering of focused mitigation measures to manage the ecological stresses arising from hydrological deficit.

43 Furthermore, active management of groundwater levels and surface flow within the Application Site in the context of environmental effects mitigation would target reversing groundwater level lowering or flow depletion reasonably attributable to mining activities. Such management would be encapsulated and enforceable within conditions attached to the consent.

44 There are inevitably uncertainties associated with natural hydrological systems and groundwater management measures, so critical technical responses have been devised to minimise the remaining levels of uncertainty. The use of best information plus iterative acquisition of investigation results and analysis for the Application Site have significantly reduced the levels of uncertainty attached to knowledge of the Site or the effectiveness of mitigation proposed. High quality information and solidifying understanding as to Site hydrological dynamics has been obtained in trials and continued layering of hydrological monitoring data.

45 A strategic outlook has also been employed minimise risk and build on best knowledge, such as the proposal to begin mining in a location with less potential hydrological or ecological effects at Mine Panel 1. This approach would progressively optimise monitoring and groundwater management systems to strengthen institutional knowledge of operating the systems and the effectiveness of mitigations in minimising effects.

46 The water quality of groundwater taken at the active mine void or pit would be a mixture of shallow and deeper characteristic compositions dominated by deeper ground water metals composition that would become fully mixed in the course of pumping and mineral processing. Following treatment, including coagulation, precipitation and settling of fine sediment and metals, the treated water would be suitable for mitigation roles (primarily in application to the ground) or discharge from Pond 4 to Canoe Creek Lagoon.

47 The concentrations of dissolved metals and metalloids released to natural water utilised in mitigation or discharged are assessed to be less than guideline values for metals and metalloids.

48 Geotechnical modelling assessments of pit wall stability during active mine, including where the pit would be located hard against the 20 metre boundary buffer and water bodies such as the Northern Boundary Drain or lagoons have demonstrated that the proposed mining void profile would be safe against collapse.

The presence of infiltration trenches and injection wells along the northern boundary would be consistent with adequate factors of safety against pit wall collapse.

49 The re-contoured, restored and rehabilitated land surface would be substantially the same surface as existed prior to mining, albeit with softened hump and hollow profile. The land surface would shed water in a similar fashion, although the improved soil drainage characteristics would slow overall land drainage with an expected enhancement of long-term water quality.

50 The construction of Ponds 3 and 4, followed by the rehabilitation of these ponds into a constructed wetland would have neutral impact on hydrological conditions in the area as either water body feature would have minimal interactions with surrounding water bodies other than via the groundwater system and would conform with ambient groundwater level states throughout its lifetime.

51 Section 105 and section 107 RMA will be achieved. Alternative water management methods have been duly investigated.

52 Considering all of the points summarised above, I have considered the proposal with regard to the freshwater objectives and policies within the National Policy Statement on Freshwater Management 2020 (in particular policies 2.2.6 and 2.2.7); New Zealand Coastal Policy Statement 2010 (in particular policy 3(1)), West Coast Regional Policy Statement (in particular policies 9.5 ((a) and (b)); West Coast Regional Land and Water Plan (in particular policies 3.3.1(2), and 4.3.2, 10.3.2, 10.3.3, 10.3.5, and Objectives 7.2.1, 10.2.1), and the proposal in its full implementation is consistent with these provisions.

53 This set of assessments have found that the proposed mining activities, combined with measures that avoid, minimise and monitor for water-related effects on the environment are consistent with the policies and objectives set out above plus the activities would have water-related environmental effects less than minor in nature. Furthermore, hydrological function of the freshwater creeks, ponds, wetlands, springs and underlying groundwater systems would be preserved during the proposed mining activities as essentially the same flow patterns would be sustained throughout.

THE EXISTING ENVIRONMENT

54 The Application Site is located on an extensive coastal landform named the Barrytown Flats. A sharply defined break in slope between the backdrop hill country and the coastal flats is a buried sea cliff cut into the toe of the hills in the last 10,000 years and nowadays marked by the State Highway 6 road alignment.

55 The Barrytown Flats include mostly buried lenses of concentrated heavy minerals encapsulated within other coastal or alluvial deposits. The Heavy Mineral Concentrate (HMC) is the mineral resource specified in the Application, that also partially hosts the shallow groundwater system conducting water from higher pastures on the Application Site to the coastal lagoons near sea level.

56 The area's surface water comprises Deverys Creek to the north, Collins Creek and Canoe Creek to the south that drain the backdrop hill slopes and cross the coastal flats to the coastal wetlands and lagoons. Canoe Creek is the largest Barrytown Flats drainage, while Collins Creek is a modest, modified water course defining much of the southern property boundary of the Application Site.

57 Gravel barrier beaches have impounded coastal lagoons and hāpua (coastal lagoons at creek mouths behind gravel bars) at the coastal fringe of the Barrytown Flats, which are largely freshwater and non-tidal. Canoe Creek makes a hāpua connection with the Tasman Sea with minor creeks combining in a string of Canoe Creek Coastal Lagoons north of the Canoe Creek mouth.

58 The evidence of Mr. Gary Teear considered the gravel barrier(s) impounding coastal lagoons such as the Canoe Creek Lagoon to be dynamically stable. Furthermore, coastal erosion would be anticipated to result in the coastline reaching the 20-m buffer to the mining panels, but only after approximately 200 years of erosive coastal processes under current and anticipated rates of advance.

59 The Application Site has been developed and maintained as pastoral farmland between the Northern Boundary Drain (on the northern margin of the Application Site) and Canoe Creek. The farmland has also more recently undergone a drainage modification called Humping and Hollowing, which creates a striped pattern of low ridges and swales connected by open farm drains for overall farm drainage.

60 What was likely to have been back-dune and forest wetlands is now grassed and humped pasture with farm tracks, farm drains and fencing, following extended farm land development in the 20th Century. Indeed drilling has encountered buried wetland remnant sediments and peat, consistent with pre-European landforms of coastal wetlands.

61 The principal water course of the Application Site is Collins Creek, which has an approximate catchment area of 2.1 square kilometres (km^2) and a mean flow of 94 litres per second.

62 The coastal flats' sediments host an unconfined and progressively semi-confined groundwater system with mixed clay, silt, sand, and fine gravel deposits. Site-specific groundwater level surveys and monitoring, aquifer testing, groundwater sampling for analysis, and intensive drilling investigations during 2022 and 2023

have characterised the groundwater systems, in addition to the previous hydrogeological investigations from 1989 to 1991 undertaken by the Australian geoscience consultancy Coffey Partners.

63 The geological layering and associated grain size composition is variable, but a general depth arrangement can be summarised as –

(a) 0 m to 3 m, clay-rich subsoils, also known as overburden,

(b) 3 m to 10 m, dark-grey silty sand, including heavy minerals and minor gravel,

(c) 10 m to 12 m, very sandy gravel,

(d) 12 m to 25 - 35 m, fine silty sand.

64 The permeability (also known as hydraulic conductivity or transmissivity) of the identified layers has been measured and quantified by pumping tests and falling head tests during 2022 and 2023 field investigations. A summary of the ranges in permeability in metres per day (m/d) is listed below,

(a) 0.01 m/d to 0.32 m/d, clay-rich subsoils or overburden.

(b) 3 m/d to 10 m/d, dark-grey silty mineral sand.

(c) 60 m/d to 80 m/d, sandy gravel.

(d) 3 m/d (estimated), fine silty sand.

65 Groundwater in the superficial and deeper layers of the groundwater flows from the east in pastures adjacent to State Highway 6 to the west for discharge in lower Collins Creek, lower Northern Boundary Drain and coastal lagoons, at gradients between 1 in 120 and 1 in 500 (0.0083 to 0.0020 metres per metre).

66 Combining the measured groundwater gradients with the measured groundwater permeabilities in paragraph 65 allows the estimation of a natural throughflow rate of 900 cubic metres per day or 11 L/s crossing the Application Site from east to west. Surface water flow in creeks is still the dominant mode of catchment drainage across the Application Site and environs.

67 The previous conceptual model for the groundwater system layering and permeability ranges (in paragraphs 63 and 64, above), lumped items (c) and (d) as a single ‘basal gravel’ layer assigned hydraulic conductivity between 55 m/d and 80 m/d. The hydrological conceptual model was revised with reference to the findings of drilling cuttings of four deep stratigraphic drill holes supported by groundwater properties’ testing.

68 Drilling and groundwater properties testing in September 2023 also determined that Collins Creek and Northern Boundary Drain were both perched and separated from flowing groundwater by clay-rich overburden, between 4 metres and 14 metres thick. Other parts of the surface water network were also determined to be more hydrologically isolated by similar clay-rich overburden.

69 The superficial groundwater has been hydro chemically characterised by the semi-regular sampling of eight (8) sampling bores (with an average depth of 11.9 metres), followed by analysis for a wide selection of ions, nutrients, metals and metalloids.

70 The water chemistry of the shallow groundwater was found to be of low dissolved oxygen content with low alkalinity although relatively dilute. The low oxygen content tends to allow the dissolution of metals/metalloids such as manganese in the shallow groundwater, which are represented in the shallow groundwater in moderate concentrations. Macro-nutrients, particularly nitrates or phosphates, are present at low to moderate groundwater concentrations in these bores.

71 The water chemistry of deeper groundwater to a depth of 16 metres was found to more oxygenated and more dilute with a Total Dissolved Solids approximately half of the concentration found at shallower depth, including dissolved metal and metalloid concentrations mostly less than the (trace) detection limit.

72 Rainfall in Barrytown Flats was measured in the Barrytown locality 2.5 km south of the Application Site and averaged 2,728 mm per annum from 1973 to 1989. Ten kilometres to the north of Barrytown locality, at Punakaiki Rocks the mean rainfall was measured as 2,584 mm per annum from 1983 to 2003. For the overlapping seven year period when Punakaiki Rocks and Barrytown rainfall sites operated in tandem, the annual mean was found on average to be 190 mm per annum higher at Barrytown than at Punakaiki Rocks, suggesting a pluviographic gradient between them.

73 Extreme dry spells are considered to be rare at Barrytown. Using Greymouth airfield Electronic Measurement Station (EWS) site rainfall data, the longest consecutive dry spell in the period 1981 to 2010 was 40 days (where daily rainfall was consistently less than 1 mm).

74 The area’s soil water balance is most often in surplus with the resulting shedding of catchment water as indicated above. Rarely, the monthly soil water balance might fall into deficit in response to ‘dry spells’. The longest recorded dry spell from 1981 to 2010 along the Grey – Buller coast was only 40 days in duration, in 2013.

75 Furthermore, the mean annual calculated evapo-transpiration for coastal flats from Greymouth to Westport generally ranges between 700 mm and 850 mm, well below total annual precipitation for the same coastal strip. This contributes to the long-

term annual precipitation excess generating runoff of groundwater recharge as calculated by NIWA being 1,671 mm at Greymouth EWS. Catchment yields of this order of precipitation excess, minus interception, can be expected in sea-draining creek drainages crossing the Barrytown Flats.

76 Surface water runoff is generated following rainfall in the hill slopes east of the Application Site, coalescing into the aforementioned creeks, Deverys, Collins and Canoe. Hydrological stage and flow monitoring has been maintained since May 2022 on Collins Creek at two sites, upstream of State Highway 6 and at the main farm ford on the lower creek.

77 There is no current or historical regional council hydrological monitoring of the sea-draining catchments between Greymouth and Cape Foulwind, including the Barrytown Flats. Otherwise, the hydrological statistics of the Application Site catchments have been drawn from the NIWA hydrological correlation models called New Zealand Rivers Map and High Intensity Rainfall Design System (HIRDS).

78 High intensity rainfall over the Barrytown Flats in the vicinity of the Application Site has been modelled using HIRDS. The 5 year, 20 year, 50 year and 100 year recurrence interval 24 hour duration downpours are modelled to be 123, 158, 181, and 199 millimetres per day under historically recorded probabilities, respectively.

79 For the downpour durations between 2 hours and 5 days, the Barrytown area is in approximately the 50th percentile (i.e., median) for downpour intensity in New Zealand. However, Barrytown Flats' rainfall accumulations are high for a coastal setting on the West Coast where there is a strong correlation between land elevation and rainfall.

80 Scientific projections utilising the general circulation models and regional circulation models of future climate suggest that high intensity rainfall at Barrytown Flats will increase. Both rainfall totals, including gentle and heavy rain, and high intensity rainfall downpours are very likely to increase. For example the 100 year recurrence interval, 24 hour duration rainfall would increase from historical levels of 199 millimetres to 213 millimetres in the representative concentration pathway 8.5 (RCP8.5) climate model, according to HIRDS.

81 Collins Creek and Canoe Creek each flow perennially with median flow rates of 0.05 m^3/s and 1.8 m^3/s (or 50 L/s and 1,800 L/s), respectively, measured in the lower reaches of the respective creeks upstream of the Canoe Creek Coastal Lagoons.

82 A systems of wetlands has remained or reverted following earlier land drainage on the north side of the Application Site. The Langridge North wetlands comprise

areas of kahikatea and flax (harakeke) vegetation associations with land saturation to form interconnected wetlands.

83 A former gold mining void to the northwest of the Application Site is known as Rusty’s Lagoon, which has fringing harakeke wetlands. The Canoe Creek Coastal Lagoons also have similar fringing wetlands.

84 The southern Langridge property between Canoe Creek and the Application site is cleared farmland on mostly alluvial soils and has up to 11 freshwater springs emerging in small creeks and swales that drain towards Collins Creek. Similar, albeit smaller such springs are found in the eastern most part of the Application Site, and these springs have been tapped and drained.

Additional onsite assessment

85 The approach to hydrological field studies has been iterative.

86 Prior to lodgement of the Application consultation was initiated with Ngāti Waeawae, including Phillippa Lynch and Susan Aitken. Subsequently, a meeting with Susan Aitken in early August 2023 conveyed more concrete guidance on Ngāti Waewae rūnanga’s perspectives on the TiGa consent applications.

87 Specifically, Ngāti Waewae requested the following –

(a) Avoidance of an over-reliance on the transfer of Canoe Creek waters into the Collins Creek and Deverys Creek catchment, resulting in the mixing of waters,

(b) Confirmation of the mass loading and ultimate concentrations of dissolved contaminants from different parts of the mine water system to strengthen knowledge as to the worst-case contaminant exposure concentrations in receiving environments,

(c) Assurances on the coinciding pit pond pumping and mitigation infiltration and injection do not lead to an underestimation of potential water acceptance rates, and

(d) Information on working examples of the proposed infiltration trenches to mitigate groundwater lowering or depleted surface flows, and limestone permeable weirs to reduce (metals) contaminant loads.

88 These requests triggered a strategic analysis of the proposed mitigation systems. The analysis resulted in the design of trials of representative sections infiltration trench, basin or wells after the Application was lodged in April 2023.

89 Separate peer reviews of hydrological assessments submitted with the Application by Mr Brett Sinclair (Wallbridge Gilbert & Aztec, NZ) for the councils in early July 2023, and Katy Grant (Pattle Delamore Partners Ltd) for TiGa (completed internally) in early September 2023, also raised questions that were addressed in the design of field investigations and trials conducted in the spring of 2023.

90 Significantly, the trials included the installation of a drilling pod adjacent to Collins Creek, including multi-depth injection and monitoring bores from 35 m to 5 m below ground. The objective was to trial injecting water into the deeper part of the basal gravel as a means of restoring groundwater levels affected by mining activities.

91 The preliminary results, confirmed by hydrological and laboratory analysis, indicated the following:

(a) Trial sections of infiltration trenches representing trials of peripheral infiltration trenches and infiltration basin demonstrated the capacities of the ground to accept water at the rates envisaged in the Application, assessment document and water management plan,

(b) The drill hole logging, aquifer testing, and injection trials provided much new information on the deep subsurface to 35 m depth, 24-hour duration pumping test aquifer parameters, creek – groundwater interaction rates and the impact of these changes to the conceptual model in terms of mining proposals and required mitigation,

(c) Drilling logs of subsequent bore holes to depths from 25 to 35 m below ground across the mining area, plus bore holes on the banks of Collins Creek and Northern Boundary Drain led to a revision of the geological model of the Barrytown Flats beneath the Application Site,

(d) Revision of the groundwater conceptual model in line with new analysis was translated into the settings of the groundwater computer model, and renewed scenario modelling of proposed mining activity effects on water flows in the ground and surface water, and

(e) Sampling of deeper water for dissolved metals, nutrients and physio-chemical parameters allowed a revision of the hydro chemical depth profile across the Application Site with significance to ultimate concentrations of contaminants on the downstream side of the mine water system.

92 The conceptual model revisions and revised modelling of mining scenarios led to a significant revision of the mine water and mitigation releases water balance. The mass load with respect to dissolved metal and metalloid concentrations also altered appreciably due to partial source shifting in the new conceptual model.

93 Water balance and scenario simulations revised since November 2023 have been incorporated within my evidence in chief (EIC). Where there is an apparent conflict between the Application hydrological assessments and the evidence in chief, this EIC should be preferred.

94 New field determinations carried out over eight days of field determinations of the variation in Application Site surface water turbidity and the relationships between turbidity to water clarity or turbidity to total suspended solids were also developed.

ASSESSMENT OF EFFECTS

95 The need to lower water levels in the sand extraction pit travelling along the mine path causes a temporary depression in the water table and changes groundwater patterns, including the flow relationships between the water table and surrounding water bodies. The potential effects arising fall into the following five categories:

- (a) The modification to drainage patterns associated with surface water;
- (b) The effects of mineral processing on flows and water levels in surface water bodies;
- (c) The effects of net plant discharges and stormwater on receiving surface water quality;
- (d) Potential seawater intrusion associated with pit pumping near the ocean; and
- (e) The effects of drainage modification associated with rehabilitation of the Site on local surface water bodies and groundwater levels.

Sand Mining Activities

96 The hydrological effect of the Application proposals for sand extraction areas would be to induce localised penetrations of the shallow aquifer and its water table. The sand mining proposal included a set of slowly traversing mining pits along 10 panels progressing west to east within the 34 hectare sand extraction area.

97 The localised penetrations (pits and pit ponds) would last for only the time taken to remove the mineral sand ore and refill the temporary void with processed sand before moving into the next area along the mine panel.

98 Water and sand would be excavated with machinery, essentially the Mining Unit Plant or MUP, on the mine bench overlooking the excavation and sent to the mineral separation plant by slurry line. To achieve a stable and workable

excavation, the ponding water in the excavation would be pumped out using a pump set in a low point in each excavation called a sump. Thus, groundwater would be extracted and sent to the mineral separation plant by either suction into the MUP or the balance required to maintain the target water level by the sump pump.

99 As is well characterised in previous alluvial mining experience, water pumping from the pit pond below the ambient water table during sand extraction induces the inflow of groundwater from the surrounding saturated sediments. This effect is much the same as a well that draws in groundwater by pumping water out.

100 Tailings and water are returned to the excavation in the wake of sand extraction and deposited in layers accumulating up to the height of the original mineral sand in preparation for land restoration. Sump pumping is not required in the tailings deposition zone of the travelling pit.

101 An accounting of exchanges of water with and from the mining processes is termed a ‘water balance’. The principal of the Application Site water balance during mine operation is that the quantity of water pumped from the pit pond is equivalent to quantity released to the Central Drain for eventual discharge to the Canoe Creek Coastal Lagoon.

102 The exceptions to this equality of abstraction and discharge, includes the following:

(a) Evaporation at the Wet Concentration Plant (WCP), or

(b) Adherent moisture exported from the site in Heavy Mineral Concentrate (HMC), or

(c) Water taken from Pond 2 and used in mitigation in any of the following discharges –

  (i) Augmentation of Collins Creek or Northern Boundary Drain,

  (ii) Infiltration trenches bolstering shallow groundwater levels,

  (iii) Injection wells bolstering medium depth and deeper groundwater levels / pressures, or

(d) Any discharge to the Canoe Creek Infiltration Basin.

103 The highest, average and lowest modelled groundwater input to the mine water system would be as follows –

(a) Maximum: 68 litres per second,

(b) Mean or average: 30 litres per second,

(c) Minimum or lowest: 13 litres per second.

These values were determined with the assistance of the computer groundwater model, which simulated the consecutive pumping of pit target water levels as the active pit moved across the ten mine panels through a 5-7 year period.

104 The water transfer rates modelled in the paragraph above would be split between water carried with sand ore to the plant *via* the Mining Unit Plant, and the balance as water pumped from the pit pond sump to achieve target water level that would also report to the plant.

105 The differences between the highest and lowest pit pond pumping rates to achieve target water levels in the pond are governed by a combination of factors, namely:

(a) The depth of base of economic mineral sands beneath surrounding groundwater levels (i.e., dewatered saturated sand depth),

(b) The permeability variations in the mineral sand, and,

(c) The proximity of a nearby fixed water level in a water body,

Outside of the above groundwater model factors, climate variation in relation to season or whether it was a ‘wet’ or ‘dry’ year would have lesser effect on the pumping rate.

Stormwater over the Active Mining Area

106 The travelling active mining area also represents a small internally draining catchment, onto which storm rainfall downpours may fall and soak into the shallow groundwater system, especially across the 0.5 hectares between the edge of clay overburden pre-stripping and the pit edge along the digging bench.

107 Using the highly conservative HIRDS RCP8.5 1 in 100 year, 24-hour duration rainfall total of 213 millimetres, the volume of stormwater accumulating across the 3.0 hectare active mining area during 24-hours would be 6,390 cubic metres.

108 The above 24-hour high intensity downpour may be accommodated within the following water withholding zones inside the active mining area perimeter:

(a) An airspace of 21,000 cubic metres within the open pit of 7 metres depth should the target water level be met in the lead up to the downpour, or

(b) An airspace of 12,000 cubic metres within the open pit above the 2-metre-deep water table should mining be suspended at the time of the downpour, or

(c) An infiltrative capacity of 14,400 cubic metres per day for an area of 0.5 hectares of exposed mineral sand with infiltration rates up to 120 millimetres per day.

109 It is assumed mining would be suspended for the duration of a downpour of 1 in 100 year, 24-hour duration. Following such a downpour and the resumption of mining activities, the excess stormwater would be accommodated within the groundwater system. Renewed pumping of the pit pond to the WCP would then be required to return the pit pond water level to its target for the resumption of sand extraction.

Potential Groundwater Responses to Mining Activities

110 The pumped removal of inflowing groundwater causes a quasi-stable hydraulic gradient inward to the travelling pit, which is analogous to well pumping drawdown.

111 While the Application Site environs do not contain water bores, pumping drawdown if left unmitigated is projected to extend beyond the Application Site and potentially result in flow depletion of wetlands, creeks or springs.

112 Part of the surplus mine water that was originally groundwater would report to the central drain, Pond 3 and Pond 4 for treatment and eventual discharge to the Canoe Creek Coastal Lagoon.

113 Part of the surplus mine water that was originally groundwater would be directed into intentional discharges into the ground or directly into water bodies potentially affected by depletion, as part of mitigation responses to mining activities.

114 Whichever fate of the mine water that was originally groundwater, the original water quality and chemical composition requires consideration in terms of any attenuation or treatment, mixing ratio with other sources of mine water, and mixing in the site(s) of discharge.

Mitigation of Water-Related Effects

115 As already mentioned in relation to the mining water balance, treated water would be released through tailored mitigation structures into different parts of the surface and groundwater system as follows –

(a) Direct surface water discharges, including to Collins Creek and/or Northern Boundary Drain particularly in relation to low flow event(s),

(b) Infiltration to the ground *via* infiltration trenches, including such trenches arranged along Lower Collins Creek – Canoe Creek Lagoon and/or Rusty’s Lagoon and Lower Northern Boundary Drain,

(c) Injection of water *via* a system of infiltration wells that extend to greater depths than the bases of infiltration trenches, and

(d) Infiltration of excess and/or more turbid water *via* the Canoe Creek Infiltration Basin.

116 Scale trials of infiltration trenching, and injection wells were undertaken in September 2023. The basic unit capacities of infiltration trenching, and injection wells have been confirmed.

117 The mitigating effect of infiltration or injection structures is to partially return groundwater to the groundwater system in a manner and at quantities that would raise local groundwater levels and diminish surface water body depletion *via* the groundwater system. The positioning of mitigation structures is guided by the selection of the better locations for achieving effective mitigation of mining activities, such as between mine panels and sensitive water-related environments.

118 Direct surface water discharges provide direct flow replacement in the water course and downstream of the point of release. The mitigation has immediate impact, although the bolstered flow rate may allow enhanced infiltration to the shallow groundwater layers in contact with the water course.

119 Infiltration trenches tend to raise shallow groundwater levels as a lineament in lower permeability superficial sediments. The mitigation has immediate and medium term impact.

120 Injection wells tend to raise groundwater levels in a radial pattern around each well, while a line of injection wells can provide a curtain of mounded groundwater level or pressure. The mitigation has medium to long term impact. Deeper, more permeable parts of the groundwater system may be targeted through the positioning of injection wells’ screens, thereby enhancing acceptance rates and allowing the pressure ‘wave’ to extend to greater distances.

121 The Canoe Creek Infiltration Basin is a structure that would be deployed infrequently to receive releases of excess water. Its mitigating capacity is to provide a means of shedding water within the mine system during periods where all other mitigating releases are at their capacity and/or the usable airspaces in ponds 1 to 4 are low, making the storage capacity momentarily minimal.

122 The infiltration basin is capable of accepting water that might otherwise exceed the turbidity or Total Suspended Solids threshold concentrations (see proposed conditions 25.2, Table B, notes) as the infiltration basin would remove suspended solids through immobilisation and filtration in basin bed materials. The infiltrated water would join the underlying water table and prevailing groundwater flow.

Specific Mitigation Systems

123 Specific mitigations for a changed groundwater flow pattern are to infiltrate or inject clean water to the groundwater system in locations that would be most or more effective for artificially restoring the groundwater flow pattern.

124 One mitigation system would involve the installation of an infiltration trench alignment along the southwest periphery. The aim of this system would be to lift local water levels and prevent water table lowering crossing the mine boundary into external areas.

125 Another mitigation system would involve the installation of an infiltration trench alignment along the northern boundary, adjacent to the Northern Boundary Drain. The aim of this system would also be to lift local water levels and prevent water table lowering crossing the mine boundary into external areas.

126 A trial section of trench was tested in September 2023 and it was concluded that the unit acceptance rate would be 2.9 cubic metres per metre of trench. This acceptance rate is consistent with the preliminary design rate indicated in the hydrology AEE and adequate for providing the envisaged infiltration.

127 Another mitigation system would involve the installation of an injection bore array near the Mineral Separation Plant, adjacent to Collins Creek, or along the Northern Boundary Drain. The aim of this system would be to raise local groundwater levels or pressures, avoiding the spread of lowered water levels or pressures beyond the Application Site boundaries. A particular objective in utilising injection wells would be in bolstering the flow of springs on the Langridge South property.

128 Another mitigation system would involve the installation of an injection bore array adjacent to the Northern Boundary Drain. The aim of this system would be to raise local groundwater levels or pressures, avoiding the spread of lowered water levels or pressures beyond the Application Site boundaries. The particular objective would be bolstering groundwater levels in harakeke wetlands between Kahikatea and Rusty’s Lagoon.

129 A trial injection well was trialled in September 2023 at a site adjacent to Collins Creek. The injection capacity for trial undertaken over 24-hours was established to be 5 litres per second with a small above ground injection pressure. As injection wells are intended to be installed and operated as arrays of multiple wells, the acceptance rate is consistent with the hydrology AEE and adequate for providing the envisaged infiltration.

130 In outlining these mitigation systems, it is worth noting that the infiltration trench systems focused on shallow groundwater level management, while injection bore had a deeper focus including the basal gravels beneath the mineral sands layers.

131 Another mitigation system entailed direct discharge of clean water into the following water courses surrounding the Application Site –

(a) Collins Creek, and

(b) Northern Boundary Drain.

(c) Note: discharges of clean water into the Canoe Creek Coastal Lagoon were already to be undertaken from Pond 4 of the Clean Water Facility.

132 Such augmentations by direct discharge are not novel and would not require trials to establish their effectiveness.

133 These direct surface water augmentation discharges would be to sustain the downstream flows of the respective water courses. Collins Creek is a perennial water body, while Northern Boundary Drain is intermittent to ephemeral and would require augmentation of its flow to augment Rusty's Lagoon, the facility would be pre-deployed ahead of such a contingency.

Seawater Intrusion

Summary

Category	Status
Assessment of Effect	Risk of seawater intrusion is very low and negligible after mitigation
Mitigation	The peripheral infiltration trench and injection wells are precautionary mitigations against lowered groundwater levels leading to reversal of groundwater flow directions between the coastline and the Application Site.
Monitoring	Groundwater level monitoring along the coastal perimeter.
Consent Condition	TiGa Minerals and Metals Ltd – Proposed Conditions of Consent: Condition 26 for Water Monitoring, includes conditions 26.2 for regulating the process of monitoring of water for flow. Condition 26.2 includes the requirement to monitor groundwater level at PZ-01, 02, 03, 04, **05, 06, 07, 08**, 09, 10, 11, 12, 13, 18 and 19 (Coastal facing piezometers in bold).

	Condition 26.2 for regulating the process of monitoring of water for water quality, including condition 26.2 includes the requirement to monitor at a range of sites and frequencies outlined in the table of clause 26.2.

Explanation and Assumptions

134 As the Application Site groundwater system is theoretically in contact with the salty waters of the Tasman Sea, a potential effect of the pit pond pumping is a change to the position of the freshwater – seawater interface within the coastal sediments.

135 It is worthy of note that the groundwater system is shielded from the Tasman Sea by the Canoe Creek Coastal Lagoons, which are freshwater (Total Dissolved Solids content is about 70 milligrams per litre, while seawater contains 35,000 milligrams per litre) and lie at water level elevations of approximately 1.8 metres above mean sea level. The coastal lagoons were created and maintained by wave action acting on coarse gravel beach sediment promoting the formation of a barrier beach ridge that dams fresh water courses as lagoons behind it (refer to EIC of Mr. Gary Teear). The barrier beach has been a dynamically stable morphological structure of the Barrytown coastline since at least 1954 when the first aerial photography showed the barrier in place.

136 Groundwater hydraulic profiles show the shallow groundwater flow paths terminating in the Canoe Creek Coastal Lagoons. Time series groundwater level analysis also reinforces this indication.

137 Groundwater levels surrounding the mining area range between 3.2 m and 8.2 m above mean sea level in the natural state, meaning that there is a high probability of groundwater beneath the mine area footprint remaining fresh at depth down to the silty sandstone basement (i.e., saline groundwater at greater than 40 m and as much as 128 m depth below ground). This thus makes it highly unlikely that saline groundwater could conceivably up-cone from beneath the Application Site.

138 It is worth noting that the Canoe Creek Lagoon opposite the proposed mining area, and intervening between the mining area and Tasman Sea is found to be dynamically stable in the coastal geomorphology evidence of Mr. Gary Teear. While the gravel beach barrier may alter in response to wave attach and storm events, the barrier is a long-term feature that would protect the mine farmland for up to 200 years are current rates of coastal erosion.

Conclusion on Seawater Intrusion

139 The following conclusions are provided

(a) The scale of the potential seawater intrusion risk is slight due to prevailing hydrological factors and the limited scale of pit pond pumping,

(b) Assumptions as to the layering and permeability distribution in the Application Site subsurface affect the soundness of the seawater intrusion assessment, while the saline intrusion estimate is conservatively framed,

(c) Mitigation proposed to return water to the periphery of the mining area in infiltration trenches and adjacent to sensitive environments would offset the impact of uncertainty or erroneous assumptions in the case of the risk of seawater intrusion,

(d) Monitoring of the sensitive area for seawater intrusion, along the Canoe Creek Coastal lagoon margin would detect anomalous water chemistry as electrical conductivity or total dissolved solids, or groundwater level decline below a nominated minimum level.

Surface Water Course Flow Depletion

Summary

Category	Status or Proposal
Assessment of Effect	Negligible after mitigation
Avoidance	The sand stockpile area between the sand extraction area and lower Collins Creek. Among the reasons for setting sand extraction further away from Collins Creek by placing the stockpile between the creek and mining was to reduce the depletion effect of pit pond pumping. The 20 metre setbacks to water bodies around the mining panels is also a means of avoiding depletion of those water bodies.
Mitigation	• Southwest peripheral infiltration trench, • Northern peripheral infiltration trench, • Injection wells along the southern and northern boundaries, and • Direct discharge of treated mine water to Collins Creek or NBD • MALF$_{7d}$ of Collins Creek estimated to be 16 L/s, • Objective is to maintain 90% of MALF$_{7d}$, • Maximum augmentation is thus 16 – 1.6 = 14.4 L/s, • Modelled, unmitigated maximum depletion of Collins Creek is 4 L/s, • Modelled, unmitigated maximum depletion of NBD is 2.4 L/s, and • Modelled, unmitigated maximum depletion of Rusty’s Lagoon is 12.3 L/s.
Monitoring	• Flow monitoring of Collins Creek, • Groundwater level monitoring on the mine periphery, including Northern Boundary Drain alignment, • Water level monitoring of Canoe Creek Lagoon.
Consent Condition	TiGa Minerals and Metals Ltd – Proposed Conditions of Consent: Condition 26 Water Monitoring, includes conditions 26.2 for regulating the process of monitoring of water for flow. Condition 26.2 includes the requirement to monitor groundwater level at **PZ-01, 02, 03, 04**, 05, 06, 07, 08, 09, **10, 11, 12, 13**, 18 and 19.

Explanation and Assumptions

140 Kahikatea Wetlands and Rusty's Lagoon Wetlands are perennially saturated and located beyond the northern margin of the mining area at a distance of 50 m to 150 m of the closest approach by the pit ponds, respectively.

141 The above water courses would be subject to some degree of flow depletion during pit pond pumping, particularly whenever the active sand extraction activity passes close to the water course concerned. The vector of such depletion would be lowered groundwater level.

142 Flow and stage information is held for Collins Creek, indications of drain flow have been collected for the Northern Boundary Drain. Land surface information is held for Kahikatea Wetlands and Rusty's Lagoon Wetlands, in addition to modelled flow information for the Deverys Creek catchment that these wetlands lie within.

143 Revised groundwater computer modelling did not include mitigation measures of infiltration to land or augmentation of some affected surface water courses, which indicated limited rates of flow depletion on surrounding water bodies as summarised above.

144 Mitigation measures, including infiltration within specifically designed trenches, infiltration via injection wells, and direct surface augmentation, has the ability to oppose groundwater level lowering or turn back flow depletion.

145 The first preference for using treated mine water would be for infiltration into groundwater, injection into groundwater, followed by direct surface augmentation (i.e., surface discharges to potentially affected water courses) to prevent the exacerbation of lowered groundwater level inducing flow depletion. Direct augmentation of Collins Creek would be restricted to periods of low flow in the creek alerted by flow monitoring at two sites along the creek in line with April 2023 AEE and Water Management, Mitigation, & Monitoring Plan.

146 Since treated mine water would be used for proposed mitigation, abstraction of natural water from other flowing sources would be significantly diminished compared to the concept of Canoe Creek flow augmentation advanced in the April 2023 AEE and Water Management, Mitigation, & Monitoring Plan.

Conclusions on Surface Water Depletion

147 The following conclusions are provided:

(a) Modelling without mitigation measures specified the revised groundwater model indicates theoretical and finite flow depletion on surrounding surface water bodies, including creeks, lagoons, wetlands and springs,

(b) Active mitigation using infiltration within specifically designed trenches, infiltration via injection wells, and direct surface augmentation is advanced and would become part of the water management protocols of the TiGa proposals,

(c) Monitoring of pivotal components of the Application Site groundwater level and Collins Creek flow would ensure that the optimal sites of mitigation, in terms of infiltration, injection or discharge, were apprehended and provided with treated mine water.

Water Quality Effects – Metals and Metalloids

Summary

Category	Status or Proposal
Assessment of Effect	Negligible water quality effects following inherent attenuation and mitigation, in terms of observance of ANZG95 guideline concentrations. The level of effect in terms of species protection would be provided by the ecological EIC of Dr Gary Bramley and Mr Mark Roper.
Mitigation	The aeration of mine water at various phases of the mineral separation and water treatment processes, plus the use of limestone permeable weirs that optimise contact water with limestone water, which would remove dissolved metals and fix them in settled sediments.
Monitoring	Quarterly sampling and analysis of – • Aluminium, Arsenic, Cadmium, Chromium, Lead, Nickel, and Zinc at - o Canoe Creek (Coastal) Lagoon, o Collins Creek Downstream, o N Boundary Drain, and o Canoe Creek Downstream.
Consent Condition	TiGa Minerals and Metals Ltd – Proposed Conditions of Consent: Condition 26 Water Monitoring, includes conditions 26.2 for regulating the process of monitoring of water for flow. Condition 25 Method of Discharge, includes 25.1 and 25.2 to conduct water for release to natural water and numerical standards for discharge into “Canoe Creek (Coastal) Lagoon, Collins Creek Downstream, N Boundary Drain and Canoe Creek Downstream”.

Explanation & Assumptions

148 Water entering the mine water system *via* pumping from pit ponds may carry dissolved metals and metalloids that remain in solution between the pit pond from which the waters are pumped, until the waters leave the mine water loops and are released back to natural water at Pond 3 and Pond 4 for ultimate discharge to Canoe Creek Coastal Lagoon.

149 Tom Lawson of IHC Mining, in his Evidence In Chief (EIC), has developed a water balance of the mining and mineral separation processes, including the groundwater pumping from the pit pond (also known in mineral technology as the “Void”) and the losses or intentional releases external to the mineral separation process.

150 This water balance indicates that the pit pond pumping rate determines the ultimate rate of release of water for further treatment or use in mitigation discharges, minus 1.5 litres per second (or 5.4 cubic metres per hour) for other minor losses and day-to-day storage fluctuations.

