

# Oparure Quarry South-Western Pit: Water Assessment

✦ Prepared for

Graymont (NZ) Limited

✦ July 2026



PATTLE DELAMORE PARTNERS LTD  
South British House, Level 2  
35 Grey Street, Tauranga 3110  
PO Box 13274, Tauranga 3141, New Zealand

Tel +64 7 985 6440  
Web [www.pdp.co.nz](http://www.pdp.co.nz)



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### DOCUMENT CONTRIBUTORS

Prepared by

SIGNATURE

Linda Shamrock

Blair Thornburrow

Celyn Khoo

Reviewed by

Approved by

SIGNATURE

Blair Thornburrow

Hayden Easton



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## Executive Summary

This report presents an assessment of water quantity and quality effects for Graymont (NZ) Limited's proposed Oparure Quarry South-Western Pit (SW Pit) and haul road (the Project). The report is to support a substantive application under the Fast Track Approvals Act. The assessment addresses potential effects on surface water and subsurface (karst) water bodies, with a focus on water quality (and related hydrological considerations) in the receiving environment and identifies mitigation and monitoring measures suitable to be incorporated into approval conditions.

The Project is located within a karst landscape where water commonly transitions between surface waterways and subsurface conduit flow via sinkholes/tomos and caves. These conditions can result in relatively rapid transport of sediment and other contaminants between source areas and downstream receptors. The assessment therefore considers both surface water and connected subsurface flow paths (consistent with the Operative Waikato Regional Plan's approach to karst waters), including key receptors associated with the Mangapu River and tributaries, the Mangawhitikau Stream (including submergence/resurgence reaches and associated cave systems), and the Camelot Stream/Pōtea Spring system.

Existing environmental conditions were characterised using catchment delineation and subsurface connectivity informed by dye tracing, development of a conceptual model of subsurface flow pathways, and review of baseline monitoring data. Baseline datasets include discrete surface water sampling and flow measurements at sites in the Mangapu River and Mangawhitikau Stream under a range of hydrological conditions, higher-frequency instream monitoring (including sonde records), and monitoring undertaken for compliance with existing Oparure Quarry consents. Where access and safety constraints limit direct monitoring within cave systems, representative upstream and downstream monitoring locations were used to infer karst system responses.

Baseline results in the Mangawhitikau Stream and Mangapu River show that turbidity/suspended sediment concentrations (SSC), total phosphorus, dissolved reactive phosphorus, total nitrogen, nitrate-nitrogen, and *E. coli* can be elevated relative to applicable guideline values (Waikato Regional Council guidelines, NPS-FM 2020 (Updated 2025); ANZG (2018)) during rainfall-driven events.

High-frequency sonde monitoring indicated low baseline turbidity in the Mangawhitikau Stream and Pōtea Spring with short duration spikes associated with rainfall. The Pōtea Spring is a location that would be most affected by activities at the existing Oparure Pit and the proposed SW Pit in the future. Sonde data also showed a reduction of baseline concentrations by a factor of 3 and reduction of peak concentrations during storm events by a factor of 8

between the upstream waterway and Pōtea Spring. This provides an indication of the attenuation of SSC that occurs through the subsurface environment.

The results indicate that agricultural land-use activities are the primary contributing factor for all the contaminants listed above, although quarrying activities may add a small contribution to suspended sediment loads in the surface waterways. The contribution of quarrying to the other observed contaminants is expected to be negligible.

The primary water quality concern for the Project is suspended sediment being entrained in stormwater, then infiltrating karst strata and flowing into the receiving environment. The greater distance and therefore travel time from the SW Pit to Pōtea Spring (3 km) is expected to increase mixing and attenuation processes within the Camelot Stream compared to suspended sediment derived from the existing Oparure Pit.

The potential for Project related changes in water quality during the operational phase was evaluated using water quality modelling alongside the conceptual understanding of hydrological connectivity. The assessment identifies suspended sediment mobilisation and transport during earthworks and operational activities, particularly during high rainfall events, as the primary potential effect pathway. Secondary considerations include the potential for contaminants associated with machinery and fuels, and the need to manage runoff pathways so that disturbed area drainage does not create direct connections to sensitive karst features.

Mitigation is based on a hierarchy of avoidance, minimisation, treatment and monitoring/response through an erosion and sediment control plan. Key measures recommended for the Project include:

- ✧ Staging works to minimise the area and duration of exposed surfaces and implementing progressive stabilisation;
- ✧ Clean/dirty water separation and drainage management to minimise connectivity of sediment laden runoff to tomos/dolines and other sensitive karst features where practicable;
- ✧ Erosion and sediment controls designed, installed and maintained for event conditions (including inspection and maintenance requirements);
- ✧ Operational controls and contingencies for rainfall triggered risk periods (e.g., pre-storm preparedness, post-storm inspections and corrective actions); and,
- ✧ Hazardous substance management (storage, refuelling, spill prevention and response) to avoid contaminant releases.

Alongside proposed erosion and sediment control management at the quarry site, a range of betterment measures are proposed to offset sediment load increases with a net reduction in sediment load. Both short- and long-term goals set out in Waikato Regional Council (WRC) Plan Change 1 (PC1) will be achieved (insofar as is relevant to the site and its contribution to these catchment / sub-catchment water quality issues). A number of options were assessed to meet a net zero sediment load discharge from the SW Pit and to also align with the policies of WRC PC1.

The options considered were:

- ✧ Native planting of eroded dolines in the upper catchment and inclusion of a silt fence at the entrance to the dolines.
- ✧ Riparian planting within the Mangawhitikau and/or Mangapu catchments.

Planting of riparian margins and steep slopes susceptible to erosion will be implemented in several locations to achieve net water quality improvements in terms of sediment load at Pōtea Spring and the Mangapu Stream compliance point. These measures will provide water quality improvements exceeding Graymont's necessary contribution towards meeting the short and long term PC1 goals at the Mangapu River compliance point.

Overall, the assessment indicates that potential effects on water values are primarily associated with event driven sediment mobilisation and transport, and that these effects can be appropriately managed through erosion and sediment controls and betterment measures. The measures outlined in this report are intended to support the development of enforceable approval conditions that manage discharges, protect downstream receiving environments, and confirm performance over the life of the Project. Ultimately, all of the Project's adverse water quality effects are considered to be minor (or less) when all of the applicable mitigation measures are applied.

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## 1.0 Introduction

Graymont (NZ) Limited (Graymont) is submitting a substantive application under the Fast-track Approvals Act 2024 for the Oparure Quarry South-Western Pit ('SW Pit') and Haul Road project ('the Project'). Graymont has engaged Pattle Delamore Partners (PDP) to prepare various technical assessments to support the application, including an assessment of effects on water quality and quantity.

The karst environment in which the SW Pit is located, hosts waterways that exist in both surface and subsurface environments. This report assesses the potential effects on water courses in the vicinity of the SW Pit, both surface and subsurface.

Modelling of water quality was conducted to assess the potential for water quality change as a result of the Project during the operative phase.

## 2.0 Existing Environment

### 2.1 Water Type Classification

Given the unique karst environment in which the SW Pit is situated, any assessment of water quality and quantity requires consideration of the hydrological processes occurring in these systems. The standard classifications of surface water and groundwater require additional context owing to the influence of karst features on hydrology.

Although water flowing through cave systems meets the scientific definition of groundwater, it behaves like surface water, moving quickly along subsurface flow paths. At points along these flow paths, referred to as 'submergence' and 'resurgence' locations, water can shift between surface and subsurface states. Slower moving groundwater exists in pores and small cracks but plays a minor role in local water movement. Under the Waikato Regional Plan (WRP), water in karst systems is classified as surface water. This report uses the term to include both traditional surface water and subsurface flow in caves, which the Waikato Regional Council (WRC) classification recognises as a connected network.

### 2.2 Surface Water Catchment Delineation

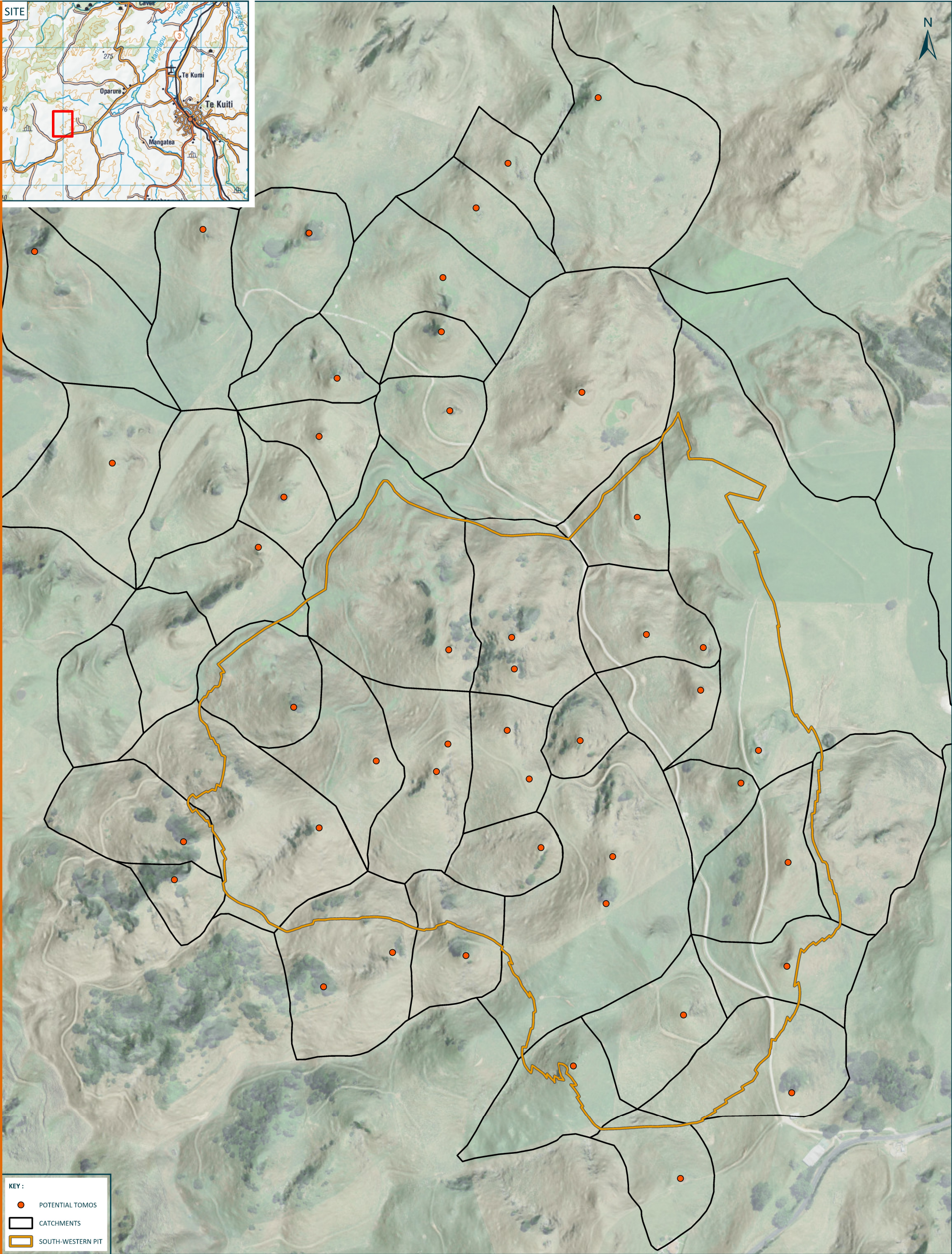
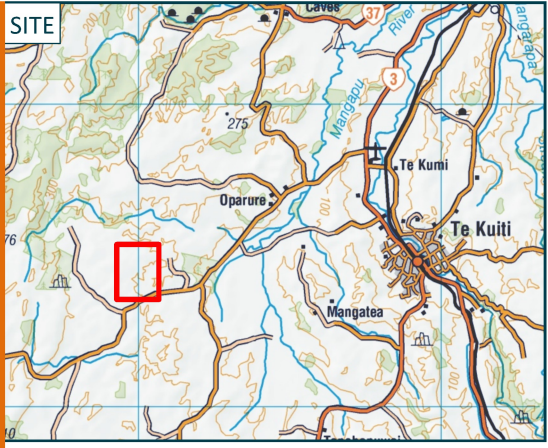
The surface water catchments within the Project area are typical of a karst landscape in which drainage catchments are very small with radial flow paths to a central tomo/doline. Due to the formation of this landscape, surface water flow paths i.e. overland flow paths, are limited to non-existent. Surface water runoff often drains via rapid infiltration to underground cave networks of various size and extent. Figure 1 presents an illustration of the sub-catchments within and directly adjacent to the Project area. The figure illustrates the influence of the karst geology in the area with surface water having small radial sub-

catchments. Appendix A presents discussion on the geological setting of the Project area and surrounds.

There are two primary catchments within vicinity of the SW Pit, containing several surface and subsurface water bodies as well as cave systems (Figure 2). To the north is the Mangawhitikau Stream catchment, which is dominated by farmland with both submerging and resurging water flow due to the karst landscape. This catchment also consists of the Spirit and Guildford Caves and the Camelot Stream. The Camelot Stream is predominantly a subsurface waterway, that is inferred to flow beneath the floor of the SW Pit. It remains subsurface and has no surface expression within the footprint of the SW Pit. No ephemeral watercourses are present within the pit footprint. To the south is the Mangapu River catchment, which is also dominated by farmland with both submerging and resurging water flow due to the karst landscape.

For purposes of illustrating the Camelot Stream, bold lines represent stream flows at ground elevation, while dashed lines indicate approximated subsurface flow paths. It is important to note that surface water catchments presented in Figure 2 serve as representations of broader catchment areas and that exact boundary locations are unclear in areas draining to tomos, such as within the SW Pit footprint.





- KEY :
- POTENTIAL TOMOS
  - CATCHMENTS
  - SOUTH-WESTERN PIT

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FIGURE

FIGURE 1: CATCHMENTS AND POTENTIAL TOMOS

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SOUTH-WESTERN PIT: WATER ASSESSMENT



### 2.2.1 Mangawhitikau Stream

The Mangawhitikau Stream is located to the north of the SW Pit. The catchment land use is dominated by agriculture, however, the Mangawhitikau Stream has greater areas of native forest within the upper catchment, as well as exotic forest. The stream is also influenced by the karst landscape in the vicinity of the proposed pit, with the stream submerging and re-emerging from underlying cave networks.

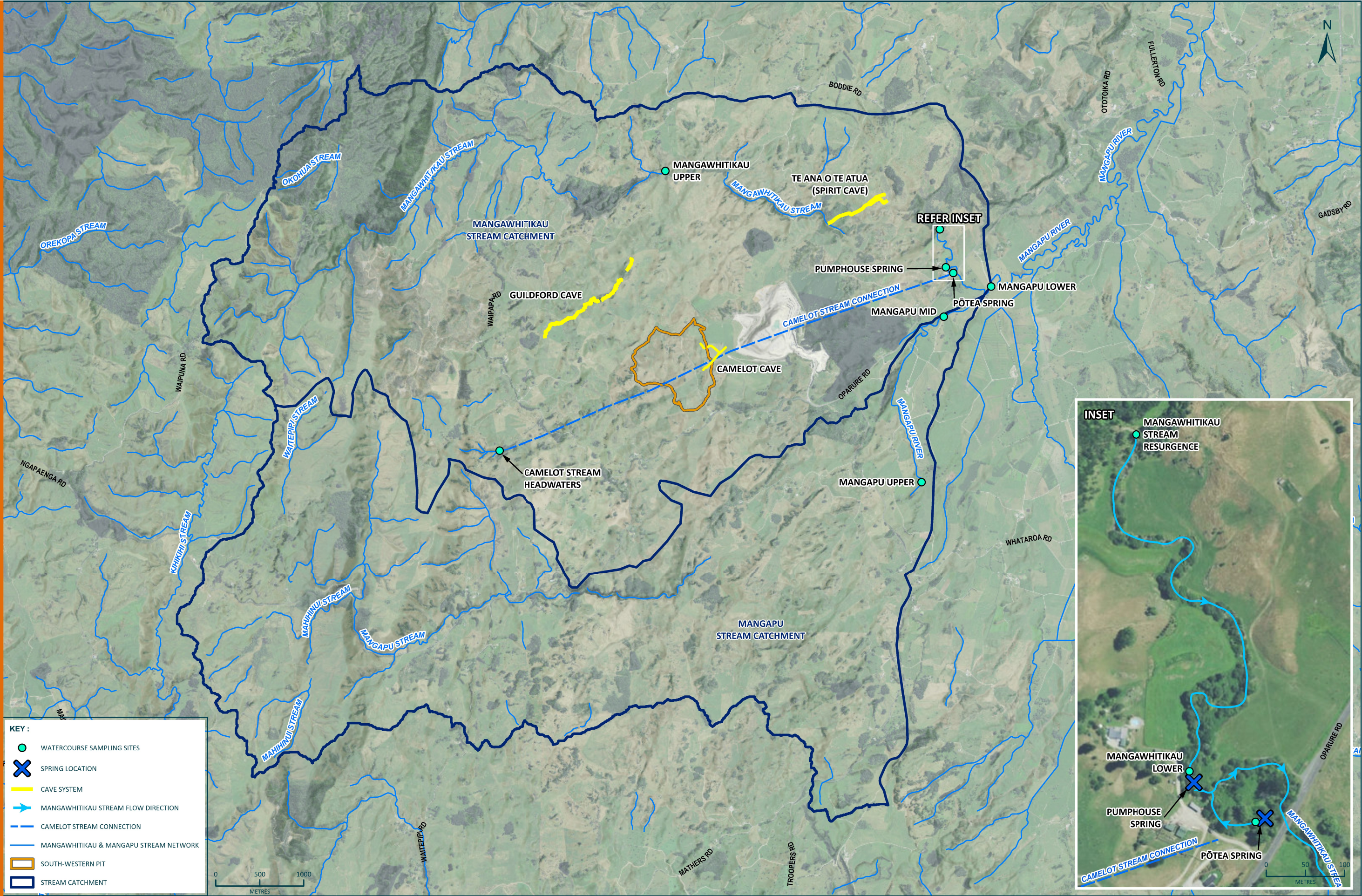
The Mangawhitikau Stream drains to the Mangapu River approximately 2 km east of the current Oparure quarry. Graymont currently undertakes monitoring within the lower reaches of the Mangawhitikau Stream to evaluate compliance with existing resource consents for the Oparure quarry.

The Guildford cave is located northwest of the SW Pit and is within the Mangawhitikau Stream catchment. As discussed in later sections of this report, dye tracing undertaken demonstrated that no discharges from the SW Pit area will enter the Guildford cave system.

### 2.2.2 Camelot Stream

As previously described, the Camelot Stream is a subterranean stream flowing within the karst cave network. The stream flows through the Camelot Cave system (discussed in the following section) and occurs at the base of an approximately 70 m deep shaft immediately east of the proposed SW Pit boundary (based on cavers' reports). Once the SW Pit is constructed, the cave hosting the Camelot Stream is expected to occur at a depth of at least 8 m below the final pit floor level (according to analysis by Baseline Geotechnical). To the southwest of the SW Pit, headwaters of the Camelot Stream flow aboveground before submerging into a cave (Figure 2).







### 2.2.3 Mangapu River

The Mangapu River is located to the south and east of the SW Pit with the catchment upgradient of the SW Pit dominated by farmland. The river has sporadic areas of overhead vegetation cover and small reaches where the river is incised. Flood plains have extents in the upper catchment of up to 50 m (based on visual observations) upgradient of the SW Pit. Due to the karst landscape, the Mangapu River submerges and resurges throughout the upper catchment with water flowing within underground cave networks in some areas.

The Mangapu River drains to the Waipa River south of Otorohanga. A WRC-operated monitoring station (both hydrometric and water quality) is located south of Otorohanga (NZTM:1790885 – 5764622).

Tangata whenua have significant regard for the Mangapu catchment. Recently, the local Oparure community (which includes Te Wharekura O Maniapoto, iwi, agencies and councils and other local community members) have obtained Waikato River Authority funding (WRA 13-051) to undertake river enhancement projects (primarily 6 km of riparian planting) within the Mangapu River catchment.

### 2.2.4 Cave Networks

Other technical reports provided in the substantive application discuss the cave networks in the vicinity of the SW Pit in further detail. As discussed in earlier sections of this report, the three streams (Mangapu, Mangawhitikau, and Camelot) all submerge into and resurge from the subsurface cave system. Runoff generated from within the SW Pit footprint will primarily drain into the karst strata via the pit floor.

To better understand the Camelot cave, professional cavers were engaged to enter the cave system and undertake technical assessments. During the first investigation (December 2020), the stream was observed to have an estimated flow of 20-30 L/s, with minor turbidity, and minor settled sediment. During this first investigation, low oxygen levels were detected in the Camelot cave, forcing the cavers to evacuate and abandon the work. A second investigation of the Camelot cave in January 2021 identified low oxygen conditions at the cave entrance preventing entry. No further direct exploration into Camelot cave has been undertaken due to the low oxygen levels and the associated health and safety risks. Efforts continue, however, to gain access to the cave in a manner that protects the health of those attempting to get samples. The most recent approach involves the prospect of drilling bore holes down into the cave, to enable samples to be collected from ground level.

Given the current inability to safely access the entirety of the cave system, Graymont and its experts have developed measures to protect the Camelot Cave, including a proposed 200 m wide buffer zone (Camelot Cave Buffer Zone) around

the projected extent of the cave system in the early stages of development, and until further investigations can be safely completed. These measures are further detailed in Baseline Geotechnical's geotechnical review appended to this substantive application as well as proposed conditions of consent.

Given the current information known about the cave system, an alternative approach was used to determine possible baseline water quality in the Camelot Cave system without physical entry to the cave system. Dye tracing was used to determine if an unnamed stream upgradient of the Camelot Cave system, which submerges into the ground around 1.6 km south-west of the SW Pit, was connected to the Camelot Stream system. Results confirmed that the unnamed stream is a connected headwater of the Camelot Stream.

Water quality sondes were then deployed at this headwater stream and Pōtea Spring to monitor baseline water quality over periods in 2021 and again in 2025/6. This approach to determine the Camelot Stream baseline water quality was discussed on 2 June 2021 with Dr Eloise Ryan of WRC and approved in principle as an accepted methodology.

### 2.3 Subsurface Catchment Delineation

Several rounds of dye tracing testing have been conducted within and surrounding the SW Pit extent to confirm catchment divides given that surface topography is an unreliable indicator of subsurface water movement in the karst environment. Divides between the Mangawhitikau and Mangapu systems, as well as between upper and lower sections of the Mangawhitikau Stream were specifically targeted.

The results of these tests were used to inform the final pit design such that any water discharges from the SW Pit area would be contained within the Lower Mangawhitikau (below its resurgence) and downstream reaches of the Mangapu River.

The first period of dye tracing testing was conducted in three rounds between 31/7/2020 and 2/12/2020. A second period of dye tracing was conducted between 12/06/2023 and 22/08/2023.

Full details of the various dye tracer tests, methodology and results are provided in Appendix C. Results are also summarised in Figure 3.

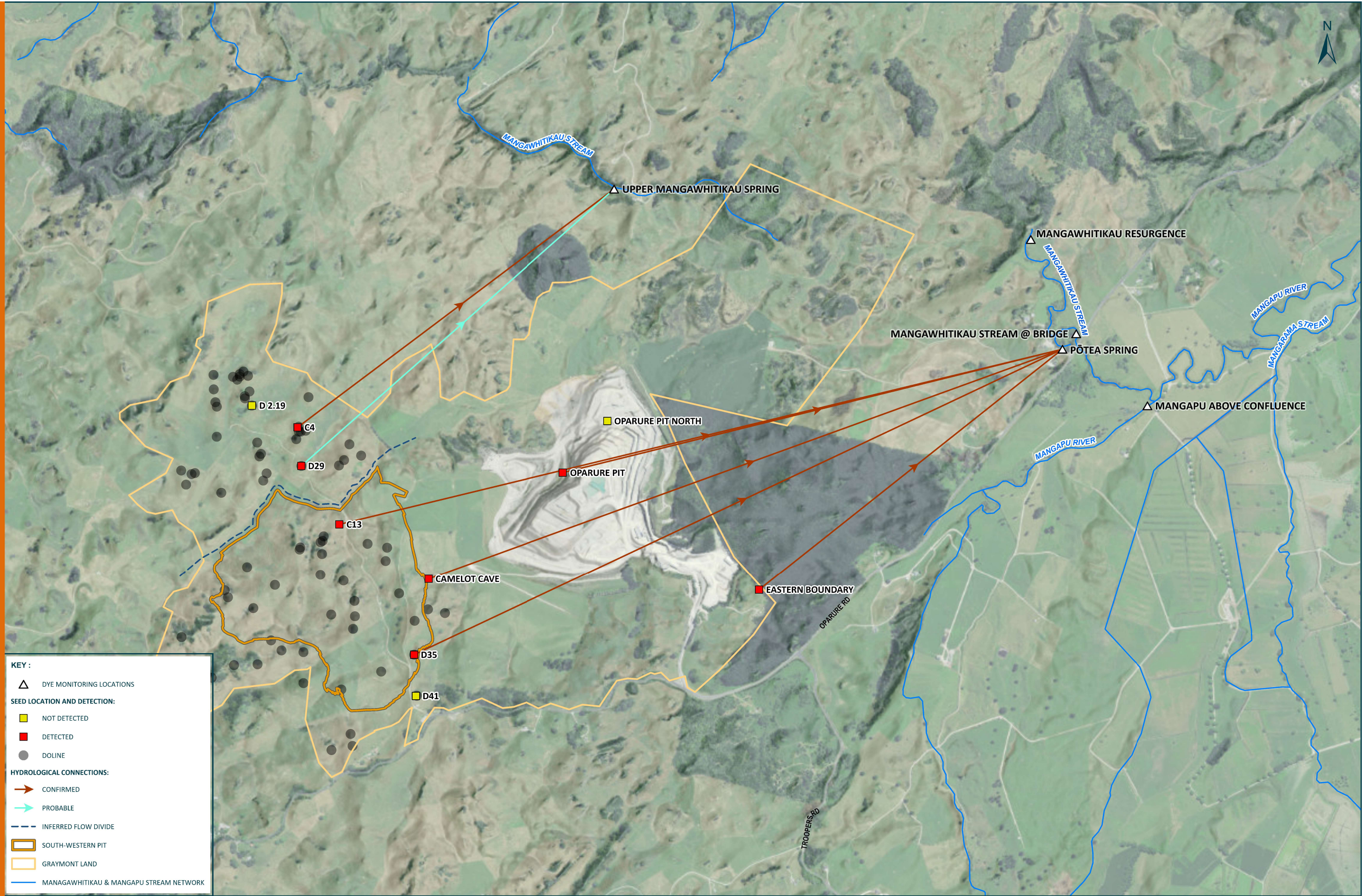
Other key observations included the following:

- ✧ These tracer tests identified the presence of a subsurface flow divide in the vicinity of the SW Pit. South of the divide, water drains through Camelot Stream to Pōtea Spring and north of the divide, water drains to the upper Mangawhitikau stream. The inferred location of the subsurface flow divide is shown in Figure 3. This flow divide informed the final design of the SW Pit such that discharges would not be directed

to the Upper Mangawhitikau Stream (i.e. upgradient of the Mangawhitikau Stream resurgence).