151 The April AEE for hydrological assessment had projected the worst case receiving water dilution ratio between the Pond 4 and Canoe Creek Coastal Lagoon at 2 times (2 x). Thus, in the worst case scenario the concentration of water following entry and mixing in the Canoe Creek Coastal Lagoon would be half that of the original groundwater concentration.

152 Groundwater dissolved metal and metalloid concentrations have been characterised on 9 November 2022 and 13 July 2023. Analyses of fluids following shake tests of *slimes* (fine-grained fraction), *tails* (tailings ex-plant), *Run of Mine* (ROM), and *Heavy Minerals Concentrate* (HMC) were conducted in March 2023. The laboratory analytical results were thus obtained that characterised the dissolved metals and metalloids concentrations.

153 Table 1, below, lists the groundwater (average depth 11.9 m below ground) and shake test laboratory results in 2022 and 2023 for mostly dissolved metals.

Table 1: Highest concentration groundwater alongside shake test metals / metalloids concentrations

Dissolved Parameter	Ground PZ-15 9-11-22 (mg/L)	Water PZ-15 13-07-23 (mg/L)	Shake Test Slimes 14-03-23 (mg/L)	Shake Test ‘Tails’ 14-03-23 (mg/L)	Shake Test ROM 14-03-23 (mg/L)	Shake Test HMC 15-03-23 (mg/L)
Aluminium	**0.100**	**0.085**	**0.12**	**0.2**	**0.12**	**0.39**
Arsenic	0.0091	<0.001	<0.02	<0.02	<0.02	<0.001
Chromium	**0.0035**[¥]	**0.0019**[¥]	<0.01*	<0.01*	<0.01*	**0.0036**[¥]
Copper	**0.0019**	**0.0033**	**0.012**	<0.01	<0.01	**0.0055**
Nickel	0.0104	**0.028**	<0.01	<0.01	<0.01	0.0016
Zinc	**0.068**	**0.030**	<0.02	<0.02	<0.02	0.0060

Note: **Bold** value text means the analytical value exceeds the relevant ANZG95 guideline. * in terms of Hexavalent Chromium. ¥ in terms of dissolved Chromium.

154 The groundwater input to the mine water needs to also include the deeper groundwater entering the pit pond and the lower dissolved metals concentrations revealed in September 2023 sampling during injection well trials. Table 2 lists the deeper groundwater concentrations from the analysis of groundwater sample taken during the pumping test of the injection well, IW-01.

Table 2: Deeper groundwater dissolved metals concentrations

Dissolved Parameter	**ANZG 95**	**Groundwater IW-01 Depth 13 – 16 m BGL 20-09-23** (mg/L)
Aluminium	0.055	< 0.003
Arsenic	0.013	0.0018
Chromium	0.001	< 0.0005
Copper	0.001	< 0.0005
Nickel	0.011	< 0.0005
Zinc	0.008	0.0018

Note: **Bold** value text means the analytical value exceeds the relevant ANZG95 guideline.

155 Groundwater modelling determined the mixing of shallow and deeper layer groundwater to be provided 80% by the deeper layer and 20% by the shallow layer. Table 4 lists the highest relevant shallow groundwater concentrations, deeper relevant concentrations, plus the result of mixing the groundwaters in accordance with a 20:80 ratio in favour of the deeper layer.

Table 4: Result of mixing the groundwaters in accordance with a 20:80 ratio

Dissolved Parameter	**Most Concentrated Shallow Groundwater Value (PZ-15)** (mg/L)	**Deeper Groundwater IW-01** (mg/L)	**20:80 Mixed Shallow and Deep Groundwater** (mg/L)
Aluminium	**0.1**	0.003	0.0224
Arsenic	0.0091	0.0018	0.0033
Chromium	**0.0035**	0.0005	0.0011
Copper	**0.0033**	0.0005	0.0011
Nickel	0.028	0.0005	0.0060
Zinc	**0.068**	0.0018	0.0150

Note: **Bold** value text means the analytical value exceeds the relevant ANZG95 guideline.

156 Mixing in accordance with the worst case 1:2 mixing ratio following release to the Canoe Creek Coastal Lagoons and concentrations arising are listed in Table 5.

Table 5: Post-discharge mixed concentrations of groundwater & shake test metals

Dissolved Parameter	ANZG 95	Proposed Consent Condition 25.2 Threshold Value (mg/L)	Groundwater after mixing of layers, and mixing in Lagoon (mg/L)	Shake Test Slimes (mg/L)	Shake Test Tails (mg/L)	Shake Test ROM (mg/L)	Shake Test HMC (mg/L)
Aluminium	0.055	0.62	0.0112	0.03	0.05	0.03	***0.0975***
Arsenic	0.013	0.013	0.00163				
Chromium	0.001	0.0033	0.00055				0.0009
Copper	0.001	0.0039	0.00053	**0.003**			**0.0013**
Nickel	0.011	0.011	0.003				0.0004
Zinc	0.008	0.008	0.00752				0.0015

Note: **Bold** value text means the analytical value exceeds consent threshold value; or ***Bold Italics*** value text means the analytical value exceeds the relevant consent threshold value and the ANZG95 guideline.

157 Not one of the calculated doubly mixed groundwater concentrations exceeded the relevant ANZG95 guideline. Minor exceedances of the relevant ANZG guideline were indicated by copper in the slimes and HMC shake tests, plus HMC shake test fluid for dissolved aluminium. The proposed discharge consent condition 25.2 threshold values are the same or no more rigorous than the Australian & New Zealand Guidelines for Fresh & Marine Water Quality for 95% species protection (or ANZG95).

158 Several additional opportunities for attenuation of dissolved metals and metalloids exist within the various phases of mineral separation that is conducted in oxidising

geochemical conditions and in the presence of dissolved organic carbon. Furthermore, limestone permeable weirs are to be installed in the central drain, and such weirs are well known for removal of metals or metalloids. Out of conservativeness, such attenuation related metals concentration reductions are not included in Table 5.

159 While assessed worst case water dilution ratios are almost uniformly specified at a ratio of 2. The exception is the Northern Boundary Drain, which is considered to have no worst case mixing potential, i.e., dilution ratio of 1:1. Flow in the Northern Boundary Drain upstream of the proposed augmentation discharge location reduces to a trickle or zero flows during dry periods. Therefore the 1:2 mixing ratio would not apply for direct discharge to Northern Boundary Drain.

160 On the basis of water sampling of Northern Boundary Drain revealing the highest metals and metalloids concentrations of any Application Site water body and the findings of the ecological survey (EIC of Gary Bramley), the Northern Boundary Drain indicates little sensitivity to metals concentrations.

Conclusions

161 Shallow and deeper groundwater metals / metalloids concentrations pumped from the pit ponds make up the bulk of these constituents entering the mine water system combining to allow characterisation of metals / metalloid mass loads.

162 Agitation of mineral sand ore in the Wet Concentration Plant (WCP) is a secondary source of these loads, as suggested in shake tests of various fractions of ore or finished product,

163 The main source of metals and metalloid concentrations or loads in mine water would be groundwater pumped from the pit pond and into the water treatment system, followed by dissolution of mineral elements from ore,

164 The use of treated mine water in mitigation discharges or indeed discharge to Canoe Creek Lagoon waters is unlikely to exceed the exposure concentration threshold proposed in consent condition 25.2, Table A – *metals and metalloids*.

165 Sensitivity in the above assessment includes the following:

(a) Source concentrations from *in situ* groundwater or dissolution of mineral elements in ore sand,

(b) The share of shallow or deeper groundwater and the characteristic concentrations of these depth layers in the pit pond pumped groundwater,

(c) Whether assumed mixing ratios manifest at the points of discharge or use in mitigation, 166 Quarterly sampling and analysis for metals in Table A is proposed at all potentially affected surface water bodies, which provides surveillance against exceedance of threshold concentration values,

167 The confluence of conservatively pitched assessment and regular water monitoring for metals and metalloids at receiving environments would result in the remaining uncertainty surrounding the effect of discharges containing residual concentrations in these being resolved,

168 The ecological and aquatic biological metals exposure tolerances are addressed in the EIC of Dr Gary Bramley, Mark Roper and Michael Fitzpatrick.

Water Quality Effects – Turbidity, TSS, visual clarity & DRP

Summary

Category	Status or Proposal
Assessment of Effect	Negligible effect on water quality in receiving waters
Mitigation	The following mitigations have been assessed for their effectiveness in ensuring effects are minimised – • Separation of the handling soils / subsoils and ore sand (pre-stripping and stockpiling), • Settling of pit pond water in the pond sump, • Water treatment in Pond 1 and 2 plus the lamellar clarifier, and co-disposal of separated slimes in the tailings, • Settling and co-precipitation in the Central Drain, • Armouring of the Central Drain, • Further treatment of water in Pond 3 and 4, • Rehabilitation and revegetation stabilisation of previously mined land.
Monitoring	Quarterly sampling and analysis of – • Electrical Conductivity, pH, Sulphate, Total Suspended Solids, Turbidity, Hardness, Dissolved Reactive Phosphorus, and Nitrate & Ammoniacal Nitrogen at - o Canoe Creek (Coastal) Lagoon, o Collins Creek Downstream, o N Boundary Drain, and o Canoe Creek Downstream. Continuous turbidity monitoring would be maintained in Pond 2 (Clean Water pond at the Mineral Separation Plant and Pond 4 at the Clean Water Facility). Routine weekly turbidity sampling or sensor measurement would be undertaken at the Central Drain

	at two sites, upstream of disturbance and immediately upstream of Pond 3 and the Clean Water Facility. Monthly sampling of the Pond 4 discharge would include analysis for electrical conductivity, pH, sulphate, turbidity, total suspended solids (TSS) or visual clarity, hardness, nitrate & ammoniacal nitrogen, and Dissolved Reactive Phosphorus.
Consent Condition	TiGa Minerals and Metals Ltd – Proposed Conditions of Consent: Condition 26 Water Monitoring, includes conditions 26.2 for regulating the process of monitoring of water for flow. Condition 25 Method of Discharge includes 25.1 and 25.2 to conduct water for release to natural water and numerical standards for discharge into "Canoe Creek (Coastal) Lagoon, Collins Creek Downstream, N Boundary Drain and Canoe Creek Downstream". Reference would be made to monthly sampling schedule for "Other Water Quality Indicators".

Explanation & Assumptions

169 Sediment and muddiness of surface water, measured as turbidity, total suspended solids (TSS) or visual clarity, detrimentally affects water quality. Sediment and muddiness of surface water may also carry entrained suspended macro-nutrients. Mining related disturbance of the ground, including silts and clays (also known as "slimes") has the potential to generate turbid waters.

170 Phosphorus and nitrogen may also be generated in land disturbance as such macro-nutrients are naturally stored with soils and subsoils comes into contact with water in the pre-stripping and materials handling processes.

171 Fine sediment suspended in groundwater entering the pit pond and pumped to the Wet Concentration Plant would be settled and separated from water in the processing, then further settled in ponds 1 and 2.

172 A back-up treatment process at the plant would include the ability to run mine water through the lamella clarifier, once the plant is fully constructed and operational.

173 Water would be transferred to Ponds 3 and 4 via the Central Drain. A portion of treated mine water would be released to either Colins Creek or Northern Boundary Drain by pumping from either the Mine Water Facility or Clean Water Facility, as required.

174 Fine sediment removed from the mine water processing plus sludges containing fine sediment from ponds would be periodically trucked to the active pit and co-disposed with tailings in emplacements that avoid remobilisation or resuspension

of the fines. Where possible these emplacements would be above the normal water table to minimise the interaction with the saturated zone groundwater.

175 Erosion of creek banks or farm drains may also generate suspended sediment, although the Central Drain transferring treated mine water would be armoured to minimise this tendency.

176 The Canoe Creek Infiltration Basin was found to have a high capacity of more than 100 litres per second to infiltrate water in a controlled manner. The infiltration basin in the proposed location over more permeable subsoils would tolerate the infiltration of more turbid water, potentially as much as 25 NTU, without losing the required capacity. Remediation of the basin subsoils remains

177 Focused erosion and sediment control measures would be deployed to avoid fine sediment and runoff generated on ancillary mining infrastructure such as vehicle tracks. The ESCP structures would be installed, shifted and maintained to enhance the capture and removal of sediments throughout construction, mine operations and restoration phases of the Barrytown project (see EIC of Graeme Ridley).

Conclusions

178 Turbid water suspending fine sediments and entrained nutrients would be specifically handled to separate these potential contaminants from mine water before using the treated water in either mitigation related releases or discharging the surplus water to Canoe Creek Lagoon or less frequently the Canoe Creek Infiltration Basin.

179 The separation in mineral processing, settling in ponds, clarification and appropriate disposal of solid fine sediments would enhance the removal of precipitated metals and other suspended nutrient-rich particles from water moving through the Application Site and wet processes.

180 Redundancy in the capacity and sites of water treatment reduces the risk of turbid water containing entrained or suspended contaminants.

Rehabilitated Land

Summary

Category	Status or Proposal
Assessment of Effect	Negligible effect on Application Site Hydrology or water quality
Mitigation	The appropriate design of land re-contouring

Monitoring	Drone surveys, including drone LiDAR digital elevation modelling to ensure that appropriate grades and contours are observed.
Consent Condition	TiGa Minerals and Metals Ltd – Proposed Conditions of Consent: Condition 1.1 The Consent Holder must carry out the mineral sand mining activities in general accordance with the application dated April 2023 and the Site Plan enclosed as Schedule 1. Conditions 5.1 and 5.2 Consent Holder must submit a programme of work (“Annual Work Programme”) for certification by the Consent Authorities.

Explanation & Assumptions

181 The average water table elevation is currently 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 *via* farm drainage.

182 The final land surface would 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.

183 The final landform would also 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 would ensure that the runoff rates to Rusty Lagoon and Canoe Creek Lagoon do not significantly change because of mining, other than as a result of operational augmentation releases.

184 The modified land relief would 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.

185 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.

Conclusions

186 While slight land surface deflation would occur as a result of volume reduction in the exporting of the Heavy Mineral Concentrate from the Site, the rehabilitated land surface would retain the existing drainage profiles.

187 The drainage profiles and soil drainage properties are the more relevant matters in avoiding effects from the rehabilitated land surface. Indeed, improved pasture quality and lessened agricultural water quality effects should be achieved with the restored land form.

Effect of Water Take on Canoe Creek

Summary

Water is required for a water take on Canoe Creek for the filling of the plant at the startup or resumption of processing following shutdown

Category	Status or Proposal
Assessment of Effect	Low
Avoidance of Effects	Canoe Creek was selected as a source of surface water since it has the largest flow rate of all surrounding creeks, thus the maximum take represents a small proportion of the low flow. The buried gallery mode of water take buffers the effect of the periodic water take on creek low flows.
Mitigation	Cultural or spiritual effects from the perspective of Māori with mixing waters has been mitigated to restricting the timing of water take to periods for filling of the plant at the startup or resumption of processing following shutdown, which is infrequent.
Monitoring	The pumping flows and volumes of water take would be monitored in accordance the National Environmental Standard (Measurement & Reporting of Water Takes).
Consent Condition	TiGa Minerals and Metals Ltd – Proposed Conditions of Consent: Condition 30 for Canoe Creek water take, includes conditions 30.1 (instantaneous take not to exceed 63

	L/s), and 30.2 – 30.6 (water take metered), and 30.7 (fish screen)

Explanation & Assumptions

188 The April 2023 application AEE for hydrology included higher levels of groundwater depletion of Collins Creek than currently assessed, resulting in the need at that time to provide for more significant and more frequent augmentation of Collins Creek or Northern Boundary Drain.

189 Consultation with Ngāti Waewae rūnanga representatives established that such a routine mitigation practice of transferring between catchments would result in significant cultural and spiritual effects by mixing waters.

190 Consequently, the water take from Canoe Creek for surface water augmentation of Collins Creek or Northern Boundary Drain was removed from the Proposal.

191 The requirement for filling the mineral separation plant tanks and ponds remained with the Canoe Creek water take being the most appropriate source in this role.

192 It had previously proposed that the Canoe Creek water take be implemented as a shallow buried gallery of appropriate dimensions to develop up to the maximum proposed rate of take, 63 L/s. The gallery would be located on the north bank (true right) of Canoe Creek approximately 50 m upstream of the Canoe Creek Infiltration Basin.

193 The seven day Mean Annual Low Flow of Canoe Creek is estimated to be 630 litres per second. Advice from Gary Bramley in discussions of take percentages of $MALF_{7d}$ identified that total surface water takes up to 10% of that statistic would be classed as low level of effect.

194 A take limit equivalent to 10% of Canoe Creek's estimated $MALF_{7d}$ is proposed, thus the maximum rate of take would be 63 litres per second. The application to take Canoe Creek water is a discretionary process, however in support of the proposed take limit the restricted discretionary rule for the taking of surface water has a threshold[1] set at 20% of $MALF_{7d}$.

195 The use of a buried intake gallery set in the Canoe Creek alluvium, boulders, cobbles, gravel, sand and silt, set back from the creek's active channel avoids the ingress of mature eels, inanga, koaro, kokopu, torrent fish or salmonids into the

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[1] Ref: West Coast Regional Land and Water Plan 18.3.3 Restricted Discretionary Takes, Uses, and Diversions of Water, Rule 55 (i).

gallery, and also provides a hydrological buffer that would serve to soften the abstractive effects on Canoe Creek low flows of pumping water from the gallery.

196 Being a buried gallery intake style of water take, the activity would not affect fish passage in the Canoe Creek main channel downstream of the intake.

197 Infiltration testing of a trial trench section within the Canoe Creek alluvium in late September 2023 established that the alluvium had high permeability and transmissivity for the transmission of water through the alluvium.

198 The presence of Canoe Creek as a hydrological fixed head would prevent the gallery pumping from extending drawdown or groundwater depletion effects into the wider alluvial groundwater system.

Conclusion

199 The proposed Canoe Creek water take for the filling of the plant at the startup or resumption of processing following shutdown has effects that are less than minor on Canoe Creek or surrounding environments.

Pit Wall Instability & Water Consequences

Summary

Category	Status or Proposal
Assessment of Effect	Negligible risk of pit wall collapse or consequent hydrological effects, even in the 20 m buffer area along the northern boundary and in the presence of infiltration based mitigation structures.
Mitigation	Avoidance of above-ground groundwater pressures arising from the utilisation of infiltration trenches or injection wells in mitigation of water body depletion.
Monitoring	Groundwater level monitoring along the northern boundary to ensure that groundwater levels do not rise in a trend that would imply the development of above ground water pressure.
Consent Condition	TiGa Minerals and Metals Ltd – Proposed Conditions of Consent: Condition 26 for Water Monitoring, includes conditions 26.2 for regulating the process of monitoring of water for flow. Condition 26.2 includes the requirement to monitor groundwater level at PZ-01, 02, 03, 04**,** 05, 06, 07, 08, 09, **10, 11, 12, 13,** 18 and 19 (Northern boundary facing piezometers in bold).

	Condition 26.2 for regulating the process of monitoring of water for water quality, including condition 26.2 includes the requirement to monitor at a range of sites and frequencies outlined in the table of clause 26.2.

Explanation & Assumptions

200 Reports prepared by Grey District Council and West Coast Regional Council under Section 42A of the Resources Management Act as Officer's Reports both referred to the risk of pit wall instability and implied the risk of an effect was unassessed.

201 The Officer's Reports assessments each arose from the WGA New Zealand reviews by Brett Sinclair of the Kōmanawa Solution's hydrology and RDCL's geotechnical assessments. Question 4.8 of the WGA review document of early September 2023 raised concerns relating to the "*pit wall stability when these injection systems are operating*." The injection systems referred to by Brett Sinclair were injection wells and infiltration trenches.

202 In order to explain the concerns raised, the synthesis of the situation giving rise to the concerns is the northern boundary of the Application Site being a crowded zone with potentially conflicting activities –

(a) The edge of the pit coming within 20 m of the property boundary,

(b) An infiltration trench laid along the 20 m corridor, outside of the pit perimeter,

(c) Injection wells being installed in the 20 m corridor between the pit wall and property boundary,

(d) Northern Boundary Drain potentially flowing within the 20 m corridor, and

(e) Wetlands in some instances, located on the other side of the property boundary.

203 Brett Sinclair's review noted that there could be cost incentives to operate the injection wells with pressures exceeding ground level. He noted that it was of key concern if injection wells were operated along the 20 m buffer zone in proximity to the active mine pit and linked hydrological and geotechnical risks in managing pit wall instability.

204 Cam Wylie has assessed pit wall instability using finite element methods to model the stability of the cut slopes outlined above, including static and seismic loading equivalent to the 1:500 year and Magnitude 8 events. In all cases, the pit wall stability remained acceptable with displacement less than 0.01m at the 20m setback boundary.

205 Cam Wylie used the assumption that the groundwater level would rest at between 0 m and 1 m below ground surface, i.e., no above ground water pressures. He further observed that the injection trial failed to achieve appreciable above ground water pressure due to pressure relief provided by discontinuities in the covering clay-rich overburden. He considered that the same limitation would constrain the potential for above groundwater pressures developing.

206 At the same time, operation of the mitigation structures can and should be managed to avoid above-ground water pressures developing within the 20m buffer zone through the following precautionary measures:

(a) Favouring the utilisation of direct augmentation of the Northern Boundary Drain in returning water to adjoining wetlands and Rusty's Lagoon while the active pit is in direct proximity to the 20 m buffer zone, and

(b) Monitoring groundwater levels and pressures along the 20 m buffer to inform the prevention of above-ground water pressures in the critical zones.

207 Additional guidance can be drawn from 2023 infiltration trialling that showed that infiltration in quantities up to 3 cubic metres per metre could be achieved while maintaining all operating water levels / pressures less than ground surface.

Consideration of Alternatives

Summary

Alternative	Consideration
Pit Pond Pumping	Other methods of wet mining for sand extraction are able to avoid pit pond pumping – • Dredging • Long-reach excavator
	Advantages include less requirement for pit pond out-pumping of groundwater to maintain a target water level. Disadvantages – • Poorer mineral grade control, • More difficult plant acquisition.
Discharge of Mine Water to the Tasman Sea	To protect freshwater quality more completely, an outfall to the ocean would result in a discharge into a lower sensitivity environment.

	Chief advantage is the avoidance of risk that water quality threshold cannot not be met before discharge Disadvantages – • Need to maintain outfall infrastructure in a dynamic, high energy environment in the surf zone • Treated mine water unavailable for mitigation releases • Alternative solution lies outside of the Application Site.
Canoe Creek abstraction exclusively for mitigation	Pumping from a gallery in Canoe Creek Alluvium to supply infiltration trenches, injection wells or direct surface water discharges.
	Chief advantage is the ability to draw clean mitigation water from a single point of take Disadvantages – • Mixing of waters between Canoe Creek and Collins, Deverys catchments with known objection from Ngāti Waewae, • Disincentive for re-using mine water in a beneficial role.

208 All alternatives were given due consideration with overlaps to many other disciplines such as mine technology, resource geology, landscape, noise, ecology, transport, cultural and coastal processes.

Matters raised by submitters

209 The applications for resource consent to Grey District Council and West Coast Regional Council have been publicly notified and attracted many submissions from members of the public and organisations.

210 Several of the submissions that indicate opposition to the applications include specific concerns for water-related matters or effects.

211 Of those submissions of individuals or organisations that indicated opposition and cite water-related concerns while stating that they wished to be heard, the submitters raised relevant themes as follows:

- water turbidity,
- water-borne contamination / contaminants,
- contaminant leaching,

- impacts on hydrological function,
- unacceptably high levels of uncertainty in relation to changes in hydrological function,
- ‘salt inundation’,
- effects on freshwater springs,
- contamination of neighbouring wetlands,
- incorrect rainfall data used in hydrology assessment,
- uncertainty as to changes to hydrological function exacerbated by future climate change, and
- lack of toxicant management plan.

212 I consider that each of these themes as they relate to the technical and water-related aspects of the consent applications have been considered adequately within the AEE assessments and this evidence. The substantive assessment documents have also been reviewed by Brett Sinclair for West Coast Regional Council and outstanding questions for clarification resolved by August 2023.

213 On the question of rainfall data raised in one or more submissions, best endeavours were made to collect historical rainfall data. However, preference was given to using the longest term and most complete rainfall records, particularly those in location climatically consistent with the site and collected using best practice for rainfall data acquisition.

214 It is also acknowledged that the Barrytown Flats have a general lack of rainfall recording stations and historical stations, while it is also inferred that an unusual degree of variability in rainfall distribution is present across the Barrytown district.

Matters raised by WCRC and GDC staff reports

215 Section 42A reports were prepared in response to the notified consent applications. The West Coast Regional Council commissioned Section 42A Staff Report was prepared by Dr Michael Durand and undated although received on 15 January 2024. The Grey District Council commissioned Section 42A Officer’s Report was prepared by Mark Geddes and dated 22 December 2023.

216 The West Coast Regional Council Staff Report was thought to contain assessments most relevant to hydrological and water quality, due to the areas of responsibility between district and regional council. However, the Grey District Council also touched on hydrological or water-related effects in paragraphs 187,

and 228 – 230 in relation to land stability, and natural habitats, ecosystems & biodiversity in relation to potential adverse effects on adjacent areas, respectively.

217 The West Coast Regional Council Staff Report concerns hydrological aspects of the Proposal or statutes, regulations or planning policies as follows:

(a) water-related activities and associated potential effects from paragraphs 100 to 110,

(b) further considerations relating to Section 104(1) cover groundwater, surface water and aquatic ecosystems in paragraphs 125 to 145, and

(c) hydrological and aquatic ecosystem effects arising from pit wall collapse in paragraphs 176 - 185.

218 Common to both of these reports to the relevant councils was the geotechnical, and hydrological aspects of potential pit wall collapse. These potential effects are covered in this statement's paragraphs 200-207, above. The Summary that the preceding paragraphs explain outline the pit wall collapse risk is negligible under conditions proposed in the Application. Furthermore, additional water management measures can be deployed to reduce what small risk remained.

219 The West Coast Regional Council Staff Report concerning potential effects of activities finds the hydrological and ecological assessments to be problematic due to the full assessment process not being followed. Specifically, the lack of hydrological and ecological surveys of neighbouring properties for which access was declined, therefore the sensitivity of the groundwater system or wetlands subject to off-site effects could not be fully characterised.

220 The planning officer for West Coast Regional Council stated "I consider that the starting point for assessing freshwater ecological effects is unclear" due to the constraints of a limited understanding. The planning officer also points to NPS-IB Policy 3 in adopting a precautionary approach to effects assessment where there are uncertainties and while there are also potentially involving significantly adverse effect(s).

221 The mitigation methods, for water-related effects and therefore relevant to terrestrial ecology and inland natural wetlands, would be to set conservatively protective trigger thresholds for restorative actions *via* groundwater levels and surface water bodies within the Application Site. The actions would primarily be the restoration of pre-mining water table levels, water course / spring flow rates (consistent with upstream inflow) and wetland water levels, through the deployment of infiltration, injection and/or augmentation. This is the approach lain out in the Water Management Plan and the statements of evidence for myself and other experts for TiGa MM.

222 While the precise sensitivity of aquatic environments beyond the Application Site boundaries cannot not be precisely known the causative vectors, primarily groundwater gradient changes, can be well predicted and monitored. Recognising this, I have confidence that focused mitigation will be deployed, which is precautionary in application.

223 It is notable that the West Coast Regional Council Staff Report does not cover water quality effects except in the outlining of relevant planning instruments.

224 The questions of pit wall collapse risk and potential entanglements of hydrological mitigation releases to the ground with geotechnical slope stability triggers have been covered in the assessment of pit wall collapse risks. This question highlighted in both the Grey District Council and West Coast Regional Council staff reports appears to have arisen from the perception that the risk factors were unresolved within the WGA peer review. In fact, mitigation related infiltration or injection of water to the ground in proximity to the active mine pit would be employed to only restore pre-mining groundwater levels rather than over-pressure parts of the pit wall toe.

Proposed consent conditions

225 I have commented and referenced relevant conditions throughout my evidence, and I am confident that they adequate capture the essential outcomes and mitigation proposed.

Responses to Commissioner Minute No. 6

226 Commissioner and Chairperson, Mr. John Maassen, wrote in Minute No. 6 a series of observations arising from pre-hearing reading by the Chairperson, dated 10 January 2024.

227 Of relevance to the hydrological assessments of the Proposal were observations inviting responses in paragraph 8 (a) – (d). Mr. Maassen gave the preamble “More generally, I make the following observations about the hydrology evidence as it relates to the lagoon(s)”.

228 Observation 8(a) was as follows: “*The mechanism for achieving hydrological protection of the Canoe Creek Lagoon is unclear to me. For example, it would be helpful to understand how mining in, for example, Panel 5 of the mining program) manages hydraulic impacts by the discharges from Pond 4. The same is true for mining in Panel 10 relative to the lagoon to the north. This is not an observation that it cannot work, but it is unclear how it would work and eliminate the potential for localised changes in hydrology.*”

229 My response is the conditions for the existence of Canoe Creek Lagoon are based on the presence of a “a mixed sand/gravel beach barrier” between the lagoon and Tasman Sea. This barrier, which is dynamically stable, backs up the waters of the lagoon. Mr. Gary Teear’s EIC covers the sedimentary controls on the beach barrier. The lagoon(s) are sometimes singular embayments and sometimes separated by permeable levies or riffles. The lagoon(s) overtop the beach barrier at its lowest point and flows into the Tasman Sea in a one-directional fashion. Lagoon water also seeps through the beach barrier.

230 The first (western most) active mine pit on Mine Panel 5 would be within 20 m of the eastern shore of Canoe Creek Lagoon at its closest approach. Pumping to achieve the target water level in the pit pond might require a rate of 30 L/s, and given the proximity of the active pit to the lagoon, depletion would gradually build to 20 L/s. Given the location of the active pit most of the mitigation water of 25 L/s would be focused for release into the southwest peripheral infiltration trench, which would tend to lift the water table along the Lower Colins Creek – Lagoon shore and thus reducing depletion intensity. Any surplus water would also enter the lagoon from Pond 4 at its tail.

231 The Canoe Creek Lagoon also has substantial buffering capacity to offset the temporary depletion of inflow to the lagoon from the following reservoirs -

(a) The water column of the lagoon,

(b) The continuing inflow to the lagoon from Deverys Creek, Rusty's Lagoon, groundwater seepage primarily from the Coates property, and Collins Creek, and

(c) The hyporheic zone of lagoon bed sediments.

232 It is doubtful that any change in the lagoon’s water level due to the groundwater depletion effect would be perceptible, i.e., more than a few millimetres.

233 The lagoon to the north of Mine Panel 10 is referred to as Rusty’s Lagoon has a higher water level than Canoe Creek Lagoon and sustained by the Deverys Creek catchment, the small surface flows of Northern Boundary Drain and groundwater seepage primarily from the Coates property. The same observations made above for Canoe Creek Lagoon would apply to Rusty's Lagoon meaning that the mitigations of infiltration trench, well injection and direct augmentation of the upstream Northern Boundary Drain would provide a beneficial offset for Rusty's Lagoon when mining activities approach or, are within Mine Panel 10.

234 Observation 8(b) was as follows: “*Based on v1 of the Offered Conditions, management of the water level of the Canoe Creek Lagoon is based on a median level, yet the ecological evidence describes the natural condition as being dynamic*

and having fluctuating water levels. What are the implications of using a median value for managing such a dynamic ecosystem?”

235 My response is that Canoe Creek Lagoon is dynamic, but fluctuates within tight bands, as outlined as follows -

(a) During the 5½ month period from 28 March to 11 September 2023 the fluctuation of water level in the main compartment of the Canoe Creek Lagoon was monitored, providing the following statistical indices:

(i)	Mean	1.827 m
(ii)	Median	1.799 m
(iii)	Minimum	1.736 m
(iv)	Maximum	2.144 m
(v)	Min-Max Range	0.408 m
(vi)	Std. Deviation	0.065 m

(b) Thus, the mean and median water level heights are within 6 centimetres of each other, while a large, one-day rise in water level of more than 30 centimetres (0.3 m) occurred in early August 2023 as a result of a storm.

(c) Defining the median water level will require attention to detail and dense monitoring data due to the likelihood that periods of relatively stable water levels would be punctuated by the effects of storms on the base level.

236 Observation 8(c) was as follows: “*How do the ‘dependencies’ work as controlling parameters in Table A Condition 25.2*?”

237 My response is that the Barrytown Sand Mine Stream Ecological Effects Assessment report prepared by Mr. Gary Bramley explains the relationship between the toxicity of certain metals and metalloids and water hardness, or equally pH or Dissolved Organic Carbon. Toxicity effects are lower in harder water and hence hardness adjustment is commonly used where the background water hardness is not high enough to avoid potential toxicity impacts on aquatic ecology.

238 Observation 8(d) was “*the Water Management Plan and Kōmanawa report (consistent with the ECIA) aim for a low impact in the relevant Boffa Miskell effect band for level variation, but the conditions aim to maintain the median. Are these materials* (metrics?) *well-aligned?*

239 My response is that the observation makes a parallel or comparison between ‘moderate’ levels of effect and median hydrological statistics. If so, the parallel or comparison is misplaced.

240 The Water Management Plan sets the goals of containing environmental effects on groundwater levels, water body water levels and water course flows so that the <u>median</u> is not reduced on pre-mining median levels or flows. This is not the same as ‘moderate’ magnitude of effect on the hydrology of these water bodies in terms of the Ecology Impact Assessment (EcIA) guidelines.

241 Further information on the water quantity thresholds is available in Section 7.4 of the Water Management Plan. Since the potential depletion of water flows in water bodies adjoining the Site under mining operations is linked by groundwater level change, action thresholds at the perimeter monitoring bore or piezometers are one of the more effective mitigations available. Groundwater level threshold actions are detailed in Section 7.5.1 of the Water Management Plan and these actions would be preventative of levels of effect approaching moderate in terms of the EcIA guidelines.

Jens Haaye Rekker

Dated this 19th day of January 2024

Appendix 1: Barrytown Mineral Sand Operation Water Management, Monitoring and Mitigation Plan

Kōmanawa Solutions Ltd

Barrytown Mineral Sand Operation

Water Management,

Monitoring and Mitigation Plan

REV 3

14/12/2023

Report No: Z22004_2

komanawa.com

Version control and source information

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Table of Contents

1. INTRODUCTION

1.1. Background

Tiga Minerals and Metals proposes to develop mineral sand extraction facilities in the Barrytown area of the West Coast region. A preliminary Water Management Plan has been developed to support a resource consent application for the site.

The proposed mineral extraction will comprise an excavator feeding a mineral processing plant. The proposed extraction area covers 41 ha of pastoral farmland between Deverys Creek and Canoe Creek with a maximum excavation depth in the order of 9 m.

Groundwater inflows to the excavation will be discharged back to local waterbodies and to groundwater recharge wells and/or trenches.

Several farm drains which convey runoff and seepages from the humps and hollows through the working area will be diverted to avoid mixing clean water with mine-affected water while the mine pit traverses the site.

Water will also be taken from the mine excavation inflows and from Canoe Creek for mineral processing.

A management plan is required to set out how these activities will be managed to avoid adverse effects on the local hydrological environment and to provide a basis for develop of operating procedures on the site.

1.2. Report purpose and scope

This report comprises two main components: a Water Management Plan (WMP) and a Monitoring and Mitigation Plan (MMP).

The purpose of the WMP is to define water management objectives and principles and present a management process which gives effect to these.

The purpose of the MMP is to provide details of the monitoring that will be undertaken to determine whether the WMP objectives are being met and to set out the actions that will be undertaken if monitoring results signal the potential for hydrological impacts to occur.

The scope of work is:

- Describe the aspects of the proposed activity which could cause hydrological effects.
- Define water management and monitoring and mitigation objectives.
- Define water quality action thresholds and the activities that will be undertaken if the action thresholds are exceeded.

A separate Erosion and Sediment Control Plan (ESCP) has been developed and hence stormwater management and sediment control fall outside the scope of this document. The WMP and ESCP are closely related, however, and hence this document should be read in conjunction with the ESCP. Sediment monitoring is included within the monitoring section of this document.

2. DESCRIPTION OF ACTIVITY

The resource consent application (TPRL, 2023) for the proposed operation provides the following description of the activity:

The proposed mining activity will involve the removal and preserving of topsoil, excavation of mineral sands by an excavator, which will be pumped to the onsite processing plant. Specifically:

1. Topsoil, approximately 0.2- 0.6m thick, and overburden will be removed and preserved (stockpiled) for rehabilitation using an 85 tonne excavator, and 40 tonne articulated trucks. This area will be approximately 0.5 ha. Once in mining sequence, topsoil will be removed ahead of mining and placed straight onto rehabilitated ground behind the mining pit.
2. The sand ore will be mined via excavator and deposited onto a mining bench of approximately 1 ha in area. The ore will then be picked up by front end loader directly to the in-pit mining hopper. The slurry will pass through a trommel and desliming circuit before being pumped to the Wet Concentrator Plant (Processing Plant).
3. Reject large material from the trommel and slimes (small particles such as clay, mixed with water) will be returned to the mine pit.
4. Mining will occur at a faster rate (approximately 350 tonnes per hour of sand ore) than processing (approximately 165 tonnes per hour), and the excess ore will be stored at the processing plant and used overnight to ensure the processing plant can run 24/7.
5. Excavated material will be processed at the Processing Plant to extract the Heavy Mineral Concentrate (HMC). Heavy minerals will be separated from the ore using a water and gravity circuit, drained of excess moisture and stored at the Processing Plant in a farm implement building with a concrete floor.
6. Un-mineralised sands will be pumped back to the pit cavity, which will be progressively filled as the mine pit progresses. Pumped tailings will be spread across an approximate 1 hectare area of the mining void. Tailings are dewatered and discharged to the mining void via cyclone. The tailings will be allowed to naturally beach out (spread out). The cyclone will be moved as required to distribute the tailings as necessary. Tailings will be levelled and contoured with the use of excavators and bulldozers ready to receive the pre stripped overburden and soil. The mining void will be progressively rehabilitated as the mining void advances. Vegetative cover (sowing of grass) is established, and the area is removed from the disturbed area once stabilised.

3. ROLES AND RESPONSIBILITIES

3.1. Project Manager

- Responsible for the implementation and enforcement of this plan.
- Authorise any personnel to perform any duties of this plan and ensure that they are competent to complete their duties.
- Ensure that the consent conditions related to water management of the site are complied with

- Inform a Compliance Officer of the Consent Authority immediately if a breach of Consent Condition(s) takes place, or when they believe that a breach may take place.
- Approve any ‘permits to work’ prior to starting tasks if required (or delegate authority)

3.2. Mine Manager

- Ensure that all personnel that enter the mining operation areas comply with this plan
- Ensure that all pre-start inspections and checklists are being completed
- Ensure all personnel operating any vehicles have been deemed competent, hold a current and appropriate permit or are under the escort of a person who holds a current and appropriate permit
- Ensure any changes to this plan are communicated to all relevant personnel when they occur

4. CONSENT CONDITIONS

4.1. Index to relevant conditions

Table 1 summarises the proposed consent conditions and provides cross references to the sections of this document which give effect to the proposed conditions.

Table 1 **Consent conditions and plan cross references**

Condition	Report section
24.2 - Annual updates of WMP	8.1
25.1 - 25.3 - Minewater treatment and discharge	7.6
25.5 - Diversion of clean water away from workings	See ESCP
26.1 - Daily inspections of water treatment facility	See ESCP
26.2 - Monitoring schedule	7.3
26.3, 26.4 - Water quality limits	7.6
26.5, 26.5 - Monitoring personnel and procedures	3.1
26.7 - Annual reporting requirements	8
29.1 – Management of excavation inflow effects	7.4 - 7.5
30.1 – 30.8 – Management of Canoe Creek water take	6.2

5. POTENTIAL EFFECTS

5.1. Overview

The Barrytown Mineral Sands Mine Hydrological Impact Assessment (KSL, 2023) describes the activities for which water management controls may be required as follows:

1. Interception of surface drains and overland flow paths to prevent inflows of clean surface water to the excavation.
2. Potential water quality impacts associated with discharge of groundwater and stormwater from the excavation and backfilling area to local surface water bodies.
3. Potential groundwater level declines due to pumping of water from the mine excavation and the associated effects on local surface water bodies.

Management of runoff diversions to avoid adverse effects associated with erosion and sediment discharges is discussed in the ESCP. The scope of this WMP for runoff management is limited to site rehabilitation to re-establish the main pre-mining catchment areas for the Northern Boundary Drain and Collins Creek/Canoe Creek Lagoon. Similarly, the actions that will be taken to manage elevated sediment concentrations in water pumped from the mining excavation and management of runoff from the rehabilitation areas are described in the ESCP and are not discussed further in this document.

5.2. Water quality effects

Potential water quality effects principally relate to sediment from the pit pond and stormwater and dissolved metals and phosphorus which are naturally present in the groundwater which will be pumped from sumps in the mine excavation. It is possible that dissolved metals could also be mobilised because of the mechanical processes of mineral separation and sand and slimes deposition during backfilling of the worked excavation. An increase in the discharge of sediment and/or these metals and phosphorus to surface waters could have an adverse impact on downstream aquatic life. A management, monitoring and mitigation process is required to ensure that this does not occur.

5.3. Water quantity effects

Pumping of groundwater inflows to the mine excavation will be required to facilitate the mineral sand extraction operations below the water table. Modelling results presented in KSL (2023) and updated in Rekker (2023) indicate that groundwater inflow to and pumping from the excavation at the expected peak rate of 70 L/s has the potential to deplete Collins Creek by up to 4 L/s, the Northern Boundary Drain by up to 13.5 L/s and cause water level declines in Canoe Creek Lagoon, Rusty Pond, the wetlands to the north and to a lesser extent the springs to the south of the site, if appropriate water management is not implemented.

Taking up to 63 L/s from Canoe Creek is not expected to cause adverse effects.

6. WATER MANAGEMENT PLAN

6.1. Water Management Plan goals

6.1.1. Operating condition goals

Groundwater management will be undertaken to create the working conditions required for mineral sand extraction below the water table whilst avoiding adverse hydrological effects.

6.1.2. Hydrological effect goals

The specific goals associated with avoiding hydrological effects are:

I. The flows from the springs on RS 4884 (Langridge property to the south) used for domestic and stock water supply are not reduced by mining;
II. The water levels in the wetlands on Lot 1 DP 3424 including "Rustys Pond" (Langridge property to the north) are not altered by mining;
III. The rate of surface water inflow to Canoe Creek Lagoon from Collins Creek is not reduced by more than 10% of the Collins Creek Mean Annual Low Flow (MALF).
IV. The flow in Collins Creek is not reduced by more than 10% of the MALF as the creek approaches low flow condition.
V. Flow consistent with the drain's intermittent hydrological function and with dry weather flows is maintained in Northern Boundary Drain downstream of piezometer PZ-10 during periods when Collins Creek approaches within 120% of its MALF, i.e., dry spells.
VI. The quality of water discharged to receiving waters will not cause adverse impacts on stream ecology and visual clarity.
VII. The rate of take of water from Canoe Creek is not greater than 10% of the MALF.
VIII. Potential adverse ecological impacts associated with discharge of naturally present toxic metals and phosphorus in downgradient surface waters are avoided.
IX. The pre-mining surface drainage patterns are restored such that the catchments areas for the Northern Boundary Drain and Canoe Creek Lagoon are not changed significantly.
X. The soil profile restoration, land contouring and surface drainage installed during mine rehabilitation does not increase the rate of groundwater drainage at the site..

6.2. Water management objectives

The water management goals will be achieved via the following actions:

A. The groundwater level in the pit will be managed via sump pumping so that excavator plant located on benches in the pit remain above the water table.
B. Pumping of groundwater will be minimised by excavation of saturated material from below the water table within the pit down to the planned maximum depth for the economic ore limit. Saturated material will be temporarily stored on the excavation bench to allow for natural drainage of entrained groundwater.

C. Water pumped from the pit will be conveyed to a treatment system for removal of particulate matter. Treated water will be recharged back to the aquifer via infiltration trenches and/or wells as required to achieve the hydrological effect management goals above.

D. The quality of any groundwater recharge water that could enter surface water will be monitored to confirm that it meets standards which are consistent with Hydrological effects goal **Error! Reference source not found.** above.

E. Detailed design information for the water management system shall be issued to WCRC for review and comment at least 16 weeks prior to the start of mining operations. Design information will include design drawings of the infiltration trenches and basin.

F. The rate of take of water from Canoe Creek will be monitored in accordance with the Resource Management (Measurement and Reporting of Water Takes) Regulations and the pumping rate will be restricted to 63 L/s.

G. The Canoe Creek intake will either comprise an infiltration gallery or a direct take. In the case of the later the intake will be installed with a fish screen which will be maintained to ensure, as far as practicable, that eels, fish and fry are prevented from passing through the intake or being trapped against the screen.

H. The rehabilitated mine area will be contoured to re-establish the pre-mining catchment areas, avoid depletion of surface water body flows and water levels and to reduce the potential for transport of nutrients to surface waterways.

6.3. Water management concept design

6.3.1. Overview

Figure 1 illustrates the main features of the water management system which will be installed to deliver the objectives above. The key features comprise:

1. Pumping of groundwater inflows from the mine excavation and conveyance of stormwater from disturbed land to the water treatment system (Ponds 1- 4) during mining for removal of sediment, phosphorus and iron precipitate coupled with hardness adjustment if required to avoid any potential toxicity effects associated with naturally occurring metals.
2. Monitoring of groundwater levels around the site boundary and flows in Collins Creek during mining to identify and respond to any areas of groundwater level/flow decline due to groundwater pumping from the excavation.
3. Conveyance of clean water to infiltration/recharge trenches/injection wells (see Figure 2) constructed along the northern and southwestern site boundaries and to Collins Creek and the Northern Boundary Drain where required. Pumping rates will be adjusted as required to maintain groundwater levels to support maintenance of flows in Collins Creek and the Northern Boundary Drain and to avoid significant groundwater level declines in sensitive locations.

6.3.2. Pit water pumping and treatment

The proposed water treatment system comprises three main components: 1) conveyance of mine-influenced water to the treatment train; 2) treatment of water to remove sediment, dissolved iron, and phosphorus; and 3) adjustment of hardness where required to manage the potential toxicity effects of naturally occurring metals in the local groundwater. Opportunity improvements in metals and metalloid concentrations are also expected to occur in the treatment process, although these are accounted for in the water quality assessment. Stormwater may be discharged directly from the pit to an infiltration basin in the south western corner of the site (see Figure 1) after high intensity rainfall events when the capacity of the treatment and infiltration system is inadequate to remove ponded water from the pit. It is expected that the infiltration basin discharge will only be used following very heavy rain conditions.

Mine water conveyance

The conveyance of stormwater from disturbed areas of the site to the treatment train is described in the ESCP. Sumps will be dug in the active excavation area of the mine pit and installed with pumps to transfer influent groundwater and stormwater to the treatment train via pumping and the Central Drain.

Suspended sediment, dissolved iron, and phosphorus removal

The water treatment system, which has been designed to remove suspended sediment from stormwater runoff from the disturbed areas of the site and the stormwater and groundwater from the mining excavation, comprises a four-pond treatment train with the addition of flocculants and filtration as required to achieve the maximum practically achievable rate of sediment removal. Filtration plant will be installed if treatment trials show that this is required to achieve the standards required for discharges to injection wells/infiltration trenches and/or surface water bodies. Aeration is also provided to promote dissolved iron precipitation (see below). Iron oxyhydroxide precipitates and other flocculants, such as alum, are also proven agents for the removal of phosphorus, which is elevated in some of the groundwater samples bores (viz., PZ-08, PZ-15).

Dissolved iron concentrations in groundwater inflows to the pit are expected to be elevated and may require some treatment to avoid accumulation of iron precipitates at the points of discharge from the treatment train. Aeration is the most cost effective and commonly used method to oxidise ferrous iron, which then forms a precipitate (iron oxyhydroxide) which can be removed via settling ponds and/or filtration. Iron oxyhydroxide formation also facilitates the removal of metals/metalloids, such as cadmium and arsenic, as well as phosphorus, via adsorption and precipitation. The central drain will be installed with rock check dams, porous limestone weirs and waterfalls to increase aeration and thus the dissolved oxygen content of water so as to promote iron oxyhydroxide precipitation in Pond 3 and Pond 4. The ponds will be closely managed to remove iron oxyhydroxide sludge and settled sediment as required to maximise the performance of the treatment system. Full details are provided in the ESCP.

Hardness adjustment

The Barrytown Sand Mine Stream Ecological Effects Assessment report[1] explains the relationship between the toxicity of certain metals and metalloids and water hardness. Toxicity effects are lower in harder water and hence hardness adjustment is commonly used where the background water hardness is not high enough to avoid potential toxicity impacts on aquatic ecology. Also, the addition of hardness using lime facilitates some removal of phosphorus via the formation of calcium phosphate and related insoluble salts.

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[1] EcoLogical Solutions 2023. Barrytown Sand Mine Stream Ecological Effects Assessment report

Hardness adjustment will be implemented via either installation of limestone rip rap or rock dams in the Central Drain or lime dosing of water pumped from the mine void to achieve, as a minimum, the hardness levels described in Table 4. A detailed design for the water treatment system will be provided in an updated version of the WMMP to be issued to WCRC at least 16 weeks prior to excavation of mineral sands from below the water table.

6.3.3. Mine boundary infiltration system

Design features

The proposed infiltration system comprises a compartmented infiltration trench installed along the western, northern, and southern site boundaries as per the schematic diagram in Figure 2, supplemented by injection wells where required. The key features of the infiltration trench concept design are as follows:

- The infiltration trench is excavated through the lower permeability overburden deposits to intercept the top of the mineral sand stratum (generally at 1 – 3 m depth).
- Infiltration testing detailed in Rekker (2023) shows that the infiltration rate is likely to be in the order of 3 m^3/d/m of trench.
- The trench is segregated into 75 m lengths via trench breakers/dams. The breakers extend 0.5 m above the top elevation of the filter sand (see below). The above ground extension of the breaker is fitted with an outlet valve/gate immediately above the top of the filter sand.
- Geotextile is fitted along the trench walls to prevent sediment ingress from the overburden.
- A perforated backwash pipe is installed in the base of the trench with an inflow pipe installed to the ground surface.
- The trench is backfilled with locally sourced river gravel aggregate.
- A 200 mm layer of filter sand is installed at the surface underlain by geotextile filter fabric.
- The upper part of the trench above the sand layer is battered to create a channel profile with stable side walls, which are vegetated or fitted with geotextile to prevent erosion. Bunding is installed where required to provide a minimum 0.5 m vadose zone between the base of the sand filter and the seasonal high groundwater level and to additionally allow for at least 0.5 m of water stage above the sand filter.
- Water is conveyed into the top of the infiltration trench and flows down the first trench compartment and into the next compartment, with a proportion of the water infiltrating to the underlying mineral sands in each trench compartment.
- The water level in each trench compartment is controlled via the trench shutter outflow valve/gate. The valve can be used to restrict the rate of flow into the next compartment and thereby increase the stage and hence driving head in individual compartments as required to control groundwater levels at the site boundary.
- The trench breakers prevent lateral flow of water between adjacent trench compartments during backwash operations such that backwash water flows upwards through the trench aggregate and sand filter and transports clogging material to the surface. Splitting the trench into compartmented sections supports generation of sufficiently high upward flow velocities through the aggregate and sand filter and filter fabric to mobilise clogging material. An outlet pipe at the lower end of the trench

compartment conveys the backwash to land adjacent to the trench, where it either infiltrates to ground or is transported to the Central Drain via overland flow.

Note that the above details are subject to confirmation and amendment at detailed design stage for the purpose of optimising the efficiency of the trench.

Infiltration management

The key features of the infiltration management are as follows:

1. Treated water from Pond 4 is pumped to the infiltration trenches/wells under the following priority system:
   - To the southern and western trench/wells when mining the area of land within strips 1 to 4 and the strip adjacent to Ponds 1 & 2 (see Hydrological Impact Assessment Report, KSL 2023).
   - To the Northern trench when mining strips 5 – 9.
2. Recharge locations and rates will be adjusted based on monitoring data from the site perimeter piezometers. For example, if the monitoring data show groundwater levels starting to fall below the action trigger thresholds (see Section 7.4), additional recharge will be supplied to that stretch of the site boundary. Targeted recharge wells will be installed if the infiltration trench is unable to recharge sufficient water to the groundwater system to maintain groundwater levels within the target range at specific locations. The procedure for this is described in Section 7.5.
3. The maximum rate of recharge to the infiltration system will be no greater than the pit pumping rate on a monthly average basis. Higher rates may be discharged for short periods (e.g. for one week, to maintain groundwater levels at the site boundary if required), by drawing down water in the treatment ponds.

6.3.4. Pond 4 discharge to surface waters

Pond 4 will be constructed with an overland flow path to Canoe Creek Lagoon and a water quality monitoring system as per Section 7.3. The outlet valve will be opened to allow overflow of water to the lagoon when water quality meets the discharge water quality standards and when water level monitoring shows that drawdown is occurring.

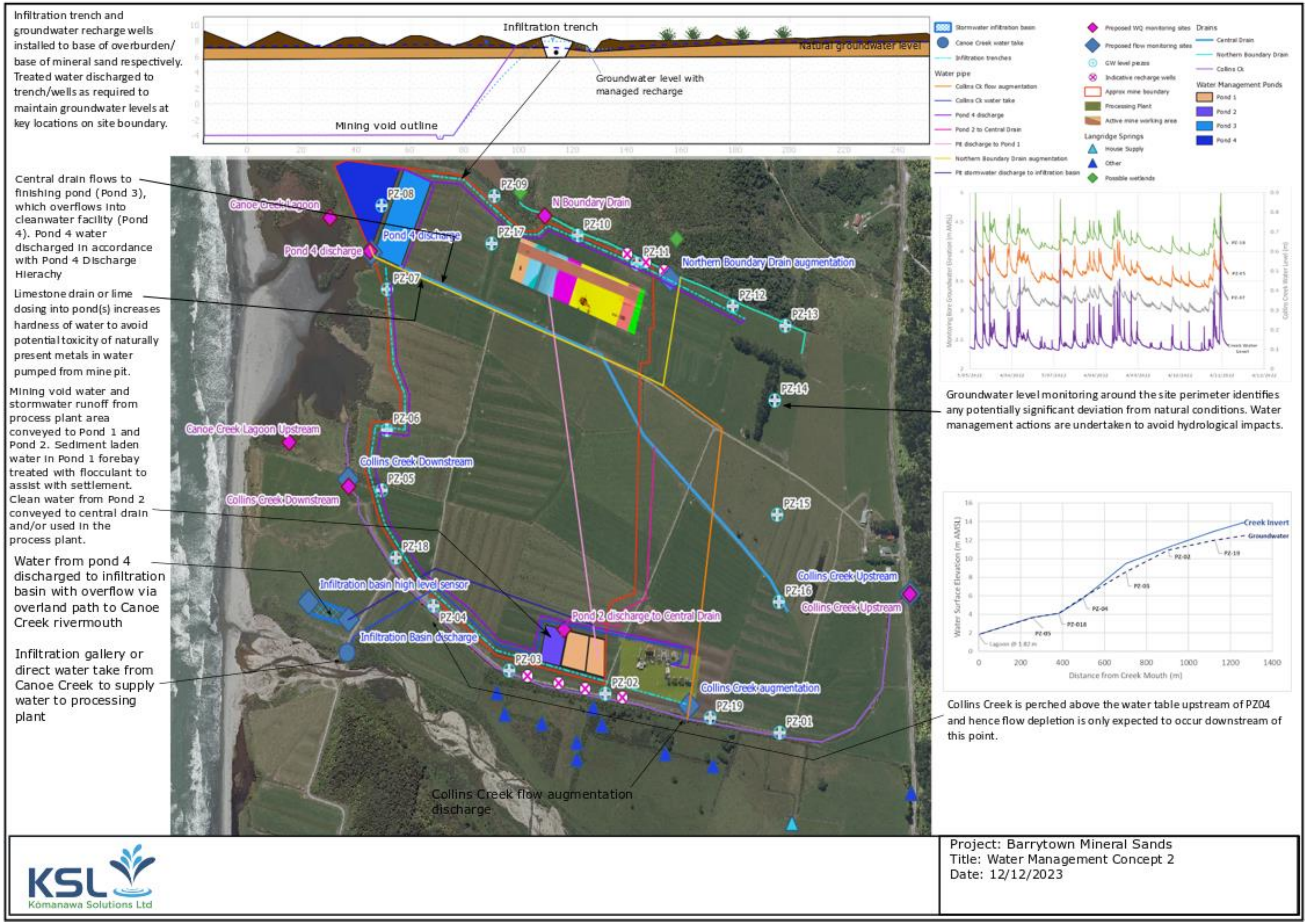
Water meeting the discharge standards may also be pumped to the Northern Boundary Drain to maintain water levels in the drain, Rusty Lagoon and the adjacent wetland. The trigger for this discharge will be based on water level monitoring in PZ09 as discussed in Section 7.4. Appropriate erosion/scour protection will be installed at the discharge location (see Figure 1).

Additionally, water meeting the discharge standards may also be pumped to Collins Creek to augment flows in the event of depletion due to pumping of groundwater from the mine pit. As above, appropriate erosion/scour protection will be installed at the discharge location (see Figure 1).

6.3.5. Infiltration basin

Stormwater accumulation in the mine excavation during periods of heavy rainfall may be conveyed to the infiltration basin (see Figure 1) for short periods of time (e.g. for 1-2 days after a heavy rainfall event). The key design features of the basin are as follows:

- The basin will be installed in the vicinity of the infiltration trial location described in Rekker (2023).
- The basin floor will comprise highly transmissive river gravel deposits with a base at least 1.5 m above the expected groundwater elevation.
- Bunding will be installed around the basin to provide for a basin water stage of at least 1 m above the basin floor elevation.
- The infiltration capacity of the basin during the initial operating period is expected to be in the order of 170 m^3/d per linear meter of trench based on the field trials described in Rekker (2023) but is likely to reduce over time due to clogging. The basin will be maintained via excavation of clogging material from the base of the trench when required. Maintenance will comprise excavation of fines and clogged river gravel from the base and replacement with clean gravel from the river.
- The basin will be fitted with a high-level sensor and alarm system to ensure that overflow does not occur. The rate of water pumped to the basin will be controlled to prevent overflow from occurring.



Infiltration trench and groundwater recharge wells installed to base of overburden/ base of mineral sand 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

Collins Creek flow augmentation discharge

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.

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Title: Water Management Concept 2
Date: 12/12/2023

Figure 1 Water management concept

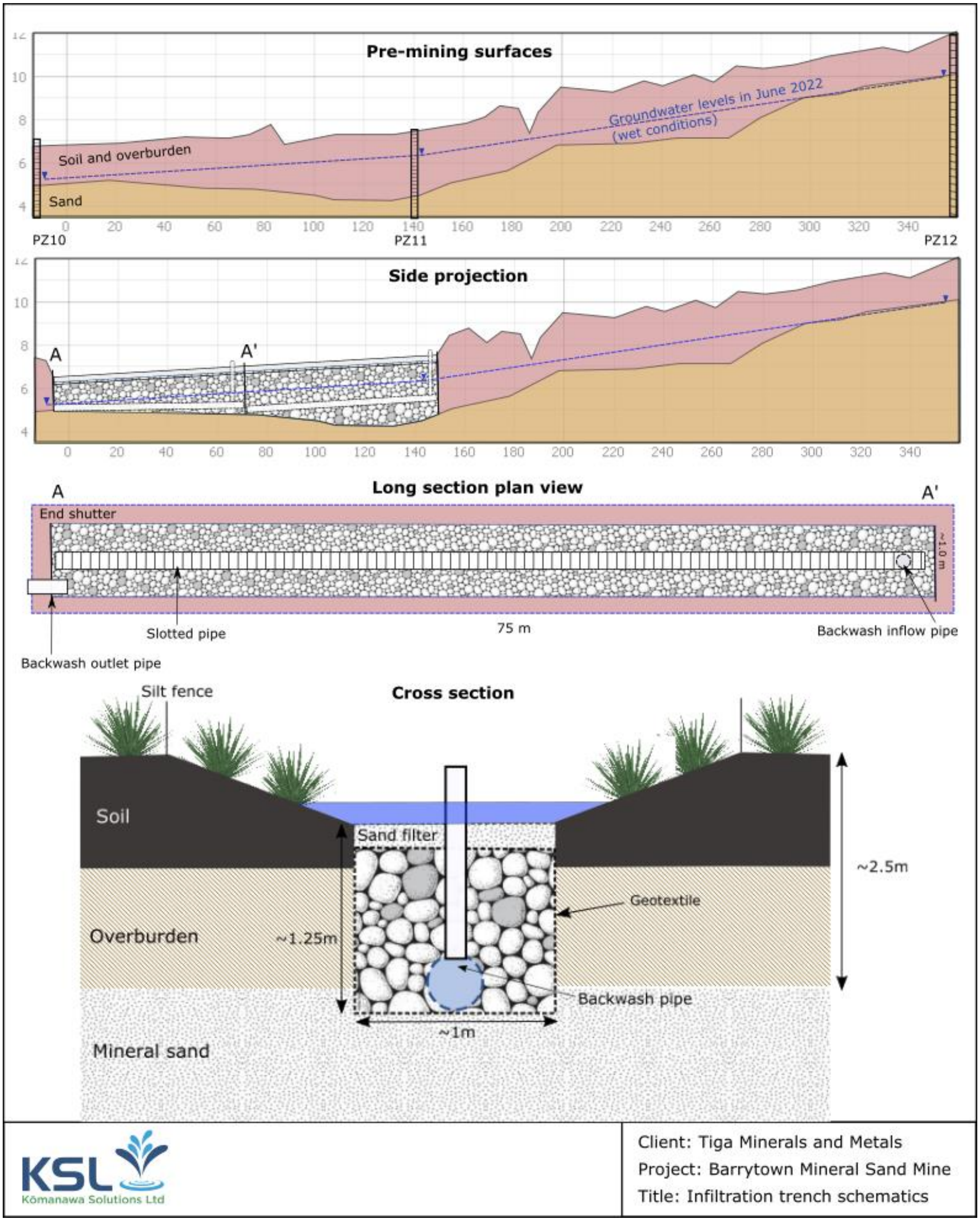

Figure 2 Infiltration trench schematic

6.4. Rehabilitation concept

Mapping of current drainage patterns (Figure 3) 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 as a result of mining.

The groundwater[2] and topography cross sections through the proposed mining area in Figure 4 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 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. This will both improve pasture quality and reduce potential for nutrient discharge to waterways. 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.

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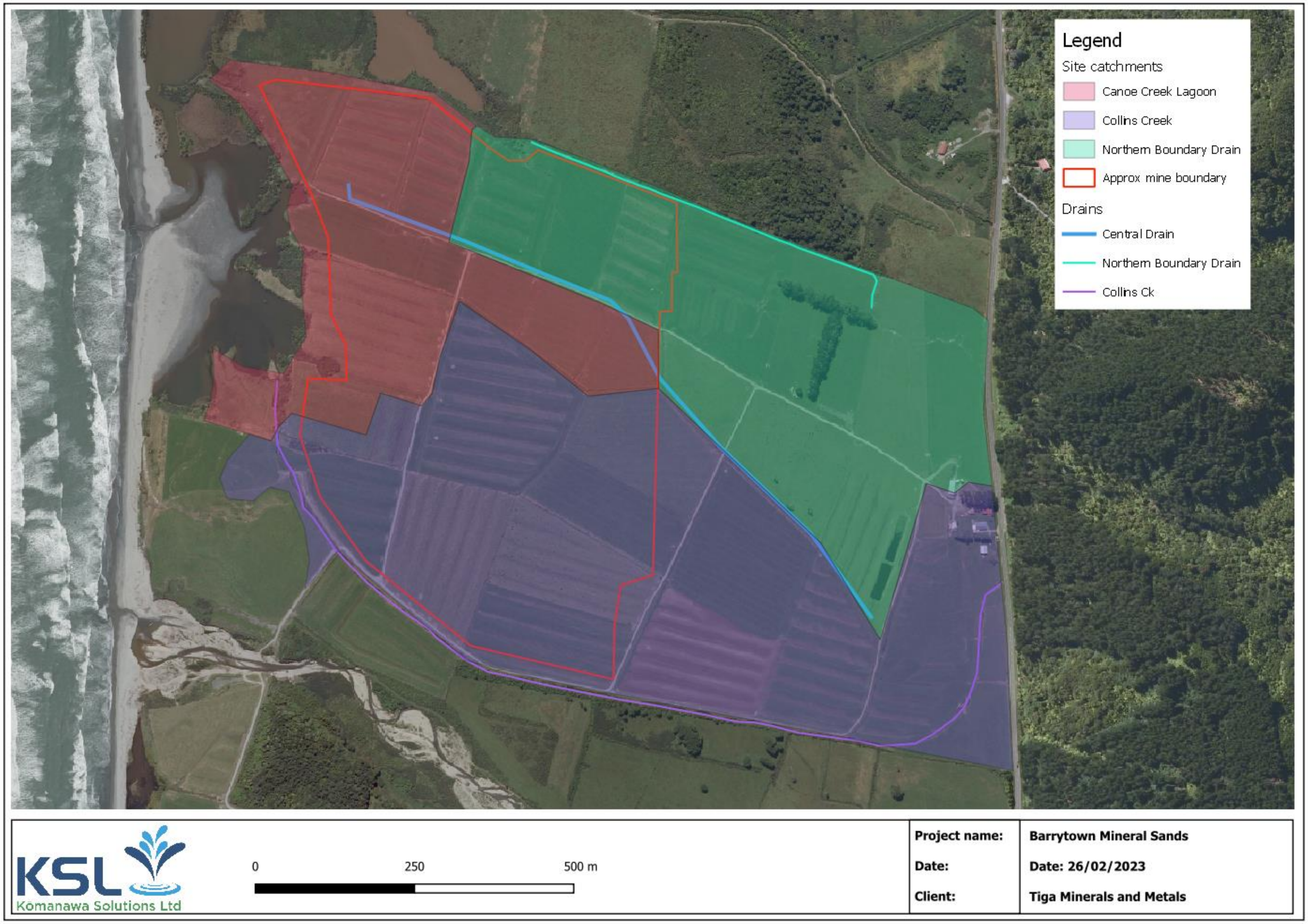
[2] Note that groundwater level data in areas with no piezometers were interpolated are therefore subject to local uncertainty. The groundwater elevations shown in some of the hollows in Figure 4 are higher than is likely to be the case.



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Date: Date: 26/02/2023

Client: Tiga Minerals and Metals

Figure 3 Pre-mining surface water catchments

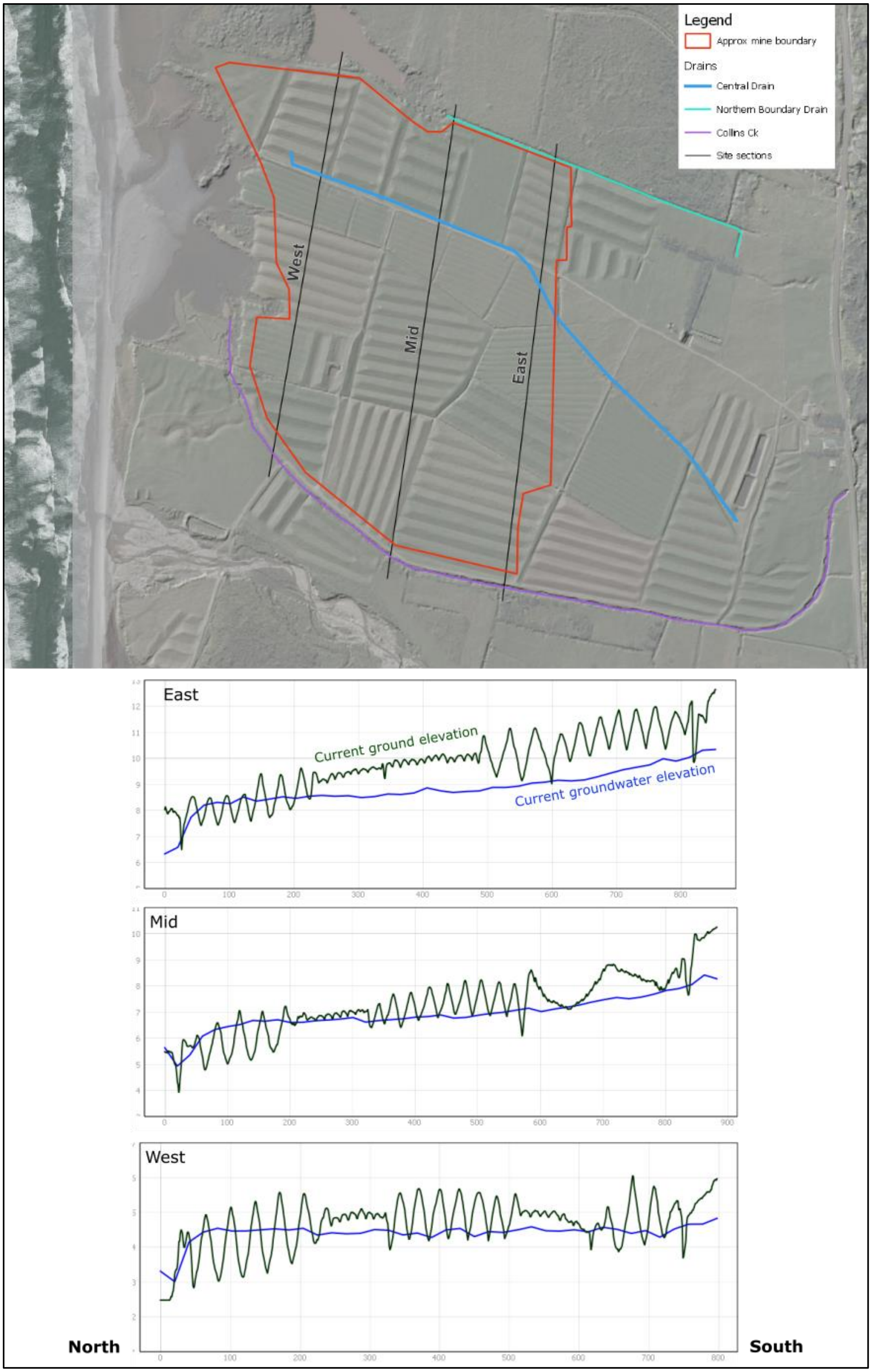


Figure 4 North – south cross sections through mining area

7. MONITORING AND MITIGATION PLAN

7.1. Monitoring and Mitigation Plan Objectives

The objectives of the Monitoring and Mitigation Plan (MMP) are as follows:

- Ensure that potential water quality impacts associated with mining activities are identified as quickly and clearly as possible via monitoring.
- Identify actions that will be undertaken to avoid, remedy or mitigate water quality effects through implementation of appropriate actions in a timely manner where required.

These objectives are achieved by:

- Specification of a monitoring programme which can robustly confirm that the water management system is working effectively and identify where adjustments are required to optimise water management and avoid adverse effects.
- Definition of action thresholds and an associated set of activities which can be implemented within a suitable timeframe to achieve the objectives of the WMP.
- Setting out reporting procedures for environmental monitoring data and consent compliance.

7.2. Baseline monitoring

The following baseline monitoring was initiated in May 2022:

1. Monitoring of groundwater levels around the site boundary to define baseline water levels.
2. Monitoring of flows in Collins Creek upstream and downstream of the site to define the natural change in flow between these points.
3. Monitoring of water quality in Collins Creek, Northern Boundary Drain and Canoe Creek Lagoon to define baseline water quality.

A water level logger was installed in Canoe Creek Lagoon on 28 March 2023.

Groundwater levels

A groundwater level monitoring network was installed around the site perimeter in April 2022. Groundwater level loggers were installed in a representative sub-set of these wells (PZ01, PZ06, PZ10, PZ12, PZ18) to collect groundwater level data at hourly intervals. Water levels in remaining piezometers are dipped periodically to establish a relationship with the logged piezometers. The groundwater level data collected from this network provide a robust set of baseline data at the site boundaries which can be used to signal the potential for hydrological effects beyond the site boundary when mining operations are underway.

Collins Creek flows

An upstream and downstream flow monitoring site were installed in Collins Creek on 03/05/22. The upstream site location is shown in Figure 1. The downstream site is currently located in the vicinity of PZ18 but will be relocated to the lower site shown in Figure 1 prior to the start of mining because hydrological modelling undertaken after the initial monitoring site installation identified the potential for minor stream flow depletion downstream of the lower site.

7.3. Operational monitoring

Operational level and quantity monitoring will include:

1. Groundwater levels around the site boundary
2. Flows in Collins Creek upstream and downstream of the site
3. Discharge rates from Pond 2 or Pond 4 to:
    a. Canoe Creek Lagoon
    b. Infiltration system
    c. Collins Creek flow augmentation
    d. Northern Boundary Drain augmentation
4. Stormwater discharge rates from the infiltration basin
5. Water take rates from Canoe Creek

Items 1 - 2 will comprise dataloggers with telemetry data transmission and an automated alert system for threshold exceedances (see below). Items 3 - 5 may comprise either a datalogger with or without telemetry system or a manual recording system, in accordance with the consent conditions.

Operational water quality monitoring will include:

- Turbidity monitoring in the Pond 2 discharge to Central Drain
- Water quality, turbidity and sediment monitoring in Collins Creek upstream and downstream of the excavation area
- Water quality, turbidity and sediment monitoring in the lower Northern Boundary Drain
- Water quality, turbidity and sediment monitoring in Canoe Creek Lagoon

Monitoring will be undertaken at or about the locations shown in Figure 5 in accordance with the schedule in Table 2 and Table 3.