- ∴ Dye introduced north of the flow divide took approximately one day (25 hours) to reach the Mangawhitikau Resurgence, whereas dye injected south of the divide took between 29-46 hours to reach Pōtea Spring.
- ∴ An additional dye tracer test (not shown in Figure 3), confirmed connection between the Camelot Stream headwaters and Pōtea Spring.





**KEY :**

△ DYE MONITORING LOCATIONS

**SEED LOCATION AND DETECTION:**

■ NOT DETECTED

■ DETECTED

● DOLINE

**HYDROLOGICAL CONNECTIONS:**

→ CONFIRMED

→ PROBABLE

--- INFERRED FLOW DIVIDE

□ SOUTH-WESTERN PIT

□ GRAYMONT LAND

— MANAGAWHITIKAU & MANGAPU STREAM NETWORK



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FIGURE

FIGURE 3: SUMMARY OF DYE TRACER INVESTIGATION RESULTS

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SOUTH-WESTERN PIT: WATER ASSESSMENT



## 2.4 Conceptual Model of Subsurface Flow

Results obtained from the various dye tracer tests carried out in the SW Pit area and surrounds provided the following information about the subsurface flow system. It is evident from the testing results that the transit time of water within the subsurface flow network depends on the point of entry, and the connection of those entry points to major subsurface flow paths. The subsurface flow network is conceptualised as being similar to a dendritic<sup>1</sup> surface stream network in which low order tributaries progressively combine to become higher order streams and rivers. A conceptual diagram of this system is presented in Figure 4.

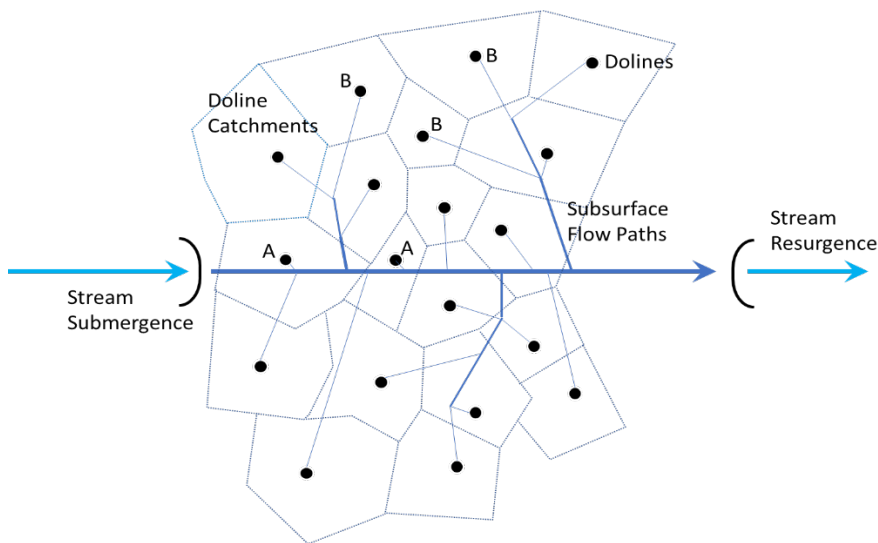
Water flow rates and velocities are greatest within the higher order flow pathways (e.g. the Camelot Stream and Upper Mangawhitikau Stream). Once water enters a main flow path, transit times to outlet points in the system (e.g. Pōtea/Pumphouse Spring/Upper Mangawhitikau Springs) are relatively short. Some dispersion and turbulent mixing will occur within the main flow pathway, with further dilution related to the relative contribution of subsequently joining flow paths.

Flow rates and velocities of water entering the system via low order pathways (e.g. individual dolines), and draining limited catchment areas, will initially be relatively low. Depending on the travel distance and connectivity with other tributaries, movement of water from the point of entry to a higher order flow path may constitute the majority of its subsurface transit time with diffusion and filtering occurring along these pathways. Significant dilution and mixing of waters in low order tributaries will occur when entering higher order flow paths with higher flow rates.

---

<sup>1</sup> Having a branched form resembling a tree.





**Figure 4: Conceptual model of subsurface flow paths in the karst system**

Based on the conceptual model described above, pulses of contaminants entering the system (such as suspended sediments) are expected to undergo differing levels of temporal attenuation depending on the point of entry. Higher attenuation will occur for contaminant pulses entering low order, poorly connected entry points (e.g. points marked “B” in Figure 4), while greater dilution will occur for pulses flowing more directly into major flow paths (e.g. points marked “A”).

## 2.5 Baseline Monitoring

The following section presents measured baseline hydrological and water quality data obtained at various locations surrounding the SW Pit. It should be acknowledged that this baseline data may be influenced by discharge effects associated with the existing Oparure quarry (located 1.7 km west of Pōtea Spring). Whilst cumulative effects are not accounted for in the baseline data (from both Oparure Quarry and the SW Pit), the data does give an indication of the water quality conditions occurring in receptors influenced by the existing quarry operations. These operations have contaminant control practices/methods similar to those proposed to be employed for the SW Pit.

### 2.5.1 Overview of Flow Monitoring

PDP conducted flow measurements in three locations within the Mangapu River and two locations within the Mangawhitikau Stream under various hydrological conditions (Figure 2). Five flow measurements were undertaken at the five Mangapu River and Mangawhitikau Stream sites in 2019. These measured flows included low flow conditions (2<sup>nd</sup> and 16<sup>th</sup> of April), mid flow conditions (28<sup>th</sup> August and 19<sup>th</sup> September) and flood flow on the 14<sup>th</sup> of August.

Water discharge measurements were obtained in conjunction with water quality samples (further discussed in Section 2.5.2). The type of sensor used (ADCP Flowtracker, or an ADCP Sontek M9 sensor with a hydroboard for higher flow/greater depth conditions) was dependent upon the health and safety risk identified at the monitoring locations (observed flow velocities and/or the water depth).

**Table 1: Surface water flows (m<sup>3</sup>/s) during PDP water quality monitoring events**

| Monitoring Date | Monitoring Location |                  |                 |                       |                       |
|-----------------|---------------------|------------------|-----------------|-----------------------|-----------------------|
|                 | Mangapu (Upper)     | Mangapu (Middle) | Mangapu (Lower) | Mangawhitikau (Upper) | Mangawhitikau (Lower) |
| 2/4/2019        | 0.017               | 0.169            | 0.358           | 0.109                 | 0.177                 |
| 16/4/2019       | 0.013               | 0.103            | 0.253           | 0.056                 | 0.123                 |
| 14/8/2019       | 1.908               | 6.193            | 8.383           | 1.931                 | 5.459                 |
| 28/8/2019       | 0.675               | 2.358            | 4.423           | 0.813                 | 1.587                 |
| 19/9/2019       | 0.503               | 2.584            | 4.747           | 1.09                  | 1.563                 |

Data from the long-term WRC water quality and flow monitoring station located south of Otorohanga in the Mangapu River was evaluated for further comparison with datasets obtained by PDP. The flow record from the WRC Mangapu monitoring station was used to develop synthetic flow records for the Mangapu River (upstream of the confluence) and Mangawhitikau Stream. Further discussion of this process can be found in Appendix B. Flow duration curves and key flow statistics for the two surface water bodies are also detailed in Appendix B: .

### 2.5.2 Overview of Water Quality Monitoring

Water quality was monitored at ten sites: eight surface water and two subsurface water sites around the SW Pit, varying in sampling frequency, duration, and parameters (Table 2). The monitoring locations are shown in Figure 2.



| Table 2: Surface and Subsurface Water Quality Monitoring Overview |                          |                    |                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-------------------------------------------------------------------|--------------------------|--------------------|-----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Water Type Classification                                         | Monitoring Location      | Sampling Frequency | Period                            | Parameters                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Surface Water                                                     | Mangapu Lower            | Discrete (n = 5)   | 2019-2020                         | <ul style="list-style-type: none"> <li>General water quality (pH, electrical conductivity, total alkalinity)</li> <li>Nutrients (nitrogen and phosphorus)</li> <li>Total suspended solids</li> <li>Carbonaceous biological oxygen demand</li> <li>Major ions (sodium, potassium, calcium, magnesium, chloride, sulphate)</li> <li>Microbial indicators (<i>E. coli</i>, faecal coliforms)</li> </ul> YSI ProDSS: <ul style="list-style-type: none"> <li>Dissolved Oxygen (measured as % sat and mg/L)</li> <li>Turbidity (FNU)</li> <li>Water Temperature (°C)</li> </ul> |
| Surface Water                                                     | Mangapu Mid              |                    |                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Surface Water                                                     | Mangapu Upper            |                    |                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Surface Water                                                     | Mangawhitikau Lower      |                    |                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Surface Water                                                     | Mangawhitikau Upper      |                    |                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Surface Water                                                     | Mangawhitikau Resurgence | 15-minute          | January to February 2020          | <ul style="list-style-type: none"> <li>Specific Conductivity (µS/cm)</li> <li>Dissolved Oxygen (measured as % sat and mg/L)</li> <li>Turbidity (FNU)</li> <li>Water Temperature (°C)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                           |
| Subsurface Water                                                  | Guildford Cave           | 15-minute          | 19 August 2019 to 10 October 2019 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Subsurface Water                                                  | Spirit Cave              | 15-minute          | 15 August 2019 to 10 October 2019 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

| Table 2: Surface and Subsurface Water Quality Monitoring Overview |                           |                    |                                                                            |            |
|-------------------------------------------------------------------|---------------------------|--------------------|----------------------------------------------------------------------------|------------|
| Water Type Classification                                         | Monitoring Location       | Sampling Frequency | Period                                                                     | Parameters |
| Surface Water                                                     | Camelot Stream headwaters | 15-minute          | 25 June 2021 to 10 September 2021 and 15 December 2025 to 26 February 2026 |            |
| Surface Water                                                     | Pōtea Spring              | 15-minute          | 25 June 2021 to 10 September 2021 and 15 December 2025 to 26 February 2026 |            |

To the north and south of the SW Pit, hydrological and surface water quality monitoring was undertaken at five locations along the Mangawhitikau Stream and Mangapu River. Water quality, physico-chemistry, and discharge were measured in 2019 under various hydrological conditions as described in 2.5.1 and included low flows, winter high flows, and a flood event in August 2019. The monitoring dataset captured a range of hydrological conditions and is considered sufficient to characterise natural variability in flow regimes and associated contaminant loads near the SW Pit. Land use has not significantly changed since this data was obtained, so results are still considered valid to understand baseline condition within these receiving environments.

All discrete water quality data collected for the Mangawhitikau Stream and Mangapu River, including results reported at or below the analytical detection limit, are provided in Appendix D.

EXO water quality sondes, collecting physico-chemical data, were also deployed at multiple locations within and adjacent to the SW Pit:

- ✧ Mangawhitikau Resurgence – Surface water within the resurgence zone of the Mangawhitikau Stream
- ✧ Guildford Cave – a cave system part of the Mangawhitikau catchment that is located to the north of the SW Pit
- ✧ Spirit Cave – a cave system part of the Mangawhitikau catchment that is located to the north-east of the SW Pit
- ✧ Camelot Stream headwaters – surface water tributary located 1.6 km south-west (upgradient) of the SW Pit
- ✧ Pōtea Spring – surface water within the downstream point of flow emergence

Water quality sondes were deployed at the Camelot Stream headwaters and Pōtea Spring to develop an understanding of the baseline water quality of the stream flowing beneath the SW Pit. Water quality data within the Camelot Stream cannot be obtained from the area directly below the SW Pit. Hence these monitoring sites represent the closest locations upstream and downstream of the SW Pit which are safely accessible for water quality monitoring. All physico-chemical data obtained by the sondes is presented in Appendix E.

#### 2.5.2.1 Graymont Resource Consent Compliance Monitoring Data

As a requirement of the resource consent conditions for the Oparure Quarry (resource consent AUTH142709.02.01 condition 6), Graymont undertakes compliance monitoring at three locations at the Mangawhitikau Stream and at the discharge from the site's storage lagoon. Discrete manual grab samples



obtained are analysed for pH, turbidity, dissolved boron<sup>2</sup>, and Suspended Solids Concentration (SSC) at each site.

Table 3 presents a summary of the minimum, average and maximum concentrations for the various parameters measured for the current site operations, and the consent limits required by resource consent AUTH142709.02.01.

It should be noted that compliance monitoring is triggered only during rainfall events exceeding 50 mm within a 24-hour period. As such, the monitoring data are weighted toward high-flow conditions and are not representative of baseline water quality within the Mangawhitikau Stream, instead reflecting elevated or worst-case conditions.

The water quality monitoring conducted to date shows full compliance with the consent conditions.

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<sup>2</sup> Not sampled at the Stormwater Pond

| Table 3: Measured Water Quality                |                                                                               |                        |         |         |         |                                                                                                            |
|------------------------------------------------|-------------------------------------------------------------------------------|------------------------|---------|---------|---------|------------------------------------------------------------------------------------------------------------|
| Sample Location                                | Period of record and number of samples                                        | Parameter              | Minimum | Maximum | Average | WRC Consent Limit <sup>1</sup>                                                                             |
| Storage Lagoon Discharge                       | 17/6/2013 - 15/7/2020, <i>n</i> = 50<br>11/1/2022 – 3/12/2025, <i>n</i> = 86  | pH                     | 7.25    | 10.91   | 9.23    |                                                                                                            |
|                                                |                                                                               | Turbidity (NTU)        | 0.34    | 136.00  | 23.29   |                                                                                                            |
|                                                |                                                                               | SSC (mg/L)             | 0.70    | 78.00   | 15.62   | Shall not exceed 100 mg/L                                                                                  |
| Upstream Mangawhitikau Stream (Sample Point A) | 25/1/2012 – 15/7/2020, <i>n</i> = 122<br>11/1/2022 – 3/12/2025, <i>n</i> = 86 | pH                     | 7.09    | 9.46    | 8.05    |                                                                                                            |
|                                                |                                                                               | Turbidity (NTU)        | 0.0     | >200    | 33.00   |                                                                                                            |
|                                                |                                                                               | SSC (mg/L)             | 0.00    | 986     | 68.25   | When SSC at point B exceeds that of point A by greater than 10, samples to be taken again at point A and B |
|                                                |                                                                               | Dissolved Boron (mg/L) | 0.009   | 0.03    | 0.013   |                                                                                                            |
| Pōtea Spring (Sample Point B)                  | 25/1/2012 – 15/7/2020, <i>n</i> = 121<br>11/1/2022 – 3/12/2025, <i>n</i> = 86 | pH                     | 6.97    | 8.51    | 7.59    |                                                                                                            |
|                                                |                                                                               | Turbidity (NTU)        | 0.0     | >200    | 21.00   |                                                                                                            |
|                                                |                                                                               | SSC (mg/L)             | 0.00    | 756.00  | 45.20   | When SSC at point B exceeds that of point A by greater than 10, samples to be taken again at point A and B |
|                                                |                                                                               | Dissolved Boron (mg/L) | 0.022   | 0.068   | 0.040   |                                                                                                            |
| Gillespies Farm Spring (Sample Point C)        | 14/8/2014 – 15/7/2020, <i>n</i> = 52<br>11/1/2022 – 3/12/2025, <i>n</i> = 80  | pH                     | 6.81    | 8.26    | 7.29    |                                                                                                            |
|                                                |                                                                               | Turbidity (NTU)        | 0.20    | >200    | 14.71   |                                                                                                            |
|                                                |                                                                               | SSC (mg/L)             | 1.00    | 116.00  | 19.89   |                                                                                                            |
|                                                |                                                                               | Dissolved Boron (mg/L) | 0.018   | 0.055   | 0.033   |                                                                                                            |
| Mangawhitikau Resurgence (Sample Point C2)     | 11/1/2022 – 3/12/2025, <i>n</i> = 47                                          | Turbidity (NTU)        | 4.00    | >200    | 96.05   |                                                                                                            |
| Gully Seep (Sample Point GS)                   | 11/1/2022 – 3/12/2025, <i>n</i> = 11                                          | Turbidity (NTU)        | 1.20    | >200    | 21.62   |                                                                                                            |

**Table 3: Measured Water Quality**

| Sample Location                                                                                                                                                                                                                                            | Period of record and number of samples | Parameter       | Minimum | Maximum | Average | WRC Consent Limit <sup>1</sup> |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|-----------------|---------|---------|---------|--------------------------------|
| Final Sediment Retention<br>(Sample Point D2)                                                                                                                                                                                                              | 11/1/2022 – 3/12/2025, <i>n</i> = 18   | Turbidity (NTU) | 1.00    | >200    | 79.46   |                                |
| Pit Floor Final Sediment Retention<br>(Sample Point D3)                                                                                                                                                                                                    | 11/1/2022 – 3/12/2025, <i>n</i> = 36   | Turbidity (NTU) | 0.00    | 55.00   | 7.07    |                                |
| <b>Notes:</b> <ol style="list-style-type: none"> <li>As per WRC Consent no AUTH142709.02.01</li> <li>When rainfall exceeds 50 mm in 24hr samples to be taken and tested from point A and B, and pond discharge for SS, pH, turbidity and Boron.</li> </ol> |                                        |                 |         |         |         |                                |



## 2.6 Water Quality Guidelines

To interpret the water quality monitoring results, several water quality guidelines were applied to determine the baseline status of water quality in the Mangapu River and Mangawhitikau Stream. These include:

- ✧ National Policy Statement for Freshwater Management (NPSFM-2020 amended 2025).
- ✧ Australia New Zealand Guidelines for Fresh and Marine Water Quality Guidelines (ANZG 2018).
- ✧ Waikato Regional Council (WRC) guidelines.
- ✧ Waikato Regional Plan Change 1.

The Waikato Regional Plan Change 1 has guidelines for the Mangapu River at Otorohanga for nitrate, ammonia and water clarity. As such, this technical report has been prepared with specific regard to these parameters.

The average water quality data obtained in the Mangapu River and Mangawhitikau Stream were assessed by comparing the data to the ANZG, NPSFM and the WRC guidelines. It must be noted however that there are some limitations in comparing our five rounds of sampling in the Mangapu River and the Mangawhitikau Stream (in the direct vicinity of the proposed SW Pit). With the low number of baseline water quality data points, it is not possible to carry out statistical analyses such as percentiles and further monitoring will be required to calculate the statistics for exact comparison with guideline values. When data is collected over a period of time two types of observations can be made:

- ✧ number of exceedances of the target, or
- ✧ comparison of some distributional quantity (e.g. mean, 80th percentile) to its target — particularly useful when the magnitude of the exceedance is important.

As such, for the purposes of understanding environmental effects associated with water quality using the ANZG, NPSFM and the WRC guidelines, the values that have been measured to date have been compared to the relevant triggers, even though those triggers are based on a longer-term dataset than is currently available. This allows conclusions to be reached about the data generally being within a certain band (excellent, satisfactory or unsatisfactory) for the WRC guidelines, within an attribute band for the NPSFM or exceeding the ANZG guidelines. It must be noted that the ANZG 2018 default guideline values for River Environment Classification (REC) classes are based on 80<sup>th</sup> percentile of the reference conditions and on the 20<sup>th</sup> percentile for clarity of the reference conditions (where reference means rivers and streams with minimal or no

anthropogenic influence). The Mangapu River and the Mangawhitikau Stream catchments are within a Warm Wet Low-Elevation (WWL) REC class.

It is also important to note that these water quality guidelines are based on chronic effects and exceedance of these guidelines is due to large scale catchment land-use impacts mostly observed during rainfall events which constitutes an acute effect.

All plots of physico-chemical data measured within the Mangapu River, Mangawhitikau Stream, Spirit Cave, Guildford Cave and Mangawhitikau Stream resurgence zone are presented in Appendix D. For purposes of understanding when water flows are changing, Spirit Cave, Guildford Cave and Mangawhitikau River resurgence plots have also been overlaid with cumulative rainfall (rainfall data obtained from the WRC automatic rainfall station Te Kuiti Rainfall in the Mangaokewa Catchment (NZTM:1789676 – 5754437)).

## **2.7 Water Quality Results & Discussion**

### **2.7.1 Mangawhitikau Stream and Mangapu River**

Table 4 and Table 5 present average water quality data obtained from Mangawhitikau Stream and Mangapu River during the five monitoring rounds as well as the relevant water quality guidelines.

Table 6 presents the average physicochemical data obtained from the Mangawhitikau Stream and Mangapu River.

**Table 4: Average water quality results obtained from Mangapu River and Mangawhitikau Stream with WRC and NPS-FM guidelines<sup>1,2,3</sup>**

| Parameter                             | units            | Mangapu (Upper)       | Mangapu (Middle)      | Mangapu (Lower)       | Mangawhitikau (Upper) | Mangawhitikau (Lower) | Waikato Regional Council Guidelines |                    |                | NPS-FM (2020; Updated Dec 2025)                   |
|---------------------------------------|------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-------------------------------------|--------------------|----------------|---------------------------------------------------|
|                                       |                  |                       |                       |                       |                       |                       | Excellent                           | Satisfactory       | Unsatisfactory |                                                   |
| pH                                    | pH units         | 7.74                  | 7.82                  | 7.74                  | 7.64                  | 7.82                  | 7.0-8.0                             | 6.5-7.0 or 8.0-9.0 | <6.5 or >9.0   |                                                   |
| Electrical Conductivity               | µS/cm            | 252 (215 - 294)       | 186 (174 - 202)       | 212 (193 - 245)       | 164 (134 - 204)       | 248 (207 - 312)       |                                     |                    |                |                                                   |
| Total Alkalinity                      | g/m <sup>3</sup> | 116                   | 82                    | 87                    | 63                    | 92                    |                                     |                    |                |                                                   |
| Chloride                              | g/m <sup>3</sup> | 8.1                   | 7.3                   | 7.4                   | 7.8                   | 7.3                   |                                     |                    |                |                                                   |
| Sulphate                              | g/m <sup>3</sup> | 5.3                   | 4.5                   | 13.4                  | 6.3                   | 23.0                  |                                     |                    |                |                                                   |
| Nitrate-Nitrogen                      | g/m <sup>3</sup> | 2.2 (1.8 – 2.6)       | 1.5 (0.9 – 1.9)       | 1.5 (1.0 – 1.9)       | 1.1 (0.8 – 1.4)       | 1.5 (1.0 – 1.8)       |                                     |                    |                | Attribute band B = 1.0 – 2.4                      |
| Dissolved Reactive Phosphorus         | g/m <sup>3</sup> | 0.018 (0.010 – 0.024) | 0.016 (0.013 – 0.022) | 0.014                 | 0.010                 | 0.014                 |                                     |                    |                | Attribute band C = 0.01 – 0.018 <sup>5</sup>      |
| Ammoniacal Nitrogen                   | g/m <sup>3</sup> | < 0.005               | < 0.005               | < 0.005               | 0.006 <sup>4</sup>    | < 0.005               | <0.1                                | 0.1-0.88           | >0.88          | Attribute band A = 0.03 <sup>6</sup>              |
| Total Suspended Solids                | g/m <sup>3</sup> | 33 (<3 - 107)         | 23 (<3 - 72)          | 28 (<3 - 82)          | 30 (<3 – 124)         | 33 (<3 – 134)         |                                     |                    |                |                                                   |
| Carbonaceous Biological Oxygen Demand | g/m <sup>3</sup> | <1.00                 | 1.11 <sup>4</sup>     | <1.00                 | 1.11 <sup>4</sup>     | <1.00                 |                                     |                    |                |                                                   |
| Total Nitrogen                        | g/m <sup>3</sup> | 2.32 (1.75 – 2.90)    | 1.69 (1.06 – 2.20)    | 1.72 (1.11 – 2.20)    | 1.22 (0.85 – 1.70)    | 1.68 (1.20 – 2.10)    | <0.1                                | 0.1-0.5            | >0.5           |                                                   |
| Nitrite-Nitrogen                      | g/m <sup>3</sup> | 0.001                 | 0.002                 | 0.002                 | 0.002                 | 0.001                 |                                     |                    |                |                                                   |
| Total Kjeldahl Nitrogen               | g/m <sup>3</sup> | 0.19                  | 0.24                  | 0.25                  | 0.18                  | 0.22                  |                                     |                    |                |                                                   |
| Total Phosphorus                      | g/m <sup>3</sup> | 0.061 (0.030 – 0.140) | 0.062 (0.034 – 0.100) | 0.054 (0.026 – 0.095) | 0.058 (0.024 – 0.140) | 0.061 (0.038 – 0.150) | <0.01                               | 0.01-0.04          | >0.04          |                                                   |
| Sodium                                | g/m <sup>3</sup> | 5.35                  | 5.67                  | 5.77                  | 5.86                  | 5.89                  |                                     |                    |                |                                                   |
| Potassium                             | g/m <sup>3</sup> | 1.04                  | 0.96                  | 1.03                  | 1.12                  | 1.08                  |                                     |                    |                |                                                   |
| Calcium                               | g/m <sup>3</sup> | 47.22                 | 31.78                 | 36.72                 | 25.38                 | 41.16                 |                                     |                    |                |                                                   |
| Magnesium                             | g/m <sup>3</sup> | 1.54                  | 1.36                  | 1.89                  | 1.45                  | 2.45                  |                                     |                    |                |                                                   |
| <i>E. coli</i>                        | MPN/100ml        | 125 (63 - >200)       | 317 (46 - 1236)       | 450 (68 - 1450)       | 566 (32 - 1989)       | 702 (28 - 2755)       | <55                                 | 55-550             | >550           | National bottom line (primary contact site) = 540 |
| Faecal coliforms                      | MPN/100ml        | 269                   | 216                   | 268                   | 427                   | 524                   |                                     |                    |                |                                                   |

**Notes:**

1. Green denotes WRC Excellent Band. Yellow denotes WRC Satisfactory Band. Orange denotes WRC Unsatisfactory Band.
2. Ranges are presented in parentheses where there is exceedance of WRC Unsatisfactory Band or ANZG 2018 80<sup>th</sup> percentile value.
3. Where values were at the detection limit, the detection limit was used in calculating the average.
4. Only one sample was measured above the detection limit.
5. Annual median based on monthly monitoring for sites visited over a range of flow conditions. Record length for grading a site is based on 5 years.
6. Based on an annual median where monitoring pH of 8 and temperature of 20°C.