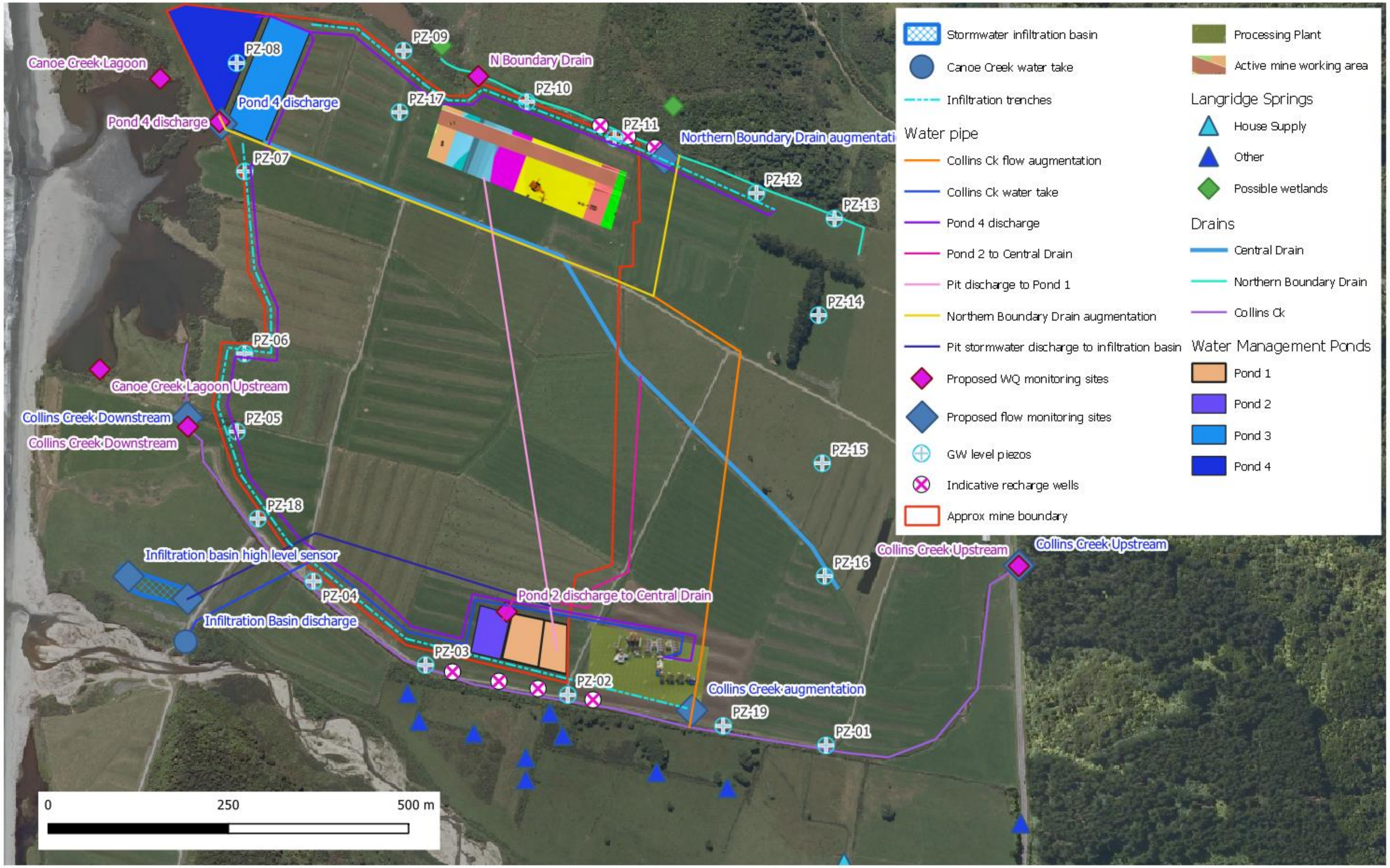
Table 2 Monitoring schedule

Monitoring site	Parameters	Minimum frequency
Boundary piezometers	Groundwater levels	Every 6 hours via data logger
Collins Creek upstream and downstream flow sites	Flow	Hourly
Pond 4 discharges to: 1. Canoe Creek Lagoon 2. infiltration system 3. Infiltration basin 4. Collins Creek augmentation 5. Northern Boundary Drain augmentation	Daily total flow	Daily
Canoe Creek water take	Flow	15 minutes

Monitoring site	Parameters	Minimum frequency
Pond 2 discharge to Central Drain	Turbidity	Daily
Infiltration basin high water level sensor	Water level	Hourly
Collins Creek upstream and downstream water quality sites	Monitoring Suite A Visual clarity	See Monitoring Suite A Weekly
Canoe Creek Lagoon water quality site	Monitoring Suite A Visual clarity	See Monitoring Suite A Weekly
Pond 4 discharge water quality	Turbidity	Daily
Northern Boundary Drain water quality	Monitoring Suite A Visual clarity	See Monitoring Suite A Weekly

Table 3 Monitoring Suite A (Q = quarterly sampling, M = monthly sampling)

Dissolved metals	***Others***
Aluminium (Q)	EC (M)
Arsenic (Q)	pH (M)
Boron (Q)	Turbidity (M)
Cadmium (Q)	TSS (M)
Chromium (Q)	Hardness (Q)
Copper (Q)	Sulphate (Q)
Iron (Q)	Amm-N (M)
Nickel (Q)	NO_3-N (M)
Lead (Q)	Dissolved Reactive Phosphorus (M)
Manganese (Q)	
Zinc (Q)	



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Date:	**Date: 12/12/2023**
Client:	**Tiga Minerals and Metals**

Figure 5 **Proposed monitoring network**

7.4. Water quantity thresholds

Hydrological thresholds are defined below to give effect to the hydrological effect goals presented in Section 6.1.2.

7.4.1. Groundwater level thresholds

Groundwater level data recorded in boundary monitoring piezometers PZ1 - PZ12 and PZ18 - PZ19 for at least 12 months prior to commencement of mineral sand excavations below the water table will be analysed to calculate the median water level in each well. These median values will be defined as action thresholds. The remaining boundary wells will be monitored for information purposes only.

7.4.2. Collins Creek flow threshold

The MALF in Collins Creek is taken to be 16 L/s based on the hydrological model-based statistic presented in Booker and Woods (2014)[3]. The maximum rate of depletion of Collins Creek is therefore 2 L/s (rounding to the nearest L/s in recognition of flow measurement accuracy limitations).

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[4] prior to the start of mineral sand excavations minus 2 L/s.

For 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 106 L/s.
- The augmentation rate in this example is therefore 100 - 106 +10 - 2 = 2 L/s.

7.4.3. Canoe Creek Lagoon stage

Inflows to Canoe Creek lagoon comprise Collins Creek and groundwater seepages from land to the east of the lagoon. On occasion, the neighbouring catchment of Deverys Creek to the north coalesces with Canoe Creek Lagoon, enlarging the upstream catchment area to 5 square kilometres. Implementations

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[3] Booker DJ, Woods RA. 2014. Comparing and combining physically-based and empirically-based approaches for estimating the hydrology of ungauged catchments. *Journal of Hydrology* **508**:227-239. See https://shiny.niwa.co.nz/nzrivermaps/

4 Note that the existing monitoring site can be used for the purpose of establishing the upstream-downstream flow change, but the new site further downstream must be monitored for at least one month whilst the existing downstream site is maintained to establish the relationship between these two lower sites.

of the action thresholds above for Collins Creek and the piezometers adjacent to the lagoon will therefore protect the water balance of the lagoon. The water level in the lagoon is strongly influenced by the beach profile to the west and is therefore highly dynamic over time due to wave erosion and deposition. Water level management based on a pre-mining baseline water level in the lagoon would therefore not provide a suitable effects threshold.

7.5. Water quantity actions

7.5.1. Groundwater level threshold actions

As noted previously, the maximum rate of recharge to the infiltration system will be no greater than the pit pumping rate on a monthly average basis, regardless of groundwater level monitoring results and the thresholds below. Higher rates may be discharged for short periods only (e.g. for one week, to maintain groundwater levels at the site boundary if required), by drawing down water in the treatment ponds.

Two action thresholds are defined for boundary monitoring piezometers PZ1 - PZ7, PZ09, PZ10 - PZ12, PZ18 and PZ19: a 7-day rolling average and a 30-day rolling average. The former comprises an operational management trigger, the latter comprises a mitigation action threshold.

If the 7-day rolling average groundwater level in any of the above boundary monitoring piezometers falls below the pre-mining median, water will be discharged to the appropriate sections of infiltration trench/infiltration wells to recharge the aquifer in the location of the groundwater level decline. Groundwater levels will be reviewed over the subsequent 48 hours after the management trigger and adjustments made to the rate of recharge until the pre-mining median groundwater level is restored (within the constraints of the pit pumping rate as detailed above).

If the 30-day rolling average groundwater level in any of the above boundary monitoring piezometers falls below the pre-mining median the following actions shall be undertaken:

- The consent holder shall contact the West Coast Regional Council within five working days with details of the threshold exceedance and the actions that will be undertaken.
- The consent holder may submit a request to WCRC for approval to maintain a lower groundwater level in the well(s) under circumstances where it can be shown (via data from background groundwater monitoring wells located away from the area of influence of the mining operation and within the same hydrological setting) that this would not cause a deviation from the natural background variability. Approval to use any such off-site background monitoring wells must be obtained in writing from WCRC at least 4 weeks prior to the start of mineral sand excavations.
- If approval to maintain a lower groundwater level is not sought or provided, relevant infiltration trench sections/infiltration wells will be investigated to determine whether the decline relates to inadequate recharge rates. Remedial actions such as backwashing or excavation and replacement of the trench filter media will be implemented.
    - If:
        - the groundwater level declines are within one or more of piezometers PZ10 - PZS12, PZ01 - PZ03, PZ06, PZ07 or PZ19; and
        - remedial actions have not restored groundwater levels within 20 working days; then

    - pumping from the mine void shall cease until further remedial actions have been implemented. Further remedial actions could include installation of recharge wells or re-engineering of the infiltration trench system.
    - Mine void pumping can recommence when the daily average groundwater level in PZ10 - PZS12, PZ01 - PZ03, PZ06, PZ07 or PZ19 have been restored to the pre-mining median.
- If:
    - the groundwater level declines are within one or more of piezometers PZ04 , PZ05 or PZ18; and
    - remedial actions have not restored groundwater levels within 20 working days
    - Flow monitoring data from the upstream and downstream Collins Creek flow monitoring sites shall be reviewed to ensure that depletion rates are less than 10% of MALF. Additional augmentation flows will be supplied to Collins Creek as required.
- If:
    - the groundwater level decline is in piezometers PZ09; and
    - remedial actions have not restored groundwater levels within 20 working days; then
    - pumping from the mine void shall cease until further remedial actions have been implemented. Further remedial actions could include additional flow augmentation of Northern Boundary Drain, installation of local recharge wells and/or re-engineering of the infiltration trench system.
    - Mine void pumping can recommence when the daily average groundwater level in PZ09 has been restored to the pre-mining median.

7.5.2. Collins Creek flow threshold

If the Collins Creek flow threshold is breached the following actions will be undertaken:

- The consent holder shall contact the West Coast Regional Council within five working days with details of the threshold exceedance and the actions that will be undertaken.
- The flow monitoring sites will be inspected and a manual flow gauging undertaken to confirm the flows if the accuracy of the flow monitoring rates is uncertain.
- The rate of flow augmentation will be increased until the upstream-downstream flow difference falls within the required range.

7.6. Water quality thresholds and actions

7.6.1. Water quality action thresholds

Metals and metalloids

Action thresholds for metals and metalloids measured in accordance with the operational monitoring programme in receiving waters at the Collins Creek Downstream, Canoe Creek Lagoon. N Boundary Drain and Canoe Creek Downstream water quality monitoring sites shown in Figure 5 are provided in Table 4.

Table 4 Water quality action thresholds - metals and metalloids

Parameter	Threshold mg/L	Dependency	Reference
Aluminium	0.62[B]	Hardness, pH, Dissolved Organic Carbon	USEPA (2018)
Arsenic	0.013	As arsenic (V)	ANZECC (2000)[c]
Boron	0.94	NA	ANZECC (2018)[c]
Cadmium	0.0002[D]	Hardness	ANZECC (2000)[c]
Chromium	0.0033[D]	Hardness, as chromium (III)	ANZECC (2000)[c]
Copper	0.0039[E]	Hardness, pH, Dissolved Organic Carbon	USEPA (2007)
Iron	1.0	As total fraction	USEPA (1986)
Lead	0.0034[D]	Hardness	ANZECC (2000)[c]
Manganese	1.9	NA	ANZECC (2000)[c]
Nickel	0.011[D]	Hardness	ANZECC (2000)[c]
Zinc	0.008[D]	Hardness	ANZECC (2000)[c]

[A] dissolved fraction, unless stated

[B] at hardness = 25 g/m^3, pH = 7.0, Dissolved Organic Carbon = 1.0 g/m^3

[C] 95%-ile trigger value

[D] at hardness = 30 g/m^3

[E] at hardness = 25 g/m^3, pH = 7.0, Dissolved Organic Carbon = 2.0 g/m^3

Turbidity, suspended sediment and visual clarity

Action thresholds for turbidity and suspended sediment and clarity are provided in Table 5.

Table 5 Water quality action thresholds - turbidity, total suspended solids, clarity, and dissolved reactive phosphorus

Parameter	Threshold	Notes
Total Suspended Solids	20 mg/L	In discharges to Collins Creek, Northern Boundary Drain or to the overland flow path to Canoe Creek Lagoon.
Turbidity	20 NTU	In discharges to Collins Creek, Northern Boundary Drain or to the overland flow path to Canoe Creek Lagoon.

Parameter	Threshold	Notes
Visual clarity	Conspicuous visual change Relevant NPS-FM (2020) attribute state for visual clarity	In the receiving water bodies above based on visual inspection at the upstream and downstream monitoring sites (see Figure 5). No change in the attribute states of the receiving surface water bodies, as an annual median and a 95%-ile, versus the baseline states. See note below.
Dissolved Reactive Phosphorus (DRP)	Relevant NPS-FM (2020) attribute state	No change in the attribute states of the receiving surface water bodies, as an annual median and a 95%-ile, versus the baseline states. See note below.

Notes:

The attribute state for visual clarity and DRP shall be either *a) defined via at least 12 months of baseline monitoring in Collins Creek, Northern Boundary Drain, Canoe Creek and Canoe Creek Lagoon; or b) assumed to be of pristine water quality (A Band*). *In the case of a), the monitoring data and attribute state assessment shall be submitted to WCRC for approval at least 4 weeks prior to the start of mining operations*

The Canoe Creek Lagoon upstream observation location shall be upstream of the Collins Creek inflow and the inflow from the Pond 4 discharge, but may change over time, given the dynamic nature of the lagoon. The Northern Drain upstream site shall be the lowest point in the stream which is a) upstream of any discharge and b) at which visible flow is occurring on the day of the observation.

7.6.2. Water quality threshold exceedance actions

The following actions shall be undertaken in the event of a water quality threshold exceedance:

- The consent holder shall notify WCRC within 5 working days.
- In the case of an exceedance within the surface water monitoring sites, the water quality data from upstream monitoring sites and the downstream monitoring sites shall be compared to determine whether it is related to natural water quality.
- The consent holder shall provide a toxicant management plan (see below) to the Regional Council. The plan will employs the effects management hierarchy to ensure the adverse effects of the discharge on aquatic life are reduced to no more than minor.

If a toxicant management plan is developed in response to a threshold level exceedance, the plan shall include the following as a minimum:

a) The actions to be taken to avoid, minimise, remedy, offset or compensate for more than minor effects.
b) The timeline in which the actions identified through (a) above will be implemented.
c) The consent holder shall implement the actions identified through Condition (a) in accordance with timeline in Condition (b).

8. ANALYSIS, REPORTING AND IMPROVEMENT PROCEDURES

8.1. Plan updates

The WMP should be updated on an annual basis in the form of an update document which identifies and summarises any amendments. Key components of the WMP to be defined for the year ahead include:

- The proposed mine area for that year.
- A description of all site activities with the potential to cause hydrological impacts.
- The water management actions that will be implemented to avoid hydrological effects.
- Audit checklists.
- An organisational chart showing staff and contractor positions and responsibilities for plan implementation.
- Relevant training and induction procedures and schedules.

The water management plan and associated procedures should be updated to improve water management practices and reduce the potential for adverse hydrological impacts in the following circumstances:

- Ongoing actions or management changes are implemented in response to breaching of any of the action thresholds.
- The hydrological monitoring system is not performing as intended (e.g. due to lack of flow in a surface water monitoring site or insufficient information being gathered to identify the cause of any water quantity or quality issues)
- A pollution incident or one or more near-misses occur which could have resulted in water quality or quantity impacts, and new procedures have been identified to reduce future risk.
- Improvement opportunities identified through the data review and analysis procedures.

8.2. Annual reporting

An annual monitoring report will be prepared by a suitably qualified and experienced person and submitted to WCRC for review. The report will include:

1. A summary of the monitoring undertaken over the preceding 12 months. The summary will:
    a. Reference the specific consent conditions under which the monitoring has been undertaken to show how the conditions have been complied with.
    b. Provide tables, graphs and summary data of the water quality, flow and water level monitoring.
2. Discussion and evaluation of the monitoring data in relation to the relevant consent conditions including a summary of compliance with conditions.
3. A summary of the actions that have been undertaken in response to any action thresholds.
4. Records of the inspections/monitoring undertaken to verify that the mine operation has not caused any of the following effects within any receiving waterbody measured at or beyond 100 metres from any discharge:
    a. Any conspicuous oil or grease films, scums or foams, or floatable or suspended materials,

b. Any conspicuous change in the colour or visual clarity,
c. Any emission of an objectionable odour,
d. Any significant adverse effects on aquatic life, or
e. The rendering of fresh water unsuitable for consumption by farm animals.

9. REFERENCES

KSL, 2023. Barrytown Mineral Sands Mine Hydrological Impact Assessment. Kōmanawa Solutions Ltd for TiGa Minerals & Metals Ltd.

Rekker, J. (2023). *Barrytown, Coates Block Hydrological Evaluations: Injection and Infiltration Trials.* Report No. Z22004. Kōmanawa Solutions Ltd for TiGa Minerals & Metals Ltd.

APPENDIX A. WATER MANAGEMENT AND MONITORING PROCEDURES

To be completed at least 8 weeks prior to start of mining

APPENDIX B. HAZARDOUS SUBSTANCES ENVIRONMENTAL MANAGEMENT PROCEDURES

To be completed at least 8 weeks prior to start of mining

Appendix 2: Additional Assessments

- Undertaken since the submission of consent applications by TiGa MM, including
    - Memorandum titled “Barrytown, Coates Block Hydrological Revision: Injection and Infiltration Trials, Conceptual & Groundwater Model Re-Model,” by Jens Rekker of KSL, Draft, 17 November 2023, and a
    - Memorandum titled ”Hand Augering 29 – 30 November 2023”, by Zeb Etheridge of KSL, dated 17 January 2024.

Kōmanawa Solutions Ltd

TiGa Minerals & Metals Ltd

Report No: Z22004-4-Rev0

Barrytown, Coates Block Hydrological Revision: Injection and Infiltration Trials, Conceptual & Groundwater Model Re-Model. DRAFT (17 November 2023)

komanawa.com

Kōmanawa:

1. ***(verb) spring, well up (of water)***
2. ***(verb) to spring, well up (of thoughts, ideas)***

Kōmanawa Solutions Limited (KSL) is a water resource consultancy and research company specialising in water resource investigation and modelling, environmental limit setting and water resource impact assessment. Our goal is to provide excellent science to facilitate the robust management of natural resources in our changing climate. Clients include New Zealand enterprises in the private sector, central and local government agencies and community groups.

Our vision

KSL delivers high quality science and research. We aspire to be at the forefront of creativity and innovation to address our increasingly complex water resource challenges; mō tatou, ā, mō kā uri ā muri ake nei (for us and our children after us).

Our mission

Our mission is to develop solutions to the increasingly challenging water resource management issues we now face by providing a clear vision of the pathway from problem to solution. We work closely with our partners, communities, and stakeholders, deploying state-of-the-art scientific methods and building trust through knowledge and honest science communication.

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Version control

Date	Report no	Issue notes
17 Nov 2023	Z22004-04 DRAFT	Revised assessment and model development to supplement the Z22004_1-Rev3 report.

Authors

Jens Rekker

Principal Hydrogeologist, Kōmanawa Solutions Ltd

Contributors

The following individuals and organisations have generously contributed their time and expertise to this project:

Suggested citation

Rekker, J. (2023). *Barrytown, Coates Block Hydrological Evaluations: Injection and Infiltration Trials.* Report No. Z22004. Kōmanawa Solutions Ltd for TiGa Minerals & Metals Ltd, Christchurch.

Executive Summary

A series of trials relating to proposed mitigations in the Barrytown Mineral Sands' Water Management, Mitigation and Monitoring Plan were undertaken in early and mid-October 2023. The trials comprised microcosms of various proposed mitigation elements within the proposed mine sand development. A map outline of the location the various trial sites is provided below.

Three independent trials of pumping, injection or infiltration were undertaken –

- Injection Well
    - Pumping test with observation piezometers
    - Injection test with observation piezometers,
- Peripheral infiltration trench operation trial, and
- Canoe Creek Infiltration Basin trial.

Most of the testing involved injecting or infiltration of water to test sections of the subsurface. A 300 mm diameter well was drilled to 34. 5 m below ground level, but the lack of permeable strata at depth resulted in the bore being screened between 13 m and 16 m BGL. In fact, the strata at this depth were still highly sand-rich, requiring a well-within-a-well and gravel packing to be installed in order to subdue the ingress of suspended fine sand during airlift development and pumping.

The thin (2 m) basal gravel was found to be moderately permeable at a transmissivity of 400 square metres, with indications of leaky aquifer hydraulics under a thick (7.5 m), clay-rich overburden layer. Injection of external water at rates between 5.8 and 6.4 L/s with approximately 3 m of above-ground overpressure achieved partial injection minus 1 – 1.5 L/s of injected water, which seeped back to the surface in induced seeps and springs within a 20 m radius of the injection well.

The peripheral infiltration trench proposal required a minimum unit length injection rate of 2.8 $m^3/d/m$ of trench. The peripheral infiltration trench trial for a 6.5 m length of trial trench indicated a relatively stable acceptance rate of 2.9 m^3/d/m of trench, suggesting the basic premise of the infiltration rate is physically well founded.

The trial intended to assess the Canoe Creek alluvial fan for infiltration of surplus water at the Canoe Creek infiltration basin used a shallow (1.6 m depth) basin excavated into the surface of the alluvial fan materials (silty sandy cobble gravels). The 5 m length trial basin had little difficulty in accepting inflows up to 25 litres per second, although steady inflows of 10 litres per second for the 5 m length basis caused less head losses across the ground interface. The calculated unit length injection rate of 172 m^3/d/m is supportive of the proposed infiltration rate for the 90 m by 18 m wide basin and is likely to maintain the minimum capacity above 100 L/s. The clogging effects of transient slugs of turbid water needs to be factored into the need for an over-hang in infiltrative capacity at the infiltration basin. The basin during operation should monitor for the ratio of inflow rate and water depth as an indication of time dependent clogging of the basin beds with threshold ratios built in to trigger remedial earthworks of the infiltration media.

Overall, the trials indicated that lower limits to the well injection that could be expected along Collins Creek, equivalent infiltration rates to those suggested in the assessment of effects and mitigation, and adequate infiltration capacity in the Canoe Creek Alluvial Fam material. Another significant outcome of the injection trial was the thin basal gravel compared to conceptual model assumptions, and the thick clay-rich overburden in proximity to Collins Creek. The clay-rich overburden was also found to have low permeability to vertical groundwater transmission alongside confirmatory determinations of steep vertical hydraulic gradient between deeper layers and the creek, consistent with the creek being insulated from significant interaction with the underlying mineral sand or basal gravel. These observations triggered wider shallow drilling along Collins Creek and Northern Boundary Drain, plus stratigraphic drilling to 30 m depth in three additional locations placed across the mineral sand prospect.

Groundwater computer modelling in accordance with the revised conceptual model demonstrated that the simulated pit inflow due to mining activity would decrease to a third of the previous modelled, meaning that revised modelled groundwater inflow was largely limited to less than 50 litres per second. The simulated surface water depletion at the Northern Boundary Drain, Rusty's Lagoon and Collins Creek was substantially reduced in the previous and revised groundwater computer model with a mean decline of 33% of the previous model, meaning that revised modelled surface water depletion was largely limited to less than 15 litres per second.

Groundwater level declines that could be termed drawdown nonetheless extend beyond the Coates property boundaries, however the proposed mitigation is demonstrated through modelling as being capable of reversing the level of ground water level declines through the deployment of active mitigation such as infiltration trenches or injection wells. In addition, field trials provided compelling indications that the previously proposed mitigation systems would perform adequately in the Barrytown setting. Overall the addition of new information consolidated and strengthened the hydrological assessment previously provided.

Contents

Figures

Tables

1 Background to Revised Hydrological Assessments

Post-application consultation with Ngāti Waewae environmental nominees (kaitiaki) precipitated re-evaluation of the water management and mitigations included in the application by TiGa Mineral and Metals for a mineral sand mining operation at the Coates property, Barrytown. The water management, mitigation and monitoring plan provided with the applications, included relatively complicated exchanges of treated mine water for mitigation of groundwater extracted in managing pit pond water level. This included contingencies for taking Canoe Creek water *via* a gallery to augment Collins Creek and offset projected depletion of Colins creek by the mining-related groundwater pumping. A balancing discharge to land (Canoe Creek Infiltration Basin) was also envisaged to even out the large surpluses that might arise from shifts in hydrological conditions and mine scheduling. Ngāti Waewae environmental nominees raised the mixing of water between Collins Creek and Canoe Creek among other concerns. In addition, the technical peer review of hydrological assessments a number of traversed questions but among them were:

- the uncertainty relating to the geological composition or hydrogeological properties of the deeper subsurface below approximately 18 m below ground, and
- the lack of on-site demonstrations of the ability to infiltrate treated mine water into the shallow and deeper groundwater system

These uncertainties had emerged with increased importance as the proposal's environmental planning broadened to include an increasingly sophisticated system of managing treated mine water. The deep groundwater conditions emerged as particularly sensitive terms in controlling the magnitude of water that needed to be managed above-ground within the mine water management system. While pump-out testing had been undertaken to determine groundwater hydraulic properties, no systematic testing of the ability to inject or infiltrate water into the ground had been previously undertaken locally.

Accordingly, a set of deep drilling, injection / infiltration trials were undertaken to fill the knowledge shortfalls identified in a post-application hydrological information review. These included –

- A deeper test well on the banks of Collins Creek, intended to provide knowledge of deep groundwater properties, creek – groundwater interactions and the feasibility to devise deep infiltration of treated mine water below the base of mining activities,
    - As it eventuated, the anticipated high injection acceptance rates did not manifest in testing due to predominately fine-grained materials extending from below the mineral sand to significant depth.
    - The more porous deep materials such as fine gravel still included significant proportions of fine sand that led to the investigator resorting to gravel pack system for curbing sand contamination of the test well,
- An infiltration trial targeting shallow overburden and mineral sands to test the capacity of a proposed peripheral infiltration trench fringing the wider mining area,
- An infiltration trial of the higher permeability Canoe Creek alluvial fan gravels for ascertaining the ability to infiltrate treated mine water into the alluvium,
- Follow-up drilling investigations –
    - Deep drilling up to 35 m focusing on the composition and properties of the deep sediments,
    - Shallower focused drilling along the banks of Northern Boundary Drain and Collins Creek to determine the depths of clay-rich overburden.

The results of the investigations undertaken from September to November 2023 are the subjects of the initial chapters of this report. The implications and significance investigation analysis were examined, and allowed revisions to the hydrological conceptual model and ultimately the numerical model to be made.

2 Injection Well Trial Pumping Tests

2.1 Injection Well

Work began on drilling and constructing an injection well on Monday 11 September 2023. The drilling of the drill hole encountered conditions not anticipated at the outset. Instead of silty clay overburden extending to (at most) 3 m below ground, the overburden extended to 7.5 m BGL. Instead of the ore sand being underlain by thick sandy gravel, the ore sand was underlain by 18 m of fine sand interrupted only by a thin gravel layer between 13 m and 16.5 m BGL. The contrast between expectations and actual lithological conditions is shown in Figure 1.

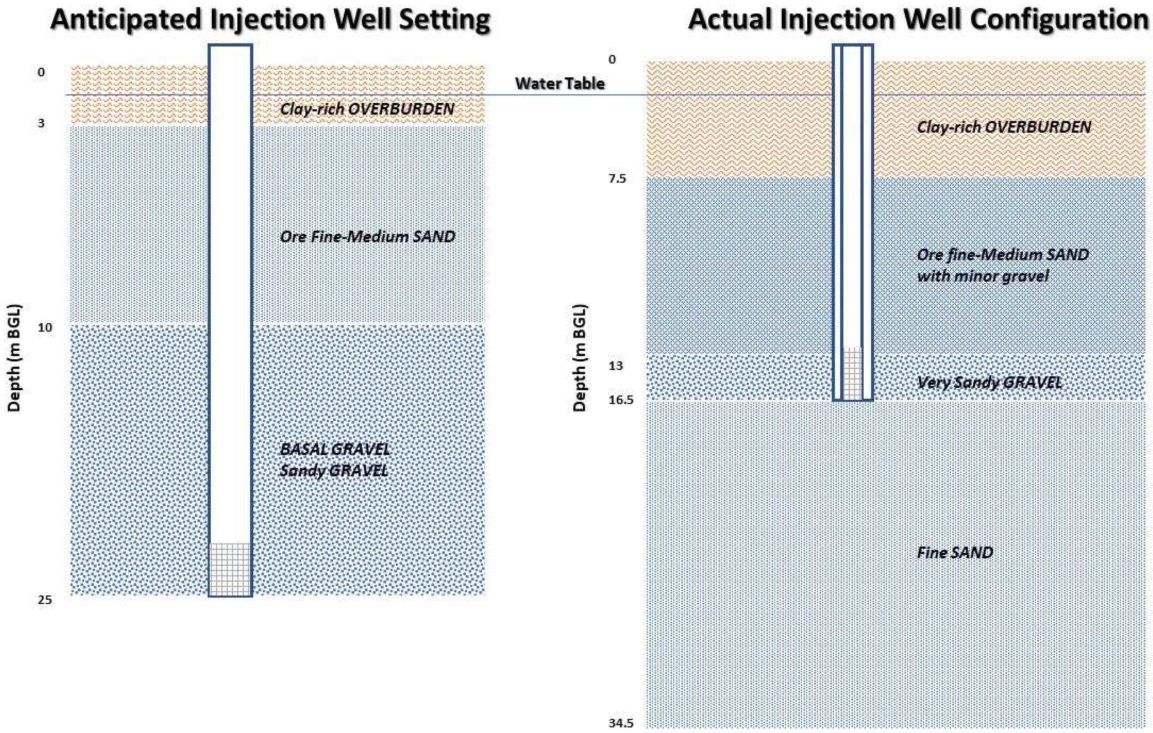

Figure 1: Difference between anticipated and actual lithological conditions found in drilling the injection well

After installing the 270 mm diameter screen between 13 m and 16 m, the well exhibited serious sand contamination. This was probably due to the setting of the screen in contact with fine, heavy sand. Figure 2, overleaf, illustrates the responses (workarounds) to obtain a functional well.

2.1.1 Injection Well Workaround

Unacceptable sand contamination was encountered when well screen development was attempted by airlift and over-pumping. High concentrations of sand were being ejected and the well screen was filling up at each attempt at development. It soon became clear that the 300 mm diameter well installation was unworkable as either a pumping or injection well. The contractor proposed a work-around plan that had some potential of recovering what would otherwise become a lost well.

The workaround plans involved obtaining a 125 mm diameter screen of 0.76 mm slot size and lowering this into the 270 mm diameter screen space. A leader, casing swell to 150 mm and centralisers were used to ensure that the smaller screen was well placed within the larger screen. Following positioning, the annular spaces between the outer screen were filled with gravel pack, and above the screens with bentonite. Figure 2 shows a schematic of the work-around bore construction, as shown in Figure 2.

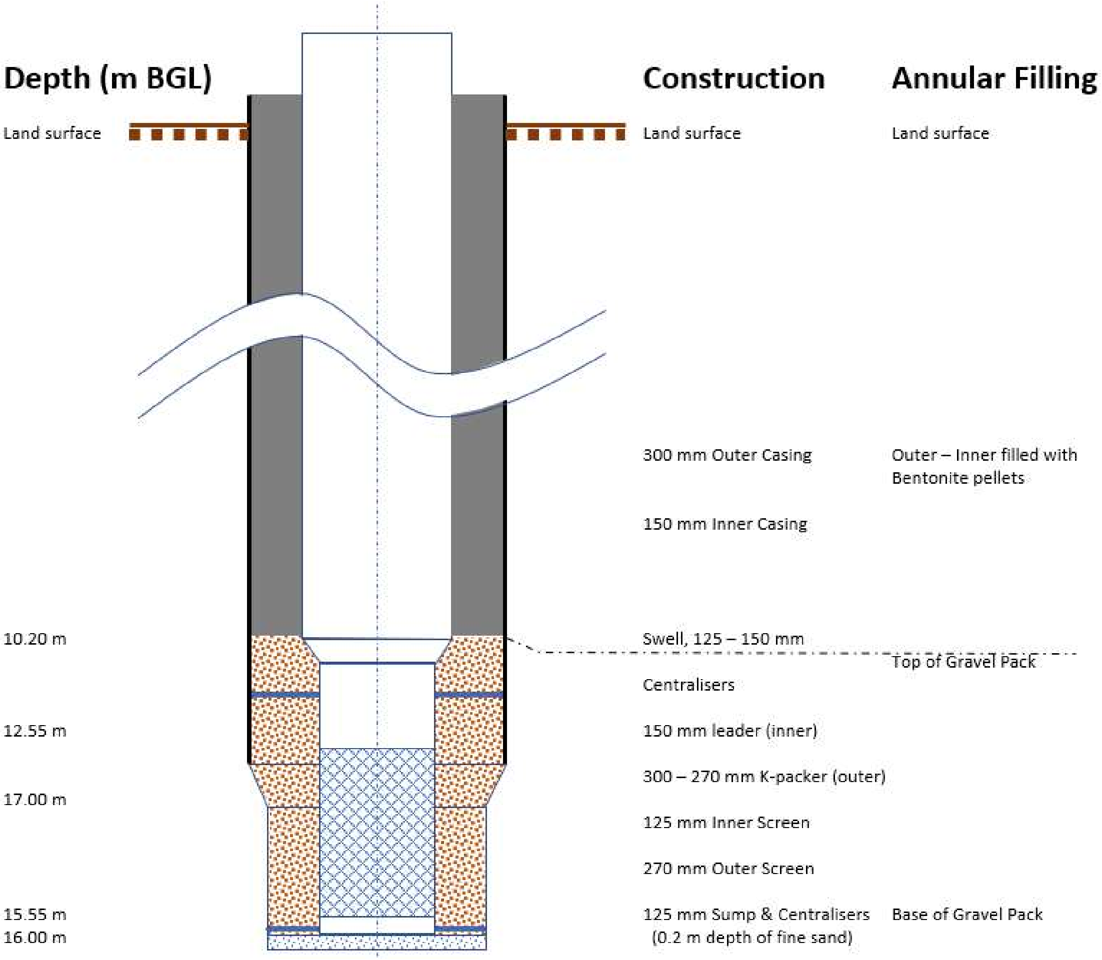

Figure 2: Schematic representation of injection well dimensioning and construction, illustrating work-arounds

The completed 150 mm diameter bore manifested a lower pumping capacity. Prior to the work-around, the pumping capacity was up to 12 L/s. Following the work-around, the pumping capacity dropped to approximately 3.5 to 4 L/s. This suggests that the increase in pumping head losses recorded in the 150 mm bore were due to the added screen and gravel pack. However, the addition of the gravel pack and narrower slot size screen stopped the sand contamination that was a feature of the previous well construction. An existing piezometer was included in the test site, at a distance of 16 m from the injection well. Two piezometers were installed within the clay-rich overburden, at contrasting depths. The layout is shown in schematic profile in Figure 3, while the approximate site layout is provided in Figure 4. The testing was supported with the following measurement equipment:

- Mag-flow water flow meter,
- 20 m range pressure-transducer datalogger for recording pumped well water level,
- 5 m range pressure-transducer dataloggers for recording water levels in piezometers (x 3),
- Water level indicator tapes for recording manual measurement of water levels (x 2),
- 5 m range pressure-transducer datalogger for recording water levels in Collins Creek (x 1), and
- Barometric pressure-transducer dataloggers for recording atmospheric pressure.

Flow was also measured in Collins Creek throughout testing at the downstream farm ford recorder site.

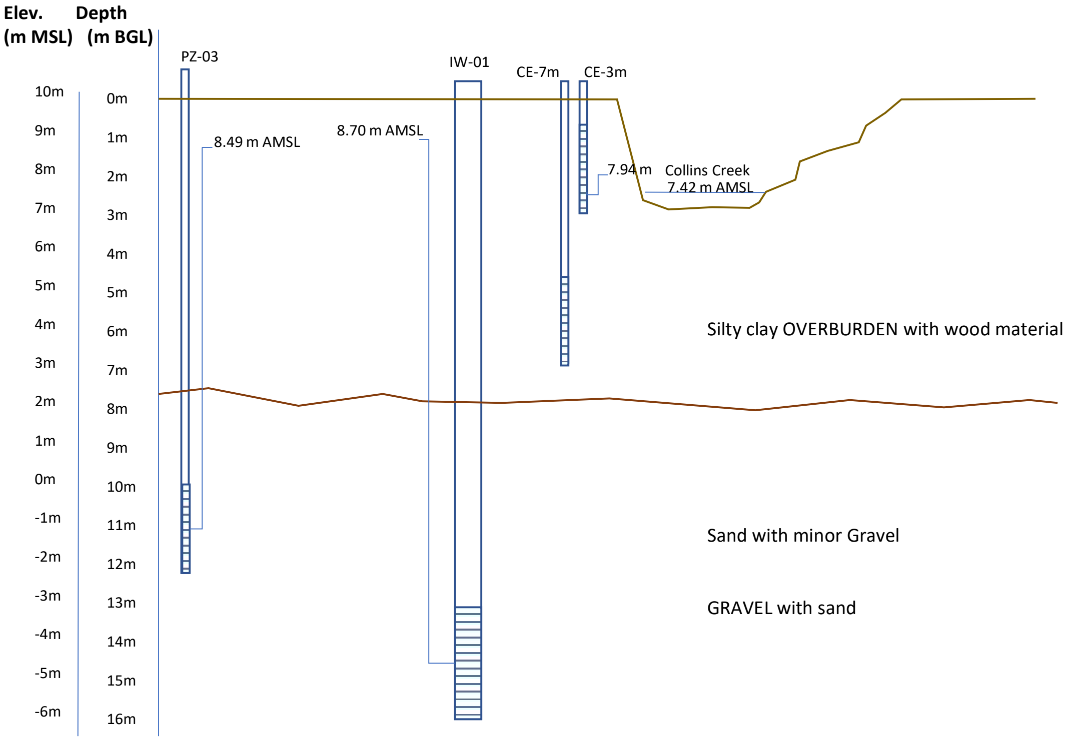

Figure 3: Schematic profile of the injection well IW-01 and surrounding piezometers PZ-03, CE-7m and CE-3m

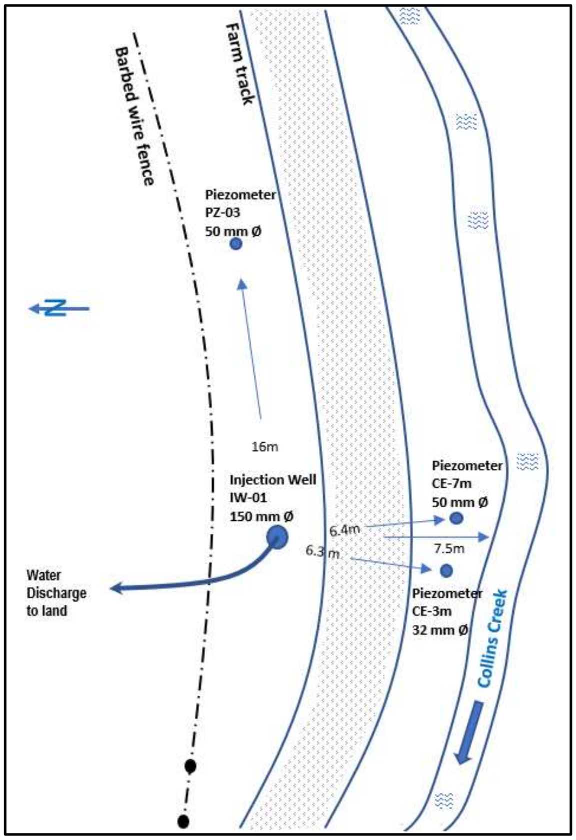

Figure 4: Schematic layout map of pumping test features

2.1.2 Pumping Tests

The step drawdown and constant rate pumping tests indicate moderate permeability of the screened water-bearing layer. The injection well with a depth of 16 m BGL was also significantly shallower than planned, meaning that the allowance for pumping head losses were less than the well screen been placed at 25 m BGL (see Figure 1). Accordingly, the anticipated injection rates of 15 - 20 L/s were not feasible in the remediated bore.