**Table 5: Average water quality results obtained from Mangapu River and Mangawhitikau Stream with ANZG values<sup>1,2,3</sup>**

| Parameter                             | units            | Mangapu (Upper)       | Mangapu (Middle)      | Mangapu (Lower)       | Mangawhitikau (Upper) | Mangawhitikau (Lower) | ANZG (2018) REC Class WWL | ANZG (2018) DGV for toxicant (99% species protection) | ANZG (2018) DGV for toxicant (95% species protection) | ANZG (2018) DGV for toxicant (80% species protection) |
|---------------------------------------|------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|---------------------------|-------------------------------------------------------|-------------------------------------------------------|-------------------------------------------------------|
| pH                                    | pH units         | 7.74                  | 7.82                  | 7.74                  | 7.64                  | 7.82                  | 7.26-7.7                  |                                                       |                                                       |                                                       |
| Electrical Conductivity               | µS/cm            | 252 (215 - 294)       | 186 (174 - 202)       | 212 (193 - 245)       | 164 (134 - 204)       | 248 (207 - 312)       | 115                       |                                                       |                                                       |                                                       |
| Total Alkalinity                      | g/m <sup>3</sup> | 116                   | 82                    | 87                    | 63                    | 92                    |                           |                                                       |                                                       |                                                       |
| Chloride                              | g/m <sup>3</sup> | 8.1                   | 7.3                   | 7.4                   | 7.8                   | 7.3                   |                           |                                                       |                                                       |                                                       |
| Sulphate                              | g/m <sup>3</sup> | 5.3                   | 4.5                   | 13.4                  | 6.3                   | 23.0                  |                           |                                                       |                                                       |                                                       |
| Nitrate-Nitrogen                      | g/m <sup>3</sup> | 2.2 (1.8 – 2.6)       | 1.5 (0.9 – 1.9)       | 1.5 (1.0 – 1.9)       | 1.1 (0.8 – 1.4)       | 1.5 (1.0 – 1.8)       | 0.065                     | 1.0                                                   | 2.6                                                   | 7.1                                                   |
| Dissolved Reactive Phosphorus         | g/m <sup>3</sup> | 0.018 (0.010 – 0.024) | 0.016 (0.013 – 0.022) | 0.014                 | 0.010                 | 0.014                 | 0.014                     |                                                       |                                                       |                                                       |
| Ammoniacal Nitrogen                   | g/m <sup>3</sup> | < 0.005               | < 0.005               | < 0.005               | 0.006 <sup>4</sup>    | < 0.005               | 0.01                      | 0.24                                                  | 0.72                                                  | 2.3                                                   |
| Total Suspended Solids                | g/m <sup>3</sup> | 33 (<3 - 107)         | 23 (<3 - 72)          | 28 (<3 - 82)          | 30 (<3 – 124)         | 33 (<3 – 134)         | 8.8                       |                                                       |                                                       |                                                       |
| Carbonaceous Biological Oxygen Demand | g/m <sup>3</sup> | <1.00                 | 1.11 <sup>4</sup>     | <1.00                 | 1.11 <sup>4</sup>     | <1.00                 |                           |                                                       |                                                       |                                                       |
| Total Nitrogen                        | g/m <sup>3</sup> | 2.32 (1.75 – 2.90)    | 1.69 (1.06 – 2.20)    | 1.72 (1.11 – 2.20)    | 1.22 (0.85 – 1.70)    | 1.68 (1.20 – 2.10)    | 0.292                     |                                                       |                                                       |                                                       |
| Nitrite-Nitrogen                      | g/m <sup>3</sup> | 0.001                 | 0.002                 | 0.002                 | 0.002                 | 0.001                 |                           |                                                       |                                                       |                                                       |
| Total Kjeldahl Nitrogen               | g/m <sup>3</sup> | 0.19                  | 0.24                  | 0.25                  | 0.18                  | 0.22                  |                           |                                                       |                                                       |                                                       |
| Total Phosphorus                      | g/m <sup>3</sup> | 0.061 (0.030 – 0.140) | 0.062 (0.034 – 0.100) | 0.054 (0.026 – 0.095) | 0.058 (0.024 – 0.140) | 0.061 (0.038 – 0.150) | 0.024                     |                                                       |                                                       |                                                       |
| Sodium                                | g/m <sup>3</sup> | 5.35                  | 5.67                  | 5.77                  | 5.86                  | 5.89                  |                           |                                                       |                                                       |                                                       |
| Potassium                             | g/m <sup>3</sup> | 1.04                  | 0.96                  | 1.03                  | 1.12                  | 1.08                  |                           |                                                       |                                                       |                                                       |
| Calcium                               | g/m <sup>3</sup> | 47.22                 | 31.78                 | 36.72                 | 25.38                 | 41.16                 |                           |                                                       |                                                       |                                                       |
| Magnesium                             | g/m <sup>3</sup> | 1.54                  | 1.36                  | 1.89                  | 1.45                  | 2.45                  |                           |                                                       |                                                       |                                                       |
| <i>E. coli</i>                        | MPN/100ml        | 125 (63 - >200)       | 317 (46 - 1236)       | 450 (68 - 1450)       | 566 (32 - 1989)       | 702 (28 - 2755)       |                           |                                                       |                                                       |                                                       |
| Faecal coliforms                      | MPN/100ml        | 269                   | 216                   | 268                   | 427                   | 524                   |                           |                                                       |                                                       |                                                       |

**Notes:**

- Yellow denotes exceedance of ANZG 2018 80<sup>th</sup> percentile DGV for physical and chemical stressors or 99% species protection DGV for toxicant. Orange denotes 95% species protection DGV for toxicant. Red denotes exceedance of 80% species protection DGV for toxicant.
- Ranges are presented in parentheses where there is exceedance of ANZG 2018 80<sup>th</sup> percentile DGV for physical and chemical stressors or 80% species protection DGV for toxicant.
- Where values were at the detection limit, the detection limit was used in calculating the average.
- Only one sample was measured above the detection limit.

**Table 6: Average physico-chemical water quality results obtained from Mangapu River and Mangawhitikau Stream**

| Parameter         | units | Mangapu (Upper) | Mangapu (Middle) | Mangapu (Lower) | Mangawhitikau (Upper) | Mangawhitikau (Lower) | Waikato Regional Council Guidelines |              |                | ANZG 2018 REC Class (WWL) |
|-------------------|-------|-----------------|------------------|-----------------|-----------------------|-----------------------|-------------------------------------|--------------|----------------|---------------------------|
|                   |       |                 |                  |                 |                       |                       | Excellent                           | Satisfactory | Unsatisfactory |                           |
| Water Temperature | °C    | 13.7            | 14.0             | 13.7            | 13.1                  | 13.2                  | <16                                 | 16-20        | >20            |                           |
| Dissolved Oxygen  | % Sat | 98.3            | 103.7            | 100.7           | 97.7                  | 97.4                  | >90%                                | 80%-90%      | <80%           | 92%-103%                  |
| Dissolved Oxygen  | mg/L  | 10.2            | 10.7             | 10.5            | 10.3                  | 10.2                  | >5                                  |              |                |                           |
| Turbidity         | FNU   | 18.8            | 11.3             | 13.1            | 17.7                  | 13.9                  | <2 NTU<3.2                          | 2-5 NTU      | >5 NTU         | 5.2                       |

**Notes:**

- Green denotes WRC Excellent Band2. Yellow denotes WRC Satisfactory Band3. Orange denotes WRC Unsatisfactory Band4. Red denotes exceedance of WRC Unsatisfactory Band or ANZG 2018 80 percentile value.

On average, the following contaminants are above the levels specified by relevant water quality guidelines (WRC guidelines, ANZG, NPS-FM):

- ✧ Suspended Sediment Concentration (SSC)/turbidity
- ✧ Dissolved reactive phosphorus
- ✧ Total phosphorus
- ✧ Total nitrogen
- ✧ Nitrate
- ✧ *E. coli*

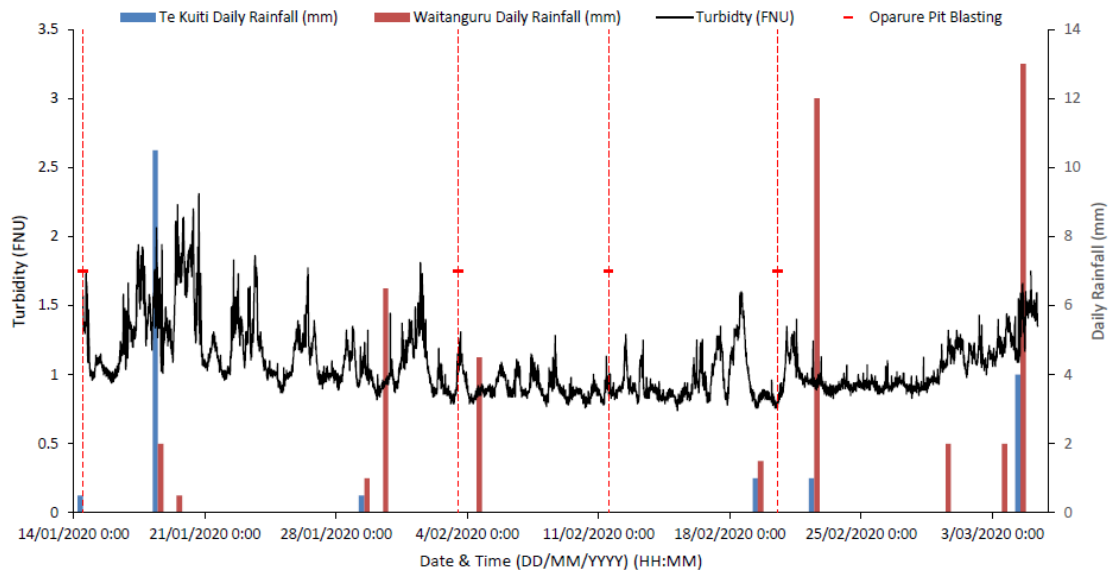
### SSC/Turbidity

Turbidity exceeded both the WRC unsatisfactory band and the ANZG 2018 DGV (Table 6). Average turbidity concentrations in the Mangapu River ranged from 18.8 NTU in the upper reaches of the Mangapu River to 30.1 NTU in the lower reaches. The turbidity is slightly less in the Mangawhitikau Stream with measured values ranging from 15.8 NTU to 18.8 NTU. The ANZG 2018 default turbidity guideline values are based on the 80th percentile of reference conditions with minimal anthropogenic influence. As a result, the WRC guidelines are generally conservative i.e. 80% of minimally disturbed catchments have turbidity greater than 5.2 NTU, which exceeds the WRC unsatisfactory band.

SSC exceeds the ANZG DGV of 8.8 mg/L at all monitored locations in both the Mangapu River and the Mangawhitikau Stream during rainfall events (Table 5; Appendix D). Again, this value represents the 80th percentile suspended sediment concentration (SSC) derived from catchments minimally affected by human activity. It must be noted however that the SSC concentrations observed during rainfall events are acute effects, whereas the ANZG 2018 DGV is a chronic effect threshold.

The additional 15-minute interval sonde sampling of turbidity in the Mangawhitikau Stream between January and March 2020, showed that turbidity did not exceed 2.5 FNU<sup>3</sup> throughout the entire monitoring period even during rainfall events and blasting within the Oparure Pit (Figure 5). The mean value for turbidity was 1.1 FNU, the maximum turbidity measurement was 2.3 FNU, which are all well within the WRC satisfactory band and below the ANZG 2018 DGV of 5.2 NTU. The longer sonde sampling is more indicative of the actual baseline condition of the stream and based on this we can conclude that the Mangawhitikau Stream is well below the chronic effects threshold set out by both WRC and ANZG 2018. This indicates that the Quarry and its operation are not the primary source of the elevated suspended sediment loads, which are more likely attributable to existing agricultural activities.

<sup>3</sup> A 1:1 NTU:FNU assumption has been made.



**Figure 5: Turbidity in the Mangawhitikau Stream (Resurgence) with daily rainfall totals and timing of blasts within Oparure Pit**

#### **Total Phosphorus (TP) and Dissolved Reactive Phosphorus (DRP)**

TP ranges between 0.026 to 0.140 mg/L in the Mangapu River and 0.024 mg/L and 0.150 mg/L in the Mangawhitikau Stream with their averages being greater than the 0.04 mg/L WRC unsatisfactory band and the 0.024 mg/L ANZG DGV (Table 4; Table 5).

DRP was found to exceed the ANZG DGV of 0.014 mg/L at the Upper and Middle Mangapu River monitoring locations, although TP was high at all monitoring locations, only the Upper and Middle locations of both waterbodies had bioavailable phosphorus. These elevated concentrations are consistent with the influence of natural limestone geology within the catchment, in combination with inputs from agricultural land use.

#### **Total Nitrogen (TN) and Nitrate**

Average TN ranged between 1.69 mg/L and 2.32 mg/L in the Mangapu River and 1.22 mg/L and 1.68 mg/L in the Mangawhitikau Stream, which is well above the 0.5 mg/L WRC unsatisfactory band and the 0.292 mg/L ANZG DGV (Table 4; Table 5).

In terms of toxicity, nitrate concentrations were within NPSFM (2025) Attribute B band (95<sup>th</sup> species protection) and ammoniacal-nitrogen were within Attribute A band (99<sup>th</sup> species protection) for all sites (Table 4). Using the ANZG (2018) toxicity Default Guideline Values, ammonia concentrations at all sites were at the 99% species protection level (Table 5).

Average nitrate concentrations were well above the ANZG DGV (0.065 mg/L) for both the Mangapu River (1.5 mg/L to 2.2 mg/L) and the Mangawhitikau Stream (1.1 mg/L to 1.5 mg/L). The elevated concentrations and their upstream occurrence indicate a catchment-scale source rather than a localised discharge. This is consistent with diffuse inputs typically associated with agricultural land-use rather than activities at Oparure Quarry.

### **E. coli**

High bacterial contamination was found within the Mangawhitikau Stream with the upper location having on average 658 MPN/100mL and 827 MPN/100mL at the lower location. Both measurements are above both the WRC unsatisfactory band of 550 MPN/mL (Table 4).

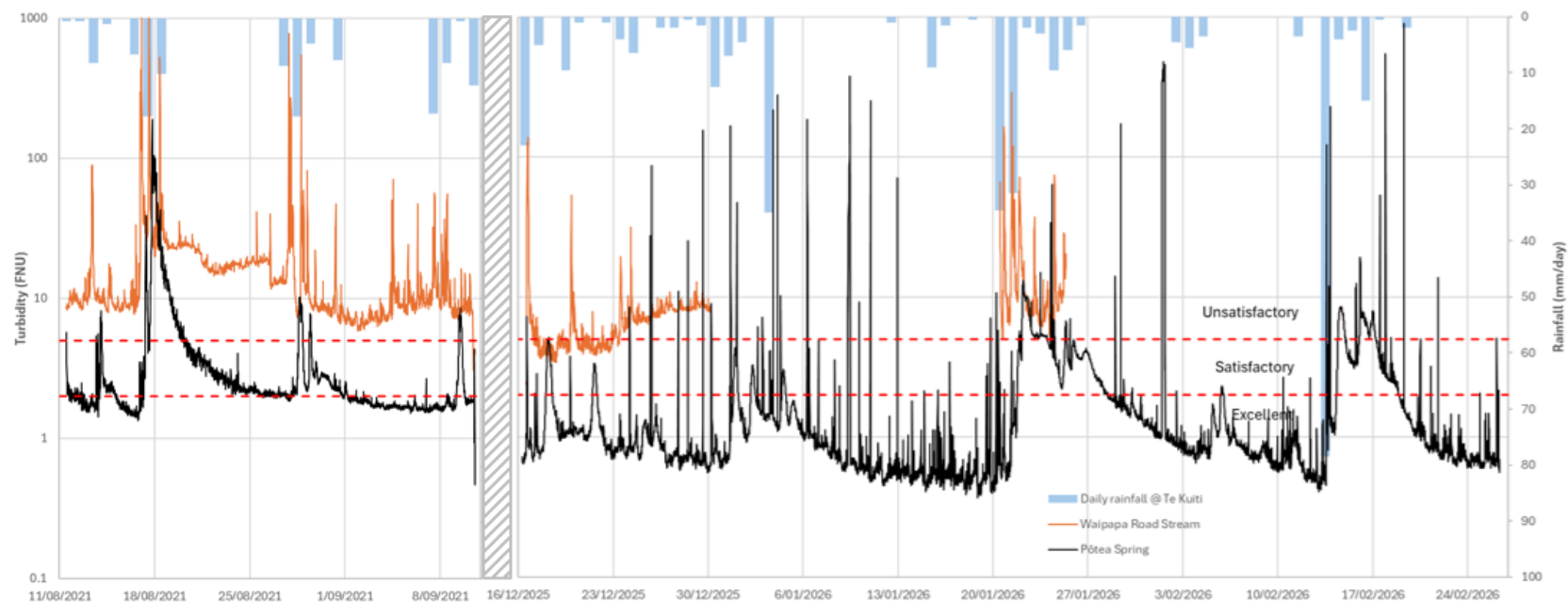
The Mangapu River has lower *E. coli* numbers but still within the WRC unsatisfactory band at the middle and lower locations. These elevated concentrations will primarily be due to agricultural land use effects and are not connected to the existence and operation of the Oparure Quarry. Similarly, the SW Pit would not contribute either.

#### **2.7.2 Camelot Stream and Pōtea Spring**

Key findings from the physico-chemical data collected at the Camelot Stream headwaters and Pōtea Spring—which receive inputs from the Oparure Pit as well as from upgradient land uses (Figure 6; Appendix E)—included:

- ✧ Turbidity in Pōtea Spring, as measured at 15-minute intervals, consistently remains within the WRC excellent band.
- ✧ Turbidity occasionally falls within the Waikato Regional Council satisfactory and unsatisfactory bands during or following rainfall events. However, these bands are based on chronic (long-term) thresholds and are not intended to apply to short-duration, rainfall-driven turbidity pulses. Accordingly, these exceedances do not indicate a deterioration in turbidity conditions.
- ✧ Higher turbidity at the Camelot Stream headwaters upstream (three to five times greater) reduces in a downstream direction, indicating effective attenuation within the catchment prior to discharge at Pōtea Spring. This suggests that sediment settles within the subsurface karst or is filtered out during its entry through tomos or dolines, resulting in less sediment reaching Pōtea Spring.
- ✧ Although downstream flow may promote dilution, the higher turbidity concentrations recorded upstream (maximum of 1,619 FNU at Camelot Stream headwaters corresponding to a maximum of 189 FNU at Pōtea Spring) suggest that the upper catchment is a primary source of sediment to the Camelot Stream receiving environment.





**Figure 6: Turbidity in the Camelot Stream headwaters (orange) and Pōtea Spring (black) against WRC turbidity guidelines and daily rainfall**

- ✧ Peak turbidity concentration at Pōtea Spring was recorded 5 hours and 45 minutes after the maximum recorded concentration recorded at the upstream site at the Camelot Stream tributary.
- ✧ Dissolved oxygen concentrations (within 1%) and pH (two percent greater on average at the downstream Pōtea Spring) were similar between both upstream and downstream sites.
- ✧ During rainfall events, pH increases at the Pōtea Spring due to passing through the limestone geology increasing the alkalinity of the water. In the upstream Camelot Stream tributary, the pH decreases during rainfall events due to the rainwater (naturally 6.5 pH) and the native forestry catchment.

The geology of the cave system is predominantly limestone, which naturally erodes and causes white suspended sediment. During floods, water flow in the cave increases, flushing out previously deposited sediment. The white suspended sediments observed at Pōtea Spring after storm events is therefore a result of both infiltration of sediment from the Oparure Pit and natural erosion and sediment processes within the cave networks.

#### 2.7.3 Spirit Cave and Guildford Cave Turbidity

Turbidity measurements within the Spirit Cave indicate very low baseline turbidity, ranging from 0.09 to 3.02 NTU (average of 0.48 NTU; Appendix E). Several turbidity spikes were observed in response to rainfall events, with five events exceeding the ANZG DGV of 5.2 NTU. This turbidity DGV represents a chronic effect threshold rather than an acute effect threshold. The highest recorded turbidity was 32.8 NTU on 6 September.

In comparison, baseline turbidity within Guildford Cave is higher, ranging from 1.95 to 13 NTU (average of 4.78 NTU), which is just below the ANZG DGV of 5.2 NTU (Appendix E). Turbidity responses to rainfall are also more pronounced, with a maximum recorded value of 352 NTU. These results demonstrate that substantial increases in turbidity can occur within the cave system under natural conditions, irrespective of any quarry-related inputs.

#### 2.7.4 Summary of Baseline Water Quality Findings

The following conclusions have been drawn from the preceding monitoring and observations:

- ✧ The Upper Mangawhitikau Stream has a greater suspended sediment concentration during flood events than compared to the Pōtea Spring monitoring location.
- ✧ The suspended sediment within the Upper Mangawhitikau Stream during flood events generally has an organic brown colour, whilst the suspended

sediment colour discharged from the Pōtea Spring can be white in colour. This observation aligns with the dye tracing results that confirmed that water which infiltrates through the Oparure pit floor does discharge to the Pōtea Spring. White suspended sediment can also enter the surface waterways due to erosion of the naturally occurring limestone strata.

- ∴ Once the white suspended sediment discharge from the Pōtea Spring mixes with the Mangawhitikau Stream, the white coloured sediment is lost, i.e. there is no conspicuous colour present within the Mangawhitikau Stream beyond the reasonable mixing zone (defined as greater than 20 m (three widths of the Mangawhitikau Stream and in accordance with the WRP suspended solids standard: Policy 3.2.4.6)). Observations made by third parties, which have identified white discolouration within the Mangawhitikau Stream during flood events, also identified that the Pōtea Spring was clear at the same time. As such, based on dye tracing results there is no indication that these more widespread occurrences of white discharges are sourced from the Oparure Pit. Rather, they are associated with suspended sediments derived from the wider limestone catchment that contributes flow to the Mangawhitikau Stream.
- ∴ Based upon the flood events observed, elevated suspended sediment concentrations within the Pōtea Spring are only typically observed for a short duration (no more than one day) and are of a minor scale relative to the turbidity effects in the wider catchment.

The baseline water quality indicates that both the Mangawhitikau Stream and the Mangapu River show water quality effects from a highly erodible limestone catchment and the impacts from agricultural land-use. The monitoring does not indicate any noticeable adverse water quality impacts arising from the existing Oparure quarry activities.

### 3.0 Proposed Activity

The proposed activities are described in the Substantive Application. Relevant to the scope of the assessment detailed in this report are activities that result in the mobilisation of sediment and other substances that may affect water quality (and by extension aquatic ecology) in the receiving environment.

### 4.0 Potential Effects on the Environment

The following provides an assessment of the proposed activity in relation to types and sources of water quality contaminants generated. A discussion about hazardous substances within the SW Pit area is also presented.

Potential contaminant loads that could be of concern in the receiving environment, based on the regional council planning framework, are:

- ✧ Sediment
- ✧ Nutrients
- ✧ Bacteria
- ✧ Hazardous substances, specifically hydrocarbon discharges.

It is important to note that the cumulative effects from the SW Pit on the baseline (which includes Oparure Pit) can be considered in terms of changes in contaminant concentrations in the receiving environment (Mangawhitikau Stream) as well as changes in contaminant loads.

The SW Pit is at a greater distance from the Mangawhitikau Stream (approximately 3 km) and is expected to result in increased dilution and attenuation within the Camelot Stream. Consequently, peak contaminant concentrations in the Mangawhitikau Stream downstream of the SW Pit are anticipated to be lower than those associated with Oparure Pit operations. When both the Oparure Pit and the SW Pit are operational, differences in travel time within the Camelot Stream are expected to result in peak contaminant concentrations from the Oparure Pit being observed at Pōtea Spring before those from the SW Pit.

Attenuation of contaminant loads in downstream receptors (Pōtea Spring, Pumphouse Spring and Upper Mangawhitikau Spring) is to be provided through stormwater management for the SW Pit. This will avoid concentrated discharge locations close to the underground Camelot Stream and ensure the stormwater is treated, as much as practicable (using the devices described in the Erosion and Sediment Control Plan), to minimise effects on the subsurface waterways. This will direct the discharge to areas with lower connectivity to the main subsurface flow pathways, which will increase the attenuation of sediment loads downstream. This rationale has informed the methodology presented in the Erosion and Sediment Control Plan.

As described in other technical reports included with the application (Geology and Soils), the SW Pit is not expected to intercept the permanently saturated groundwater system (i.e. the water table). Underdrainage of overlying soil and rock strata to the underground cave networks maintains a deep regional water table throughout the SW Pit area. This is supported by observations during excavation of the adjacent Oparure Pit, in which there have been no observed groundwater inflows.

#### **4.1 Camelot Stream and Cave**

Camelot Stream is recognised as having the potential as a relatively rapid conduit through to Pōtea Spring. Graymont has therefore proposed the following management actions to restrict potential elevated sediment discharges to the Camelot Stream:



- ✧ No quarry excavation or overburden placement can be undertaken in the 'Camelot Cave Buffer Zone' area (as detailed in Baseline Geotechnical's report as part of the substantive application) until such time as the extent and geometry of the cave system has been confirmed and certified. Note this is also reflected in the proposed conditions of consent.
- ✧ To test the available void mapping techniques multiple geophysics surveys were conducted in 2022 and 2023. The combination of various geophysical techniques as well as surface mapping, sinkholes and dye tracing can be used to provide indications of cave structures that can then be drill tested in areas further from the immediate intended mining area (i.e. within the 'Camelot Cave Buffer Zone'). This approach allows time to provide further investigation while the existing mine plan progresses.
  - During 2023 the C-ALS (Cavity Auto-Scanning Laser System) method of scanning voids by lowering a LiDAR (Light Detection and Ranging) probe into a drill hole or existing opening was proven to be accurate in mapping voids in three dimensions.
  - Current incremental mining utilises pattern drilling for grade control and limestone resource identification in advance to maintain minimum separation of the active mine. Grade control drilling to a depth of 30 m and production blast drilling to 5 m in the risk zone would allow for a 25 m standoff distance.
  - Drill rigs use MWD (Measurement While Drilling) sensors which allow voids to be logged and investigated before quarrying commences.
- ✧ This is consistent with performance of the existing Oparure pit (which also sits above, and has not intersected, the expected karstic flow level).
- ✧ Graymont's intention is to develop Phase 1 from the north to the south to maximise offset from the Camelot system.

The information gained from the Phase 1 quarry can also be used to ensure effective measures remain in place for the subsequent phases of the SW Pit such that the potential for damage to the cave system is minimised.

## 4.2 Sediment Concentrations

The sediment concentrations measured within the Mangawhitikau Stream (downstream of Pōtea Spring) include existing effects arising from the quarrying operations at Oparure. This provides a practical basis for the effects that are anticipated to arise from the SW Pit operation. Sediment concentrations at Pōtea Spring are lower than those within the Mangawhitikau Stream to which it discharges, during both baseflow and storm (quickflow) conditions. The greater

distance from the SW Pit to Pōtea Spring (3 km) compared to Oparure means that any sediment pulses associated with rainfall events will take longer to arrive. In addition, the proposed erosion sediment control measures, specifically the design of the sediment retention ponds in the SW Pit will in general terms remove all but the finer grained particles from stormwater. Hence, stormwater leaving the SW Pit is expected to comprise finer grained particles than suspended sediment coming from Oparure Quarry.

This difference in travel time is expected to result in temporally offset sediment pulses, corresponding to minimal increases in suspended sediment concentrations in Pōtea and Pumphouse Spring and the Mangawhitikau Stream. Additionally, progression of the SW Pit will coincide with progressive backfilling of the Oparure Quarry and its eventual rehabilitation. Therefore, the contribution to cumulative effects on sediment concentrations at Mangawhitikau Stream are expected to be no greater than the existing concentrations measured. Because the sediment concentrations discharged from Pumphouse Spring and Pōtea Spring are likely to remain lower than the Mangawhitikau Stream, which has a much greater flow, there is expected to be no measurable increase to the resultant concentration after complete mixing. On this basis, effects on suspended sediment concentrations after complete mixing are expected to be less than minor.

On a similar basis, any other diffuse discharges of water from the SW Pit that may enter the Mangawhitikau via pathways other than Pōtea Spring will have an even smaller effect than what might be observed at the springs. As a consequence, any associated adverse effects are also expected to be minimal.

### 4.3 Sediment Loads

Although concentrations at Pōtea Spring are expected to remain within a similar range as current conditions, there may be a temporary increase in the cumulative sediment load in the wider Mangapu catchment associated with development of the SW Pit while Oparure Quarry remains in operation, which will require mitigation.

The potential impact of these sediment loads is relevant because of Waikato Regional Council (WRC) Plan Change 1 (PC1) where it is acknowledged that the overall Mangapu catchment already has a high sediment load, so any additional load requires mitigation. WRC (via PC1) has set rules to improve water quality over time. Accordingly, any activities that would increase sediment loads would not comply with PC1, unless mitigation measures are implemented that contribute to an overall reduction in catchment sediment loads over time.

Betterment measures are proposed to reduce sediment loads arising from other sources in the catchment. While the SW Pit may temporarily increase sediment loads, increases will be more than offset by sediment load reductions in other

parts of the catchment. Given these measures, at worst there is expected to be a net zero increase of sediment load (i.e. the status quo will be maintained). More likely, the proposed mitigation measures will reduce the overall sediment load entering the Mangawhitikau Stream catchment and in turn the Mangapu catchment. Given this, the development and operation of the SW Pit will either generate no adverse effects in terms of sediment load, or will, more probably, result in a net beneficial effect.

PC1 requires a two-stage improvement to water clarity within the Mangapu catchment. The first water clarity target is to be achieved in 10 years after the plan becomes operative and this is referred to as the short-term target. The second (long-term) target is to be met 80 years after the plan becomes operative. We have modelled mitigation requirements aligned to the SW Pit staging milestones.

Sediment loads anticipated to enter the subsurface karst system as a result of the quarrying activities have been estimated using a Water Management Model approach, the details of which are described in Appendix F. Outputs of the model were analysed to assess average sediment loads exiting the quarry via infiltration through the base of sediment retention ponds, plus via cracks and pores in the quarry floor. The model was updated based on the pit staging plans for the SW Pit and results are presented in Table 7.

**Table 7: SW Pit – Estimated Annual Average Suspended Solid Loads**

| Scenario                      | Year 0 | Year 1 | Year 5  | Year 8  | Year 13 | Year 33 | Year 53 |
|-------------------------------|--------|--------|---------|---------|---------|---------|---------|
| Disturbed area (ha)           | 12.3   | 12.3   | 17.4    | 23.2    | 28.3    | 46.9    | 59.6    |
| Suspended Solids Load (kg/yr) | 66,172 | 66,545 | 100,658 | 139,109 | 180,837 | 160,603 | 100,766 |

**Notes:**

1. The suspended solids loads per hectare of disturbed area decrease beyond Year 13 due to advancement of backfill placement within previously excavated parts of the pit.

#### 4.4 Nutrients

The proposed activity does not involve the intentional application of nutrients. However, some nutrient mobilisation may occur during earthworks due to disturbance of topsoil containing legacy nutrients from historical agricultural land use and blasting operations through the use of explosives.

Nutrient discharge is expected to occur primarily in particulate-bound form (particularly phosphorus) via sediment runoff. As such, nutrient effects are intrinsically linked to sediment generation and transport. Implementation of the Erosion and Sediment Control Plan, including routine maintenance of control measures, will minimise sediment discharge and therefore associated nutrient losses.

An additional nutrient source specific to quarrying activities is nitrogen in the form of nitrate derived from explosives. While this represents a potential source, the majority of nitrogen is volatilised during detonation, and blasting is undertaken only during stable weather conditions (i.e. not during rainfall). This reduces the likelihood of residual nitrate being mobilised and discharged via surface runoff. Any discharge that does occur would be short-term (acute) rather than ongoing (chronic).

A conservative, order-of-magnitude assessment indicates that unrealistically high proportions of residual nitrogen would be required to approach permitted activity loading thresholds, and this scenario is considered highly unlikely in practice. Accordingly, nitrate contributions from explosives are expected to be minimal relative to existing catchment inputs, particularly from agricultural land use. This is supported by existing water quality data, which show that total nitrogen and nitrate concentrations in the Mangapu River and Mangawhitikau Stream already exceed relevant guideline values due to catchment-wide influences and natural geology, rather than quarrying activities.

In this context, the proposed activity is unlikely to result in a measurable increase in nutrient concentrations within the receiving environment.

#### 4.5 Bacteria

Elevated concentrations of *E. coli* have been identified in receiving waters, consistent with patterns typically associated with agricultural land use. The primary source of *E. coli* within the catchment is considered to be diffuse inputs from livestock, including grazing sheep currently present within the proposed SW Pit.

The proposed land use change from pastoral farming to quarrying will remove this existing source of faecal contamination within the activity area. As quarrying activities do not generate *E. coli*, the proposal is expected to reduce, rather than increase, bacterial inputs from the site.

Accordingly, the potential effects of the proposed activity on *E. coli* concentrations in receiving waters are assessed as negligible, with an overall improvement in microbial water quality anticipated relative to the current baseline.

#### 4.6 Hazardous Substances

A mobile crushing plant will be operated within the Project area. Operation of the plant requires the use of diesel, as well as hydraulic fluids, oils, and greases.

Diesel will be supplied to the mobile crusher via a 5,000 L mobile diesel tanker. The tanker will incorporate appropriate spill prevention and response measures, including:

- ∴ Use of a suitable diesel transfer nozzle designed to minimise spill risk.



- ✧ Emergency shut-off systems to immediately stop fuel dispensing.
- ✧ Availability of a spill response kit located with the tanker.

In addition, the mobile crushing plant will not be located in close proximity to stormwater management devices (e.g. ponds and diversion drains), nor within or directly above the Camelot Stream. These spatial controls further reduce the likelihood of any contaminants entering surface water.

Hydraulic fluids, oils, and greases will not be stored within the proposed SW Pit area. Instead, these substances will be stored within the existing Oparure Quarry site, which operates under current consents.

Graymont operates an established Spill Response Plan for the Oparure Quarry, which is applicable to the hazardous substances associated with the proposed activity. This plan provides an appropriate framework for managing spill risks and responding effectively in the unlikely event of a release.

Overall, only limited quantities of hazardous substances will be present within the Project area. For those substances that are required, appropriate management measures and procedures are in place to avoid or minimise accidental discharges during normal operations.

On this basis, the potential for hazardous substances to enter the environment and result in adverse effects is considered to be less than minor.

#### **4.7 Summary of Effects**

A summary of the environmental effects associated with water discharges from the proposed SW Pit operation is provided in Table 8.

**Table 8: Summary of Environmental Effects from Water Discharges**

| Activity                                                                       | Potential Issues                                                                                  | Management Strategy                                                 | Resulting Environmental Concentration Effect                                               | Resulting Environmental Load Effect                                                                                                                                   |
|--------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|--------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Discharge of stormwater and sediment due to blasting and excavation activities | Effects on waterways within the karst system and surface water quality downstream of Pōtea Spring | Erosion and sediment control measures within the quarry             | Less than minor/negligible effects relative to wider land-use impacts within the catchment | Increase in sediment load therefore further mitigation (offsetting) is required.<br><br>With the proposed betterment, this will reduce to a nil to beneficial effect. |
| Discharge of nutrients                                                         |                                                                                                   | Erosion and sediment control measures within the quarry             | Negligible effects relative to wider land-use impacts within the catchment                 | Negligible effects relative to wider land-use impacts within the catchment                                                                                            |
| Discharge of bacteria                                                          |                                                                                                   | Stormwater from areas with stock will be directed away from the pit | Negligible effects relative to wider land-use impacts within the catchment                 | Negligible effects relative to wider land-use impacts within the catchment                                                                                            |
| Use of hazardous substances                                                    |                                                                                                   | Good management practices                                           | Less than minor/negligible                                                                 | Less than minor/negligible effects relative to wider land-use impacts within the catchment                                                                            |

## 5.0 Alternative Water Quality Management Options

Alternative options to manage water discharges from the operative quarry were considered. These options included:

- ✧ Collection and discharge of water to an onsite reticulated stormwater network which then discharges to the Mangapu River and Mangawhitikau Stream.
- ✧ Collection of surface waters for onsite water reuse.

The purpose of the above options is to eliminate/reduce the potential for contaminants of concern (sediment, nutrients and bacteria) from entering into a receiving environment.

### 5.1 Stormwater Reticulation Networks

This option would require the collection of all surface water flow from the activity area, treatment of these collected waters, and discharging of these waters into an onsite reticulated network. Stormwater would then be discharged as a point source (rather than the proposed diffuse discharge) to a surface receiving environment other than underlying cave networks i.e. such as the Mangapu River. This discharge could allow mixing of greater volumes of stormwater (potentially providing dilution) and discharging to a surface water receiving environment with possibly greater assimilation capacity (assuming that the stormwater outfall is located in a receiving environment further downstream of the proposed quarry).

The difficulty for this option is that the geology in the Project area enables high infiltration rates to occur. Consequently, being able to collect surface waters to convey in an area with high infiltration capacity is considered to be unfeasible. Furthermore, being able to achieve collection of surface water from the entirety of the sub-catchments where active quarrying is being undertaken is impracticable.

### 5.2 Onsite Water Reuse

As part of the proposed activity carried out at the SW Pit, some surface water runoff will be collected and used onsite (i.e. for dust suppression purposes). The potential to obtain all surface water for water reuse purposes, thereby eliminating the discharge from the site, is however considered to be unachievable due to water demand not being significant enough. Furthermore, it is recognised that the proposed quarry resides in a drainage catchment that is fully allocated. Consequently, this option would require obtaining a resource consent for taking water over and above a net-zero volume.

### 5.3 Summary

Based upon the review of the alternative options considered, the proposed approach is considered to be the most appropriate and technically feasible option.

### 6.0 Proposed Mitigation

Betterment measures to reduce sediment yields from other sources in the catchment are proposed to result in neutral sediment load, or better, when considering to the loads estimated to be produced from the SW Pit development. On this basis, the SW Pit development will contribute to meeting both short- and long-term PC1 objectives in the catchment. The timing for the short-term PC1 objective is anticipated to correspond to the year 13 mine plan, which also corresponds to the maximum predicted suspended solids load (180,837 kg/year; Table 7).

The proposed sediment reduction mitigations outlined in Table 9 provide an estimated 185,022 kg/year of sediment load reductions within the Year 13 timeframe (102% of target). Additional net sediment reductions in addition to those presented here will be realised following rehabilitation of the Oparure pit, at which time continuation of cropping field management currently associated with that activity will provide ongoing benefit beyond the period of quarrying activities at Oparure.

As the sediment load from the SW Pit will progressively decrease after Year 13, the proposed betterment measures will be retained after the closure of the quarry, which will result in net reduction in the sediment load entering the Mangapu catchment and hence achieving the long-term PC1 objective.

Estimates of sediment yield reduction rates associated with proposed betterment measures have been derived from the Auckland Council Contaminant Load Model (AC, 2010; AC, 2006). These rates, alongside each proposed measure and their sediment load reduction rates are presented in Table 9. Slope has been analysed for the proposed betterment areas and utilised in the sediment load reduction estimates.

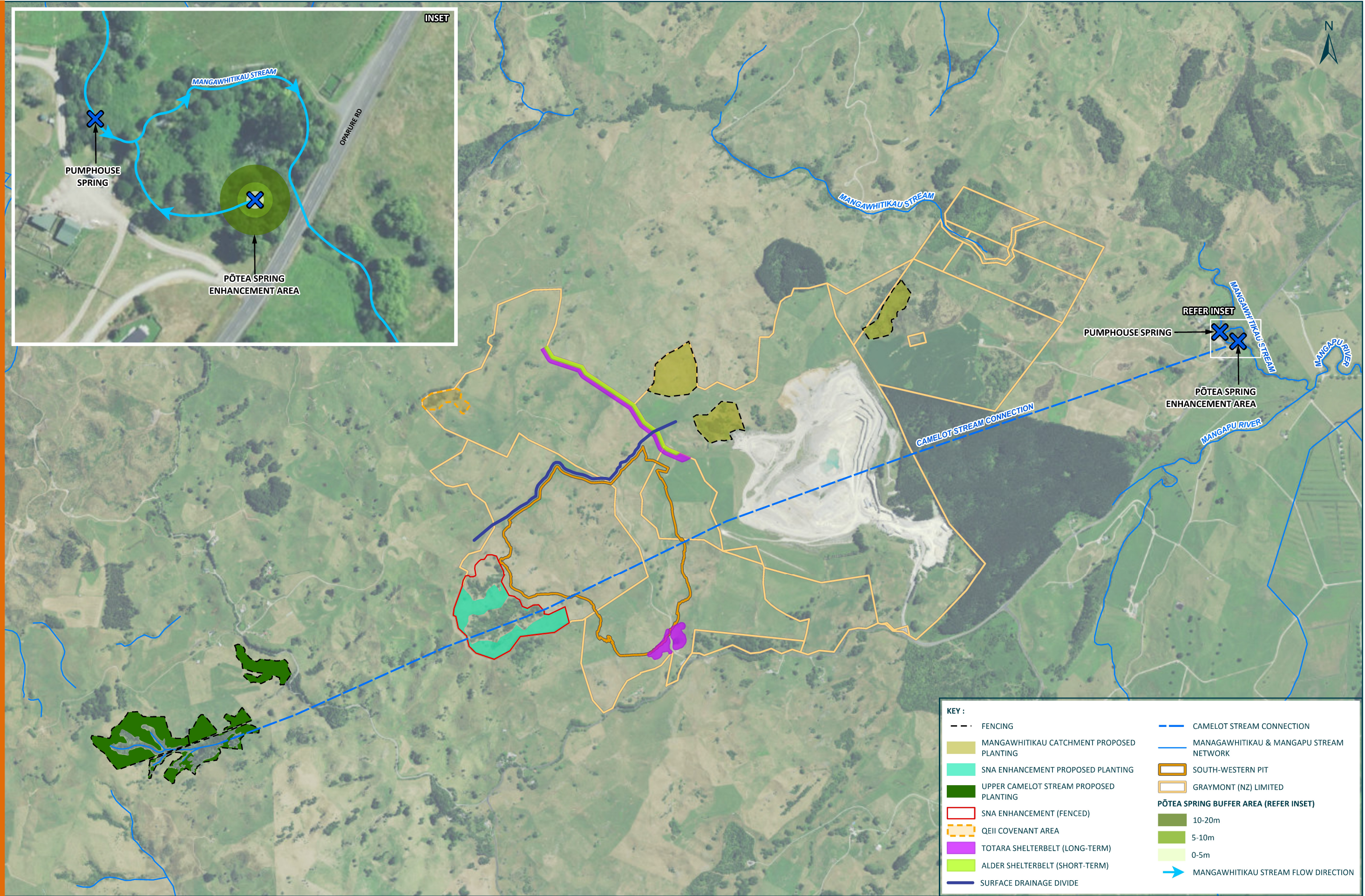


**Table 9: Proposed measures for SW Pit sediment load reductions**

| <b>Measure</b>                                                                                                                                                                                                                                                           | <b>Sediment load reduction rate (kg/ha/year)</b> | <b>Total area proposed (ha)</b> | <b>Sediment load reduction (kg/year)</b> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|---------------------------------|------------------------------------------|
| Riparian Planting (Upper Camelot Catchment)                                                                                                                                                                                                                              | 6,731                                            | 11.8                            | 79,426                                   |
| Planting in Mangawhitikau Stream Catchment                                                                                                                                                                                                                               | 6,627                                            | 9.4                             | 62,294                                   |
| Planting of area between/around SNAs                                                                                                                                                                                                                                     | 6,463                                            | 6.7                             | 43,302                                   |
| <b>TOTAL</b>                                                                                                                                                                                                                                                             |                                                  | <b>27.9</b>                     | <b>185,022</b>                           |
| <p>Notes:</p> <p>Sediment load reduction rates for planting were calculated based on comparison of farmed pasture to stable bush (AC, 2010). A composite sediment load reduction rate is presented according to the composition of slopes within each planting area.</p> |                                                  |                                 |                                          |

Betterment measures relating to sediment and ecology are summarised in the Betterment Plan and shown in Figure 7.





0 250 500  
Meters  
SCALE : 1:17,500 (A3)

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| A   | FINAL             | JUN 26 | MS |
| A   | ISSUED FOR REVIEW | JUN 26 | MS |
| NO. | REVISION          | DATE   | BY |

SOURCE:  
1. AERIAL IMAGERY (FLOWN 2023-2024) SOURCED FROM NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH  
2. CADASTRAL/TOPOGRAPHICAL INFORMATION AND INSET DERIVED FROM LINZ DATA.  
3. WATERWAYS SOURCED FROM LINZ  
4. PROPERTY PARCELS SOURCED FROM LINZ.

CLIENT



GRAYMONT

FIGURE

FIGURE 7: BETTERMENT PLAN OVERVIEW

PROJECT

SOUTH-WESTERN PIT: WATER ASSESSMENT



## 7.0 Proposed Monitoring

### 7.1 Reasonable Mixing Zone

Based on the preceding information it is considered that any effects from the SW Pit on downstream waterways will emerge at Pōtea Spring, Pumphouse Spring, which both flow into the Mangawhitikau Stream.

As previously discussed, the Camelot Cave system could not be physically accessed for detailed monitoring due to high health and safety risk. Use of a piezometer within the quarry footprint for sample collection was also considered. However, this was considered flawed and discounted as a viable option because:

- ✧ reasonable mixing processes would not have been accounted for;
- ✧ collection of samples directly outside of the SW pit footprint (via a piezometer) cannot be achieved as surveying of the cave system to date has not been to a sufficient accuracy to ensure a piezometer can be successfully located to intersect with the Camelot Stream;
- ✧ even if this was achievable, it would not be possible to confirm that a representative sample could be obtained i.e. the sample location physical characteristics will be unknown (e.g. the location directly downgradient of a pool, run or riffle etc).

The first point at which the discharge would be observable is at Pōtea Spring or Pumphouse Spring. The reasonable mixing zone for any discharge is considered to be the reach of the Mangawhitikau Stream extending over a distance of 20 m downstream of the confluence with each spring discharge location.

Rationale for this determined mixing zone and length is based on:

- ✧ It is not practicable to have a mixing zone defined before the water emerges at Pōtea Spring or Pumphouse Spring – no compliance within the karst system would be practicable or enforceable.
- ✧ Based on results obtained from the water quality sonde deployments, there is natural sedimentation and increased turbidity occurring in the karst system unrelated to the Graymont activities which may be indistinguishable from any quarry effects.
- ✧ Given the nature of the discharge (and the effects), it would be unreasonable to have no mixing zone downstream of the spring.
- ✧ The opportunity for mixing/dilution occurs where Pōtea Spring, Pumphouse Spring merge with the Mangawhitikau Stream.

- ✧ The length of this mixing zone has been determined as three widths of the Mangawhitikau Stream (as defined by the WRP suspended solids standard: Policy 3.2.4.6).

It is also noted that 20 m downstream of the Pōtea Spring confluence, the Mangawhitikau Stream is a meander. A 20 m mixing zone length therefore also aligns with where mixing will naturally occur due to changes in the water flow direction caused by the stream geomorphology.

Discharges from the SW Pit to the Mangawhitikau Stream (via Pōtea Spring, Pumphouse Spring) will be induced by rainfall. When discharges from the quarry are occurring, the Mangawhitikau Stream will also be responding to rainfall in the catchment. Consequently, the Mangawhitikau Stream water level will be elevated and have an increased contaminant load (consistent with water quality sampling presented in Appendix D and discussed in Section 2.7.4).

The flow rate within the Mangawhitikau Stream is always greater than the flow rate from Pōtea Spring. This difference is greatest during rainfall events, and as such, the rate of mixing within the Mangawhitikau Stream is rapid due to the turbulent movement of the water during fresh/flood flow events.

## 8.0 Conclusions

Water that may seep into the ground at and around the SW Pit has been shown by dye tracing to emerge into surface water at Pōtea and Pumphouse Springs which then mixes with the Mangawhitikau Stream. Other more diffuse discharges may occur to nearby parts of the Mangawhitikau Stream, but based on the results of the tracer tests, are of a small scale resulting in undetectable effects.

Baseline water quality assessments identified that the following were potential contaminants of concern within the Mangawhitikau Stream and Mangapu River catchments:

- ✧ Suspended Sediment Concentration (SSC)/turbidity
- ✧ Dissolved reactive phosphorus
- ✧ Total phosphorus
- ✧ Total nitrogen
- ✧ Nitrate
- ✧ *E. coli*

The majority of these contaminants are sourced from the existing agricultural practices that occur within the Mangawhitikau and Mangapu catchments.

Investigations into the source of sediment in the Mangawhitikau Stream have determined that the Upper Mangawhitikau Stream has a greater suspended

sediment during rainfall events than suspended sediments observed at the Pōtea Spring. Elevated sediment concentrations at Pōtea Spring are only observed for a short period of time (no more than one day) and at lower concentrations than observed in the Mangawhitikau Stream. It was concluded from the investigations that most sediment originating from the Upper Mangawhitikau was sourced from the general catchment, which is dominated by agricultural land use whereas sediment in Pōtea Spring and Pumphouse Spring will include a contribution of sediment from the naturally occurring karst strata and any contribution from the currently operating Oparure Quarry.

A range of potential contaminants from the SW Pit activity have been assessed as potential sources of environmental effects. Of these, only sediment was determined to potentially contribute in any meaningful way to the targets set out in PC1 to the Waikato Regional Plan. However, due to the large separation distance (3 km and 2 km) to the points of emergence at Pōtea and Pumphouse Springs, any effect is expected to be of a less than minor scale in terms of suspended sediment concentrations in the receiving waterway.

Alongside proposed erosion and sediment control management at the quarry site, a range of betterment measures are proposed to offset sediment load increases with a net reduction in sediment load whereby both short- and long-term goals set out in PC1 are achieved (insofar as is relevant to the site and its contribution to these catchment / sub-catchment water quality issues). A number of options were assessed to meet a net zero sediment load discharge from the SW Pit and to also align with the policies of WRC PC1.

The options considered were:

- ✧ Native planting of eroded dolines in the upper catchment and inclusion of a silt fence at the entrance to the dolines.
- ✧ Riparian and native planting within the Mangawhitikau and/or Mangapu catchments.

Riparian planting and planting of steep land will be implemented at several locations to achieve net water quality improvements in terms of sediment load at Pōtea Spring and the Mangapu Stream compliance point. These measures will provide water quality improvements exceeding Graymont's necessary contribution towards meeting the short and long term PC1 goals at the Mangapu River compliance point.