Conventional pumping tests were undertaken in the injection well prior to it being used for injection testing. An electric submersible pump was used with the discharged water being applied to land in the adjacent paddock, carried away by farm drains to the north and ultimately the coastal lagoon. The closest approach of Collins Creek to the injection well was approximately 8 m. Rainfall between 17 and 20 September was moderate; 9.8 mm at 9am on 17 September, 2 mm at 9am 18 September and 8 mm at 9am on 19 September 2023. Barometric pressure varied approximately 5 cm (hydrostatic) across the 24-hour pumping test. Pressure-transducers were corrected for barometric variation.

The barometric efficiency of piezometer PZ-03 was examined by comparing the measured groundwater and barometric (atmospheric) pressure variations during a 4½ hour period of concurrent transducer operation without pumping disturbance (either pumping, recovery or injection). The concurrent pressure measurements from the groundwater and barometric transducers were plotted against each other, which allowed a correlation relationship to suggest that for every 1 cm of barometric change only 0.29 cm of barometric influence was evident in PZ-03 groundwater pressure (i.e., 30% barometric efficiency). As the maximum barometric variation throughout the pumping tests was 0.043 m (4.3 cm), the total potential groundwater influence would be 0.013 m (1.3 cm), at a ratio of only 0.035 the barometric influence this was considered insufficient to bias the 0.363 m of measured drawdown in the constant rate test at piezometer PZ-03. Accordingly, barometric corrections were not made.

2.1.2.1 Step Rate Test (SRT)

The bore was tested at pumping rates of 1.0, 1.7, 2.5, and 3.4 L/s starting at 10:30am 18 September 2023. The step final drawdowns were 1.57 m, 3.21 m, 4.77 m, and 6.88 m, respectively. Each step spanned 30 minutes. The final operating water level in the well was clear of the submersible pump intake, so it was decided to run the constant rate test at 3.5 L/s. The raw data recorded in the step rate test is plotted in Figure 5, including overlay of manual measurements, with automatic pressure-transducer datalogger outputs at 1 minute intervals. Good agreement was obtained between the two means of recording measurements.

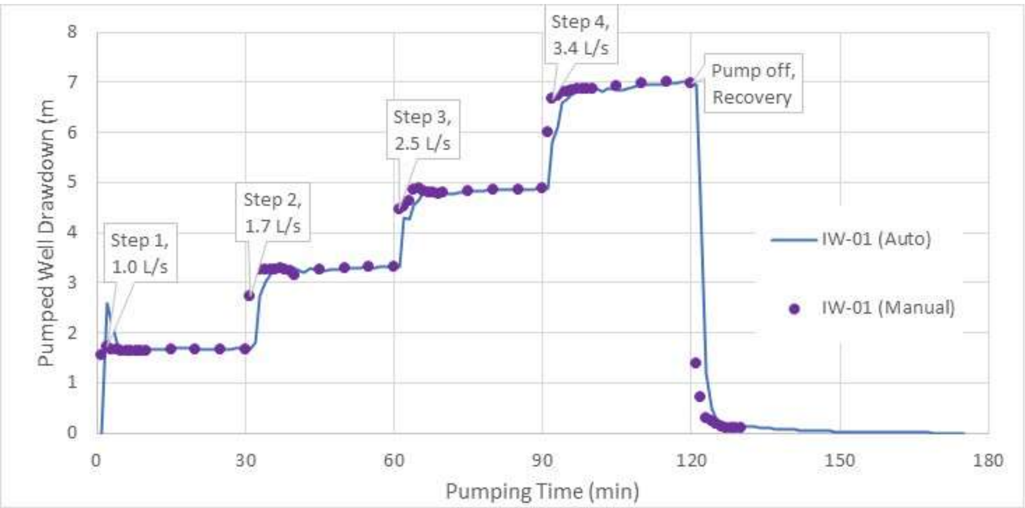

Figure 5: Plot of auto-logger and manually measured drawdown with pumping steps and recovery

The data was interpreted with the Eden & Hazel method. Figure 6 to Figure 9 illustrate the analysis steps of the Step Rate Test

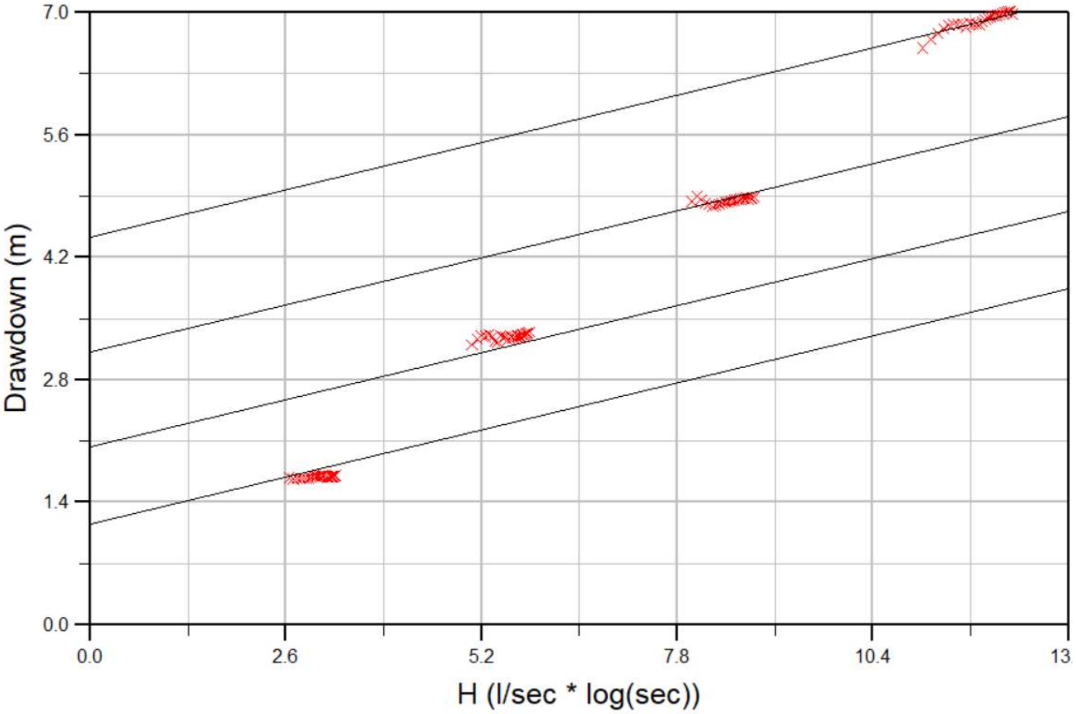

Figure 6: Part 1 Eden & Hazel curve fitting for four steps

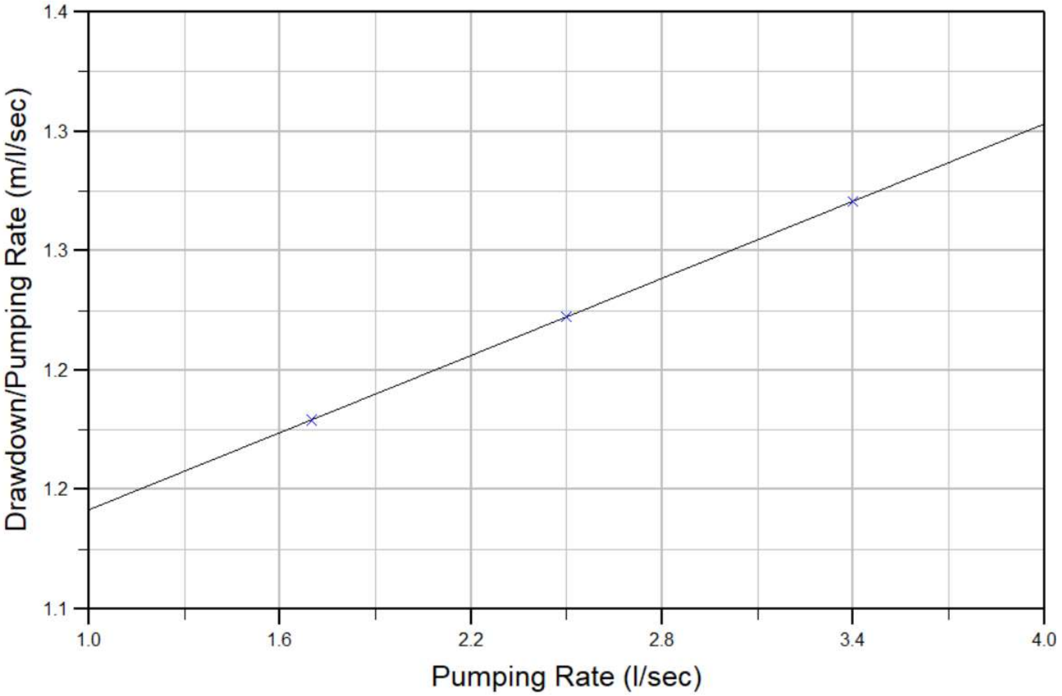

Figure 7: Part 2 Eden & Hazel curve fitting of drawdown/rate ratio versus pumping rate

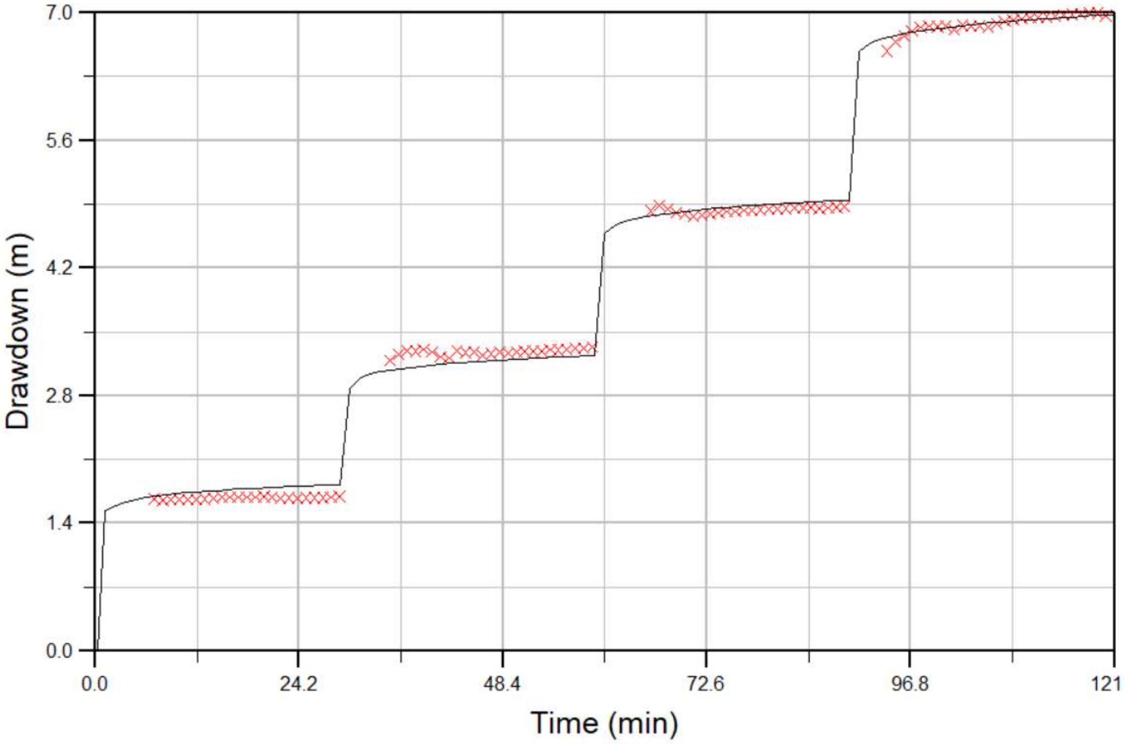

Figure 8: Overplotting of measured drawdown (red crosses) with derived drawdown curves (black lines)

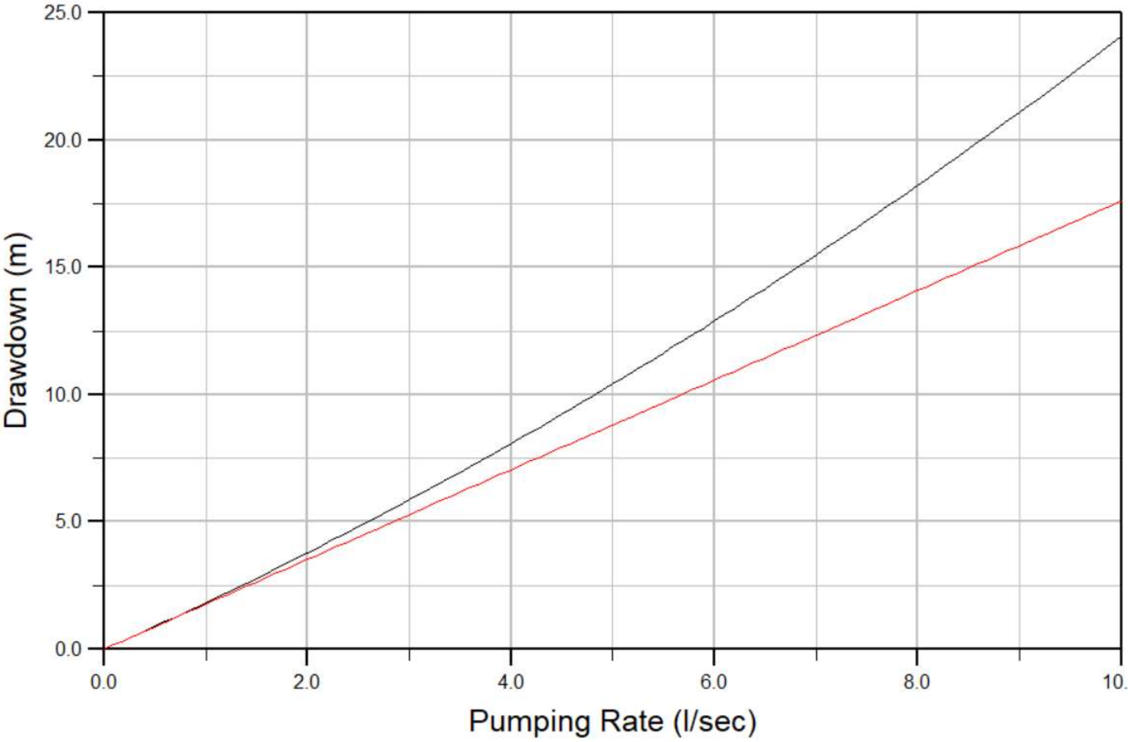

Figure 9: Modelled short-term pumping rate vs drawdown for total drawdown (black) and aquifer-only (red)

The Eden & Hazel methodology relates well drawdown, pump rate and derived coefficients using the following equation –

$S_w =$ $[A + B*\log(t)]*Q + CQ^2$

Where:

S_w = total drawdown inside the well (m),

Q = pump rate (m^3/d),

t = time of pumping (days), and

A, B, & C = the coefficients relating the pumping conditions to well screen hydraulic performance

A. = 0.0125993
B. = 0.00240043
C. = 0.0000086613 (8.6613×10^{-6})

The Eden & Hazel Equation can be used to calculate the pumped well drawdown of 8.04 m following 30 minutes of pumping at 3.4 L/s, similar to the value of drawdown measured in the last step of the test. The equation and Figure 9 demonstrate that the tested injection well is relatively efficient (circa 80%) at pumping rates such as 3.4 L/s. The indicated aquifer transmissivity from the pumping test was 76 square metres per day. The Step Rate Test derived transmissivity is probably merely an order of magnitude indication of the true value.

2.1.3 *Constant Rate Test (CRT)*

The CRT commenced at 2:00pm on 19 September 2023 and was shut down 24 hours later. The CRT pumping rate fluctuated between 3.4 L/s and 3.5 L/s throughout the test period. The constant rate 24 hour test indicated that surrounding piezometers are varying depths of screening all responded to the pumped drawdown (see Figure 10).

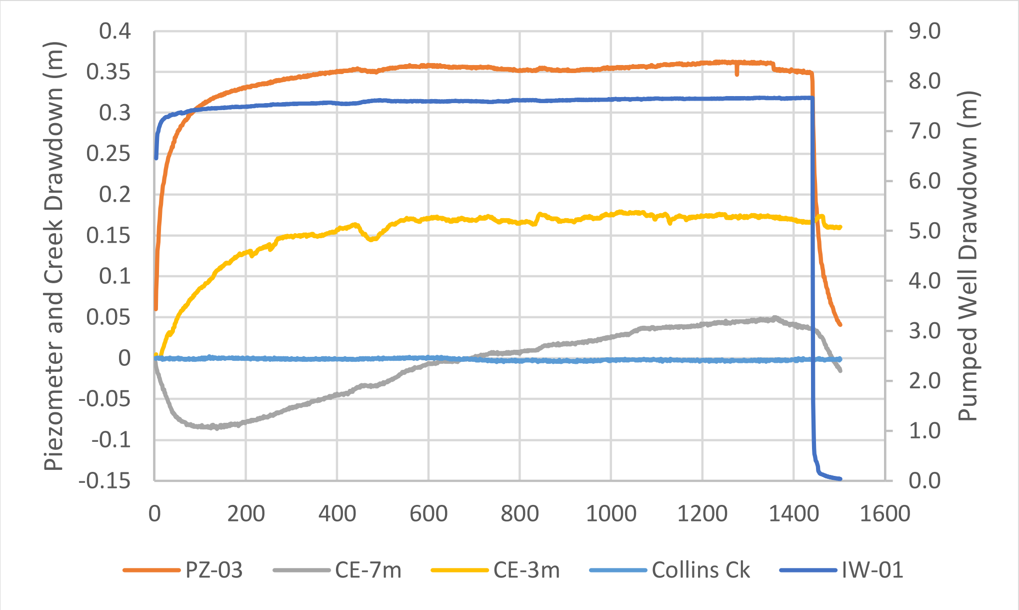

Figure 10: Plot of well, piezometer and Collins Creek drawdown during and after Constant Rate Test at 3.4 L/s

Final 24 hour drawdown of 7.66 m was recorded in the pumped well. Maximum drawdowns in the other monitored points are listed in Table 1.

Table 1: Maximum recorded drawdowns in pumped well and piezometers within Infiltration Well Site

	Infiltration (Pumped) Well IW-01	Piezometer at 13 m Depth in sand with gravel & 16 m Distance PZ-03	Creek Edge Piezometer at 7 m Depth in Overburden and 6.3 m Distance CE-7m	Creek Edge Piezometer at 3 m Depth in Overburden and 6.4 m Distance CE-3m	Collins Creek at Infiltration Well Site
Maximum Final Drawdown (m)	7.665	0.363	0.050	0.179	0.002

Figure 10 shows that the recorded water level in the creek-edge piezometer of 7 m depth (CE-7m), screened within the silty clay overburden, initially rose leading to a period of negative drawdown in Figure 10 followed by positive drawdown after approximately 700 minutes of pumping. This may be attributable to the Noordbergum Effect[1], which is a known poroelastic groundwater level response between semi-confined aquifers with adjacent low permeability layers. By contrast, Figure 10 illustrates a simple, but small, drawdown effect without the Noordbergum Effect in the creek-edge piezometer of 3 m depth (CE-3m). Collins Creek barely changed water level during the constant rate test, rising 2 mm by the end of the CRT.

The existing piezometer PZ-03 is screened at between 9.3 m and 12.3 m below ground level, which approaches the depth of the top of the infiltration well (IW-01) screened interval (12.55 m to 15.6 m BGL). Consequently, piezometer PZ-03 could be considered to be screened in the same water bearing layer as the pumped well. Figure 11 illustrates the response of the piezometer in terms of calculated drawdown, while Figure 12 shows the matching of a Hantush – Jacob curve to the field data.

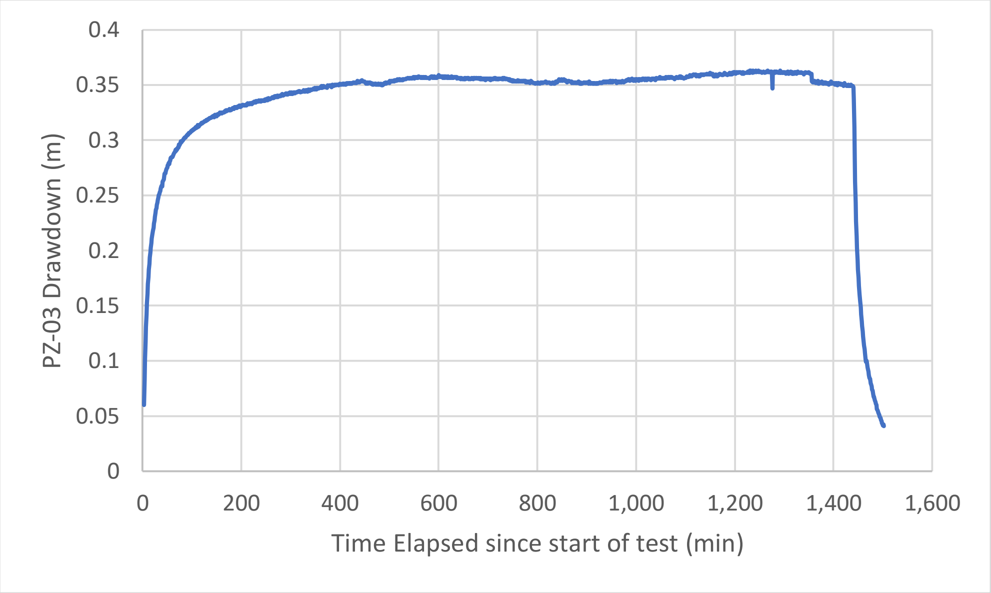

Figure 11: Drawdown versus time measured in piezometer PZ-03 during the 24-hour constant rate test

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[1] Reverse water-level fluctuation refers to a pumping-induced change in hydraulic head that is opposite in direction from what is expected to occur under normal conditions. Typical references include the following: *Rodrigues, J.D., 1983. The Noordbergum effect and the characterization of aquitards at the Rio Maion mining project, Ground Water, vol. 21, no. 2, pp. 200-207.* And *Verruijt, A., 1969. Elastic storage of aquifers. In: R.J.M. DeWiest (ed), Flow Through Porous Media, Academic Press, New York, pp. 331-376.*

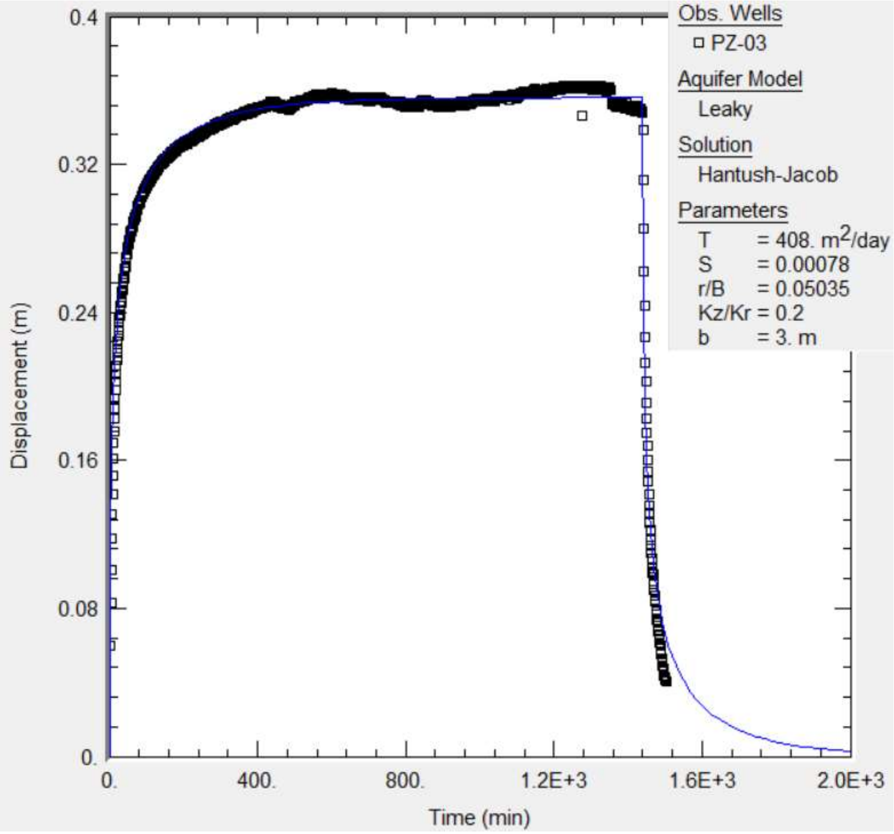
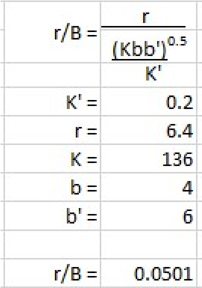


Figure 12: Hantush – Jacob curve match to drawdown data points from piezometer PZ-03 during the 24-hour pumping test

The drawdown data to curve Hantush – Jacob match indicated an aquifer transmissivity of 408 square metre per day (m^2/d), somewhat higher than the 76 m^2/d transmissivity implied in the interpretation of the step rate test. Additional information is provided in the Hantush – Jacob interpretation that implies that the permeability (i.e., hydraulic conductivity) of the overlying silty clay overburden layer is 0.2 m/d. This hydraulic conductivity was back calculated from the parameter of r/B referred to in the results pane of Figure 12. The equation and working below shows the conversion from the r/B ratio to overburden hydraulic conductivity (symbolised as K').



$$r/B = \frac{r}{\frac{(Kbb')^{0.5}}{K'}}$$

K' =	0.2
r =	6.4
K =	136
b =	4
b' =	6
r/B =	0.0501

Where:

K'= overburden hydraulic conductivity (m/d)

r = radius between pumped well and piezometer (m)

B = leakance (m)

K = pumped aquifer hydraulic conductivity (m/d)

b = thickness of aquifer (m)

b’= thickness of overburden (m)

r/B = radius / leakance ratio (derived as 0.050 in the results pane of Figure 12)

To provide an independent measure of overburden hydraulic conductivity, slug testing as a falling head test was also undertaken in the two creek-edge piezometers (CE-7m and CE-3m) to ascertain estimates for the localised hydraulic conductivity surrounding their respective screened sections. Interpretation of the falling head slug test indicates that the lower part of the silty clay overburden was tested as 0.3 m/d for hydraulic conductivity, while the upper part of the overburden was tested as 0.01 m/d (see Figure 13 and Figure 14). The CE-7m hydraulic conductivity result compares well with the aquitard parameter determination from the Hantush – Jacob interpretation of the 24 hour CRT pumping test.

Table 2: Derived hydraulic conductivity from interpretation of slug tests and injection well pumping test

	Creek Edge Piezometer at 7 m Depth in Overburden and 6.3 m Distance (CE-7m)	Creek Edge Piezometer at 3 m Depth in Overburden and 6.4 m Distance (CE-3m)	Silty clay overburden layer hydraulic conductivity as determined from the back calculation of IW-01 pumping test r/B
Derived Hydraulic Conductivity (m/d)	0.32	0.01	0.20

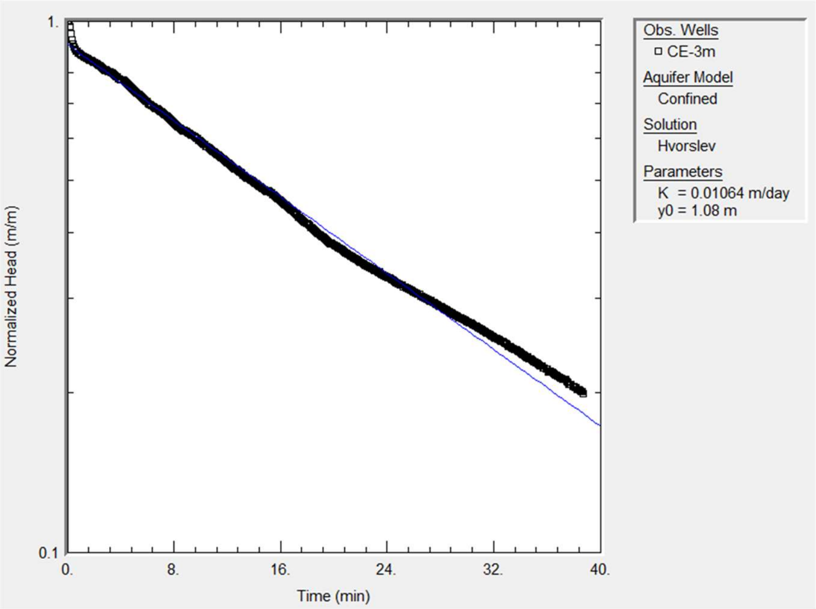


Figure 13: Hvorslev falling head test analysis of Creek Edge 3 m piezometer

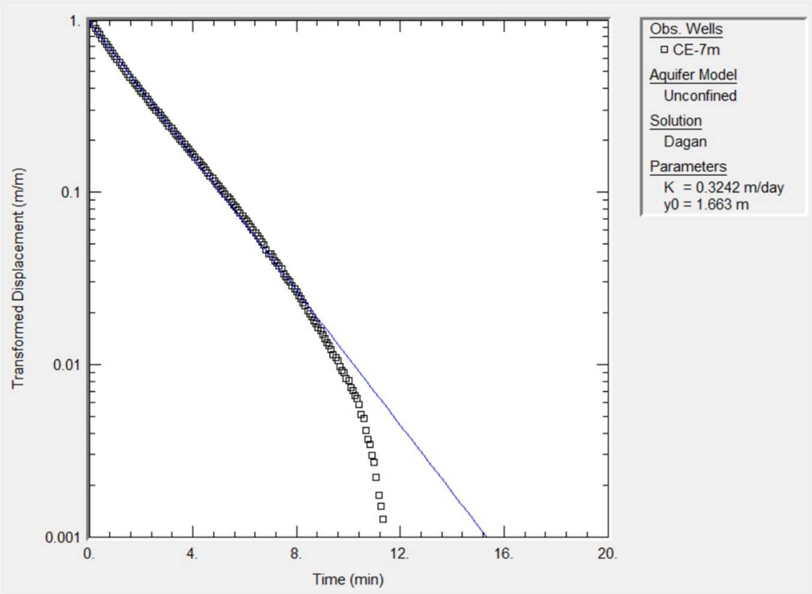


Figure 14: Dagan falling head test analysis of Creek Edge 7 m piezometer

A summary of pumping test results is provided in Table 3.

Table 3: Summary of Injection Well Testing derived Parameters

Parameter	Value	Comment
SRT Transmissivity (m^2/d)	76	From Eden & Hazel analysis. Probably not accurate
CRT Transmissivity (m^2/d) @ PZ-03	408	From Hantush – Jacob analysis, more reliable
CRT Storage Coefficient @ PZ-03	7.8×10^{-4}	Dimensionless coefficient relating to the elastic storage properties of the water-bearing layer
CRT Leakage ratio of aquitard, r/B	0.05	From Hantush – Jacob analysis
CRT aquitard (overburden) hydraulic conductivity, K' (m/d)	0.2	Derived from back calculation of leakage ratio. Approximate K'/B' ratio = 0.0267
Falling Head Test hydraulic conductivity @ CE-7m and CE-3m of clay overburden (m/d)	0.01 – 0.32	Derived from slug (falling head) test analysis on both creek-edge piezometers

Note: SRT = Step Rate Test; CRT = Constant Rate Test; r/B = ratio of testing radius over leakance coefficient; B = Leakance coefficient, i.e., the vertical hydraulic conductivity of an aquitard divided by its thickness.

2.2 Injection Well Testing

2.2.1 Well Set Up

Pre-injection observations of static water level across the injection site noted in Figure 3 revealed that there was a strong upward hydraulic gradient in the groundwater system. This would suggest the potential for seepage into Collins Creek adjacent to the injection site, but the degree of seepage would have been controlled by the thick clay-rich overburden. The analysis of the constant rate pumping test indicated that the clay-rich overburden is thick and likely lies between the sand - gravel water-bearing layers and the bed of Collins Creek. It is reasonable to conclude that while the groundwater hydraulic gradient would provide conditions for upward seepage into Collins Creek that the rate of seepage would be significantly constrained by low intervening vertical hydraulic conductivity.

The initial intentions for the injection testing were to establish a large diameter well in highly permeable sandy gravel at depths between 25 m and 30 m BGL. It was anticipated that the high permeability relative to overlying silty fine sand and the depth of burial would somewhat isolate the injection well from surface influences. As it eventuated the sole zone of predominantly sandy gravel was located at the shallower depth of 13.5 m BGL and of modest thickness, approximately 2.5 m so that the base of the well screen extended to 16.5 m BGL.

As outlined previously, significant layers of fine sand were indicated in the screen interval and the 2.5 mm slot stainless steel screen admitted copious volumes of said fine sand during an attempt at developing and natural pack formation of the larger diameter screen. The solution was to build a smaller diameter screen inside the outer casing and casing. The cylindrical gap (annulus) between the outer and inner screens was filled with artificially graded 2mm grain size ‘gravel pack’ filled from above until the screens were amply covered. This well engineering solved the problem of runaway sand entry into the well and 11 hours of over-pumping completed the repacking and development of the artificial gravel pack. The step rate and constant rate pumping tests preceded the injection testing and the stability of pumping induced drawdown during the pumping tests (see Figure 5 and Figure 10) proved the stability of the aquifer – well interfaces (screens and gravel pack).

Injection involves construction of a pressure proof headworks on the injection well. Figure 15 show the minimum headworks, including welds between outer and inner casing (300 mm to 150 mm nominal diameters), a welded flange to the 150 mm casing top, bolted flange plate with neoprene gasket, and fittings for 2-inch pipework (elbow, coupling and valve). Invisible from view in Figure 15 was a 2-inch pipe section extending to beneath the water level so that initial cascading or air entrainment would not occur.

Figure 15: Injection well headworks, including welded outer & inner casing and flanged cap

The well head also included an analogue pressure gauge threaded into the flange plate socket, as shown in Figure 16. The pressure-tight well head was connected using 2-inch cam-lock fittings, including a flow meter as shown in Figure 17. The injection circuit was completed with a section of 2-inch lay-flat hose to the pump positioned within the water source.

Figure 16: Headworks connected to injection circuit, including surface pressure gauge

Figure 17: Mag-flow water flow meter used to measure injection rate, showing 5.7493 L/s injection

A pressure-transducer datalogger was strapped to the downpipe within the injection well at a depth approximately 2.42 m below the height of the flange plate. The analogue pressure gauge had its intake at the heigh of the flange plate, so the down-hole pressure transducer would need to be adjusted by subtracting 2.3 m. This was calibrated during the injection test at 08:45 on 21 September 2023 when the pressure transducer indicated a water pressure above the flange plate of 2.01 m and the pressure gauge indicated a pressure of 3 pounds per square inch, equivalent to 2.0 m above the plate at the same time. The pressure-transducer datalogger displayed higher precision and absolute pressure accuracy.

2.2.2 Injection Well Trial

The trial began at 4:00 pm 20 September 2023 with the injection pump being started and water being introduced to the injection circuit. Pressure initially spiked to 3.60 m above the flange plate (approximately 4.0 m above ground level). Pressure built to a peak of 3.6 m hydrostatic at 7:22 pm but fell steadily thereafter. This is believed to be the time at which organic matter at the water source partially blocked the pump intake causing a decrease in pumping rate from 6.4 L/s to 5.8 L/s (0.6 L/s or 10% reduction).