Details of the proposed betterment approach are provided in the Betterment Plan.



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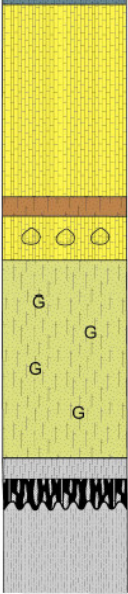
The geology of the area has a significant bearing on the surface and underground water resources in and around the quarry area. Therefore, the geological features are described in some detail due to their influence on the water resources.

The regional stratigraphic sequence is shown in Figure A1. The basement low permeability greywacke strata is overlain by the Te Kuiti Group, which in the wider area comprises coal measures, sandstone and limestone. The high-grade limestone at Oparure Quarry and SW Pit is found primarily in the Otorohanga Limestone Formation which is in the upper part of the Te Kuiti Group, deposited around 34 million years ago. The limestone was formed in shallow seas adjacent to a low-lying landscape that intermittently contributed terrestrial sediments into the area. As a result, much of the limestone is very pure with very high carbonate content.

Limestone deposition finished abruptly around 24 million years ago when basin subsidence resulted in the deposition of Mahoenui Group mudstone. This is a thick mudstone unit. It is coarser grained at the base where it lies unconformably over the limestone. It also contains some coarser grained siltstone and sandstone seams that can provide a pathway for water seepage and the emergence of springs.

The youngest deposits in the area, excluding alluvial deposits, are Quaternary volcanic ashes originating from the Taupo Volcanic Zone. These tend to be highly weathered and clay-rich.

The Otorohanga Limestone and Mahoenui Mudstone sediments are generally gently dipping and are little disturbed by faulting and folding. Within the existing quarry area, the limestone beds dip gently at 3° – 5° towards northeast. A major regional fault, the northerly trending Waipa fault lies around 1 km east of the Oparure Quarry property and the few faults seen on the quarry property are expected to be offshoots of this main fault.

| Age        | Thickness range (m) | Graphic log                                                                        | Group    | Subgroup       | Formation              | Lithologic description                                                                                                                                                               |
|------------|---------------------|------------------------------------------------------------------------------------|----------|----------------|------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Quaternary | 0-12                |   | Mahoenui |                | Kauroa Ash             | Undifferentiated volcanic ash, weathered clay-rich, multiple rhyolitic and andesitic tephra deposits and associated paleosols                                                        |
|            | 0-300               |                                                                                    |          |                | Taumatamaire Formation | Massive to weakly bedded calcareous mudstone to fine sandy mudstone, locally interbedded limestone                                                                                   |
| Miocene    |                     |  | Te Kuiti | Upper Te Kuiti | Otorohanga Limestone   | Light blue-grey to white, flaggy, pure bioclastic limestone, some units knobby/blocky, large scale cross bedding common                                                              |
|            | 0-65                |                                                                                    |          |                |                        | Mainly massive, calcareous muddy, glauconitic fine-medium grained sandstone with scattered shells                                                                                    |
|            | 0-15                |                                                                                    |          |                | Waitomo Sandstone      | Limestone ranging from massive, sandy to glauconitic and pebbly through to pure, flaggy bioclastic limestone and characteristic thick oyster beds                                    |
|            | 0-65                |                                                                                    |          | Lower Te Kuiti | Orahiri Limestone      | Massive or poorly bedded, calcareous fine-medium grained sandstone and sandy calcareous siltstone, commonly glauconitic, with a basal, flaggy or cross-bedded, glauconitic limestone |
|            | 0-120               |                                                                                    |          |                | Aotea Sandstone        | Massive, glauconitic, calcareous siltstone with silty fine-grained sandstone in the upper part and in the south, a local, basal, sandy bioclastic limestone                          |
| Oligocene  | 0-180               |                                                                                    |          |                | Whaingaroa Siltstone   | Brown carbonaceous mudstone with muddy quartzose sandstone, carbonaceous shale, subituminous coal seams and rare conglomerate; siderite concretions in upper part                    |
|            | 0-36                |                                                                                    |          |                | Waikato Coal Measures  |                                                                                                                                                                                      |
|            | 0-7,000             |                                                                                    | Murihiku |                | Basement               | Indurated sandstone, siltstone, interbedded sandstone and siltstone common, greywacke/argillite/conglomerate                                                                         |

**Figure A1: Stratigraphy of the Te Kuiti area (from Hansen, 2008)**

The surface geology of the local area is shown in Figure A2 for an area described by Frostad (2004) as the Oparure Block, as shown in the inset to Figure A2. Both the Oparure Quarry and the SW Pit are located within the Oparure Block. It is bounded to the west and east by north-north-easterly trending regional faults – the eastern bounding fault is the Waipa fault, the western bounding fault is unnamed. The Oparure block is bounded to the north by Boddies Road, which approximately follows a catchment divide and the southern limit is immediately south of the junctions between Oparure Road and Trooper's Road and Oparure Road and Waipapa Road.



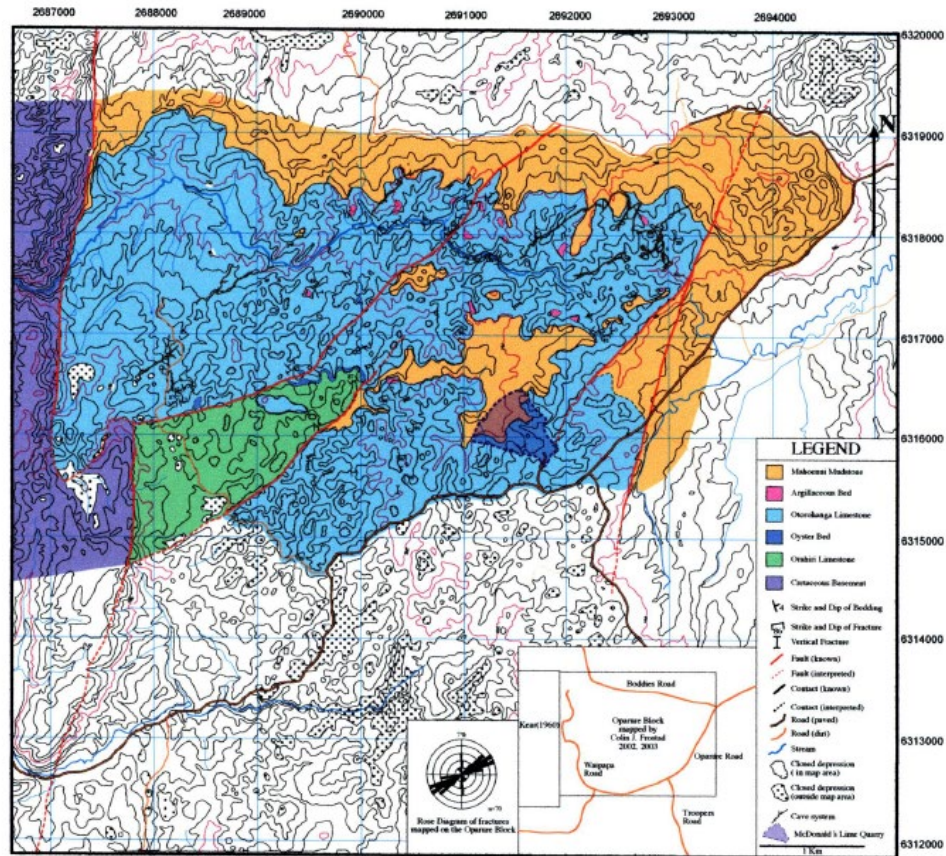
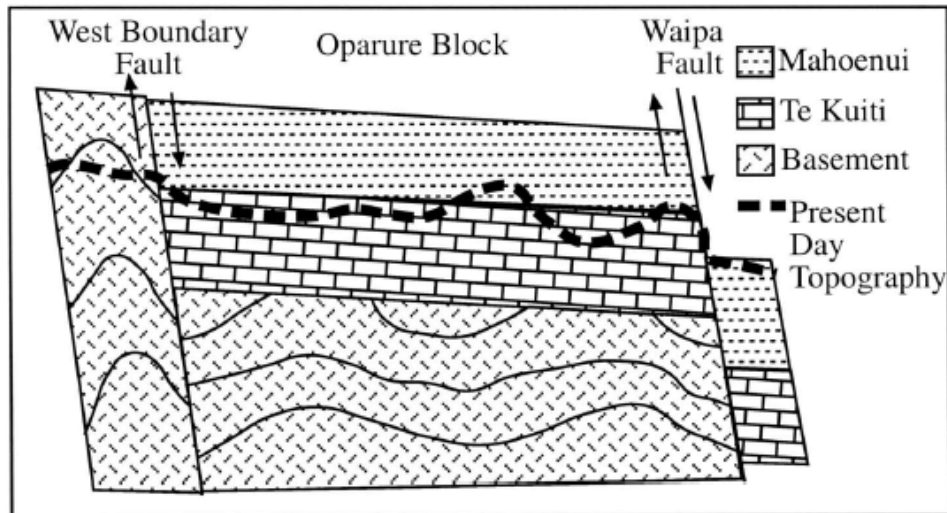


Figure A2: Geological map of the Oparure Block with corresponding rose diagram. Grid is a UTM system based on the New Zealand geodesic 49 map datum.

### Figure A2: Geological map of the Oparure Block (from Frostad 2004)

Phelps (2001) describes the geology at the Oparure quarry as comprising a more than 115 m thickness of hard limestone and calcareous sandstone (Te Kuiti Limestone), of which around 75 metres is high grade limestone rock. This limestone unit is overlain by approximately 15 metres of sandy calcareous siltstone (Mahoenui Formation) which in turn is mantled by about 9 metres of soft yellowish brown volcanic clay, silt (Maeroa Ash) and thin topsoil.

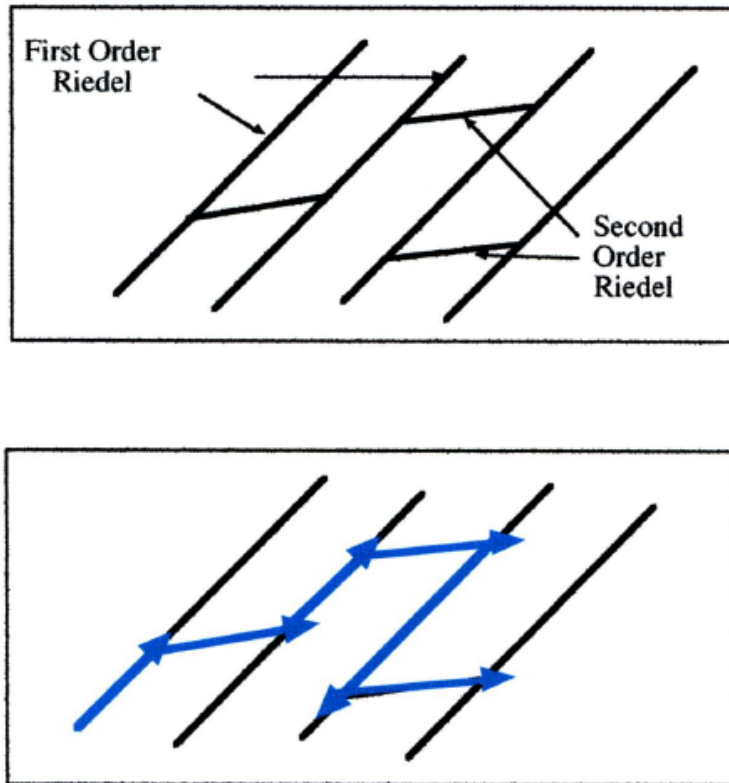
Figure A3 shows the original depositional sequence and the subsequent faulting and erosion that has led to the present day topography.



**Figure A3: Schematic west-east cross section of the Oparure Block, showing the regional dip, and the present day topography (from Frostad 2004)**

The Otorohanga Limestone Formation has a characteristic contrasting bedding system derived from pure precipitated limestone beds (which are mechanically strong, but easily dissolved by mildly acidic water), interbedded with seams of land derived sediments, which are mechanically weaker, but are resistant to chemical dissolution.

In addition to this bedding pattern, the Otorohanga limestone displays a well-developed fracture system that has promoted the formation of caves. The fracture pattern (known as a Riedel shear pattern) is generated by the movement of faults. Frostad (2004) notes that the resulting arrangement consists of a primary (first-order) set of fractures that forms at an oblique angle (20-40°) to the main faults. A second-order (secondary) set of fractures forms approximately 40-60° to the primary Riedel shear and roughly orthogonal to the main fault. This pattern is observed in the Oparure Quarry and is shown schematically in Figure A4. These fracture zones also create coarse grained angular breccia zones that provide pathways for water movement leading to the creation of the cave systems. Similar geologic characteristics can be expected to occur at the SW Pit.



**Figure A4: Riedel Shear Pattern a) (above) Fracture arrangement in the Mangawhitikau System b) (below) water flow through fracture network, to the east (down dip). (Frostad 2004).**

The Oparure Quarry property and surrounding farmland (including SW Pit) exhibit many karst features including collapse and solution dolines, tomos, dry valleys, sinking streams, caves and springs. Figure A5 shows the typical strata exposed within the Oparure Quarry demonstrating the variations in erodibility of the relatively horizontal bedding and the extensive vertical fracture systems.





**Figure A5: Fractured limestone on quarry wall (Frostad, 2004)**

Within the Oparure Quarry area two caves have been identified (Figure A6). The Blasted Cave was discovered in a quarry face following a blast and was investigated by a local caving group who followed it for a short distance until it became impassable. The Digme Cave is at a lower level and is a much longer cave that meanders beneath the northern quarry floor. It was discovered and surveyed in the 1980s. It is now considered to be unsafe to enter and will eventually be partially quarried.





**Figure A6: Caves identified within the Oparure Quarry (from Miller, 2014)**

The known cave system that is downgradient from the proposed northern expansion area of the Oparure Quarry is the eastern (downstream) end of the Mangawhitikau cave system. This comprises two main caves:

- ✧ The Mangawhitikau Cave which is around 8 km long and is connected to the current Mangawhitikau Stream channel; and
- ✧ Te Ana o te Atua (the Cave of the Spirit), which is thought to have originally been connected to the Mangawhitikau Stream channel, but subsequent down-cutting by that stream has left this as an abandoned dry cave.

Both these cave systems are dominated by northeast – southwest oriented passages ( $050^{\circ}$  –  $065^{\circ}$ ), which is a similar orientation to the primary Riedel shear pattern and fracture systems within the limestone strata (Figure A4).

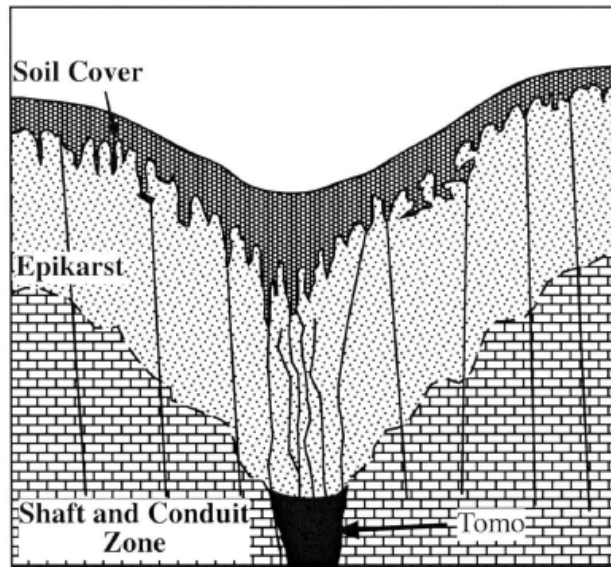
The formation of the Mangawhitikau Cave System is described as follows, based on information presented in Frostad (2004).

The Mangawhitikau Stream incised into the Mahoenui Mudstones trending approximately due east, concordant with the regional dip direction of the strata. As the surface water cuts through the overlying mudstones, it interacts with groundwater to form a more permeable weathered zone at the contact between the Mahoenui Group and the Otorohanga Limestone (i.e. the epikarst zone). The water in this zone actively dissolved the limestone along fracture planes. By the time the stream erosion exposed the Te Kuiti Group there were already well-developed dolines in the epikarst and open conduits that formed along fracture

breccias in the shaft and conduit zone. This can be seen in present day, as the topography on the Mahoenui Group is dimpled with dolines (Figure A7), some of which form open tomos through the mudstone and into the Te Kuiti Group (Figure A8).



**Figure A7: a) (above) Aerial photograph of doline field over the Mangawhitikau Cave b) (below) Interpretation of (a) showing the location of dolines, represented by black ellipses. Large ellipse in the centre of photo is known as Long Tomo. (Frostad, 2004).**



**Figure A8: Cross section of a doline, vertical lines represent tectonic fractures, black fill represents open vertical shaft (tomo). The amount of water that percolates down into the shaft and conduit zone will be dependent on the permeability of the soil cover, and the presence of well-developed fractures (from Williams, 1985).**

As the surface waters of the Mangawhitikau Stream flowed over top of the northeast striking fractures, flow was transferred into the open conduits, which provided a flow path of least resistance rather than eroding through the more competent layers of limestone. The main entrance into Te Ana o te Atua is the first recognisable open conduit to capture the Mangawhitikau Stream. The water within the open conduit still needed to flow in the direction of the regional hydraulic gradient (to the east) and was further prevented from advancing north by the higher hydraulic pressures from the Boddies Road ridge. Furthermore, the breccia-controlled conduits die out vertically and horizontally. Where the conduit dies out the water again travels in the down-dip direction, to the east, either along bedding planes or secondary Riedel shear fractures, until it intersects another more permeable fracture/ breccia network. This can be seen on the cave map of the Mangawhitikau Cave System, as the cave originates in a long, straight, open passage, the dimensions of which (100 m long by 10 m wide) are consistent with the large breccias seen in the Oparure Quarry.

During the time at which the stream was diverted into Te Ana o te Atua Cave, both the epikarst and the shaft and conduit zones were continuing to evolve in adjacent and deeper strata. Breccias upstream of Te Ana o te Atua continued to enlarge and develop into open conduits in the subsurface. At the location of the present submergence of the Mangawhitikau System, the stream was once more captured, and diverted into its present-day position, leaving behind the dry valley

between the current point of submergence of the stream into the Mangawhitikau Cave and the abandonment of the previous stream flow that passed through the Te Ana o te Atua Cave.

The first 200 m of the present submergence of the Mangawhitikau Cave is remarkably similar to the opening reaches of Te Ana o te Atua, a long, straight, relatively wide, open passage. This is consistent with the concept of well-developed fracture breccias developing into large open conduits that capture the stream flow and divert it to the northeast, oblique to the regional easterly flow. Second-order shear zones (near east-west in the eastern portion of the Oparure) develop into short, east-west conduits that bring the flow back towards the east in the down dip direction. Similarly oriented flow paths can be expected to occur at the SW Pit.

### **Identified Areas of Geological Significance**

#### *New Zealand Geopreservation Inventory*

The Geoscience Society of New Zealand is an organisation of amateur and professional members with an interest in the Earth Sciences within Aotearoa New Zealand. Their website<sup>4</sup> notes that the society has a Geoheritage Subcommittee which is concerned with the identification and protection of the best representative geological features and landforms of New Zealand. During the 1980s and 1990s, the subcommittee oversaw the completion of a New Zealand Geopreservation Inventory, which identified, listed, graded and documented around 3,200 different geological features under different subject categories. The Inventory is not a static listing and is continually being upgraded and reassessed as new information comes to hand.

The New Zealand Geopreservation Inventory has an entry called “Pakeho Polygon Karst” which occupies an area of around 346 ha. Of that, around 60 ha overlaps with the SW Pit, as shown in Figure A9. The inventory describes its characteristics as follows:

- ✧ Significance: Unforested polygonal karst and largest autogenic karst aquifer in North Island.
- ✧ Description: Largest autogenic karst aquifer in North Island. Area of polygonal karst with numerous dolines. Scattered limestone outcrops with patchy bush but mostly in grassed farmland that is quite smooth and probably blanketed in ash. Mapped from aerial photography.
- ✧ Importance: C (of regional scientific, aesthetic or educational value).

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<sup>4</sup> <https://gsnz.org.nz/about-us/sub-committees-and-advisory-boards/#GeoheritageSC>



*Operative Waitomo District Plan*

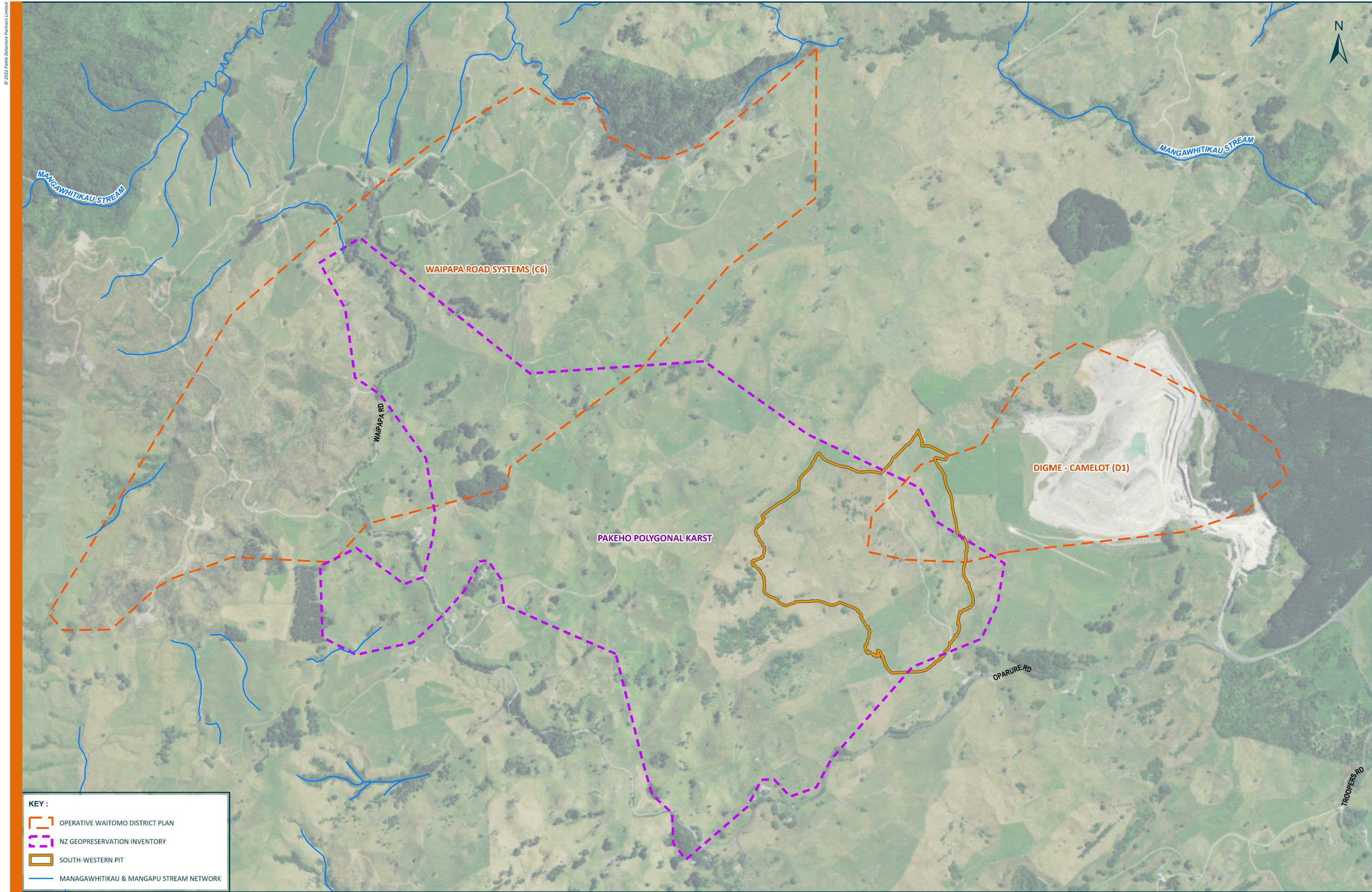
Appendix 6 of the Operative Waitomo District Plan identifies significant karst features of Waitomo District. Two of these areas occur at or near the SW Pit (as shown in Figure A9). In order of decreasing significance, they are:

- ✧ Regional Significance: Location C6: Waipapa Road Systems. Multiple caves in two systems. Length, high recreational use. Speleothems (best calcified tree roots in region). Includes Rumbling Gut, Catherwoods, Waipapa, Lembergs, Guildford, Yoyo.
- ✧ High Significance: Location D1: Digme-Camelot. Only example of gypsum rope in New Zealand (Digme). Part of largest autogenic karst system known in North Island. Troglodytic biota. Two caves. Large streamway (Camelot).

Location C6 (Waipapa Road Systems) does not overlap with the SW Pit and is separated from the northern boundary of the pit by a distance of over 400 m.

Location D1 occupies an area of around 98 ha and overlaps with the existing Oparure quarry. Around 10 ha at the south-western end of Location D1 overlaps with the SW Pit.