The trial injection continued until 4:00 pm 21 September 2023 when pumping was shut down. Manifold pressure immediately preceding shut down was measured at 3.03 m above the flange (approximately 3.4 m above ground level), representing a 0.57 m decline in hydrostatic pressure between the onset of partial pump blockage and trial conclusion.

All surrounding piezometers responded rapidly to the onset of injection as a pressure response.

Table 4: Final Pressure Displacement in surrounding Piezometers

	Infiltration (Pumped) Well IW-01	Piezometer at 13 m Depth in sand with gravel and 16 m Distance PZ-03	Creek Edge Piezometer at 7 m Depth in Overburden and 6.3 m Distance CE-7m	Creek Edge Piezometer at 3 m Depth in Overburden and 6.4 m Distance CE-3m	Collins Creek at Infiltration Well Site
Maximum Final Displacement (m)	4.22	0.62	overflow, >2.06	1.57	0.013 m decline then 0.003 m rise

The hydrostatic pressure displacements during the injection trial are shown in Figure 18, below -

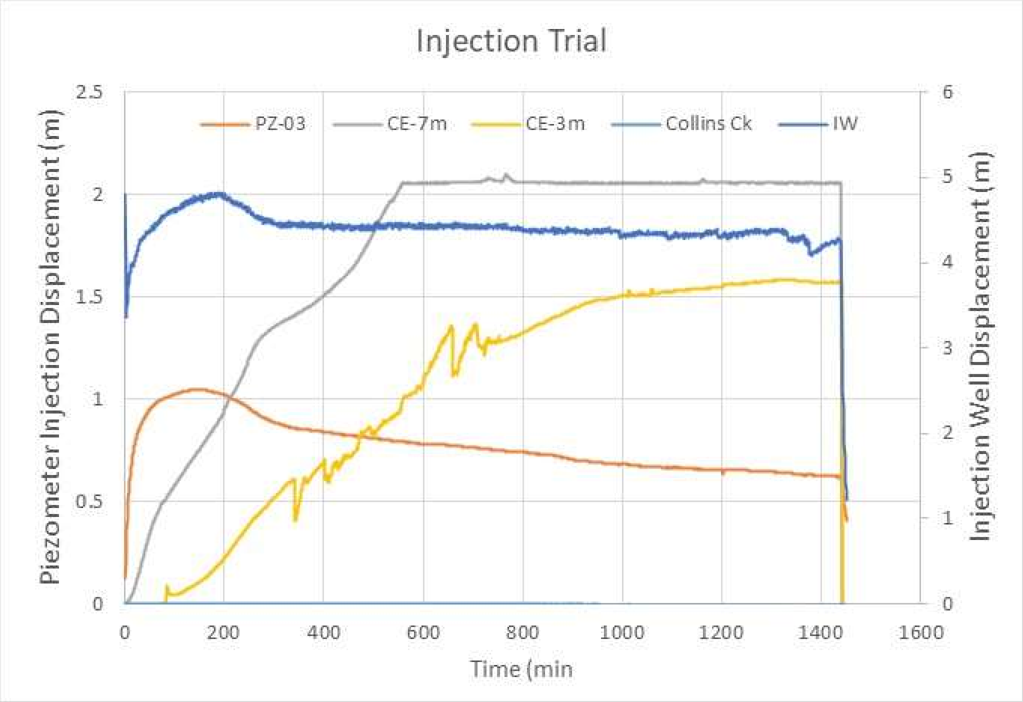


Figure 18: Injection well and piezometer displacements during the 1,440 minute injection trial

Individual piezometers and the creek stage recorders are discussed as follow –

Piezometer PZ-03

The piezometer in the same water-bearing layer responded in close correlation with pressure recorded in the injection well. The regression correlation had an R^2 regression coefficient of 0.68 with the formula -

$\text{Pressure}_{PZ\text{-}03} = 0.71 * \text{Pressure}_{IW\text{-}01} - 2.3561$

The pressure mounding at PZ-03 was generally 15% that of the pressure displacement at the injection well.

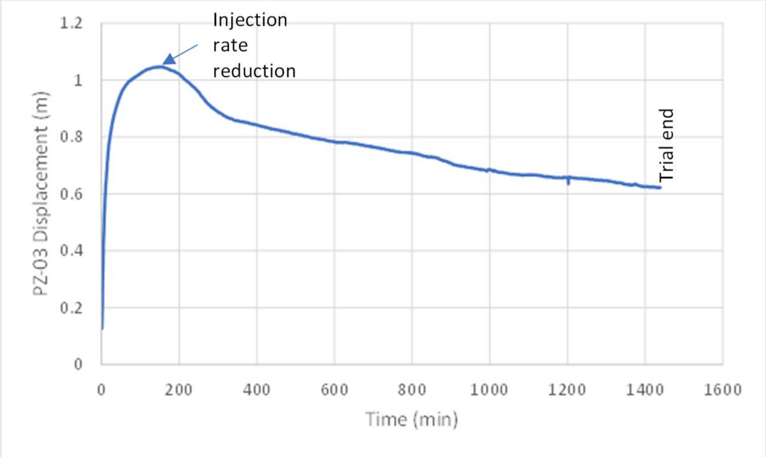


Figure 19: Injection trial displacement (by groundwater mounding) in piezometer PZ-03

Piezometer CE-7m

The piezometer installed in the base of the clay-rich overburden responded less rapidly but displayed the highest magnitude of displacement of all piezometers, reaching 2.06 m before overflowing at the top of the piezometer casing (0.33 m above ground) at 01:20 am on 21 September, approximately 560 minutes into the 1440 minute trial. The pressure response was less clearly affected by the change in pump injection rate, although a deflection in the gradient of pressure rise at about 240 minutes may have been a delayed artifact. Depth to water in the piezometer had been 2.05 m below casing top (about 1.7 m BGL) before the start of injection. The displacement was significantly greater than the shallower overburden piezometer CE-3m that lies at much the same distance from the injection well.

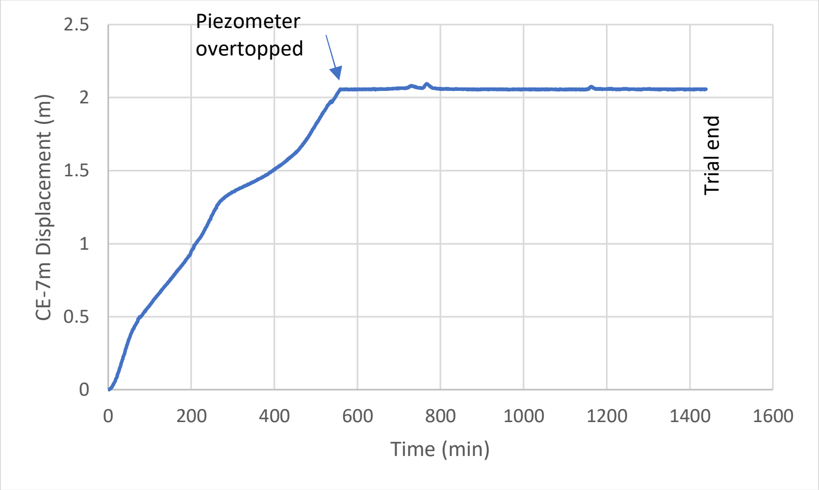


Figure 20: Injection trial displacement (by groundwater mounding) in piezometer CE-7m

One interpretation is that CE-7m became connected to the sand with gravel water-bearing layer by a discontinuity (essentially, a decaying root or crack) within the clay-rich overburden, bridging across the low permeability material beneath the base of the piezometer.

Piezometer CE-3m

This piezometer responded to injection slowly but steadily until the pressure displacement stabilised at 1.57 m of mounding or a water level 0.59 m below the top of casing (about 0.25 m below ground level). The pressure response was less clearly affected by the change in pump injection rate.

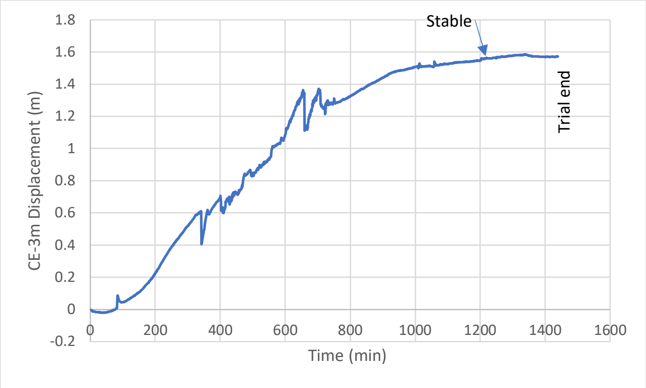


Figure 21: Injection trial displacement (by groundwater mounding) in piezometer CE-3m

One interpretation is that CE-3m lying higher and more embedded in the clay-rich overburden, failed to have a connection to the sand with gravel water-bearing layer by any discontinuity. While being in closer proximity to the injection well than PZ-03, the piezometer in clay-rich overburden is buffered against more volatile fluctuations in pressure due to the overburden's lower permeability.

Collins Creek

The creek stage level at the injection site went through a steady decline over 1,400 minutes amounting to 1.3 cm of water level reduction. A 1.2 cm water level reduction was recorded at the downstream permanent hydrological flow monitoring site over the same period, equivalent to a reduction in Collins Creek flow from 97 L/s to 87 L/s, i.e., 10 L/s. It is inferred that the creek flow decline was due to natural variation in upstream inflows rather than any injection trial effect.

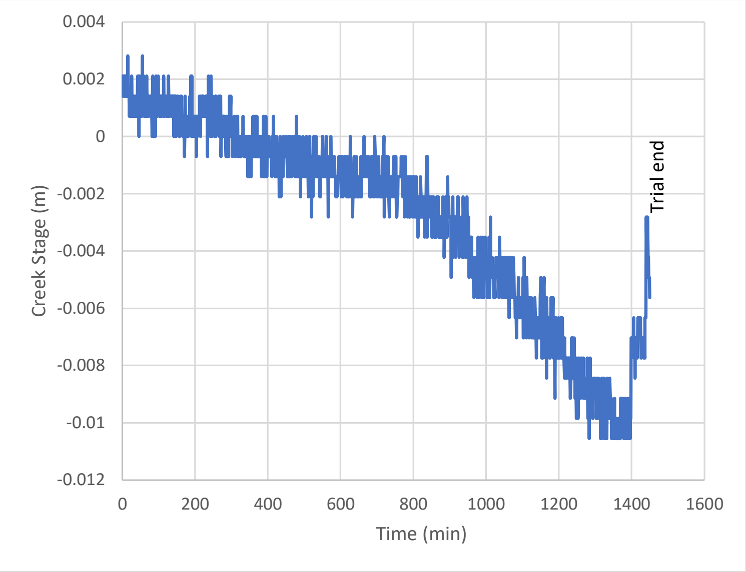


Figure 22: Colins Creek stage height at the injection trial site

Bypass and Seepages

Bypass and seepage were noted immediately following the start of injection. The water emerging at the surface in the immediate vicinity of the injection well could be channelled into a section of casing and allowing the timed filling of a 10 litre bucket.

Three bypass / seepage measurements were made -

20 September 2023 at 4:45 pm	0.71 L/s
21 September 2023 at 8:45 am	0.91 L/s
21 September 2023 at 2:14pm	1.10 L/s

There was a trend of increasing bypass throughout the trial. Seeps and small springs were noted throughout the injection trial that were not evident prior to injection. These included –

- Seepage from a crack in the nearby farm track (see Figure 4 for position of farm track),
- A spring in the paddock approximately 12 m to the northwest of the injection bore, and
- Horizontal lines of seeps in the northern bank of Collins Creek.

Figure 23: *Ad hoc* collection of direct injection water bypass / seepage for measurement with a 10 litre bucket

At least 90% of seepage drained into the farm drainage network reporting eventually to the Canoe Creek coastal lagoon rather than Collins Creek. It is inferred that the seepage waters had traversed the clay-rich overburden within discontinuities in the overburden (e.g., bedding partings and vegetation jumbles). Considering the surface seepages around the well casing and distributed more widely, the sand and gravel water-bearing layer would not have accepted the full injection pumping rate. Indeed, the manifold pressure initially rose to 7 pounds per square inch (4.8 m H_2O) before falling to 4.5 pounds per square inch (3.33 m H_2O) within two minutes as the seepages sprung up around the injection site. It is inferred that the pressure release provided by the emergence of surface seepages represented a ceiling on the manifold pressure that could build within the injection water-bearing layer.

2.3 Peripheral Infiltration Trial

2.3.1 Trial Set-Up

The 'Mine Site' infiltration trench intended for installation along the periphery of the mining area had the following ground conditions –

- 0 – 1.7 m topsoil and clay overburden,
- 1.7 – 2.1 m carbonaceous clayey vegetation layer, approaching an immature peat in consistency,
- 2.1 – 2.4 m dark grey silty fine sand.

A pressure-transducer datalogger was installed in the trench beneath the standing water level in the trench. The standing (static) water level in the trench stood at 0.3 m over the trench bottom (i.e., 2.1 m below ground level). The test was run over a little more than 7 hours from 10:30 am to 5:00 pm. Approximately 140 minutes was required to achieve the fixed water level (1.45 m above the trench bottom or logger level 1.18 m).

The earthworks contractor dug a trench of 6.5 m length, 2.4 m depth and approximately 2.2 m width. The upper 1 metre of trench in clay overburden was laid back, leaving a distinct transition to vertical walls for the bottom 1.5 m of the trench. It was decided to undertake a constant head inflow test using this transition as the target constant head mark. The white plastic pipe used for mounting the level logger was kinked at the transition and this kink can be used as a guide as to the target constant head in Figure 24 showing the filling phase, and Figure 26 showing the water level hold point.

Figure 24: Water level in infiltration trial trench during initial filling, vegetation layer visible as darkened material above water level

2.3.2 *Constant Head Infiltration Test*

The infiltration test involved holding a near constant water level at a height approximately 1.5 m above the base of the trench (0.7 m below ground level and 1.18 m above the static water level). The silty sand was thus subjected to additional hydrostatic pressure of about 1.2 m for approximately 4½ hours. The filling, hold and shutdown of infiltration pumping leading to a decline in water level is graphed in Figure 25 in terms of the upward displacement of water level in the trench.

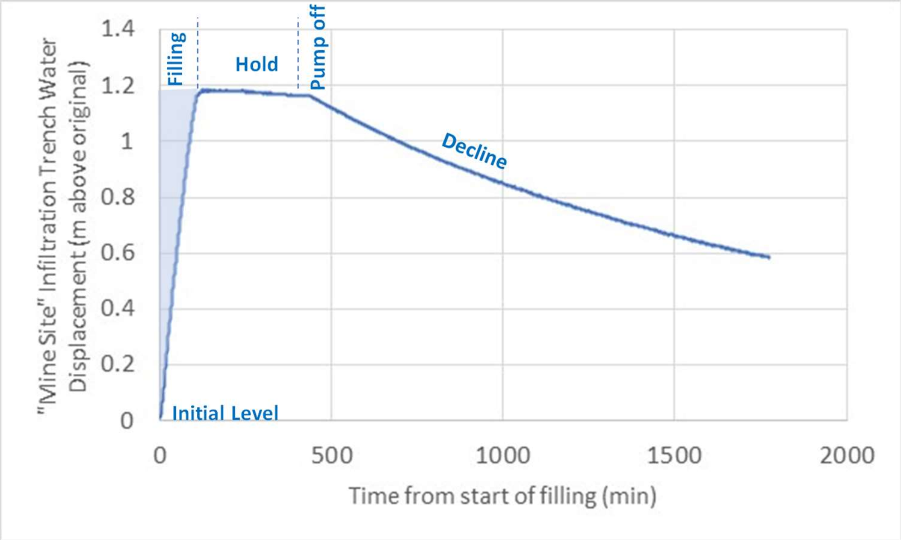


Figure 25: Time series of the trench water level displacement

Figure 26: Water level following filling to hold level

Inflow rate was measured using the timed filling of a 25 litre vessel. Once the constant level was achieved inflow pumping was reduced to 0.33 L/s at 11:40am (68 minutes), which eased the rate of water level increase until semi-stability was achieved at 12:32pm (120 minutes). The infiltration acceptance rate was initially 0.85 L/s over the filling of the trench, then 0.33 L/s, declining to 0.22 L/s in the last hours of the test. The inflow had eased off to 0.22 L/s by the end of the trial at 5:00 pm. This last inflow rate could be assumed to approach the steady state infiltration rate for dimensions of the trench. Up to 9 cubic metres of water was injected over 6½ hours, approximately 1.4 m^3/hour. However the infiltration rate during the period in which groundwater level achieved stability (see Figure 27) was measured as 0.22 L/s (19 m^3/d). As the trench base was 6.5 m long, the linear steady state infiltration rate was calculated at 2.9 m^3/d/m of trench line.

The test was also observed at the existing piezometer PZ-04, approximately 20 m to the south of the temporary infiltration trench and between the trench and Collins Creek. Unfortunately, the hand-augered, 3.0 m depth piezometer adjacent to the infiltration trench failed to demonstrate connection to the silty sand groundwater, probably due to plugging of the slotted interval. So, it could not be used as a proximal groundwater level monitoring point in the observation of the constant head test.

Approximately, 0.08 m (8 cm) of water level rise was measured in PZ-04, although the displacement was lagged by about 2¾ hours (165 minutes). The ratio of groundwater level response at PZ-04 versus the displacement in the trench was 0.067 (6.7%). This demonstrated that a groundwater level response was discernible in the surrounding silty sand water-bearing layer. However the response, measured as it was 20 m from the infiltration point, was muted.

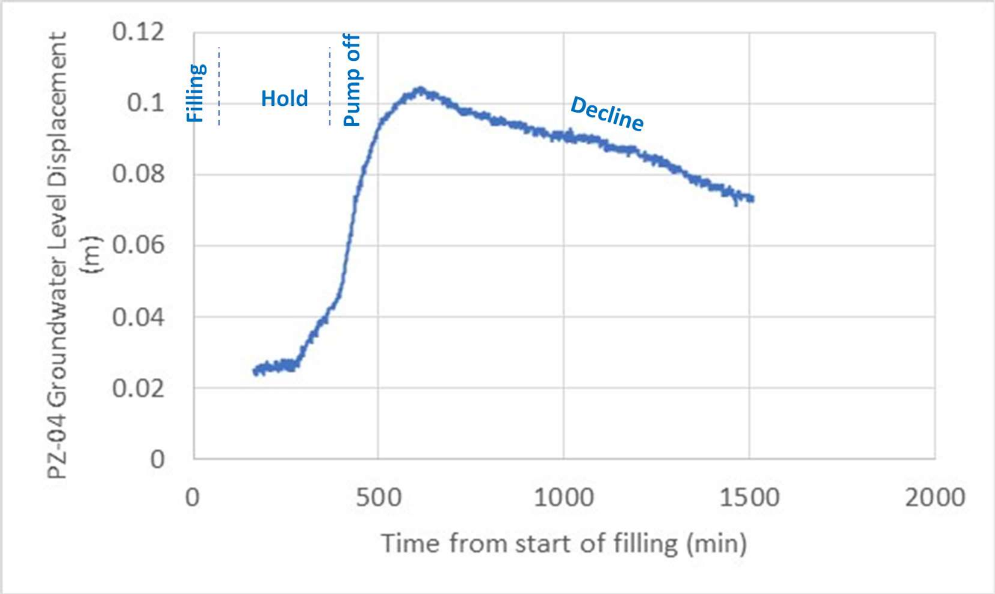


Figure 27: Groundwater level response as net displacement measured at piezometer PZ-04

2.4 Canoe Creek Infiltration Trial

2.4.1 Infiltration Trial Set-Up

This trial infiltration trench was targeted at testing the infiltration properties of the Canoe Creek alluvial fan near the creek mouth with the Tasman Sea. The Canoe Creek alluvial fan was proposed as an area for infiltration of treated or semi-treated mine water as a fall-back during periods when mine water volumes exceed the requirement for use in mitigation in injection, infiltration or direct discharge to Collins Creek. The Canoe Creek infiltration basin would be installed at the location of a former "standoff pad". The standoff pad comprises a 60 m long x 20 m wide pad surrounded by 1 – 1.5 m bunds. The pad would be reprofiled and the base scraped to create a 100 x 20 m basin on the Canoe Creek river terrace gravels. The Canoe Creek Infiltration Trench trial was placed on an area of Canoe Creek River terrace gravel deposits to simulate the subsurface hydrogeological conditions anticipated.

The trench was excavated to 1.6 m depth in a grazing paddock between Canoe Creek and Collins Creek. The length of the trench base was 5.0 m, width 2.1 m, and the height from base to land surface 1.6 m. The trench sides were laid back at 1:1 slope so that the overall disturbed length was 8.3 m, and width 5.0 m. A pit was dug nearby to 3.3 m below ground level (BGL) and a slotted piezometer tube placed at its base while the pit was backfilled with gravel around the tube. Manual measurements of the groundwater level within the piezometer were taken before and during the trial to ascertain the extent to which the water table beneath the infiltration trench would rise and make contact with the base of the trench. Groundwater was measured in the piezometer at a level of 2.67 m BGL, meaning that the water table lay approximately a metre below the base of the trench without the addition of infiltrating water.

2.4.2 Stepped Infiltration Trial

The trench was filled to the brim within 17 minutes at a flow rate of 46 L/s. The pumping rate was adjusted down as soon as it was apparent that the trench would not sustain the higher pumping rate. The new pumping rate after 17 minutes was 25 L/s, as the trench began to lap over its edge. The pumping was held at 25 L/s, allowing the pumping to balance the pumped inflow with losses through its base for a further 43 minutes, after which flow was adjusted to 16 L/s for an hour resulting in a slight drop in pond water level below the lip.

A further adjustment of pumping rate down to 10 L/s was held for a further hour, which also led to a further drop. The trench water level responded to each reduction in pumping rate by declining 0.07 m and 0.28 m from 25 - 16 L/s, and 16 - 10 L/s, respectively.

The water level in the piezometer 3.5 m from the trench edge measured rises within minutes of the trench becoming filled, indicating that the water table responded to the infiltration of water and this impulse was transmitted beyond the pit margins. Based on the piezometer water level response, the water table beneath the infiltration trench is likely to have risen to meet the base of the trench within 15 – 20 minutes of filling beginning. Figure 28 is a schematic cross-section of the Canoe Creek basin trial site to illustrate the elements of infiltration trench and piezometer used in the trial to track the movements in the water table.

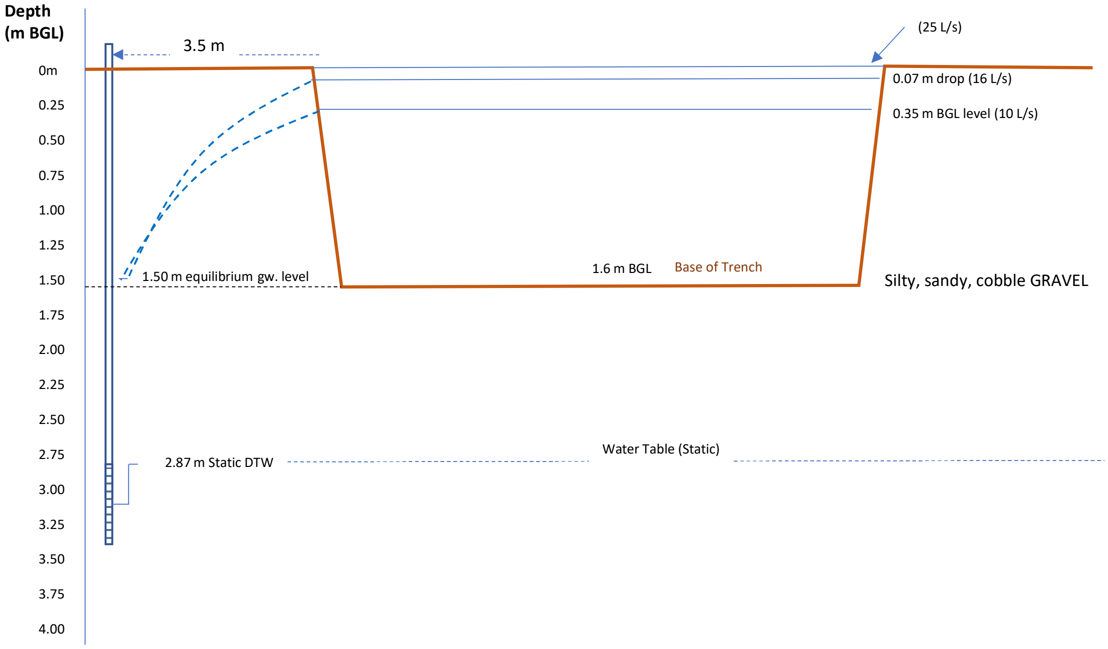


Figure 28: Schematic cross-section of Canoe Creek basin infiltration trial site showing water table movements

The water table rose rapidly as measured in the piezometer located 3.5 m to the west of the trial trench edge. Figure 29 plots the rise and fall in the water table in response to decreasing infiltration and the cessation of infiltration at 180 minutes (3 hours). The stepped reduction in infiltration rate tends to flatten the water table response, especially following the transition from 16 L/s to 10 L/s. The recovery at the close of infiltration displays a decline with a fitted regression correlation suggesting the water table would pass through residual displacement of 1.05 m (1.62 m BGL depth to water), 1 hour after the cessation of infiltration (240 minutes or 2:00 pm), which correlates with the observed draining of the last pocket of free water at 1.6 m BGL in the infiltration basin.

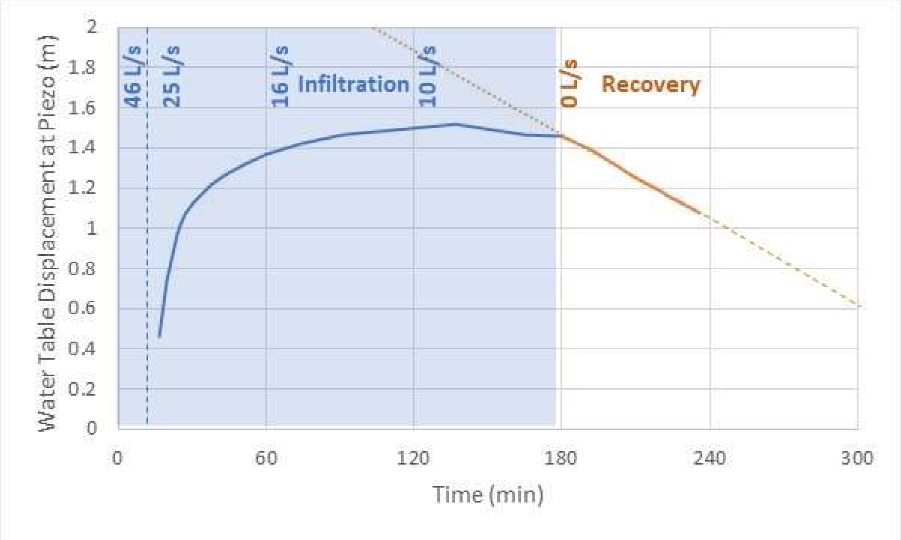


Figure 29: Measured plot of water table displacement at nearby piezometer during infiltration trial

The hydraulic gradient between trench and piezometer would be very low gradient as the water table declined back to its static water level. The recovery regression correlation also suggests full recovery to previous water table elevation after 3½ hours following the cessation of infiltration. Approximately 205 cubic metres of water was infiltrated into the Canoe Creek alluvial fan through the floor and walls of the trial trench, averaging 19 L/s across three hours of infiltration. The infiltration trench is pictured full of infiltrating water in Figure 31, and draining away after 30 minutes following the end of pumping into the trench in Figure 32.

The specifications of the infiltration trial were transposed into the Hantush (1967[2]), including the rise in the water table into the trench (increase of 2.67 m) and the inflow rates averaged across the 3 hour period of the test. The transposition of these values suggested a hydraulic conductivity of 32 m/d. Similarly, the AQTESOLV aquifer test interpretation package was used with the Murdoch (1994[3]) solution which is based on the Witherspoon & Gringarten (1972[4]) solution. The Murdoch methodology considers a trench of finite, specified length and the measured displacement of the water table at specified distance from the trench. This was better suited to the measured water table displacement and infiltration rate data collected as part of the infiltration trial. The analytical analysis also allowed the variable infiltration rates to be explicitly specified in the curve matching as hinted at by the shape of the type curve before infiltration shutdown. This methodology matched with the piezometer water table response data (see Figure 30) indicated the best match would include the following aquifer parameters –

- Hydraulic conductivity (K_x) of 93 m/d, and
- Specific storage (S_s) = 0.3 (dimensionless).

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[2] Hantush, M S. 1967. Growth and decay of groundwater-mounds in response to uniform percolation. Water Resources Research, 3(1). pp. 227-234. DOI: 10.1029/WR003i001p00227.

[3] Murdoch, L C. 1994. Transient analyses of an interceptor trench. Water Resources Research, vol. 30, no. 11, pp. 3023-3031.

[4] Gringarten, A C; and Witherspoon, P A. 1972. A method of analyzing pump test data from fractured aquifers. Int. Soc. Rock Mechanics and Int. Assoc. Eng. Geol., Proc. Symp. Rock Mechanics, Stuttgart, vol. 3-B, pp. 1-9.

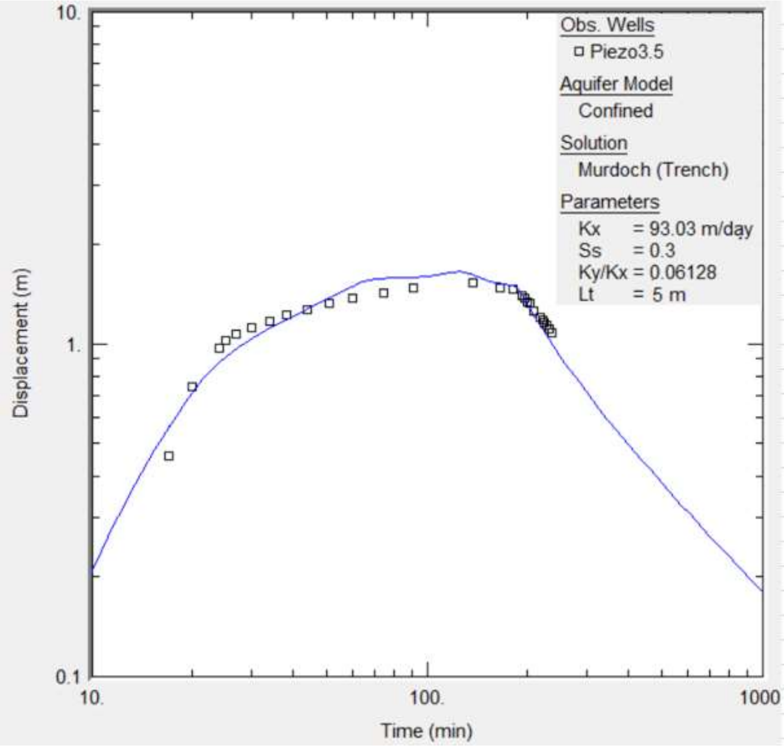


Figure 30: AQTESOLV analysis using the Murdoch (1994) trench test solution

Figure 31: Infiltration trench following filling to the brim and holding at a pump rate of 25 L/s (10:40 am)

Figure 32: Draining infiltration trench 30 minutes after the cessation of infiltration (piezometer in background)

The derived parameters are broadly in line with the lithology of the silty, sandy gravels uncovered in excavating the trench. The hydraulic conductivity is broadly consistent with expectations for silty, cobbly gravel. The specific storage (S_s) derived in the test analysis is higher than the expected range (0.05 – 0.25) of values for the lithology. The general accuracy of the testing approach would be adversely affected by geometric factors, such as the water table rising above the base of the infiltration trench. However, the primary objective of the trial was to derive unit acceptance rates rather than hydraulic parameters. Table 5 suggests that a linear infiltration acceptance rate of 172 cubic metres per linear meter of trench should have long-term reliability.

Table 5: Semi-Quantitative Results from Canoe Creek Trench Trial

Trial Scenario	Trial Infiltration Rate (L/s)	Linear Infiltration Rate ($m^3/d/m$)	Comments on Conditions
Highest Infiltration	25	432	The 1.6 m deep trench was barely accepting all pumped inflow, so the linear infiltration acceptance rate indicates the short-term, maximum infiltration reasonably anticipated from trial data
Middle Infiltration	16	276	The 1.6 m deep trench more readily accepted the pumped inflow and dropped to provide a 0.1 m freeboard, i.e., 1.5 m above trench base. The water table also declined indicating that the base of the pit and water table were in saturated coupling
Lowest Infiltration	10	172	The trench was operating with a comfortable freeboard and the nearby water table also stabilised, indicating saturated coupling but a quasi-equilibrium had established. The pumped inflow rate could be considered indicative of the long-term acceptance rate.

The proposed Canoe Creek Infiltration basin based on the footprint of the old stand-off pad would have a long dimension of 90 m and width of about 18 m. The proposed maximum infiltration rate was 150 L/s. Setting aside the additional width of the proposed basin, the linear infiltration rate of 172 $m^3/d/m$ over 90 m would provide infiltration volumetric capacity of 15,550 m^3/d (180 L/s). Reduction in this capacity due to clogging with entrained fine particles should be expected. Time delay against the onset of clogging would be provided by the ability to spread infiltration across an 18 m width of the infiltration basin. Even so, extended reliance on the infiltration basin especially in the case of turbid water infiltration would require periodic mitigation through the cessation of use, drying of the infiltration media and ripping to break up the clogging material.

The Canoe Creek Infiltration Basin should accommodate infiltration of 100 L/s over periods of several days to weeks. As mentioned, periodic ripping of the basin infiltration media would be indicated if infiltration basin water levels begin to increase while accepting roughly the same inflow rate.

3 Stratigraphic & Creek-Edge Drilling

In light of the geological and hydrogeological information provided by the injection site investigations follow-up drilling and logging of geological and groundwater conditions. The drilling investigations used a track-mounted reverse circulation drilling rig. The following foci of drilling investigations were observed –

- Determining the depth of clay-rich overburden along the Collins Creek edge,
- Determining the depth of clay-rich overburden along the Northern Boundary Drain, and
- Determining the depth and thickness of any distinct basal gravel deposits within the Coates property.

The base of the clay-rich overburden had been logged and modelled as a surface by RSC geological consultants, based on reverse circulation drilling rig investigations in approximately 190 drill holes. Most of the reverse circulation sand resource drill holes were placed in the core of the potential sand mining area rather than on the periphery (see Figure 33 for map). Statistics of the depth of clay-rich overburden are listed in Table 6, revealing the normal overburden depth is about 4 m.

Table 6: Depth to Base of Overburden Statistics from TAC-### Holes (n = 186)

Statistic	Value
Mean	3.98
Median	4
Minimum	1
Maximum	10
Standard Deviation	1.78

Figure 33: Location of TAC-### reverse circulation drill holes from 2022 (dotted line indicates mining area)

In contrast, the creek-edge drilling to determine the depth of the base of overburden found greater depths of the base of clay-rich overburden than the 4 m norm for the sand resource drilling holes (compare Table 6 and Table 7). The median and median depth to the base of the overburden in creek-edge drill holes was 8.6 m and 9.5 m, respectively (see Table 7).

Table 7: Depth to Base of Overburden in Creek-Edge Drill Holes (n = 12)

Statistic	Value
Mean	8.58
Median	9.5
Minimum	4
Maximum	14
Standard Deviation	3.53

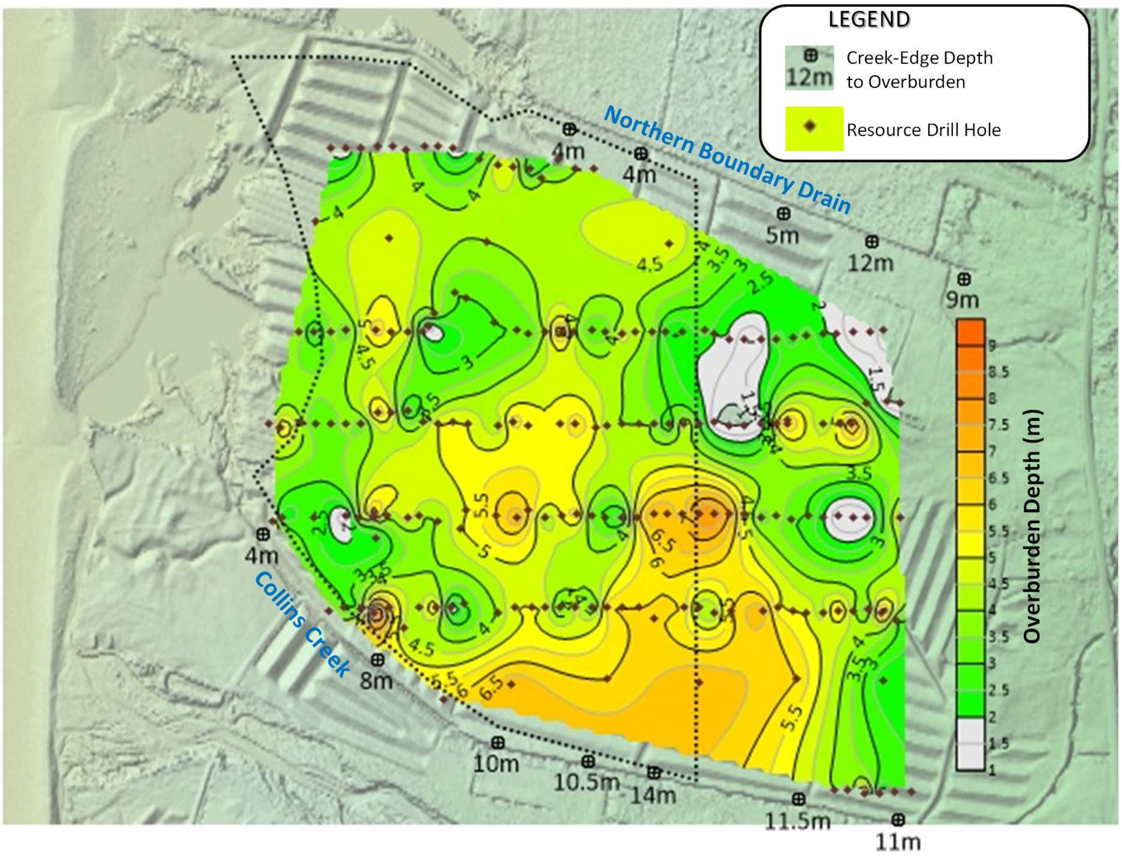


Figure 34: Mapped depth of the base of the overburden for TAC### resource drill holes (contoured) and Creek-edge base of overburden depths along Collins Creek and Northern Boundary Drain

There is an identifiable deepening of the overburden in the south of the mining area adjacent to the middle reaches of Collins Creek, albeit based on smaller densities of measurements. In general, the creek-edge overburden depth was greater than the adjoining farmland overburden depths, especially in the east of the Coates property for both water courses. It was also noted that the alignment of both water courses was constructed or artificial, so either the choice of alignment or method of construction may have had some influence over thickening of the clay-rich overburden adjacent to the water courses discernible today.

4 Analysis of Hydrogeological Conditions arising from Field Investigations

4.1 Background

Previous assessment of the effect of sand extraction pit dewatering had relied on a conservatively high basal gravel thickness of 15 m. The thickness was based on observations of 14 m of sandy gravel thickness made in 1990 drilling along Burke Road, with measured hydraulic conductivity of approximately 56 m/d. Parameter estimation and conservativism led to the setting of the basal gravel layer at 15 m thickness and 75 m/d hydraulic conductivity, indicating a layer transmissivity of 1,125 m^2/d. Within the Coates property resource drilling, the top of the basal gravel to no more than 18 m had been characterised, but no deeper drilling extended much beyond 3 m beneath the top of the basal gravel.

As outlined in preceding sections, drilling investigations in October and November 2023 encountered contrasting hydrogeological conditions. Indeed, a thin basal gravel comprising very sandy gravel was found to be present beneath the main mineral sand ore zone, while sand dominated sediments with relatively minor or encapsulated gravel lenses were found from depths of 16 m to 18 m below ground to end-of-hole depths between 25 m and 34.5 m BGL. The hydrological implications of the drilling observations can be summarised as follows –

- The hydraulic conductivity (permeability) of the thin sandy gravel can be correlated with the approximately 75 m/d value estimated from the injection well constant rate pumping test, and
- The hydraulic conductivity of the sand dominated sand with minor gravel is governed by the sand groundmass in which the coarser clasts rest, therefore the value of hydraulic conductivity would be in the order of 3 m/d.

4.2 Discrete & Composite Hydraulic Conductivity Field

MODFLOW and other numerical model codes require discretisation into model layers. In the previous model, two model layers were implemented, as summarised in Table 8. The Layer 1 comprising mineral sand was partially saturated and varied in thickness in accordance with the topography, hence Table 8 lists its thickness and layer transmissivity as variable. The hydraulic properties were also varied in alignment with the grain sizes encountered in resource drilling investigations in 2022. In contrast, a fully saturated, constant thickness and hydraulic conductivity for the deeper, Layer 2 was included in the previous model discretisation. The thickness and transmissivity of the deeper layer were conservatively pitched, but based on a single, short-term test conducted off-site along Burke Road and assumptions as to the composition of the deeper aquifer beneath the Coates property.

Table 8: Summary of Model Layering and Hydraulic Property Assignment in Previous Model Iteration

		Model thickness (m)	Model K_h (m/d)	Layer T (m^2/d)	Effective K_h (m/d)
Layer 1	Ore SAND with minor gravel	Variable	Variable	_	3
Layer 2	Basal Gravel	15	75	1125	75

The revised composite hydraulic properties used in recent model scenarios are summarised in Table 9, including the splitting of the deeper Layer 2 into a thin sandy gravel and fine gravel encapsulating minor gravel lenses. The sub-layer transmissivities were summed together to allow the calculation of a composite or effective hydraulic conductivity of the deeper layer.

Table 9: Summary of Effective or Composite Hydraulic Properties based on more recent Characterisation

Model Layer Status		Model thickness (m)	Model K_h (m/d)	Sub-Layer T (m^2/d)	Total Transmissivity (m^2/d)	Effective K_h (m/d)
Conductance*	Clay-rich Overburden	7.5	0.2	1.5	_	0.2
Layer 1	Ore SAND with minor gravel	Variable	Variable		Variable	3
Layer 2a	Basal GRAVEL, mainly sandy GRAVEL	2	75	150	189	12.5
Layer 2b	Fine SAND with minor gravel	13	3	39		

Note: * See Table 11 and Equation 1 for workings for calculating conductance.

Table 9 reveals that the composite hydraulic conductivity of the deeper layer would be assigned with a value of 12.5 m/d.

The conceptual groundwater throughflow rate, combining shallow and deep groundwater compartments, can be calculated as follows –

Mineral sands (elevations from land surface to -5 m MSL)

Q = (K b) i W
= (9.14 m/d x 10 m) x 0.0083 x 800
= 607 m^3/d (or 7 L/s)

Where:

K = Mean horizontal hydraulic conductivity
= 9.14 m/d
b = Mean saturated thickness
= 10 m
i = Mean groundwater hydraulic gradient
= 0.0083 m/m
W = Groundwater flow front
= 800 m

Basal Gravels (elevations from -5 m to -20 m MSL)

Q = (K b) i W
= (56 m/d x 15 m) x 0.002 x 800
= 300 m^3/d (or 3.5 L/s)

Where:

K = Mean horizontal hydraulic conductivity
= 12.5 m/d
b = Mean saturated thickness
= 15 m
i = Mean groundwater hydraulic gradient

= 0.002 m/m

W = Groundwater flow front

= 800 m

The layer 1 and 2 throughflow can be summed as follow –

Table 10: Sum of Shallow and Deep Layer Groundwater Throughflow within Coates Property

Throughflow Calculation Layer	Throughflow Rate [m^3/d (or L/s)]
Top 10 m to 15 m Depth of Sediments Throughflow	607 m^3/d (or 7 L/s)
Basal Gravel (model Layer 2) Throughflow	300 m^3/d (or 3.5 L/s)
Combined Throughflow	907 m^3/d (or 10.5 L/s)

Therefore under averaged, passive hydraulic gradients, we can anticipate that the Coates Property groundwater throughflow rate can be estimated to be just over 900 m^3/d or 10.5 L/s. It is expected that the rates of throughflow and the pattern of groundwater flow would change once mining activity results in the water table being locally depressed towards the base of layer 1. Flow rates would increase, a drawdown centre would focus on the active mine pit pond and surface water would be depleted from water courses bounding the Coates property.

4.3 Bounding Surface Water Course Conductances

The other matter arising from September - October 2023 fieldwork was the thickened clay-rich overburden between the mineral sand groundwater system and water courses that bound the Coates property. Collins Creek was found in drilling investigations to be underlain by clay-rich overburden, possibly flood debris material, that was measured to have a low hydraulic conductivity. The overburden would thus control the interaction between the creek and the underlying water-bearing layer. The question arises as to the best method to simulate the semi-permeable interaction between creek and groundwater. MODFLOW and other numeric model codes use a boundary condition for simulating surface water courses mediated by a variable conductance value. Equation 1 for calculating conductance and the definition of the equation terms is provided below –

$$C = \frac{\mathbf{K\,L\,W}}{\mathbf{B}} \qquad \textbf{Equation 1}$$

Where:

C = Conductance (m^2/d)

K = Hydraulic conductivity of creek bed (m/d)

L = Length of creek segment (m)

W = Width of creek (m)

B = Thickness of creek bed (m)

The resulting conductance value is primarily a function of the hydraulic conductivity and thickness of the creek bed since the geometric factors of length and width are mostly inherent to the layout of the creek segment. The model cell, node or element arrangement of the numeric model has a significant influence on the geometric dimensions used to calculate conductance.

The previous modelling exercise had assigned conservatively high conductance values by assigning a hydraulic conductivity (K) of 2,000 m/d. In effect, this made a direct and unimpeded hydraulic connection between Collins Creek and lower Northern Boundary Drain surface water boundaries. However, two lines of evidence have become available in 2023 –

- A photographic survey of Northern Boundary Drain in late summer 2023 when surface runoff was assumed to be low and any drain flow considered to be groundwater seepage, and
- A drilling survey in October 2023 that determined the thickness or depth of clay-rich overburden on the edge of Collins Creek and Northern Boundary Drain.

The visual survey found that the upper reaches of the Northern Boundary Drain was devoid of flow, while the lower reaches immediately upstream of Rusty's Lagoon sustained only weak seepage inflows. As outlined in Figure 34 and associated discussion, the water courses are separated from the underlying mineral sand water-bearing layer by between 4 m and 14 m. The corollary would be that the effective hydraulic conductivity for the interchange between mineral sand water-bearing layer and water courses is significantly less direct than assumed in previous model studies. In fact, direct measurements of the permeability of the clay-rich overburden layer on the edge of Collins Creek were made at the injection well trial site using falling head tests and less directly by leaky aquifer interpretation of a 24-hour pumping. The adjacent creek also does not feature as a direct hydraulic boundary in the pumping test interpretation. Injection testing revealed that the groundmass of the overburden capped the water bearing layers, allowing over-pressures to develop that were relieved only by bore seal bypass and discrete discontinuities within the overburden.

Overburden hydraulic conductivities in the range of 0.01 m/d to 0.32 m/d were measured in the aquifer testing. The assumed overburden hydraulic conductivity was assigned as 0.2 m/d at the injection well trial site. Since the clay-rich overburden is the functional control on the exchange of water between the respective water courses and the underlying water-bearing layers, it is reasonable to set the hydraulic conductivity to be used in calculating conductance at 0.2 m/d as well. In this manner, Collins Creek conductance was assigned in the revised modelling to 4.14 m^2/d (see Table 11). Since Figure 34 suggests the over-thickened overburden follows the full length of the lower Northern Boundary Drain and Collins Creek, the assignment of a lower bed conductance was used instead of laying in a new surficial layer simulating the overburden.

Table 11: Summary of Parameters used in the Calculation of Bed Conductance

Model Status	Material	Bed Hydraulic Conductivity (m/d)	Creek Bed Length (m)	Creek Bed Width (m)	Creek Bed Thickness (m)	Creek Bed Conductance, C^* (m^2/d)
		K	L	W	B	$C = \frac{KLW}{B}$
Surface Water Boundary Condition	Clay-rich Overburden	0.2	20.72¥	1§	1	4.14

Note: * see Equation 1; ¥ Creek bed length (L) of 20.72 is consistent with the length of model cells; § A width of 1 m is consistent with the mean widths measured along Collins Creek from pool – run – riffle – pool sequences.

A different groundwater – surface water interaction situation pertains to Canoe Creek and its associated gravel braided channels. The higher creek bed conductance based on a hydraulic conductivity of 2,000 m/d was retained for Canoe Creek since there were ample indications of a relatively unimpeded and direct hydraulic connection between the creek and Canoe Creek alluvial fan material.

5 Groundwater Model Revision

5.1 Background to Documentation Prior to Revision

The hydrological assessment provided with the April 2023 consents applications (*Barrytown Mineral Sands Mine Hydrological Impact Assessment*, Kōmanawa Solutions technical report No: Z22004_1-Rev3, 17 April 2023) included the use of groundwater computer modelling to provide times series predictions of the following –

- Pit pond groundwater inflow as induced by pumping to maintain a depressed pond water level,
- External groundwater level changes induced by the depressed water level, and
- Depletion of flow in surrounding water courses such as Collins Creek or Northern Boundary Drain.

These predictions guided the design and sizing of the water management and mitigation proposals further detailed with the water management plan (*Barrytown Mineral Sand Operation Water Management, Monitoring and Mitigation Plan*. Kōmanawa Solutions technical document No: Z22004_2, 17 April 2023). Therefore, the revision of the conceptual and groundwater computer model would have consequences for our understanding of the geo-environmental responses to mining activity and need for management, mitigation and monitoring measures to minimise environmental effects.

5.2 Extent of Revision

The extent to which the models would be revised is contained within the following –

- The hydraulic conductivity and transmissivity of the deeper groundwater layer beneath the Barrytown Flats would be revised downwards,
- Low permeability clay-rich overburden would intervene between the area's water courses and the groundwater system, thus moderating the degree of interchange, and
- The effects of mining activity would be assessed in a non-mitigated state before predictions of the effect of mitigations are applied.

The proposed revisions to conceptual model have already been outlined in section 4 Analysis of Hydrogeological Conditions arising from Field Investigations. New layer 2 hydraulic conductivity and water course conductances are detailed in that section of the report. Revised surface water interface conductivities and conductances are outlined immediately below.

5.3 Specific Groundwater Computer Model Revisions

5.3.1 Layer 2 Hydraulic Conductivity and Transmissivity

Layer 2 is assigned a uniform top and bottom elevation of -5 m and -20 m with respect to mean seal level (MSL) in the existing and revised model. Accordingly, a uniform saturated thickness of 15 m prevails throughout the layer. Table 8 for the previous model, and Table 9 for the revised model list the parameters that were assigned for the entirety of Layer 2 within the Telescopic Mesh Refined (TMR) portion of the Barrytown Flats groundwater model. The overall arrangement of the layering taken from field data is shown as a composite of the geological model based on drilling to -8 m MSL, which showed subsoil or overburden, mineral sand, basal gravel and basal fine silty sand deposits. These informed the setting of model layer transition elevations. The arrangement is illustrated in Figure 35.

The previous layer top for layer 1 is untouched, having been set in accordance with the LiDAR land surface. The saturated thickness of layer 1 is variable, as is the hydraulic conductivity assigned as 5 x zones across the model layer. A uniform transition from layer 1 layer 2 is placed at -5 m MSL. The base of layer 2 is set at a uniform elevation of -20 m. With uniform hydraulic conductivity of 12.5 m/d and uniform thickness of 15 m, the layer transmissivity equates to 189 m^2/d.

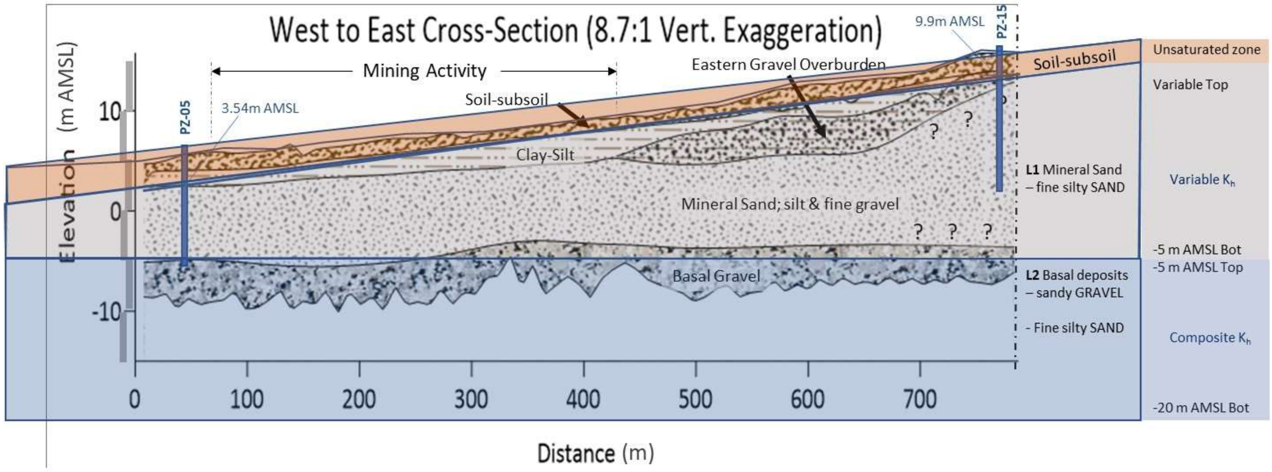


Figure 35: Cross-section overlying lithological data with hydro-stratigraphic simplifications into model layers

5.3.2 Simulation of Surface Water Boundary Conditions

The previous model used river (RIV) boundary condition cells organised into reaches to simulate the presence and interactions of the lower Northern Boundary Drain and the lower Colins Creek. River boundary conditions were assigned for the lower parts of both water courses to be conservative, since rivers can both receive and give water with the model layer (aquifer) depending on hydraulic gradients and permeabilities active in the model around the boundary condition. Therefore, the boundary condition can contribute water adjacent to drain reaches simulating the effect of mine pit pond pumping in layer 1 and thereby increase the volume of water entering pit pond by depleting the water course flow.

The revised implementation of the water course was achieved by retaining this arrangement and adjustment of the river conductance in accordance with the conductance specified in Table 11. The river boundary was specified attached to layer 1 but would connect to layer 2 as exchange through layer 1.

6 Revised Groundwater Computer Model Results

6.1 Effects measured as Changes to the Groundwater Balance

6.1.1 Pit Pond pumping Rates

The overall effect of the revisions outlined in section 0 on the ground water balance is one of the most useful means of examining and assessing effects of changes to water management. The previous MODFLOW TMR model provided the following plot of groundwater pumping requirement from the pit ponds as they moved across the sand mining panels from west to east and south to north. Figure 36 and Figure 37 compare the pit pond pumping requirements of the previous model and the revised model. There is an apparent reduction in the requirement arising from the revisions detailed in section 6.

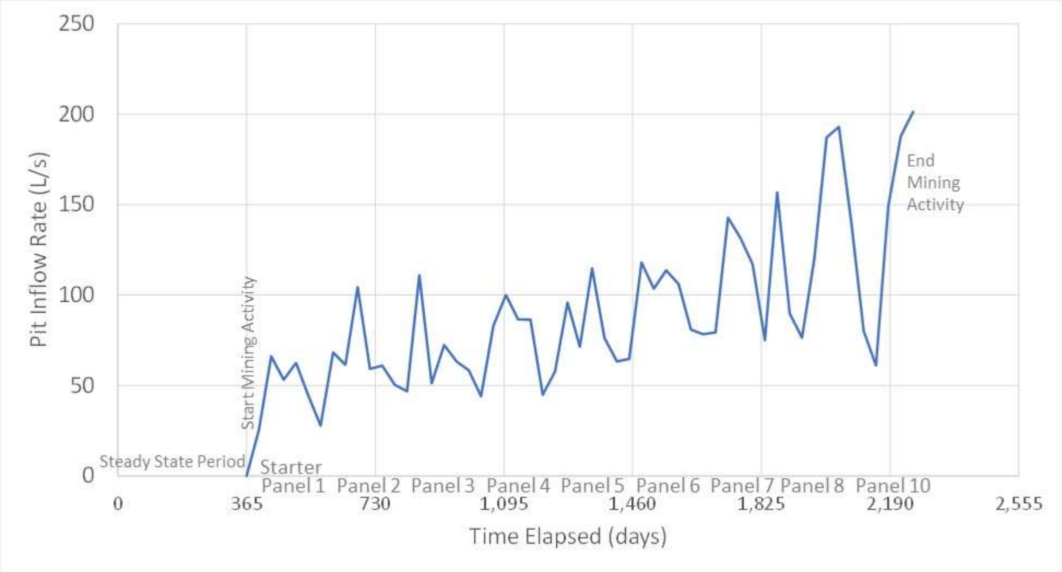


Figure 36: Time series plot of the previous model pit pond pumping from start to end of mining activity

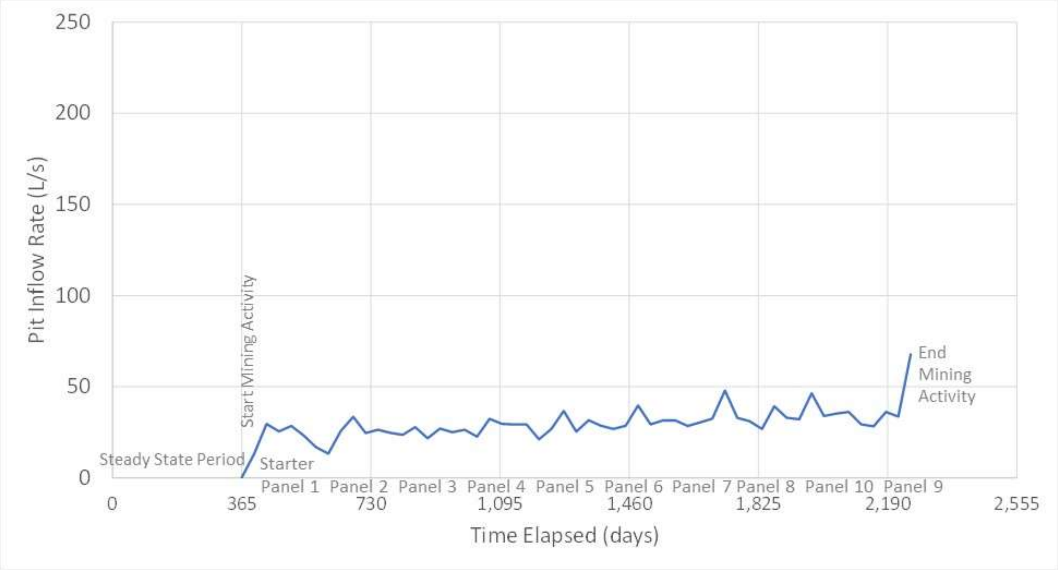


Figure 37: Time series plot of the revised model pit pond pumping showing reduction in requirement

The pumping requirement for the pit ponds under water table depression is essentially groundwater inflow that needs to be pumped away into the mine water system. Apart from mine panel 9 in Year 6 (Year 5 of mining activity), the pumping requirement of up to 200 L/s in the previous model was reduced to less than 50 L/s in the revised model.

6.1.2 Implications for Water Management and Mitigations

The reduction in pumping requirement from the pit ponds has significant impacts on a number of matters relating to hydrology and water management. These can be summarised as follow –

- The mine water system would have significantly less water being added from the groundwater system,
- The net surplus of water from the mine water system would be significantly reduced on that previously directed to mine water treatment and discharge, and
- As groundwater level decline and surface water depletion effects are directly proportional to the rate of groundwater removal at the mine pit, the reduction in pumping requirement at the pit ponds would result in lesser water level decline of flow depletion surrounding the mining area.

6.1.3 Surface Water Depletion

The ground water balance time series plots are instructive in examining the effect of pit pond pumping on the flow within water courses. The previous model pointed to significant depletion, i.e., reduction in water course flow rate, arising from mining activities. Figure 38 and Figure 39 illustrate time series plots of flow depletion in Northern Boundary Drain and Collins Creek under the previous and revised models, respectively. The plots are placed on the same page and with common X and Y axis magnitudes to allow easier comparison.

Both water courses bounding the mining area, Northern Boundary Drain and Collins Creek, were found in simulations to be significantly affected by pit pond pumping in the previous model that included high surface water conductances and higher layer 2 hydraulic conductivity. On average, the effect on lower Collins Creek was 15.5 L/s with a maximum depletion effect of 56.2 L/s. On average, the effect on lower Northern Boundary Drain and Rusty's Lagoon was 22.1 L/s with a maximum of 74.2 L/s. Considering that Collins Creek is estimated to have a Mean Annual Low Flow ($MALF_{7d}$) of approximately 16 L/s, the peak depletion of 56.2 L/s would have a profound effect on creek habitat. Therefore, mitigation including peripheral infiltration and injection wells to raise shallow groundwater levels, and augmentation with Canoe Creek water in periods of low creek was planned. The reason that Rusty's Lagoon was added to the lower Northern Boundary Drain depletion total is that the two cannot be readily segregated in a hydrological sense.

Both water courses bounding the mining area, Northern Boundary Drain (plus Rusty's Lagoon) and Collins Creek, were found in simulations to be much less affected by pit pond pumping in the revised model. On average, the effect on lower Collins Creek was 1.4 L/s with a maximum depletion effect of 4 L/s. On average, the effect on lower Northern Boundary Drain and Rusty's Lagoon was 5.8 L/s with a maximum of 14.1 L/s. The higher rates of depletion tended to be highest when the active mine panels were in closest proximity.

The upshot of the lower surface water depletion rates under the revised model is to remove some of the pressure for active mitigation. This is particularly the case for Collins Creek and its higher habitat values. With a peak depletion potential indicated in revised model of only 4 L/s, the augmentation of lower Collins Creek low flows is less likely to be required.

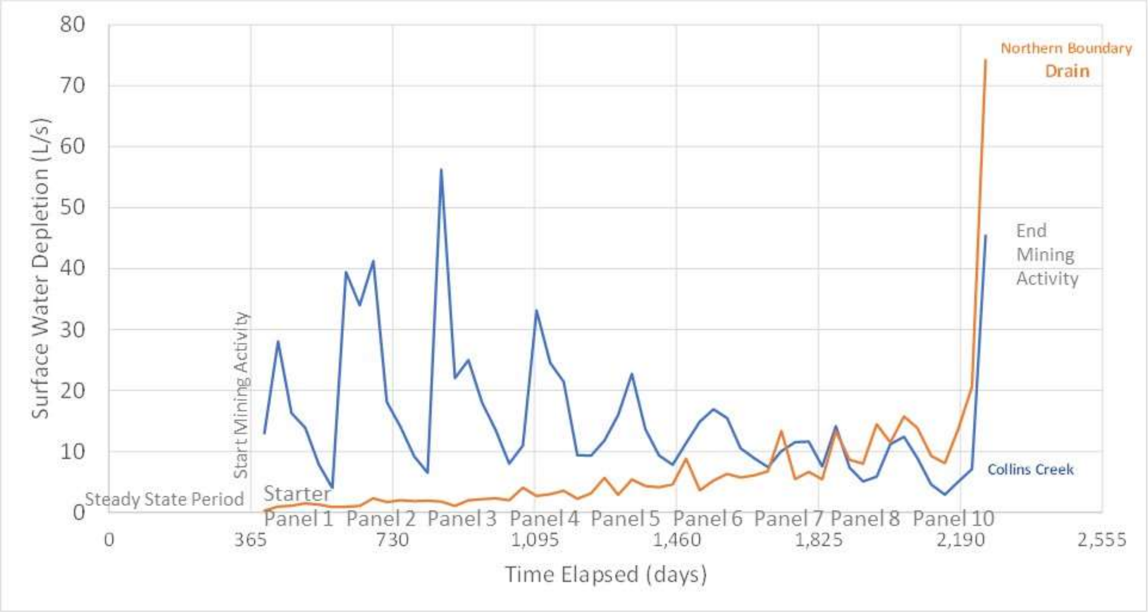


Figure 38: Water course flow depletion due to mine pit pond pumping in the previous model

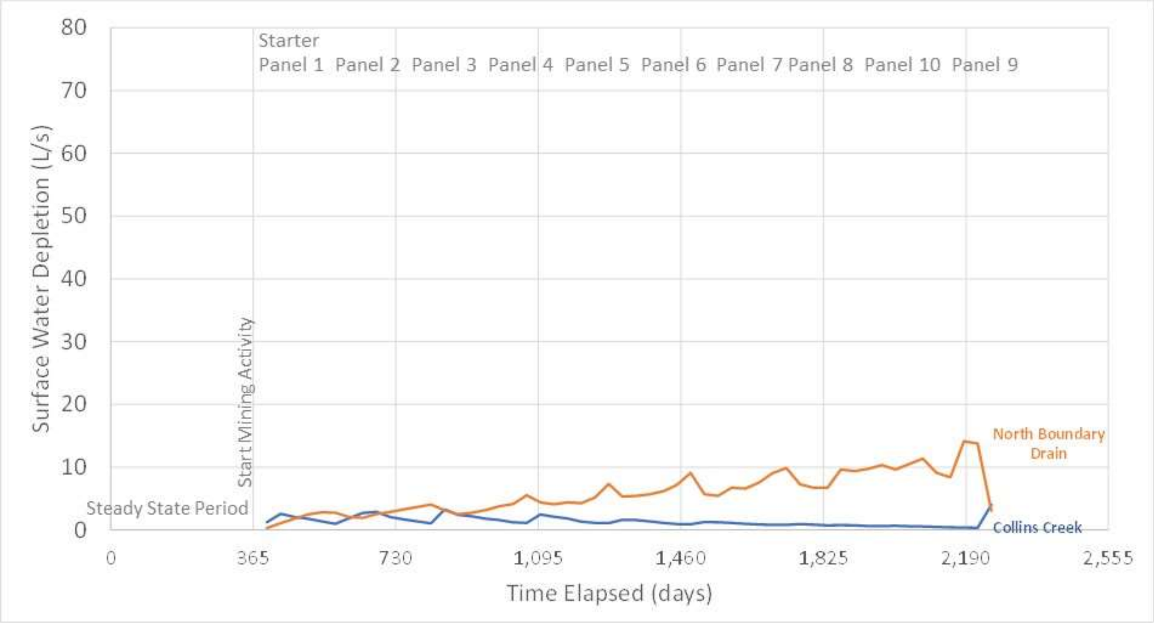


Figure 39: Water course flow depletion due to mine pit pond pumping in the revised model

6.2 Ground Water Level Effects

The unmitigated groundwater level effects of the mining activities, particularly pit pond pumping extending beyond the mining area boundaries. The ability of surrounding groundwater levels to be affected is increased by the revision of water course conductance, since the previous surface water boundary simulations with high conductance in Northern Boundary Drain and Collins Creek would have dampened water level changes extending outward.

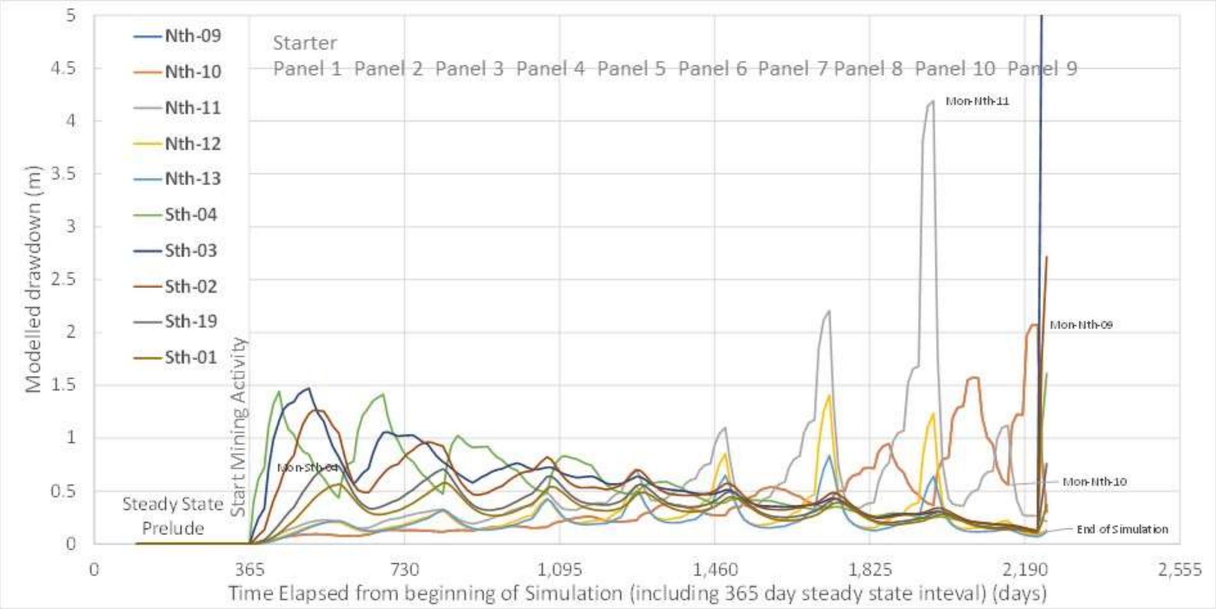


Figure 40: Revised model drawdown at hypothetical monitoring points along the northern (*Mon-Nth-##*) and southern (*Mon-Sth-##)* margins of the Coates property

Figure 40 displays the time series trend in ground water level declines along the northern and southern property margins (along Northern Boundary Drain and Collins Creek). The drawdown is less than 1.5 m until late in the fourth mining year, primarily in southern boundary monitoring points. Thereafter, periodic spikes in drawdown occur as the active pit passes the particular model monitoring points, primarily in northern boundary monitoring points.

It is important to note that the ground water level declines presented above in Figure 40 are without any form of active mitigation such as infiltration trench or injection wells. Previous modelling had demonstrated the ability for the proposed and modelled mitigation to reduce ground water level declines to negligible values. The ability of the mitigation systems to achieve amelioration of water level effects are illustrated in Figure 41 and Figure 42 in relation to the previous model.

Figure 41 shows the modelled water level declines as measured in monitoring points along the northern boundary and without any form of simulated mitigation. Unsurprisingly, as the mine panels closest to the northern boundary is approached the magnitude of water level decline is seen to increase. These water level declines in Figure 41 from the previous model are relatively close to the declines indicated in Figure 40 for the revised model.

Figure 42 shows the modelled water level declines as measured in monitoring points along the northern boundary and employing simulated mitigation. In fact, the water level declines are effectively negligible with the exception of a single spike of 0.4 m towards the end of the simulation at mining Year 5. This demonstrates the proposed mitigation as being capable of reversing the level of ground water level declines through the deployment of active mitigation such as infiltration trenches or injection wells.

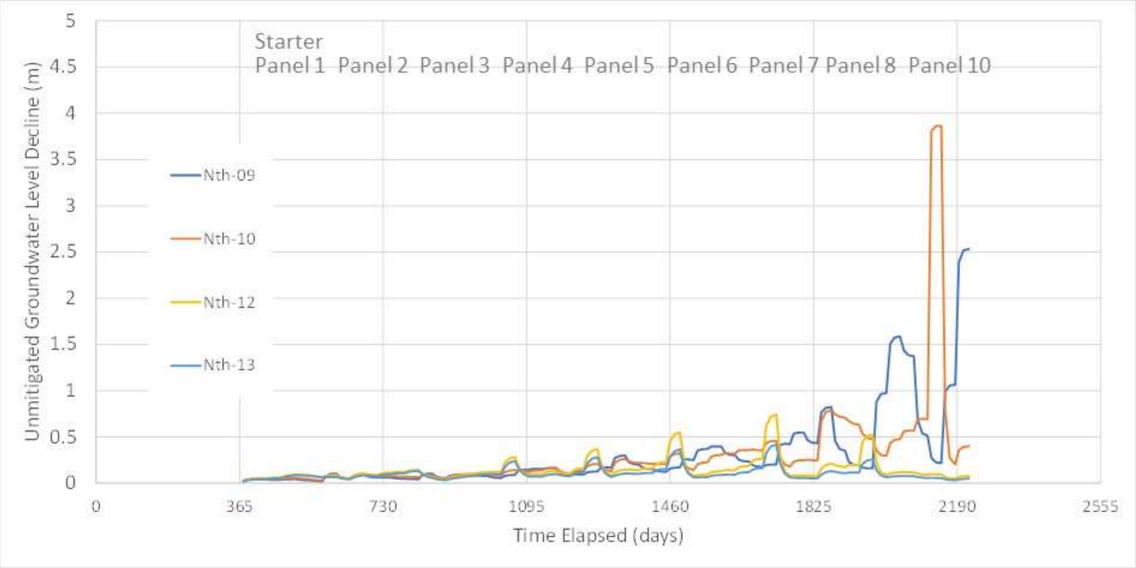


Figure 41: Unmitigated ground water level decline along northern boundary in previous model

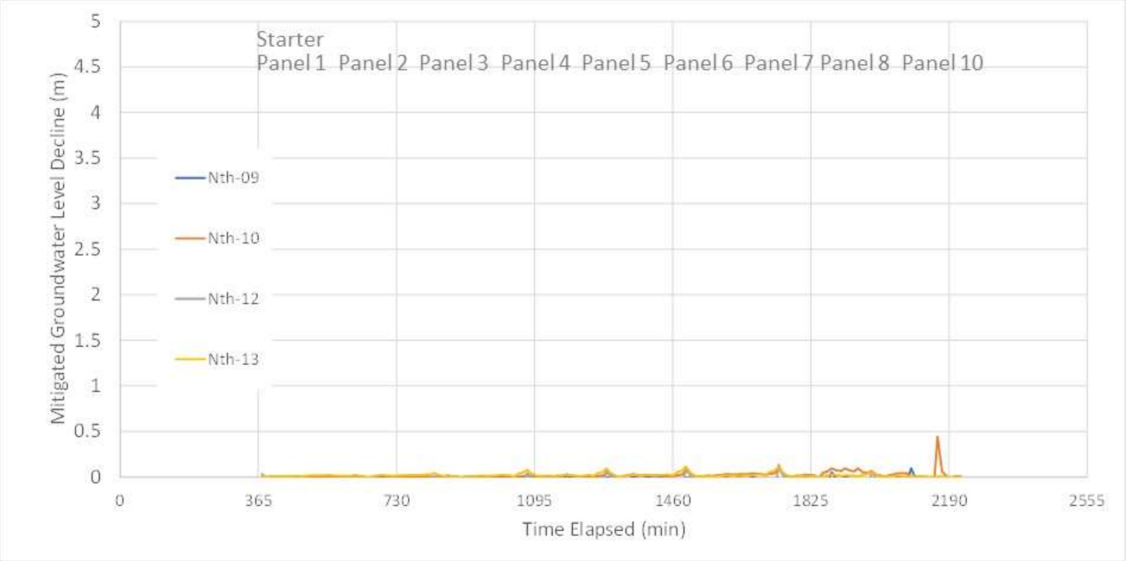


Figure 42: Mitigated ground water level decline along northern boundary in previous model

7 Conclusions

The following conclusions are drawn from the analysis of injection and infiltration trials.