KEY :

- OPERATIVE WAITOMO DISTRICT PLAN
- NZ GEOPRESERVATION INVENTORY
- SOUTH-WESTERN PIT
- MANAGAWHITIKAU & MANGAPU STREAM NETWORK



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| A   | ISSUED FOR REVIEW | MAR 26 | MS |
| NO. | REVISION          | DATE   | BY |

SOURCE:  
1. AERIAL IMAGERY (FLOWN 2023-2024) SOURCED FROM NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH.  
2. CADASTRAL/TOPOGRAPHICAL INFORMATION AND INSET DERIVED FROM LINZ DATA.  
3. OPERATIVE WAITOMO DISTRICT PLAN DATA DERIVED FROM CAVES OVERLAY WDC.  
4. NZ GEOPRESERVATION INVENTORY DATA DERIVED FROM NEW ZEALAND PRESERVATION INVENTORY ACCESSED MARCH 2026 <http://www.geomarine.org.nz/> NZGI/

CLIENT



FIGURE

FIGURE A9: AREA IDENTIFIED AS HAVING GEOLOGICAL SIGNIFICANCE

PROJECT

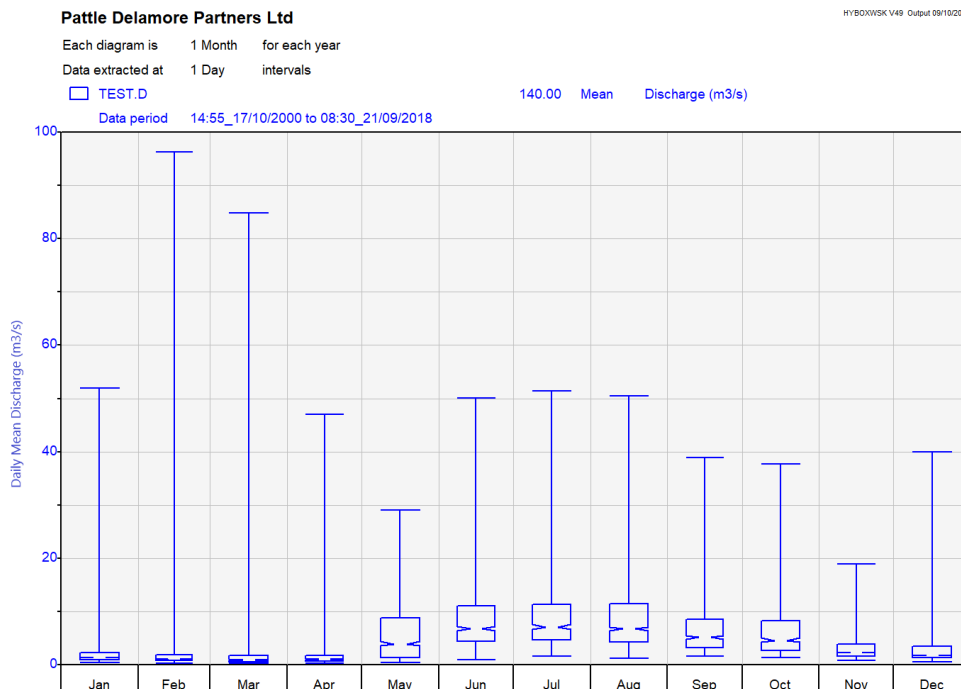
SOUTH-WESTERN PIT: WATER ASSESSMENT



**AAppendix B: Mangawhitikau Stream and  
Mangapu River Flow Statistics**

No flow records are available in close proximity to the Oparure Pit (i.e. the Mangawhitikau Stream). A long-term time series record was therefore obtained from the Waikato Regional Council for the Mangapu River (site: SH 3 above Mangaokewa Confluence on the Mangapu River to estimate flows for the Mangawhitikau Stream.

Figure B1 presents a box and whisker plot for the Mangapu River long-term dataset. The data illustrates seasonal variability of flows at the site. During summer months, the stream experiences lowest flows, but is also subjected to the greatest large flow events (likely to be cyclonic events). Greatest mean daily flow typically occurs during the cooler winter months (May to October).



**Figure B1: Box and Whisker plots of Daily means for each month for the Mangapu River flow record**

A specific discharge calculation using the Mangapu River was used to derive a flow record for both the Mangawhitikau Stream and the Mangapu River (above the Mangawhitikau Stream confluence).

It is recognised that this method of determining flows for these locations do have some limitations, such as the applications of the following assumptions:

- ✧ Geological conditions are consistent within the catchments.
- ✧ Land use characteristics are consistent.
- ✧ Rainfall characteristics are consistent.



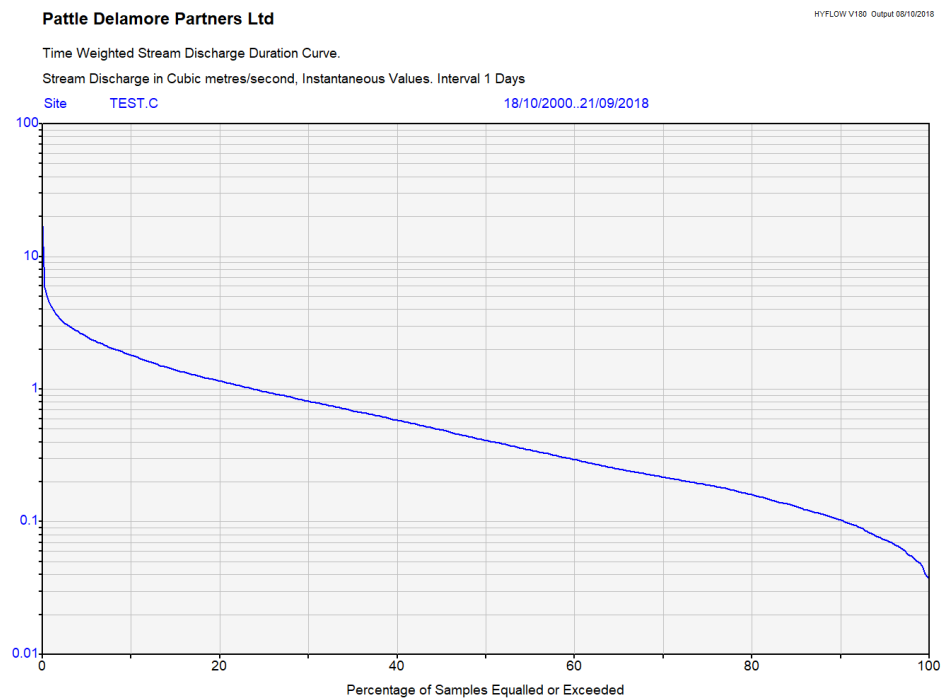
However, it provides a useful estimate of the potential flow variability that can be experienced within the reaches of these waterways, based on the available data.

Using the developed synthetic flow relationship, a seven-day low flow analysis was conducted for each waterbody. Rationale for this analysis is to assess the potential hydrological regime of the Mangawhitikau Stream and Mangapu River during a worst-case scenario when changes in surface flows might have their biggest impact.

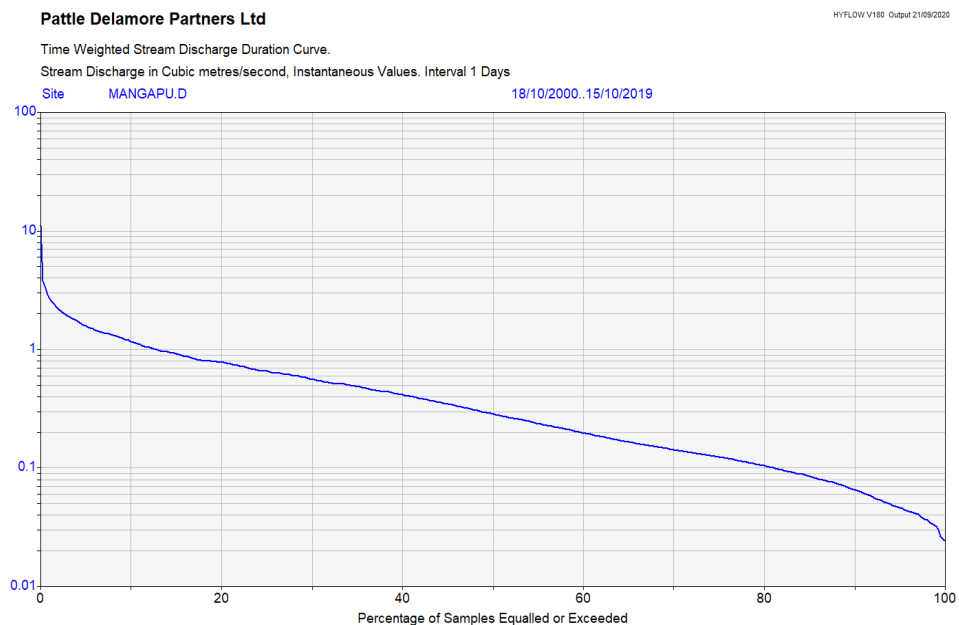
Table B1 presents the numerical data for the low flow analysis conducted for the Mangawhitikau Stream and Mangapu River (upstream of the Mangapu River and Mangawhitikau Stream confluence).

| <b>Table B1: Derived Seven Day Low Flow Frequency Analysis for Mangawhitikau Stream and the Mangapu River (at the Confluence)</b> |                                             |                                         |
|-----------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|-----------------------------------------|
| <b>Mangawhitikau Flow Value (m<sup>3</sup>/s)</b>                                                                                 | <b>Mangapu Flow Value (m<sup>3</sup>/s)</b> | <b>Annual Recurrence Interval (ARI)</b> |
| 0.2415                                                                                                                            | 0.1103                                      | 1.01                                    |
| 0.0924                                                                                                                            | 0.0652                                      | 2                                       |
| 0.0851                                                                                                                            | 0.0608                                      | 2.33                                    |
| 0.0619                                                                                                                            | 0.0444                                      | 5                                       |
| 0.0494                                                                                                                            | 0.0334                                      | 10                                      |

Figure B2 and B3 present the flow duration curve for the derived flow Mangawhitikau Stream and Mangapu River (upstream of the Confluence), respectively. Again, data to present these figures have been derived using the synthetic discharge relationship.



**Figure B2: Derived flow duration curve for the flow Mangawhitikau Stream**



**Figure B3: Derived flow duration curve for the flow Mangapu River (upstream of the Confluence)**

The shape of the flow duration curve provides an indication of the hydrology that occurs within the catchment. Given that tail of both flow duration curves (the higher percentages of exceedance) are rather flat, indicates that both waterbodies do have an apparent base flow that is sufficient to withstand drought extremes. Similarly, the head of the flow duration curves (the lower percentages of exceedance) are also considered to be flat. This implies that the catchments do not experience regular extreme flow events or are influenced by high impervious areas. That pattern of hydrologic flow is consistent with the large water storage characteristics of the limestone strata.





# Pakeho Pit Dye Tracer Groundwater Monitoring

✦ Prepared for

Graymont New Zealand Limited

✦ January 2021



PATTLE DELAMORE PARTNERS LTD  
Level 5, PDP House  
235 Broadway, Newmarket, Auckland 1023  
PO Box 9528, Auckland 1149, New Zealand

Tel +64 9 523 6900  
Website <http://www.pdp.co.nz>  
Auckland Hamilton Tauranga Wellington  
Christchurch Invercargill



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Prepared by

SIGNATURE



Morgan Harvie

Reviewed by

SIGNATURE



Hayden Easton

Approved by



Peter Callander

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## Executive Summary

An investigation into the subsurface migration of soakage discharges at the proposed Pakeho pit was undertaken via tracer tests using two fluorescent dyes, Rhodamine (RWT) and Fluorescein (FLT) at two recharge points: one with a flowing stream (Camelot Cave) and the other being a doline with no known direct connection to flowing water (known as D41). Figure 1 shows the dye detection locations within the Mangawhitikau stream.

Three dye tracer rounds were carried out. In the first tracer test, there was no dye detected in the downstream catchment. Three reasons were proposed as to why the dye was not detected this included:

- ✧ Poor connectivity of the doline entrance to the main water body;
- ✧ Dilution of the dye before reaching the emergence location;
- ✧ Dye emerged at a location where monitoring was not occurring. This was the least likely possibility.

In the second dye tracer round, the RWT dye was introduced into the flowing cave Camelot and was measured present by the cyclops RWT sensor dye at the G-Gun site 26 hours after injection. 6 hours later the peak of the dye was measured (maximum 4 ppb) and took a further 29 hours to reach baseline concentrations.

In the second tracer test RWT dye was introduced into Cave Camelot and FLT dye into D41 to identify the specific emergence spring location/s. Both dyes were measured present at the to emerge at the Gate Spring and Pumphouse Spring by the handheld fluorometer. The travel time from the tracer to the G-Gun site was quicker than round one, almost 20 hours later, perhaps owing to the antecedent hydrological state of the catchment due to the rainfall prior. The peak RWT dye concentration was measured at 2.5 ppb almost four hours later and an additional 9 hours later baseline concentrations were reached.

The monitoring results for RWT emergence were similar to previous dye tracer testing by PDP at the Oparure pit. The dye was shown to re-emerge at the Gate Spring location and some dye was present in the Pumphouse Spring. The ultimate receiving environment is therefore, the lower Mangawhitikau catchment.

The RWT and FLT dyes were released into the dolines at a source concentration of ~181,000 ppb (minimum dilution concentration). The dilution (from the doline) through the aquifer system was evident in comparing the high concentration of dye injected into the doline to the peak concentration measured in the springs and main stem of the Mangawhitikau Stream.





KEY :

- DYE DETECTION SITES
- NO DYE DETECTED
- STREAM



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FIGURE

FIG 1: DYE DETECTION LOCATIONS

PROJECT

OPARURE PIT DYE TRACER GROUNDWATER MONITORING



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## 1.0 Introduction

Pattle Delamore Partners (PDP) were engaged by Graymont New Zealand Limited (Graymont) to complete an investigation into the subsurface migration pathway of soakage discharges at the proposed Pakeho pit. This report aids in assessing the groundwater flow paths and provides an insight into transit times through the karst system.

### 1.1 Karst Landscapes

The proposed Pakeho pit is surrounded by a karst landscape which is characterised by the natural dissolution of limestone from slightly acidic rainwater. An underground drainage system is created which drains to streams further downgradient in the catchment (Parise, 2018). The water that re-emerges at the surface comes from two sources. One of the sources is subterranean streams i.e. streams that infiltrate into the groundwater network and re-emerge further down in the catchment. The other source is infiltrating rainwater. Rainwater is infiltrated throughout the entire catchment through the soils and through recharge zones along the catchment, dolines (also known as tomos) and sinkholes. Infiltration through the soils throughout the catchment occurs at a much slower rate and therefore, sediment and contaminants can be filtered out of the water. Recharge zones directly feed water into active conduits which results in more rapid infiltration. Infiltration through recharge zones leads to less filtration of large particles which may result in greater dispersal of contaminants and sediment through the karst system. The discharge points of this infiltration are in the form of natural springs (Goldscheider, 2008).

In the limestone karst formations, groundwater flows through fractures, caves and dissolution channels. These types of groundwater flows can cause increased flow speeds, in comparison to other types of groundwater flows. These groundwater flow speeds can vary greatly and can depend on the flow state of the network (Brackman & Brusseau, 2002). Exact flow paths through these networks can also be difficult to determine as flow lines may not be primarily determined by overlying topography and can also be influenced by the geology and climate in the region (Condon & Maxwell, 2015).

### 1.2 Water Tracing

Water tracing techniques are used in karst environments to obtain hydrological information about the groundwater flow characteristics and contaminant transport where groundwater paths are unknown. Tracing techniques can include the use of fluorescent dyes, salt dilution and particle tracers (Goldscheider, 2008).

The dye tracer method was used for this experiment. Dyes used were Rhodamine-WT (RWT) and Fluorescein (FLT). These dyes are synthetic organic compounds that absorb light at specific wavelengths and emit fluorescent light at longer wavelengths (Goldscheider, 2008). Dye tracers are easy to monitor in the downstream catchment as they can be visually observed in streams, in comparison to other types of tracer techniques.

The selection of the dye injection site is dependent on the objectives of the investigation, with dolines being the preferred choice as they carry water with the tracer directly into the karst system and infiltrate into active conduits. Known cave systems with streams can also be perfect for this type of testing as water can easily make its way through the path of the flowing water.

The primary result of the dye tracer experiment is a Breakthrough Curve (BTC). A BTC is a time series of concentration data points which can provide an insight into the groundwater network, the water velocities through the network and contaminant transport (Goldscheider, 2008). The BTC reveals the time at which the dye is first measured in the downstream network to a maximum peak measurement and the time it takes for all the dye to go through the system. These measurements can be used to calculate a recovery time i.e. the time to return to baseline measurements, which can provide some insight into other features of the network.

Water particles moving through the karst network do not flow at a single velocity but experience a range in velocities (changes in both the speed and direction of flow). Rapid flows can be achieved in the centres of large conduits and slower flows in adjacent voids. This change in velocity is referred to as dispersion and is displayed by the width of the BTC i.e. shape of the BTC, including the lag time for all the dye to be removed from the system (the recovery time). A wider BTC indicates more dispersal within the groundwater network with a longer range of travel times. A shorter width of the BTC indicates fast flows and large conduits (Goldscheider, 2008).

Previous dye tracer testing undertaken by PDP, 2020, shows the emergence locations of water within the Mangawhitikau Stream from dolines located within the Oparure Pit. The dye emerged from these dolines at the Gate Spring.

### 1.3 Project Aims

The aim of the dye tracer project was to identify the emergence location(s) and flow directions of water entering subsurface waterways within the karst system. The entry points chosen were dolines and the stream flowing through the Camelot Cave system. Emergence zones were to be determined in the broad catchment scale i.e. Mangawhitikau vs. Mangapu and emergence via specific springs within each of these catchments.



This project also aimed to broadly characterise the transit times through the groundwater network and provide some information about the concentrations of dye emerging in the surface water. This information was to be acquired by observing broad scale changes in concentrations and could likely be used in future to inform water quality monitoring requirements.

## 2.0 Methodology

### 2.1 Dye Seeding

To trace the water through the karst system, each of the two types of fluorescent dye powders (RWT & FLT) were mixed through 20 Litres of water, resulting in source concentrations of 90,720,000 ppb. The 20 Litre solution was funnel fed into the dolines and cave system. Followed by the seeding of the dye, approximately 10,000 Litres of water was fed into the system for a total dye concentration of 181,000 ppb. It is not likely that all the dye mixed with the 10,000 Litres resulting in a seeding concentration of between 181,000 and 90,720,000 ppb. The conservative dilution approach and minimum injection concentration of 181,000 ppb is used to compare to the emerging concentrations, noting that the real concentration/ the actual dilution occurring within the karst system, may likely have been higher.

On 31/7/2020, dye was seeded into two locations within the proposed pit. One location to the north of the proposed pit (D29) and one location to the south of the proposed pit (D35), as shown in Figure 2.

On 13/11/2020, dye was seeded into the Camelot cave system located just outside of the proposed pit footprint, as shown in Figure 2. This tracer test confirmed the presence of dye (and therefore emergence location/receiving environment) as RWT dye was recorded present in the Mangawhitikau Stream at the G-Gun site by the Cyclops sensor.

A third dye tracer test was then carried out on 2/12/2020 to check the specific emergence springs within the Mangawhitikau Stream catchment and the Mangapu River. The two locations seeded were the D41 doline at the very southern extent of the pit and Cave Camelot system (Figure 2) to confirm the spring within the Mangawhitikau Stream the dye emerged from.

### 2.2 Instrumentation

For the first round, a G-GUN-FL24 (G-Gun) was installed in the Mangawhitikau Stream catchment at the bridge before the convergence with the Mangapu River. The logger had optics to measure both RWT and FLT. The G-Gun was only used for round one as it became inundated during a flood event between the first and second round.

The Turner Cyclops-7F (Cyclops) Fluorometer with RWT optics only was installed in the Mangawhitikau Stream at the lower reach of the Mangawhitikau catchment where the G-Gun was previously located in round one. This logger recorded rhodamine dye concentrations at regular 15-minute intervals (on the hour) during tracer testing to provide high temporal resolution of dye concentrations at a broad catchment scale.

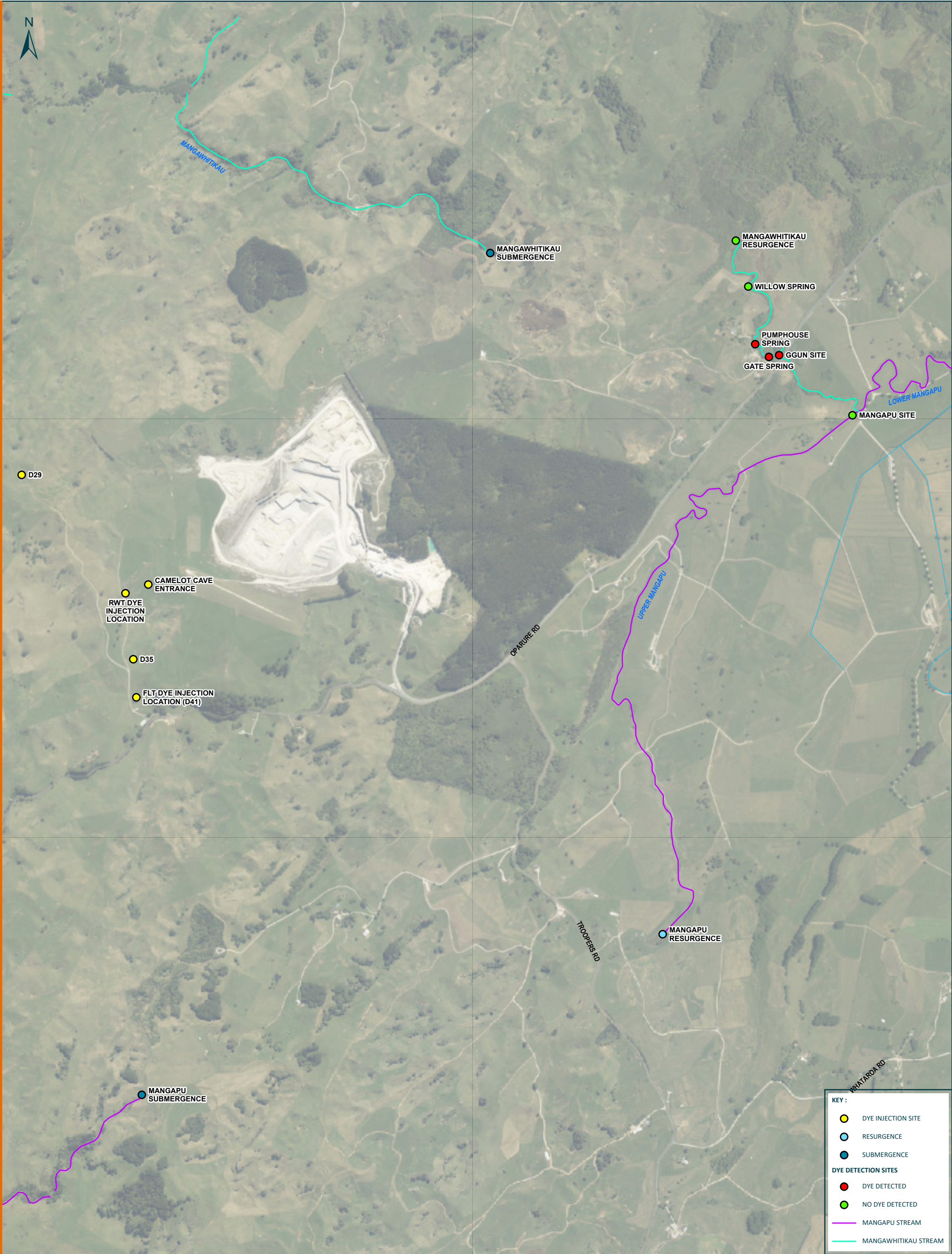
A separate manual sampling regime using a Turner Designs AquaFluor Handheld Fluorometer was completed to provide data for specific locations of interest at a coarser temporal resolution. This device had dual channel capability to measure both RWT and FLT dye tracers. The AquaFluor was calibrated using known concentration standards using the recommended calibration method prescribed for the instrument.

### **2.3 Manual Sampling Locations**

The Mangawhitikau Resurgence is located downgradient of the dolines and cave system. The Mangawhitikau Stream was determined as the receiving environment of other dolines located within the Oparure pit from previous dye tracer testing (Appendix A). Separate springs along the Mangawhitikau Stream were monitored using the handheld fluorometer. These points along the stream were named the Resurgence, the Willow Spring, Pumphouse Spring, Gate Spring, and a manual sample taken at the location of the named G-Gun site.

Monitoring all possible downstream locations including the neighbouring catchments downgradient increases the chance of successful dye detection. Therefore, the Mangapu River was also monitored at the resurgence and downstream locations shown in Figure 2.





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FIGURE  
**FIG 2: DYE INJECTION LOCATIONS**

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OPARURE PIT DYE TRACER GROUNDWATER MONITORING



### 3.0 Round One Results

In the first round of dye tracing, rhodamine dye was added into two dolines (X, X) within the proposed pit. No dye presence was recorded during this monitoring round. This may have been due to one of three possibilities:

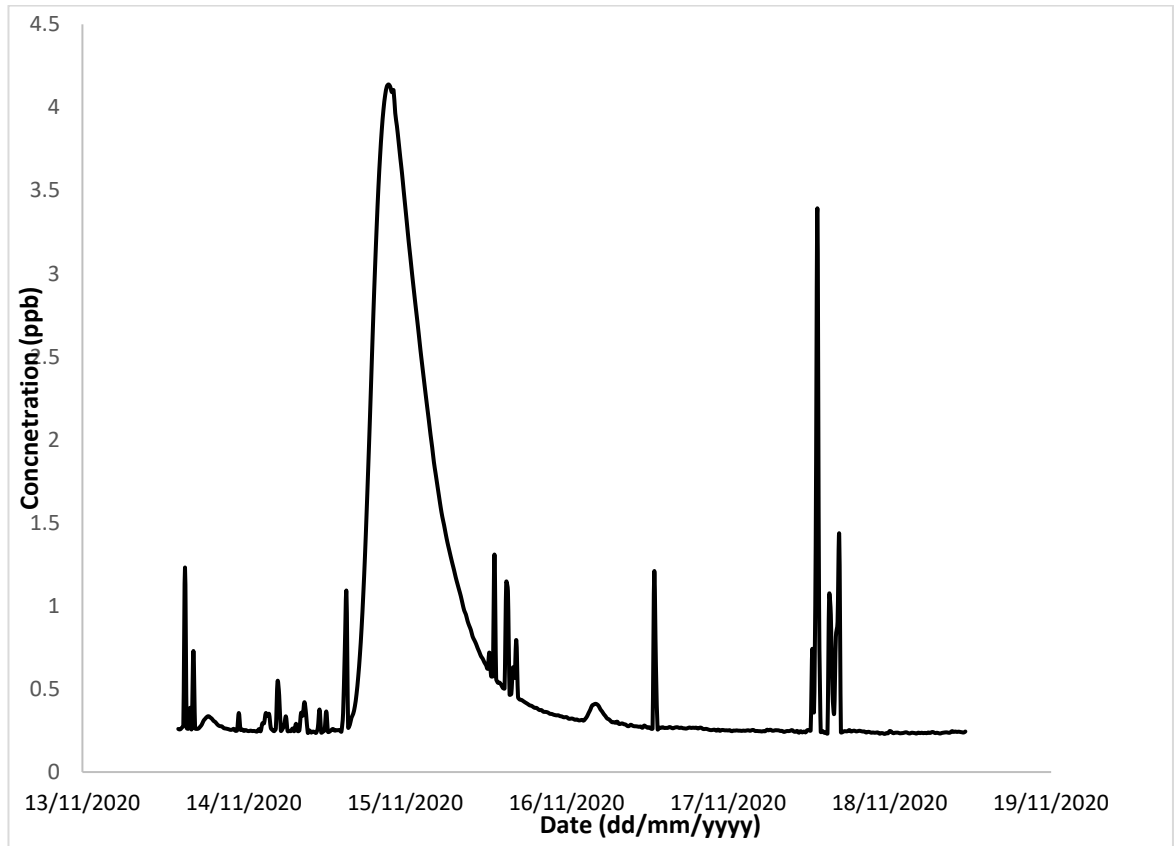
- ✧ There is poor connectivity to allow dye to pass from the dye injection locations to a receptor;
- ✧ There is large dispersion and dilution processes occurring, thereby causing monitoring sensors to not be able to detect dye presence; or,
- ✧ Dye emerged at a location where monitoring was not occurring. This was the least likely possibility.