1. Unanticipated ground conditions were encountered in the preparations for injection well testing –
    a. Thick (7.5 m) clay-rich overburden subsoils,
    b. Basal gravels of only 2.5 m thickness, underlain by more than 18 m of fine sand.
2. As a result, an injection well at shallower than intended depth (13.5 -16.5 m) was constructed as follows:
    a. A well-within-a-well and gravel pack was required to halt sanding of the well, and
    b. A second screen of finer slot size was also required.
3. Consequently, the well had a lower yield and was screened shallower than might have been achieved with the larger diameter screen with a natural pack against gravel deposits.
4. Aquifer testing determined a transmissivity of between 75 and 410 square metres per day for the slender sandy gravel screened in the well, while storage coefficient was estimated at 8 x 10^{-4} from Hantush-Jacob hydraulic analysis.
5. Independently estimations of the overlying aquitard determined the saturated vertical hydraulic conductivity in the range of 0.1 – 0.3 m/d.
6. The synthesis of the arrangement of hydro-stratigraphic units, groundwater hydraulic gradient and derived parameters for hydro-stratigraphic units indicated that the groundwater dynamics within the sand – gravel water-bearing layer had minor influence over Collins Creek flow rate.
7. A 24-hour injection trial of the completed well achieved injection rates between 5.8 and 6.4 L/s, however almost immediate and visible induced seepages indicated that vertical losses of the injected water were often the preferential paths for injected water and lateral aquifer acceptance was a fraction of overall injection.
8. A trial of a section of silty ore sand was exposed to a steady head over 6½ hours to simulate peripheral infiltration trench operation. The infiltration after stabilisation settled at 2.9 cubic metres per linear metre of trench.
9. A trial of a section of silty, sandy cobble gravel, part of the Canoe Creek alluvial fan near the creek mouth, was exposed to between at least 1.25 m and 1.60 m of head over 3 hours at infiltration rates between 10 L/s and 25 L/s.
10. The infiltration rate of 10 L/s (864 m^3/d) in the trial section of the Canoe Creek alluvium infiltration trench was acknowledged as closer to a long-term acceptance rate, which for a 5 m long trench equated to an infiltration rate of 172 cubic metres per linear metre of trench.
11. Recent stratigraphic drilling and logging of 15 drill holes focused on deep and shallow targets demonstrated the following –
    a. Instead of a consistent sandy gravel, the deeper subsurface to 35 m below ground beneath the Coates property was shown to be predominately fine grained, and
    b. Creek-edge drilling showed the water course of Northern Boundary Drain and Collins Creek to be separated from the mineral sand groundwater by thick measures of clay-rich overburden.
12. The conceptual model of Barrytown Flats hydrogeology in the area of the proposed mining area can be revised to reflect the deeper water-bearing layers to be dominated by a fine groundmass with the impact that the deeper layer has lower permeability than previously assumed and modelled.
13. A calculated composite transmissivity and hydraulic conductivity of the deeper water-bearing layer can be estimated as 189 square metres per day and 12.5 metres per day, respectively.
14. The implied conceptual passive groundwater throughflow towards the coastline and low-lying water courses would be 10.5 L/s.
15. The impact of the clay-rich overburden would require that the water course bed conductance should be revised to 4.1 square metres per day.

16. A revision of the previous groundwater computer model retained a two layer format but included a composite hydraulic conductivity of the deeper layer (Layer 2).
17. A revised approach to simulating the water courses of Northern Boundary Drain and Collins Creek was limited to changing the model boundary bed conductance to 4.1 square metres per day in accordance with the conceptual model.
18. The simulated pit pond pumping requirement was substantially reduced in the previous and revised groundwater computer model with a mean decline of 33% of the previous model, meaning that revised modelled groundwater inflow is largely limited to less than 50 L/s.
19. The simulated surface water depletion was substantially reduced in the previous and revised groundwater computer model with a mean decline of 33% of the previous model, meaning that revised modelled surface water depletion is largely limited to less than 15 L/s.
20. Groundwater level declines that could be termed drawdown nonetheless extend beyond the Coates property boundaries, however the proposed mitigation is demonstrated as being capable of reversing the level of ground water level declines through the deployment of active mitigation such as infiltration trenches or injection wells.

Memo

To: Jens Rekker
From: Zeb Etheridge
Date: 11/12/2023
Subject: Hand Augering 29-30/11/2023

Hand auger geological logging was undertaken on the southern boundary of the Coates property on Burke Road and the northern boundary of the Coates "Cowan Block" on 29-30/11/2023 as shown in Figure 1. The geological logs in Table 1 below show that mineral sand is present at the surface at Auger site Ag1 on the Burkes Rd property; further inland all auger holes encountered peat and clay to the maximum investigation depth. These findings align with anecdotal information from George Coates, who observes that the paddocks around Ag1 are free draining and the paddocks to the east are poorly drained.

Augering on the Cowan Block encountered brown-grey clay to the base of each auger hole, which terminated when impenetrable buried wood was encountered. A 1.4 m deep piezometer was installed in the Cow1 auger hole and the elevation of the top of the piezometer was surveyed relative to the existing PZ12 piezometer. Details are as follows:

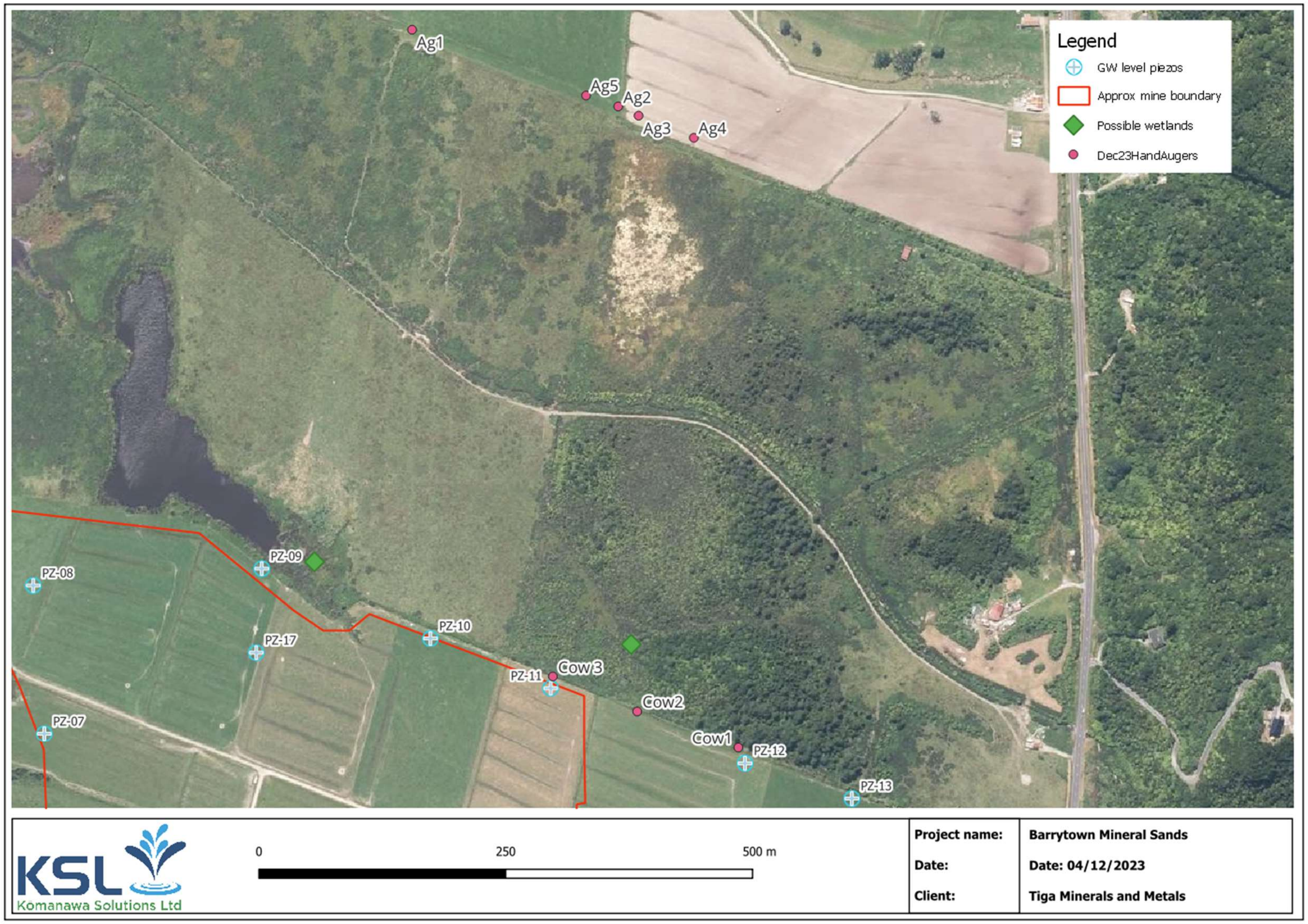
- PZ12 groundwater level = 3.47 m bgl on 30/11/23 at 10:40 am
- Cow1 groundwater level = 1.30m bgl on 30/11/23 at 10:50 am
- Cow1 ground level = PZ12 ground level minus 0.59 m
- Cow1 groundwater level = 1.58 m above PZ12 groundwater level

Note that the Cow1 groundwater level was slowly increasing in response to water seepages from the surrounding clay material; the rest water level is therefore likely to be >1.6 m above the PZ12 groundwater level. The latter is screened in mineral sand strata between 9.7 and 12.7 m depth. The groundwater level data are therefore consistent with the expected hydrogeology of this part of the site: perched groundwater is present in the surficial clay, supporting the growth of wetland vegetation on the Langridge property to the north of the Cowan block.

Table 1: Lithological logs

Auger hole name	Depth (m) and lithology
Ag1	0 – 0.05: sandy soil. 0.05 – 0.5: fine grey sand (mineral sand)
Ag2	0 – 0.2: firm blue-grey clay 0.2 – 1.3: soft brown peat with some clay 1.3: fine grey sand (mineral sand) Saturated from 0.4, groundwater at 0.4 on completion
Ag3	0 – 0.4: blue-grey clay with minor organic matter 0.4 – 1.4 very soft organics/peat with grey clay. NB: very minor returns from augering, 1.4 – 3.0: soft blue-grey clay Groundwater at 0.2 on completion
Ag4	0 – 0.8: firm blue-grey clay 0.8 – 2.0: soft blue-grey clay with some peat (wet)
Ag5	0 - 0.4: firm blue-grey clay 0.4 – 2.0: very soft wet organics/peat with grey clay. NB: very minor returns from augering 2.0 soft wet blue-grey clay
Cow1	0 – 1.7: firm becoming soft wet brown and grey clay 1.7: wood fragments, unable to penetrate

Auger hole name	Depth (m) and lithology
Cow2	0 – 0.85: firm becoming soft brown and grey clay 0.85: wood fragments, unable to penetrate
Cow3	0 – 2.2: firm becoming soft brown and grey clay 2.2 wood fragments, unable to penetrate



Project name:	**Barrytown Mineral Sands**
Date:	**Date: 04/12/2023**
Client:	**Tiga Minerals and Metals**

Figure 1: **Hand Auger investigation locations**

Appendix 3: Additional Reporting

- Memorandum titled Revision of Assessed Pit Seepage Rates and pumped Groundwater Metals Concentrations in the light of recent Injection & Infiltration Trials, dated 13 October 2023

Memo

To:	Luke McNeish, Kate McKenzie, Zeb Etheridge, Mike Fitzpatrick, Gary Bramley
From:	Jens Rekker
Date:	13 October 2023
Subject:	Revision of Assessed Pit Seepage Rates and pumped Groundwater Metals Concentrations in the light of recent Injection & Infiltration Trials

1 Background

The water-related impact assessments of had framed the hydrogeology of the Cowan Block, Barrytown as follows:

- 0 – 3 m BGL Overburden (low permeability)
- 3 – 12 m BGL Ore SAND with minor gravel (Low to moderate permeability)
- 12 ~ 27 m BGL Non-ore sandy BASAL GRAVEL (Moderate to high permeability)

The geological consultants RSC modelled a basal gravel at the base of the ore sand throughout the deposit. This was based on bore holes that were limited in depth to about 12 m below ground level, roughly the base of the economic mineral sand reserves. There was no deeper drilling to confirm the presence or extent of the basal gravel. Some pre-existing (1990's) information on the properties of deeper gravels along Burke Road was available that suggested the basal gravel had hydraulic conductivity of 75 m/d and a thickness of 15 m. It became accepted that a thick, high permeability basal gravel should be included in the conceptual model.

The numerical model duly carried over the assumptions of the conceptual model into the numerical model. It came as no surprise that the conservative setting of high permeability for the basal gravel layer in the groundwater model resulted in the basal layer carrying and delivering most of the groundwater that was pumped out of the active mine pit. Any model formulation with two or more contrasting layers would complicate the seepage rates plus the source and mixed concentrations of groundwater chemical constituents. The schematic cross-section below displays the proportions of pit inflow that applied in the case of previous numerical modelling at Barrytown:

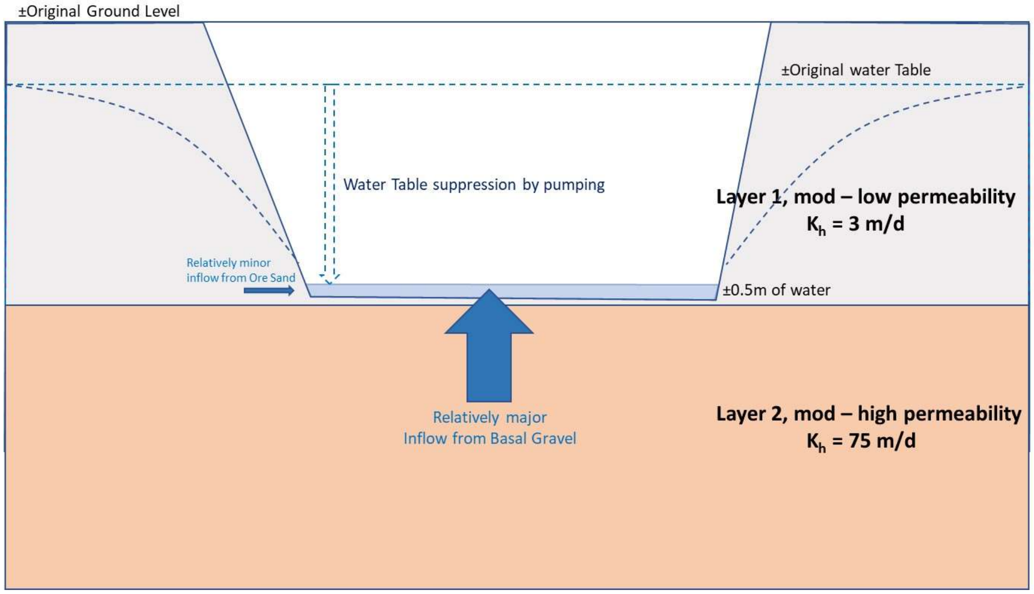


Figure 1: Explanatory schematic of dewatering and the mixing proportions of shallow & deep groundwater

However, our groundwater contaminant concentrations and comparison against standards exclusively used sampling wells were screened in the shallow ore sand rather than the basal gravel.

What's Wrong with this Approach?

Two main issues arise from recent infiltration and injection trials (11 – 22 September). These issues are both relevant to the question of whether the metals concentration mixing model is still valid. The particular findings of the injection well investigation can be summed up as follow –

- No thick basal gravel was found in drilling that was extended to 34.5 m below ground (see Figure 3 for comparison of anticipated and encountered),
- A water sample that was taken after lengthy pumping from a thin gravel layer at 16.5 m depth was very different to the previously referenced groundwater metals concentrations, indeed the metals concentrations were markedly lower, and
- The clay-rich overburden lining Collins Creek was found to be over-thickened relative to previous assumptions and aquifer testing demonstrated that depletion of Collins Creek is much diminished compared to model predictions.

The implications if the same or similar pattern of subsurface conditions is found across the Cowan Block might be summarised as follow –

- Smaller quantities of groundwater should enter the active pit compared to predicted in existing assessments, and
- The volumetric contributions of basal gravels should still dominate and thus the net pumped pit water should be lower in metals.

The consequences might be that less depletion effect would be exerted on surrounding receptors, there would be less requirement to infiltrate or inject excess water into mitigation structures such as infiltration galleries or injection wells. There may be less requirement to make direct flow mitigation discharges to Collins Creek containing mine water, with the sensitivity to metal concentrations that such discharges entail. The assessment of lower metals concentrations in the mine water also more generally assists the immediate pre-hearing consultation and with any adoption of new metals concentration guideline values.

Composition of Shallow and Deep Groundwater

Background on Purging and Sampling

Comparing the 9 November 2022 groundwater samples with the 20 September 2023 injection well sample requires the following background on purging and sampling –

- Water samples from PZ-## piezometers were taken using a D25 foot-valve pump and 13 mm diameter NTP clear plastic tubing,
- Water was purged from the 32 mm diameter piezometers using the foot-valve pump until approximately 3 x piezometer water volumes (approximately 86 litres or 0.086 cubic metres) had been removed before a sample was taken into the sample bottles,
- A single water sample was taken from the 16.5 m injection well (IW-01) during a September 2023 pumping test, after the well had been pumping continuously for 21¼ hours at a pump rate of 3.4 L/s (i.e., after the pumping removal of 260 cubic metres of groundwater),
- A water sample taken from the 11.3 m pumping bore PB-01 in November 2022 had been pumping continuously for 4½ hours at a pump rate of 4 L/s (i.e., after the pumping removal of 65 cubic metres of groundwater)
- In terms of the degree of purging the 16.5 m deep injection well IW-01 and the 11.3 m pumping bore PB-01 are the most similar,
- Despite the similarity in volume of groundwater purged for IW-01 and PB-01, the dissolved metals concentrations in the shallower PB-01 bore registered higher metals concentrations, particularly iron, manganese and boron.

Comparison of Shallow and Deep Groundwater (Metals) Concentrations

A comparison of groundwater chemistry and reference to the ANZG 95% habitat protection concentrations for metals is provided as follows –

Table 1: Groundwater sampled and analysed in Wells IW-01, PB-01 and shallower Piezometers (PZ-##)

		Injection Well	Depth Range 11.4 m to 12.5 m BGL									Guideline
	Units	IW01 (16.5 m)	PZ-15	PZ-08	PZ-17	PZ-13	PZ-06	PZ-18	PZ-02	PZ-01	PB-01	ANZG 95
Sum of Anions	meq/L	0.95	1.86	0.98	0.99	1.15	0.89	0.94	0.87	1.43	1.41	N/A
Sum of Cations	meq/L	0.94	2	0.95	1	1.1	0.86	0.93	0.87	1.4	1.85	N/A
Turbidity	NTU	0.26	240	880	22	118	75	176	1.45	166	121	N/A
pH	pH	7.3	7.4	7.7	7.6	7.5	7.6	7.6	7.6	7.6	7.3	N/A
Total Alkalinity	g/m^3	35	55	34	35	36	31	33	31	57	51	N/A
Bicarbonate	g/m^3	43	67	41	42	43	38	40	38	70	62	N/A
Total Hardness	g/m^3	29	47	30	31	33	25	28	29	43	40	N/A
Electrical Conductivity	mS/m	10.1	20.6	10.7	11	12.3	9.5	10.2	9.7	14.8	14.9	N/A
Dissolved Calcium	g/m^3	7.2	13.7	7.6	7.7	9.2	5.7	6.7	8.4	10.6	11.7	N/A
Dissolved Iron	g/m^3	0.54	3.2	< 0.02	0.16	< 0.02	0.03	0.02	0.03	0.04	11.1	
Dissolved Magnesium	g/m^3	2.6	3.1	2.6	2.7	2.5	2.6	2.7	1.87	3.9	2.6	N/A
Dissolved Potassium	g/m^3	3.9	6.3	2.8	2.8	1.68	4.1	4.5	1.86	2	2	N/A
Dissolved Sodium	g/m^3	5.7	15.8	6.6	7.1	8.7	5.7	5.9	5.5	9.9	12.6	N/A
Chloride	g/m^3	6.6	22	7.6	8.1	10.9	7.2	7.8	7.4	9	12.5	N/A
Nitrite-N	g/m^3	0.002	0.24	< 0.002	< 0.002	0.004	< 0.002	< 0.002	0.017	0.004	< 0.02	N/A
Nitrate-N	g/m^3	0.012	1.18	0.29	0.33	0.76	0.029	0.022	0.183	0.048	< 0.02	N/A
Nitrate-N + Nitrite-N	g/m^3	0.014	1.42	0.29	0.33	0.77	0.03	0.023	0.2	0.052	< 0.02	N/A
Sulphate	g/m^3	2.9	1.5	3.1	2.1	3.6	2.6	2.9	1.4	0.9	1.6	N/A
Dissolved Organic Carbon	g/m^3	<0.5	6.7	2.4	0.8	1.1	2.2	1.2	1.4	3	4.7	N/A
Dissolved Aluminium	g/m^3	<0.003	**0.1**	0.005	0.005	< 0.003	0.012	0.008	0.009	0.007	< 0.003	0.055
Dissolved Arsenic	g/m^3	0.0018	0.0091	0.0106	0.0021	0.0021	0.0017	< 0.0010	**0.036**	0.0025	0.0081	0.013
Dissolved Boron	g/m^3	0.006	0.014	0.008	0.007	0.009	0.006	0.006	0.006	0.009	0.011	0.94
Dissolved Cadmium	g/m^3	<0.00005	< 0.00005	< 0.00005	< 0.00005	0.0001	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	0.0002
Dissolved Chromium	g/m^3	<0.0005	**0.0035**	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	0.0008	< 0.0005	< 0.0005	0.001
Dissolved Copper	g/m^3	<0.0005	**0.0019**	0.0014	**0.0017**	**0.0018**	< 0.0005	**0.0055**	**0.0026**	**0.002**	< 0.0005	0.0014
Dissolved Lead	g/m^3	<0.0001	0.00113	< 0.00010	0.0003	< 0.00010	0.00038	0.00017	0.00023	0.00013	< 0.00010	0.0034
Dissolved Manganese	g/m^3	0.027	0.29	0.0076	0.059	0.031	0.11	0.0183	0.0105	0.11	0.29	1.9
Dissolved Nickel	g/m^3	<0.0005	0.0104	< 0.0005	0.0006	0.0019	< 0.0005	**0.045**	0.0053	**0.122**	0.0012	0.011
Dissolved Zinc	g/m^3	0.0018	**0.068**	**0.0151**	**0.039**	**0.074**	0.0012	**0.0198**	**0.104**	**0.046**	**0.0122**	0.008

Note: **Bold** values indicate that they are in excess of the ANZG 95% protection guideline.

IW-01 stands out for having no metals exceedance of the ANZG 95% protection guideline whereas all others, except PZ-06, exceed the guideline for at least one metal. Plotting the sum of dissolved metals concentrations (excluding iron) for all groundwater samples in Table 1, the injection well (IW-01) had the lowest concentration of all other samples, as illustrated in Table 1. Pumped bore PB-01 stands out as having among the highest metals mass per groundwater sample.

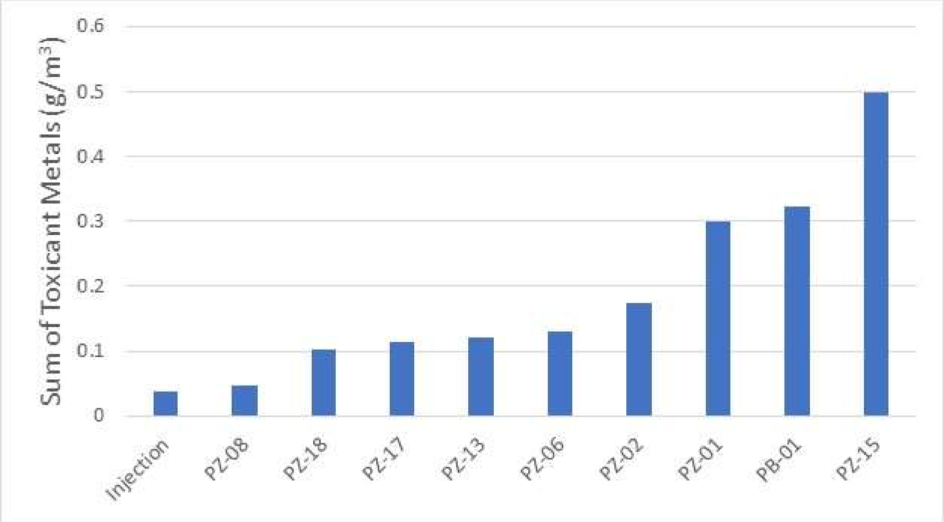


Figure 2: Sum of dissolved metals concentrations, excluding iron, across the wells, bore and piezometers

The injection well IW-01 has the clearly defined lowest sum of dissolved metals from all samples in Table 1, although piezometer PZ-08 comes closest to matching IW-01. The ions and dissolved iron are also strikingly similar between PZ-08 and IW-01, despite their significant physical offset from each other (875 m between them). PZ-08 also has the relative absence of dissolved iron and markedly low manganese.

One factor that may link the two groundwaters in IW-01 and PZ-08 is that the latter has the lowest elevation drill hole collar and stands alongside the Canoe Creek Lagoon. So, this 12 m piezometer with a thin overburden layer may be more likely to extend to deeper parts or receive upward seepage from deeper parts of the groundwater system. If the latter alternative is the case, this setting may share parallels with the proposed active sand extraction pits shown in Figure 2, since water level lowering within the future pits would be expected to induce upward seepage from the underlying deeper parts of the groundwater system.

Experience of Injection Well Drilling – Unanticipated Hydrogeology

The drilling of the drill hole encountered conditions not anticipated at the outset.

- Instead of silty clay overburden extending to (at most) 3 m below ground, the overburden extended to 7.5 m BGL.
- Instead of the ore sand being underlain by thick sandy gravel, the ore sand was underlain by 18 m of fine sand interrupted only by a thin gravel layer between 13 m and 16.5 m BGL.

The contrast between expectations and actual lithological conditions at the injection site is simplified and shown in Figure 3.

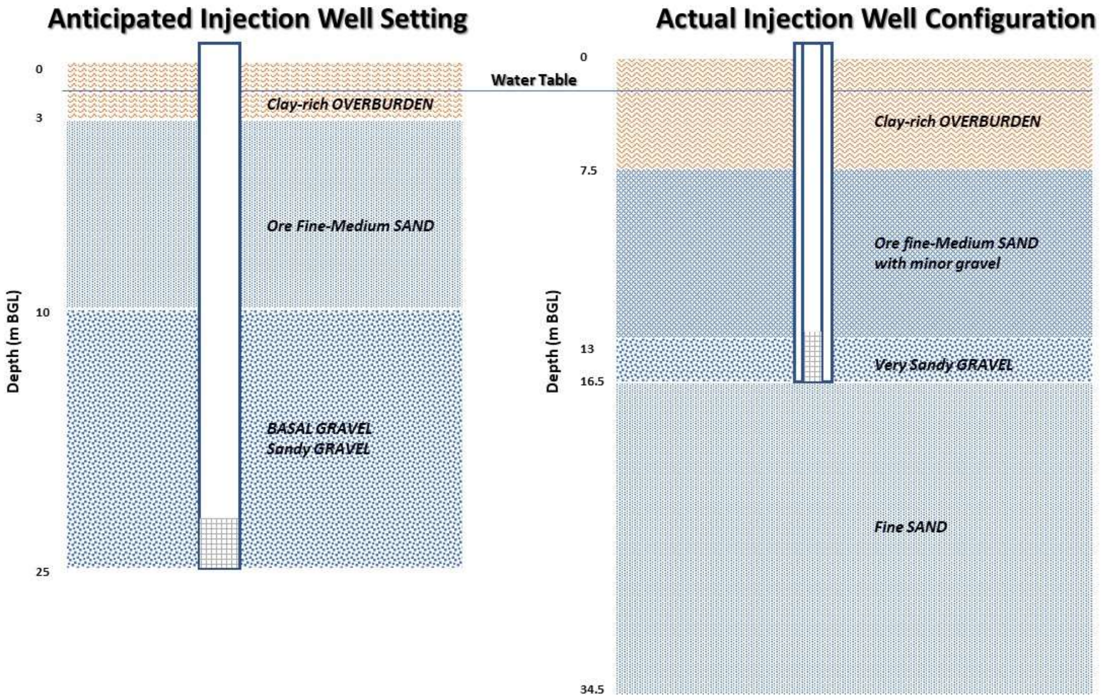


Figure 3: Difference between anticipated and actual lithological conditions found in drilling the injection well

If these lithological conditions were found to extend over a wider area, encompassing the proposed sand mining panels, then the quantity and composition of the pumped seepage waters at the proposed sand extraction pits would differ markedly, as shown in the schematic below (see Figure 4).

The ore sands in direct contact with the pit walls is choked for groundwater inflow due to lower permeability and a narrow saturated contact periphery along the pit walls (also known as a 'seepage face'). The underlying sandy gravels have a higher vertical hydraulic conductivity than the ore sand and a narrow saturated thickness. Nonetheless, underlying sandy gravel receives larger lateral groundwater inflows due to its high permeability plus seepage from finer sediments beneath it. So, the deeper sediments beneath the ore sand contribute overall the bulk of the water pumped out of the pit. This has an impact on the metals composition reporting to the pit and pumped into the mine water system.

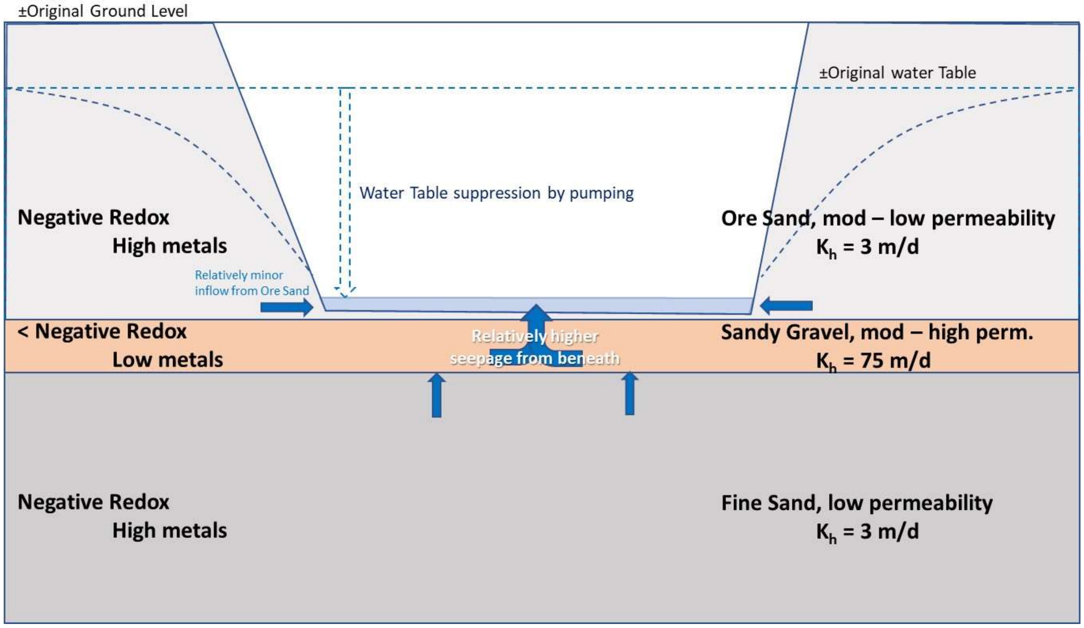


Figure 4: Groundwater quantity and metals composition in the case of thin basal gravels beneath mine pit

The less negative redox (oxidation – reduction potential or ORP) and consequent lower metals concentrations groundwater within the sandy gravel layer would have a dominating influence on the mixed pit water reporting to the sump pump(s) due to its higher hydraulic conductivity.

What is the Impact on Water Quality?

Thick Basal Gravel Scenario

In the 2022 sand extraction effects modelling that included the thick basal gravel scenario, the indicative split between shallow and deep layer contribution to mine water was as follows[1]:

- Shallow (ore sand) 12 L/s (15% of total pumping)
- Deep (sandy gravel) 67 L/s (85% of total pumping)
- Total pumping 79 L/s

The impact on pumped mine water metals concentrations would have been to significantly reduce concentrations due to the dilution effect of the lower metals concentrations in the deep groundwater in sandy gravel (Basal Gravel). The projected impact on final concentrations using the 15:85 split is developed in Table 2.

Table 2: Summary of Calculated Metals Concentrations considering a 15:85 Split for Shallow and Deep Layers

	Mean Gw. Concentration (g/m^3)		Pump Rate to maintain pit water level (L/s)		Mine Pit Pumping Mass (g/d)		Combined Mass	Combined Concentration
	Shallow	Deep	Shallow	Deep	Shallow	Deep	(g/d)	(g/m^3)
Cooper	0.0024	0.0005^	12	67	2.5	2.9	5.39	0.0008*
Zinc	0.0421	0.0018	12	67	43.6	10.4	54.1	0.0079#

Note: Gw. = Groundwater; ^Injection well IW-01 copper concentration equalled <0.0005 g/m^3, so in the interests of conservatism the concentration in the calculations was specified as 0.0005 g/m3 rather than 0 g/m^3; * ANZG 95 guideline value of 0.0014 g/m^3; # ANZG 95 guideline value of 0.008 g/m^3.

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[1] These seepage values were taken from an active pit located in the middle of the area to be mined. These values were considered to be broadly representative of the seepage rates, although significantly higher seepage rates were modelled at the periphery as the active pit approached hydrological boundaries. The proportions of seepage contributions are more significant than absolute values on concentrations.

The calculation used the approach of multiplying the concentrations by respective pumping rates to derive the daily masses for copper and zinc. The masses were then combined and divided by the combined pumping rate to derive the representative pit concentration for each dissolved metal. Both combined concentrations would fall below the relevant ANZG 95% protection level guideline, but only just in the case of zinc.

Thin Basal Gravel underlain by Sand

Figure 4 illustrates the thin gravel underlain by fine sand hydrogeological scenario. It is consistent with the pattern observed in the drilling / logging of the injection well earlier in September 2023. No groundwater modelling yet exists for scenario, so estimated groundwater seepage contributions guided by the indicative split between shallow sand, deep gravel and deep sand in terms of both saturated thickness and permeability. The split of pumping per layer is estimated as follows:

- Shallow (ore sand) 10 L/s (20% of total pumping)
- Deep (sandy gravel) 35 L/s (70% of total pumping)
- Deep (fine sand) 5 (10% of total pumping)
- Total pumping 50 L/s

The impact on pumped mine water metals concentrations would have been to reduce concentrations due to the dilution effect of the lower metals concentrations in the deep groundwater in the thin sandy gravel layer. The higher concentrations in the deep fine sand would tend to counteract the dilution but the deep fine sand seepage rate contribution is relatively minor. The assumption is made that the deep fine sand groundwater has metals concentration the same as the mean concentrations for the shallow sand. The projected impact on final concentrations using the 20:70:10 split is developed in Table 2.

Table 3: Summary of Calculated Metals Concentrations considering a 20:70:10 Split for Three Layers

	Mean Gw. Concentration (g/m^3)			Combined Mass	Combined Concentration	ANZG 95 Guideline
	Shallow sand	**Gravel**	**Deep sand**	**(g/d)**	**(g/m^3)**	**(g/m^3)**
Cooper	0.0024	0.0005*	0.0024	4.64	0.0011	0.0014
Zinc	0.0421	0.0018	0.0421	60.2	**0.0140**	0.0080

Note: Gw. = Groundwater. * Injection well IW-01 copper concentration equalled <0.0005 g/m^3, so in the interests of conservatism the concentration in the calculations was specified as 0.0005 g/m^3 rather than 0 g/m^3. **Bold** indicates the combined concentration exceeds the relevant ANZG 95 guideline.

The combined concentration for copper would fall below the relevant ANZG 95% protection level guideline, while the zinc combined concentration is above. These estimated concentrations are based on a series of assumptions, so the assumption would benefit from listing –

- Assumed general layering of sand, sandy gravel and sand is taken from the injection well drilling log (see Figure 3),
- Assumed commonality in ore sand and deep sand permeability as 3 m/d (see Figure 4),
- The assumption is made that the higher horizontal and vertical hydraulic conductivity of the sandy gravel would allow gravel layer groundwater to dominate the inflow of water to the sand extraction pit,
- The assumption is made that the total seepage from all layers would be lower for the Thin Basal Gravel underlain by Sand scenario versus the Thick Basal Gravel scenario, and
- The assumption is made that the deep sand would hold high metals concentrations, even though deep circulation and the probable absence of electron donors from organic material mitigates against it.

Concluding Comments

The following concluding comments are offered.

1. Previous metals concentrations assessment had not considered the possibility that contrasting geochemical conditions in the underlying hydrogeological layer could alter the pumped pit water metals concentrations,
2. Groundwater metals concentration in a single deeper well recently screened in the deeper gravel layer was marked lower, in fact the lowest of any groundwater samples taken within the Cowan Block,
3. Given that previous quasi-three dimensional numerical modelling had indicated that the deeper gravel layer was the predominant source of water pumped out of the active mine pit, projected mine water metals concentrations could be expected to be lower than previously indicated,
4. The recently drilled deeper well log also indicated the basal gravel may be thinner and underlain by fine (less permeable) materials, suggesting the following –
    a. The overall seepage rates pumped from the mining areas would be lower than previously assessed, and
    b. The metals concentrations reporting to the mine pits and pumped into the mine water system would have lower concentrations than previously indicated, including for dissolved copper and zinc that had been found to commonly exceed their respective ANZG 95 guideline concentrations in sampling of shallow groundwater.
5. Preliminary estimation of alterations to potential mine water metals concentrations focusing on copper and zinc, indicate that such concentrations area likely to fluctuate but should be generally lower than concentrations indicated from November 2022 shallow groundwater sampling.