### 4.0 Round Two Results

In the second round of dye tracing, the RWT dye was measured by the Cyclops sensor at the G-Gun site in the Mangawhitikau Stream. Figure 3 shows the RWT dye tracer at the G-Gun location at the lower reach of the Mangawhitikau Stream. The BTC from round two shows a faster rising limb than falling limb of the dye tracer.

The results obtained by the Cyclops sensor shows the RWT tracer was measured 26 hours after injection into the Cave Camelot system. The peak of the tracer was detected 6 hours later and took a further 29 hours to return to baseline concentrations. The total emergence time and therefore, BTC was 61 hours or two and a half days. The peak concentration was measured at 4.1 ppb.





**Figure 3: Round Two RWT Dye Tracer Test Results from Cyclops Sensor**

## 5.0 Round Three Results

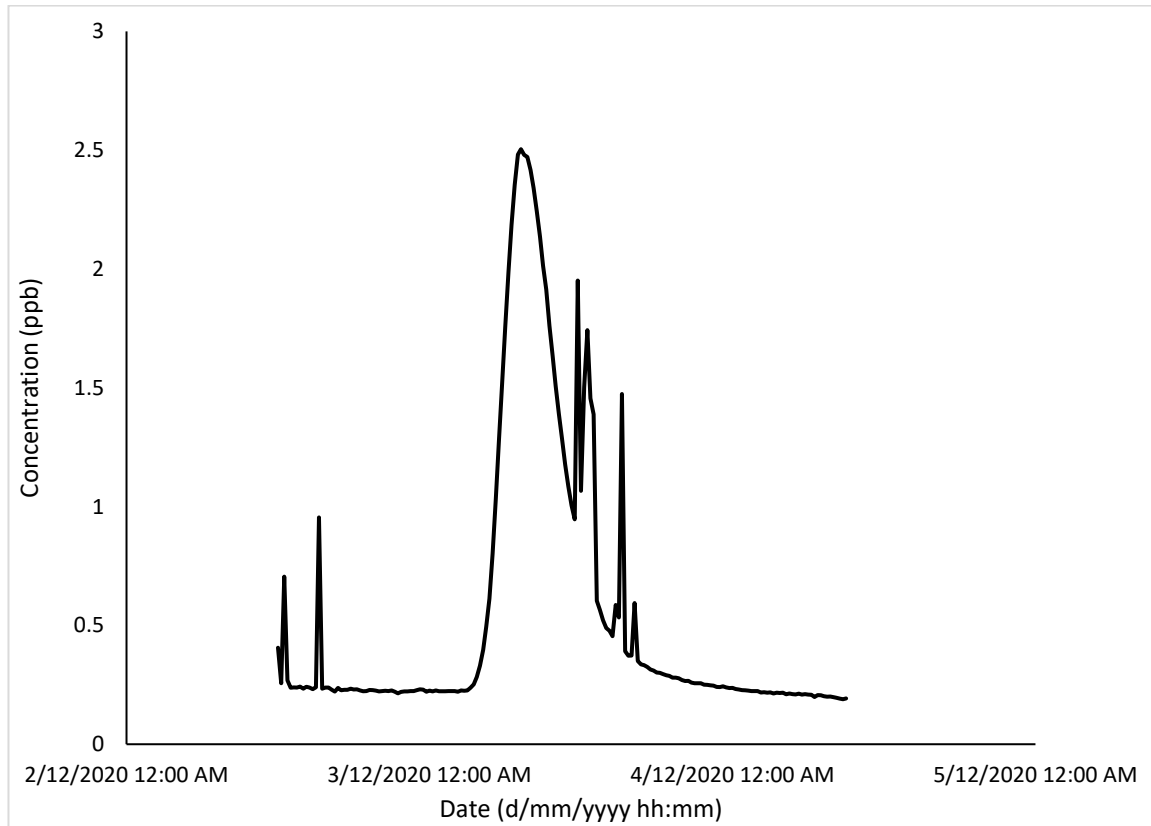
The third round of dye tracing was used to confirm the specific emergence location of the dye. It was known the RWT tracer emerged within the Mangawhitikau catchment, but it was still not understood which spring(s) the dye emerged from.

The third round of dye tracing revealed the dye emerged from the Gate Spring and Pumphouse Spring. Dye was not present within any of the other springs within the Mangawhitikau Catchment. The dye was also not detected in the Mangapu River (locations shown in Figure 2).

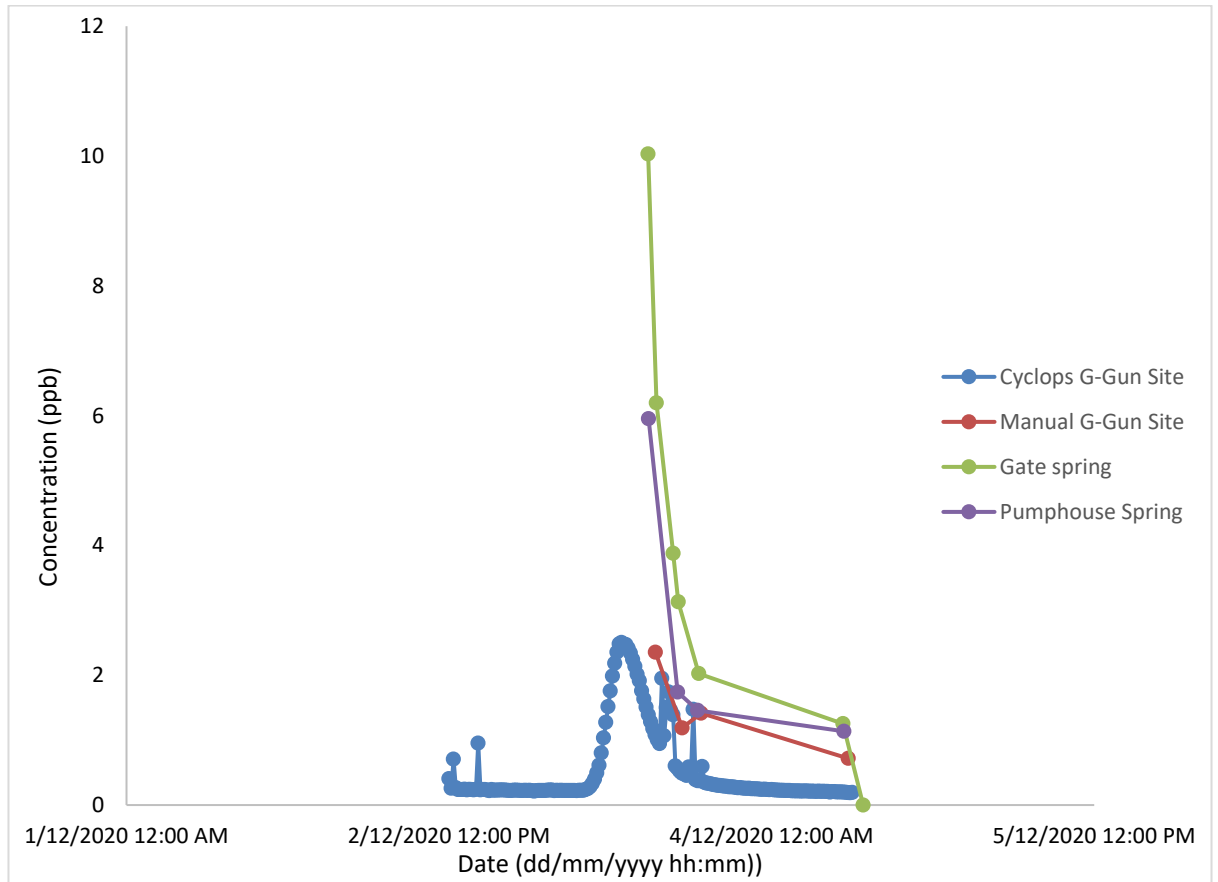
The RWT dye was seeded at 8:30 am on 2<sup>nd</sup> December and was first detected present at 4:00 am on 3<sup>rd</sup> December, 19 hours and 30 minutes later. The peak concentration of 2.48 ppb was measured at 7:30 am, 3 hours and 30 minutes later. The tracer took a further 9 hours to return to baseline concentrations (Figure 4). The pattern of measurements at sites where the RWT dye was detected is shown in Figure 5.

This result was much different than the previous round two tracer test, just a few weeks prior. The peak concentration was also much less at 2.5 ppb.

The FLT dye was introduced at doline D41 and was detected present at the Gate spring and subsequently at the G-Gun site, however measurements at the G-Gun site were very diluted (Figure 6).



**Figure 4: Round Three RWT Dye Tracer Test Results from Cyclops Sensor**



**Figure 5: Round Three RWT Dye Tracer Test Results from Cyclops and Handheld Sensor at the G-Gun Gate Spring and Pumphouse Spring**



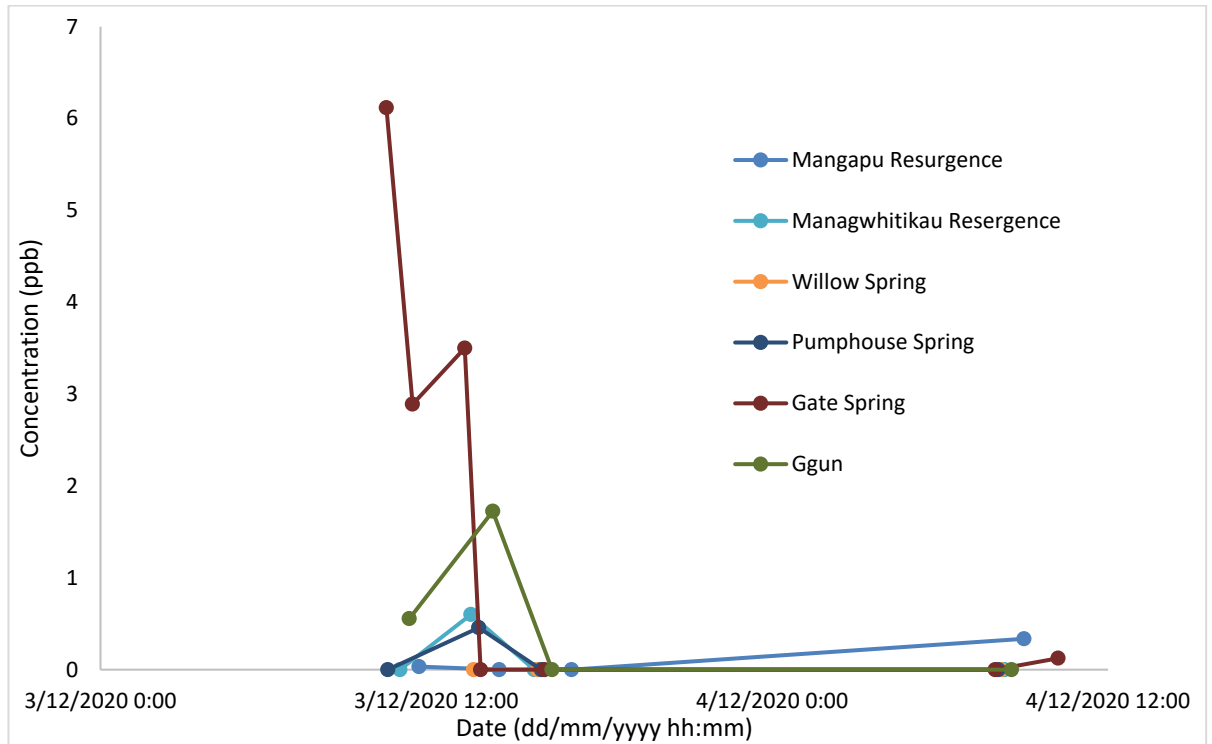


Figure 6: Round Three FLT Dye Tracer Results from Handheld Sensor

## 6.0 Discussion

The result of the dye tracer tests confirmed the emergence locations of the dye tracers and subsequently, gave an insight into flow paths within the cave system and information to broadly characterise travel times and velocities.

### 6.1 Flow Paths

#### 6.1.1 Catchment Scale (Mangapu vs Mangawhitikau)

The focus of this tracer test was to determine the groundwater flows paths from the areas of recharge (dolines) to discharge (springs).

Dye was not measured in the Mangapu River at any of the sites or tributaries including the Mangapu wetland. Both dyes were present within the Mangawhitikau Stream catchment at the Gate Spring and Pumphouse Spring and therefore, measured present in the downstream G-Gun site in the main stem of the Mangawhitikau Stream.

#### 6.1.2 Mangawhitikau Catchment

The exact emergence location of the RWT dye in round two was unknown however, it was detected present at the G-Gun site in the Mangawhitikau Stream catchment. In round three, the dye was detected present at the Gate Spring and Pumphouse Spring, which then flows to the mainstem of the Mangawhitikau Stream. Consequently, dye was also detected present at the downgradient G-Gun monitoring location.

Manual measurements confirmed the specific spring emergence of the dye tracer however, peak concentrations in the springs were unknown.

**Table 1: Characteristics of Breakthrough Curves for the RWT tracer**

| Tracer test                                                 | Monitoring Site | Straight-line distance to monitoring site (km) | Time from seeding to start of rising limb (hours) | Time from seeding to peak concentration (hours) | Duration of rising limb (hours) | Peak Concentration (ppb) | Duration of falling limb (hours) |
|-------------------------------------------------------------|-----------------|------------------------------------------------|---------------------------------------------------|-------------------------------------------------|---------------------------------|--------------------------|----------------------------------|
| Round Two                                                   | G-Gun           | 3.15                                           | 26                                                | 32                                              | 6                               | 4.1                      | 29                               |
| Round Three                                                 | G-Gun           | 3.15                                           | 19.5                                              | 23                                              | 3.5                             | 2.5                      | 9                                |
| <b>Notes:</b><br>1. Hours are rounded to nearest half hours |                 |                                                |                                                   |                                                 |                                 |                          |                                  |

## 6.2 Travel Times and Velocity

Flow times from the dye injection locations are summarised in Table 2 below.

| Table 2: Travel Times                                                                                                                                           |                 |                                                |                                                        |                               |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|------------------------------------------------|--------------------------------------------------------|-------------------------------|
| Tracer test                                                                                                                                                     | Monitoring site | Straight-line distance to monitoring site (km) | Travel duration to measured peak concentration (hours) | Straight-line velocity (m/hr) |
| Round Two                                                                                                                                                       | G-Gun           | 3                                              | 32                                                     | 94                            |
| Round Three                                                                                                                                                     | G-Gun           | 3                                              | 23                                                     | 130                           |
| Notes:<br>1. The minimum straight-line distance is determined from doline to monitoring site however, it was not likely that the flow path was a straight line. |                 |                                                |                                                        |                               |

The RWT dye injected into the flowing Camelot Cave system took approximately 26 hours to be first detected at the G-Gun site.

Transit times from recharge zones are also dependent on the initial flow state of the system. Flow state is influenced by weather and climate conditions which can change on many different timescales. For example, after storm/high rainfall events, it is expected that due to the volume of water flowing through the karst system, flow times may be faster, and the dye may become more diluted. Hydrographic data is needed to show the effect of changes to the weather and climate.

It is likely that a variety of different flow speeds were achieved owing to the karst network with different sized conduits and caves. The straight-line distance reported in Table 2 above indicates a broad scale approximation of travel times. The RWT tracer had an average travel time of approximately 94 m/hr in round one and 130 m/hr in round two. However, it is likely that the real flow path from the doline to the spring would have been more tortuous (and therefore longer). The real velocities are therefore likely to have been faster than those calculated, due to the longer more convoluted flow path. The dissolution channels beneath the ground can cause fast ground water flows as shown in these tests. The two tests also show the velocities are variable depending on antecedent conditions.

### 6.3 Antecedent Hydrological Conditions

An important discussion is the initial hydrological state which can alter flow velocities through the system. In previous Oparure tracer testing, much slower velocities were recorded. The velocities from the doline to the spring during the Oparure testing were 12 m/hr and 23 m/hr. This may have been owing the drought which occurred in the summer of 2020. During round two of Pakeho tracer testing, the dye travelled at an average speed of 94 m/hr. During the month of October, 374 mm of rainfall was recorded by the WRC Waitanguru gauge. Greatest daily rainfall totals reached 32 mm, 30 mm and 28 mm in October and a total 13 mm of rainfall was recorded the week preceding the round two tracer test.

During round three of the tracer testing, the dye tracer travelled even faster due to the substantial rainfall that occurred the week prior. A cumulative total of 155 mm (WRC Waitanguru rainfall gauge) was recorded in November, with two daily totals reaching 46 mm and 40 mm. The week prior to the dye tracing a total of 80 mm of rain was recorded at the Waitanguru rainfall gauge site. The velocity from the Camelot Cave system to the Mangawhitikau Stream was 130 m/hr, perhaps owing to the more saturated soils/karst catchment.

Water level data from the WRC Mangapu River site show different hydrological flow states. The WRC Mangapu River measurement site is located at State Highway 3 (SH3) ~12 km downstream from the Mangawhitikau Stream G-Gun site. When the peak concentration of dye was measured in the Mangawhitikau Stream in the second round, the Mangapu River water level was approximately 2.4 m (Figure 7). In the third round, the water level at peak concentration in the Mangapu River site was approximately 2.8 m (Figure 8). Both tracer tests occurred after significant rainfall and occurred during descending water levels.



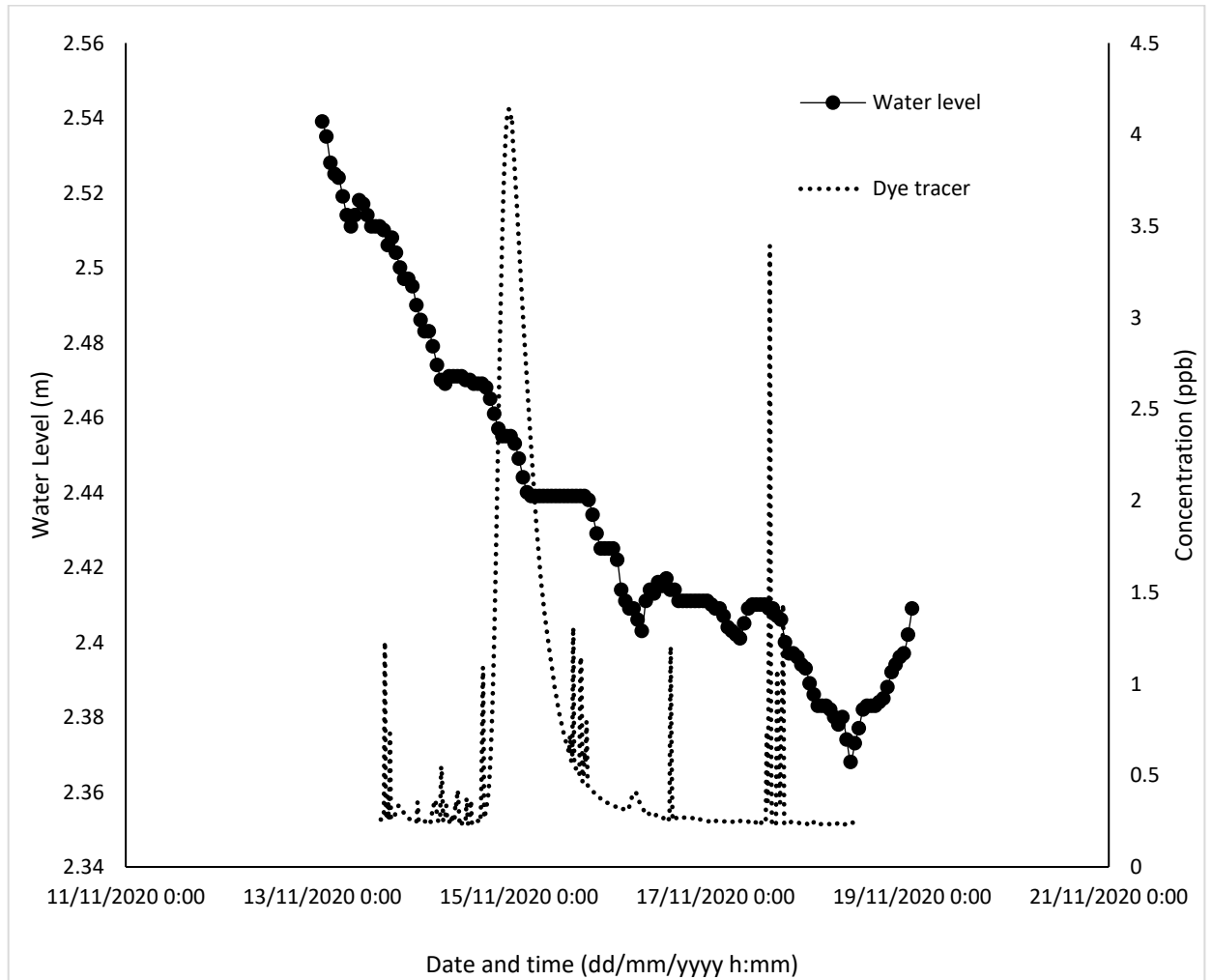
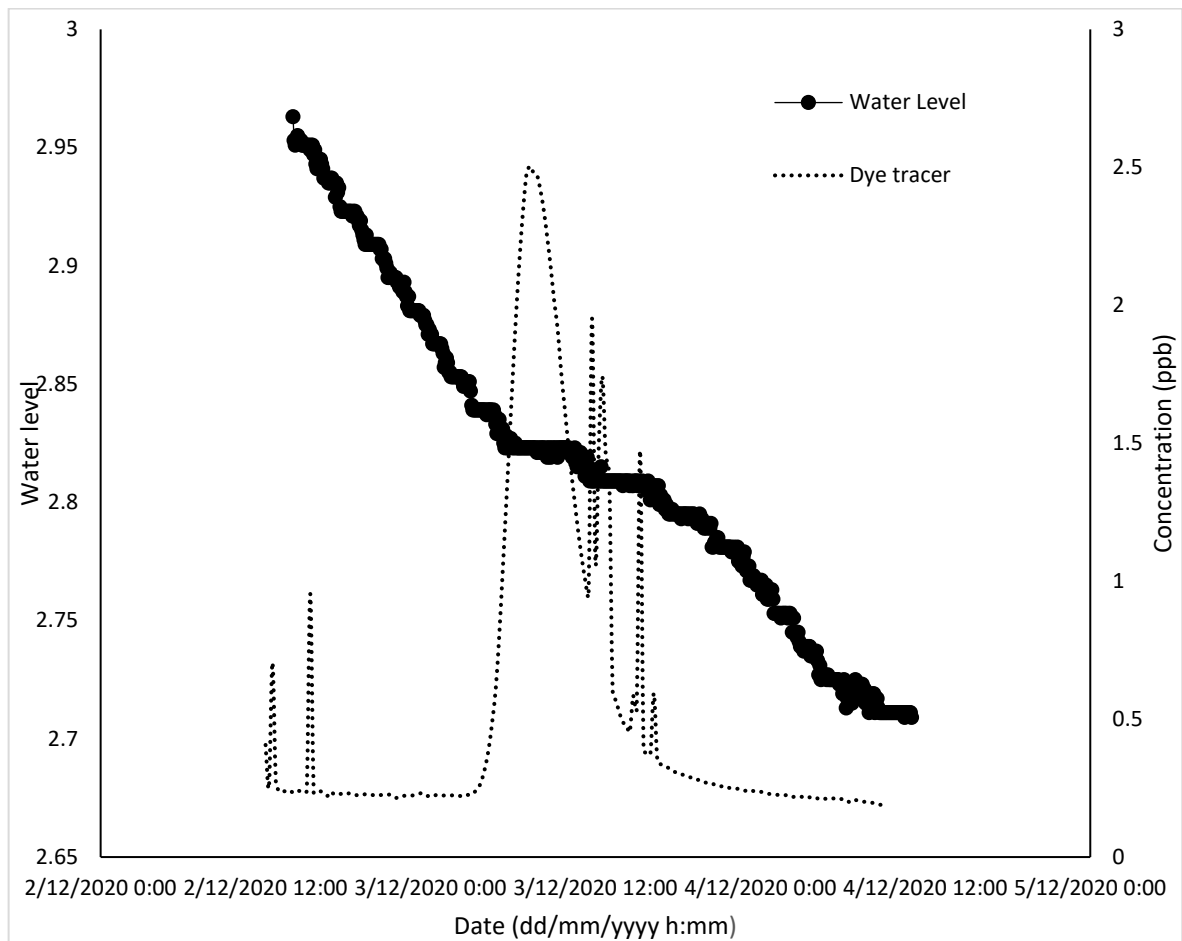
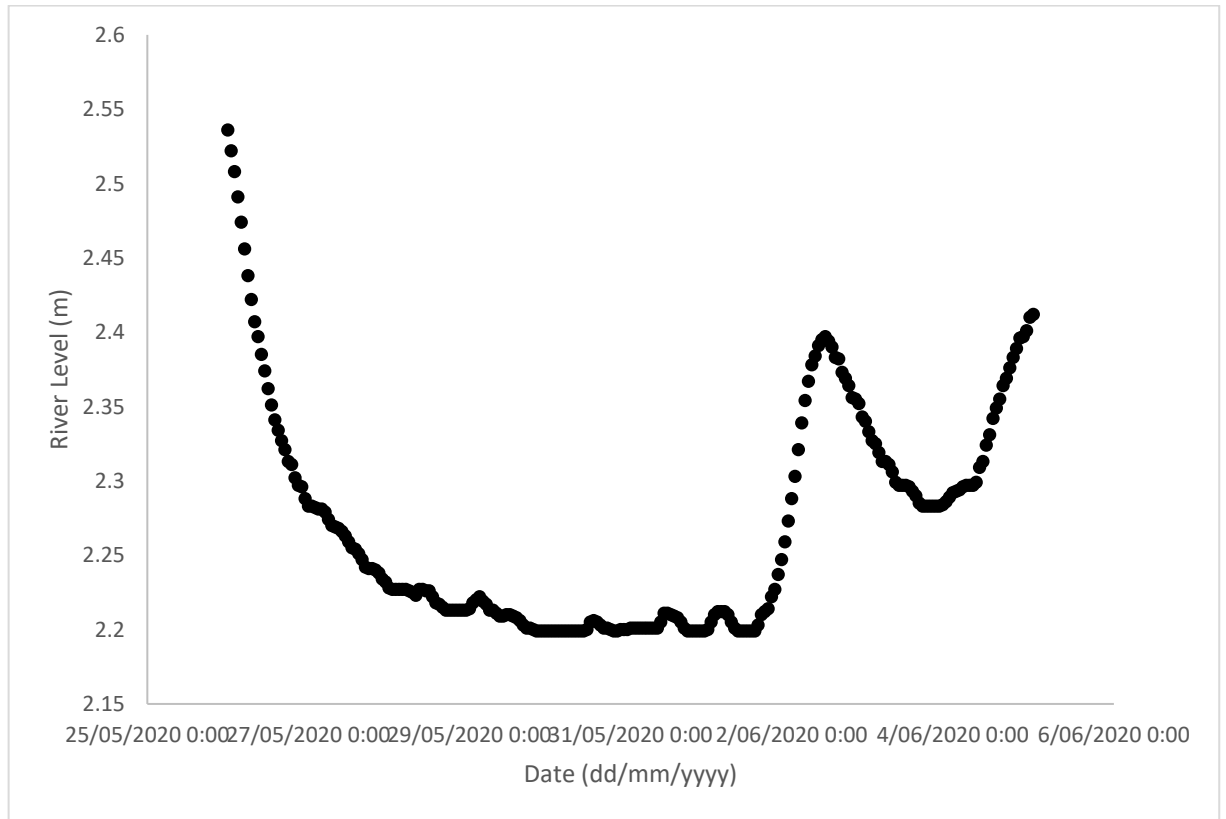


Figure 7: Mangapu River Water Level from the Round Two Dye Tracer Test



**Figure 8: Mangapu River Water Level from Round Three of the Dye Tracer Test**

Previous dye tracer testing (in May 2020) at the Oparure pit had shown the water took 2.5 days to reach the Gate Spring emergence location. A total of 18 mm of rainfall was recorded at the WRC Waitanguru rainfall gauge in March and a total of 115 mm of rain fell in April. No rainfall was recorded the week prior to the dye tracing. This reduced antecedent rainfall likely led to a much slower travel time than compared to when the karst system has experienced greater rainfall within the catchment. When the dye came through the karst system during May, the water level at the Mangapu River SH3 site was approximately 2.2 m (Figure 9).



**Figure 9: Mangapu Water Level during Oparure Dye Tracer Test**

## 6.4 Dilution

Table 3 summarises the dilution occurring at each site.

| Table 3: Dilution                                                                                                                                                      |        |                  |                                         |                                                      |                |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|------------------|-----------------------------------------|------------------------------------------------------|----------------|
| Tracer test                                                                                                                                                            | Tracer | Monitoring site  | Concentration of tracer at source (ppb) | Peak concentration measured at monitoring site (ppb) | Dilution ratio |
| Round Two                                                                                                                                                              | RWT    | G-Gun            | 181,000                                 | 4.1                                                  | 1:44,000       |
| Round Three                                                                                                                                                            | RWT    | Gate spring      | 181,000                                 | 10                                                   | 1:18,000       |
| Round Three                                                                                                                                                            | RWT    | Pumphouse spring | 181,000                                 | 5                                                    | 1:36,000       |
| Round Three                                                                                                                                                            | RWT    | G-Gun            | 181,000                                 | 2.5                                                  | 1:72,000       |
| Notes:<br>1. The conservative 181,000 ppb was used to calculate the dilution ratio however, it was likely the concentration was between 181,000 ppb and 90,720,000 ppb |        |                  |                                         |                                                      |                |

Table 3 shows the dyes were highly diluted, i.e. large dilution ratios are reported. The dilution ratio was calculated using the conservative dilution approach accounting for the 10,000 L of water that followed the 20 L dye injection. It was likely that not all the dye mixed with the 10,000 L and the real source concentration may be much larger (between 181,000 ppb and 90,720,000 ppb).

In round two, the RWT dye was highly diluted when measured present at the G-Gun site. The maximum concentration of dye at the peak was 4.1 ppb. This is two-fold less than the previous dye tracer testing at Oparure.

Round three identified the specific springs in which the dye emerged from. This was the Gate and Pumphouse Springs however, peak concentrations were unknown, as only manual grab sampling was conducted at these locations. The peak concentration measured by the Cyclops in the Mangawhitikau Stream was 2.5 ppb. The dilution factor was almost two-fold less than compared to the round two result. As previously discussed, this result is likely to be due to the antecedent rainfall conditions.



## 6.5 Result Implications

The BTC curve shows a sharp fast short-lived pulse of dye with low concentrations (compared to injection concentrations) in the receiving environment. The total time of the pulse for the second round was 35 hours from first detection back to baseline. For the third round, the duration of the pulse lasted 12.5 hours. The dilution, velocities, and therefore, total effect of the pulse on the receiving environment is dependent on the antecedent hydrological conditions. This includes both rainfall amount and intensity, and water levels. The initial conditions, therefore, will determine the resultant effect on the receiving environment.

## 7.0 Conclusion

These tracer tests provided information on the emergence of groundwater from dolines in the proposed Pakeho pit catchment, while providing some information of flow times through this network.

Dye tracer testing conducted clearly demonstrated that groundwater that currently flows within the Camelot Cave emerges at the Gate Spring and Pumphouse Spring in the Mangawhitikau Stream catchment. No dye was present in the Mangapu River catchment or in the wetlands. It was also evident in the results collected that there is significant dilution of the dye measured at the emergence locations and further downstream in the main stem of the Mangawhitikau Stream.

Dye introduced at other locations was not detected and is assumed to migrate through such a tortuous flow path that it causes no detectable effect in the Mangawhitikau and Mangapu Streams.

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# Oparure Pit – Dye Tracer Groundwater Monitoring

Graymont New Zealand Limited

# Oparure Pit Dye Tracer Groundwater Monitoring

✦ Prepared for

Graymont New Zealand Limited

✦ December 2020



PATTLE DELAMORE PARTNERS LTD  
Level 5, PDP House  
235 Broadway, Newmarket, Auckland 1023  
PO Box 9528, Auckland 1149, New Zealand

Tel +64 9 523 6900  
Website <http://www.pdp.co.nz>  
Auckland Hamilton Tauranga Wellington  
Christchurch Invercargill



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### DOCUMENT CONTRIBUTORS

Prepared by

SIGNATURE



Morgan Harvie

Reviewed by

SIGNATURE



Hayden Easton

Approved by



Peter Callander

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## Executive Summary

An investigation into the subsurface migration of soakage discharges at the Oparure pit was undertaken via a tracer test using two fluorescent dyes, Rhodamine (RWT) and Fluorescein (FLT), at two different recharge points. Figure 1 shows the monitoring locations and which of the sites were dye detection locations.

The results from the monitoring displayed similar flow paths to those shown by previous work, Williams, 1979. The dye was shown to re-emerge at the Gate Spring and was subsequently, detected at the Hay bales and G-Gun monitoring sites in the Mangawhitikau Stream catchment. No dye was present further upstream in the catchment, at the Mangawhitikau Resurgence or Willow spring. There was also no measured presence of dye (FLT or RWT) within the Mangapu River. Therefore, there is not likely a flow path from either the Pit Doline or Woods Doline to the Mangawhitikau Resurgence or Willow Spring in the Mangawhitikau catchment or a flow path from the dolines to the Mangapu catchment upstream of the Mangawhitikau confluence.

The RWT dye emerged in the Mangawhitikau Stream approximately two and half days after dye injection into the Woods Doline and FLT emerged approximately seven days after injection into the Pit Doline. Transit times varied between the two dolines, which corresponds to the Pit Doline being further away from the emergence location. Another likely reason for the delay in flow times could be a greater dispersal rate achieved by the FLT dye tracer. Straight line velocities to the peak detection concentration were around 11 and 22 m/hr.

The dilution (from the doline) through the aquifer system was evident by comparing the high concentration of dye injected into the doline to the peak concentrations measured in the Mangawhitikau Stream. The RWT and FLT dyes were released into the dolines at a source concentration of ~91,000 ppb (minimum dilution concentration). The peak measured concentration at the Gate Spring was 23.4 ppb for RWT and 16.2 ppb for the FLT dye tracer. Further dilution was shown when comparing the Gate Spring monitoring location to the main stem of the Mangawhitikau Stream at the G-Gun site. The G-Gun site had maximum peak concentrations of 4.3 ppb and 3.9 ppb for RWT and FLT, respectively.







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## 1.0 Introduction

Pattle Delamore Partners (PDP) were tasked by Graymont New Zealand Limited (Graymont) to complete an investigation into the subsurface migration pathway in the karst system surrounding the Oparure pit. This report aids in assessing the groundwater flow paths and provides an insight into transit times through the karst system.

### 1.1 Karst Landscapes

The Oparure pit is surrounded by a karst landscape which is characterised by the natural dissolution of limestone from slightly acidic rainwater. An underground drainage system is created which drains to streams further downgradient in the catchment (Parise, 2018). The water that re-emerges at the surface comes from two sources. One of the sources is disappearing streams i.e. streams that infiltrate into the groundwater network and re-emerge further down in the catchment. The other source is infiltrating rainwater. Rainwater is infiltrated throughout the entire catchment through the soils and through recharge zones along the catchment through dolines (also known as tomos) and sinkholes. Infiltration through the soils throughout the catchment occurs at a much slower rate and therefore, sediment and contaminants can be filtered out of the water. Recharge zones directly feed water into active conduits which results in more rapid infiltration. Infiltration through recharge zones leads to less filtration of large particles which may result in greater dispersal of contaminants and sediment through the karst system. The discharge points of this infiltration are in the form of natural springs (Goldscheider, 2008).

In the limestone karst formations, groundwater flows through fractures, caves and dissolution channels. These types of groundwater flows can cause increased flow speeds, in comparison to other types of groundwater flows. These groundwater flow speeds can vary greatly and can depend on the flow state of the network (Brackman & Brusseau, 2002). Exact flow paths through these networks can also be difficult to determine as flow lines may not be primarily determined by overlying topography and can also be influenced by the geology and climate in the region (Condon & Maxwell, 2015).

### 1.2 Water Tracing

Water tracing techniques are used in karst environments to obtain hydrological information about the groundwater flow characteristics and contaminant transport where groundwater paths are unknown. Tracing techniques can include the use of fluorescent dyes, salt dilution and particle tracers (Goldscheider, 2008).

The dye tracer method was used for this experiment and the dyes used were Rhodamine-WT (RWT) and Fluorescein (FLT). These dyes are synthetic organic compounds that absorb light at specific wavelengths and emit fluorescent light at longer wavelengths (Goldscheider, 2008). Dye tracers are easy to monitor in the downstream catchment as they can be visually observed in streams, in comparison to other types of tracer techniques.

The selection of the dye injection site is dependent on the objectives of the investigation, with dolines being the preferred choice as they carry the water with the tracer directly into the karst system and infiltrate into active conduits.

Sampling for these types of experiments is best undertaken at the most likely downstream emergence sites and springs, along with possible and unlikely sites. Taking measurements at unlikely sites increases the likelihood of successful dye tracing and confirms the zone of emergence of the tracer.

The primary result of the dye tracer experiment is a Breakthrough Curve (BTC). A BTC is a time series of concentration data points which can provide an insight into the groundwater network, the water velocities through the network and contaminant transport (Goldschieder, 2008). The BTC reveals the time at which the dye is first measured in the downstream network to a maximum peak measurement and the time it takes for all the dye to go through the system. These measurements can be used to calculate a recovery time i.e. the time to return to baseline measurements, which can provide some insight into other features of the network.

Water particles moving through the karst network do not flow at a single velocity but experience a range in velocities (changes in both the speed and direction of flow). Rapid flows can be achieved in the centres of large conduits and slower flows in adjacent voids. This change in velocity is referred to as dispersion and is displayed by the width of the BTC i.e. shape of the BTC, including the lag time for all the dye to be removed from the system (the recovery time). A wider BTC indicates more dispersal within the groundwater network with longer travel times. A shorter width of the BTC indicates fast flows and large conduits (Goldscheider, 2008).

Previous dye tracer work in the area undertaken by Williams, 1979, (Appendix A) shows the passages to the Mangawhitikau Stream from 'dead man's tomo' and 'whistling tomo'. These flow paths are to be confirmed in this research as well as an estimate of underground paths from dolines from within the Oparure pit. Karst landscapes are continuously being modified by the water that flows through them and therefore, a variety of flow patterns can be observed over time. The underground connections were shown by Williams, 1979, to emerge at the Gate Spring and Pump House spring. The eventual discharge locations corresponding to the entry points chosen in this experiment were unknown.

### 1.3 Project Aims

The aim of the dye tracer project was to identify the emergence location(s) and flow directions of water entering subsurface waterways within the karst system. The entry points chosen were dolines, one location inside of the pit and another dye seeding location situated outside of the pit. Emergence zones were to be determined in the broad catchment scale i.e. Mangawhikau vs. Mangapu and emergence via specific springs within the Mangawhikau catchment.

This project also aimed to broadly characterise the transit times through the groundwater network and provide some information about the concentrations of dye emerging in the surface water. This information was to be acquired by observing broad scale changes in concentrations and could likely be used in future to inform water quality assessments.

## 2.0 Methodology

### 2.1 Dye Seeding

To trace the water through the karst system, each of the two types of fluorescent dye powders (RWT & FLT) were mixed through 20 Litres of water, resulting in source concentrations of 45,360,000 ppb. The 20 Litre solution was funnel fed into two dolines, one for each dye. Followed by the seeding of the dye, approximately 10,000 Litres of water was fed into the system for a total dye concentration of 91,000 ppb. It is not likely that all the dye mixed with the 10,000 Litres resulting in a seeding concentration of between 91,000 and 45,360,000 ppb. The conservative dilution approach and minimum injection concentration of 91,000 ppb is used to compare to the emerging concentrations, noting that the real concentration may likely have been higher.

Two dye seeding locations were selected to inject the two dyes in the Northern and Southern edges of the Oparure pit. One doline located inside of the pit (Pit Doline) and one doline located just outside of the pit (Woods Doline), shown in Figure 2.

### 2.2 Instrumentation

Two logging fluorometers were deployed, one in the Mangawhikau catchment, and the other in the Mangapu catchment. These loggers recorded dye concentrations at regular 15-minute intervals during tracer testing. The two instruments were set up in the lower reaches of each watercourse to provide high temporal resolution of dye concentrations at a broad catchment scale.

The G-GUN-FL24 (G-Gun) was installed in the Mangawhikau Stream catchment at the bridge before the convergence with the Mangapu River. The logger had optics to measure both RWT and FLT.





KEY :  
● DYE INJECTION DOLINE



0 30 60 120  
METRES  
SCALE : 1:5,000 (A3)

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FIGURE  
FIG 2: DYE SEEDING LOCATIONS

PROJECT  
OPARURE PIT DYE TRACER GROUNDWATER MONITORING



A Turner Cyclops-7F (Cyclops) with RWT optics only was installed in the Mangapu River before the convergence with the Mangawhitikau Stream.

These loggers were not calibrated therefore, measurements are an indication of the presence of dye and not absolute values. Both loggers were set to measure every 15 minutes on the hour.

A separate manual sampling regime using a Turner Designs AquaFluor Handheld Fluorometer was completed to provide data for specific locations of interest at a coarser temporal resolution. This device had dual channel capability to measure both RWT and FLT dye tracers. The AquaFluor was calibrated using known concentration standards using the recommended calibration method prescribed for the instrument. The FLT calibration curve had a slope of 8.97 with a fit of 1.00, and the RWT calibration curve had a slope of 0.60 with a fit of 0.995.

### 2.3 Monitoring

Initial levels were recorded for baseline measurements of FLT and RWT with the G-Gun and Cyclops loggers prior to the release of dyes. Background levels could then be used to inform the presence or absence of dye in the streams even at low concentrations.

In order to record the tracer breakthrough, manual sampling started downstream as soon as the tracer was injected and recorded background concentrations of RWT and FLT with the handheld fluorometer. There were some initial fluctuations with the handheld measurements, RWT varied from 0.3 – 3 ppb, and FLT varied from 0.5 – 1.3 ppb i.e. an increase in concentration measurements above these initial levels for a period of over two to three samples determined that dye was present.

### 2.4 Manual Sampling Locations

The Mangawhitikau Resurgence zone and separate springs along the Mangawhitikau Stream were monitored using the handheld fluorometer. These points along the stream were named the Resurgence, the Willow Spring, Gate Spring, Hay bales and manual sample taken at the location of the G-Gun (Figure 3). Locations along the main stem of the Mangawhitikau Stream were also sampled named Oxbow, Gravel Bank and Style. These locations were to confirm the absence of dye at intervals within the main stem due to any unknown springs.

Monitoring of unlikely emergence zones can increase the chance of successful detections of the tracer in case presumptions of the flow lines are incorrect. Therefore, a handheld measurement was taken from the Mangapu River at the location of the Cyclops logger. A negative result in the Mangapu could be used to authenticate the positive tracer measurements collected within the Mangawhitikau Stream.





KEY :

 DYE MONITORING LOCATION

 STREAM



0 15 30 60

METRES

SCALE : 1:2,500 (A3)

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CLIENT



GRAYMONT

FIGURE

FIG 3: DYE MONITORING LOCATIONS

PROJECT

OPARURE PIT DYE TRACER GROUNDWATER MONITORING



## 2.5 Experimental Procedures

On 26/05/2020 at 11:00 am the Fluorescein (FLT) dye was injected into the doline located inside of the Oparure pit (Pit Doline). Following the FLT injection, the rhodamine (RWT) injection occurred at 14:00 pm into the second location located just outside of the Oparure pit (Woods Doline). Both dye injections were completed using a funnel with a pipe attached to reach directly into the doline to minimise spill. Both injections were followed by approximately 10,000 Litres of water from a watercart through a lay flat hose directly into the tomo. It was noted that drainage of the Woods Doline was much faster in comparison to the Pit Doline.

Concentration measurements in part per billion (ppb) were taken using the handheld fluorometer at each of the sampling locations in the morning, at midday and at end of the day (in winter sunlight hours 7:30 am – 5.30 pm) to get an (close to) accurate dye breakthrough curve.

## 3.0 Results

### 3.1 Fluorescein (FLT)

FLT was first recorded with handheld fluorometer at the Gate Spring 165 hours (almost seven days) after the initial injection into the Pit Doline and subsequently, measured present at the Hay bales and G-Gun monitoring site. The stream was monitored for a further 72 hours (three days) before an increase in turbidity was observed, due to a fresh passing down the stream. The BTC for FLT is shown in Figure 4. The dye was not deemed present at the other monitoring sites including the Resurgence and Willow spring. There were also no measurements of FLT present in the Mangapu catchment recorded by the manual fluorometer.

The peak concentration of FLT recorded was 16 ppb at the Gate Spring and a peak concentration of 3.9 ppb was recorded at the G-Gun site in the Mangawhitikau Stream. The G-Gun measured an increase in FLT correlating with the increase in FLT measured with the manual fluorometer (Figure 5). It also measured variable concentrations throughout the monitoring period. This variability is not uncommon at low concentrations (as recorded during this tracer test) and possible variability may also be present due to air bubbles in the water.

### 3.2 Rhodamine (RWT)

RWT was recorded with the handheld fluorometer present at the Gate Spring and subsequently, the Hay bales monitoring site and G-Gun monitoring site. This presence was measured approximately 66 hours (just more than two and a half days) after the injection into the Woods Doline. The dye took a further 96 hours (four days) after the initial dye measurement to return to baseline levels of RWT at the spring and only 48 hours (two days) to return to baseline levels at the

G-Gun site. The BTC for RWT is shown in Figure 6. The dye was not deemed present at any of the other monitoring sites including the Resurgence and Willow spring. There was also no RWT measured in the Mangapu catchment by the manual or cyclops logger. The peak concentration of RWT measured at the Gate Spring by the manual fluorometer was 23 ppb and the peak concentration measured at the G-Gun site was 4.3 ppb.

The G-Gun site did not record initial dye measurements and subsequent maximum peak (perhaps a fault of the G-Gun) but measured the approximate decline from the maximum and possible pulses of the dye after the initial dye maximum (Figure 7). As with the FLT measurements, the G-Gun gave variable measurements throughout the monitoring period that were not related to the tracer release.

Data from the Cyclops data logger in the Mangapu Stream shows background levels of RWT indicating no rhodamine dye was present throughout the entirety of the test (Figure 8). These measurements agreed with the manual measurements taken at the Cyclops monitoring site. There was a sharp increase in concentration on 5/06/2020. This increase correlated with rainfall which is likely to have led to elevated turbidity within the stream.



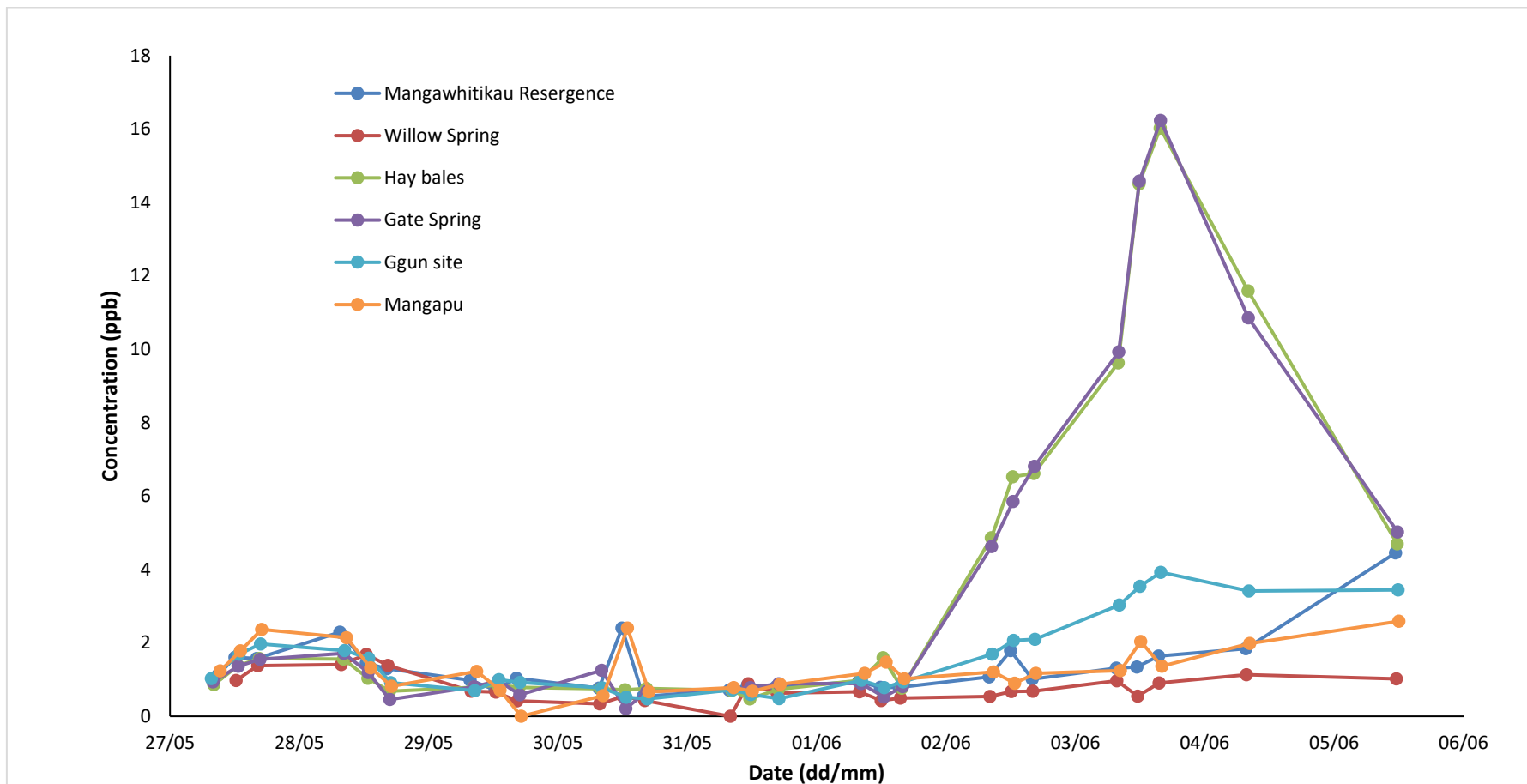


Figure 4: BTC (FLT) Manual Measurements comparison of springs in the Mangawhitikau Catchment and Mangapu Catchment

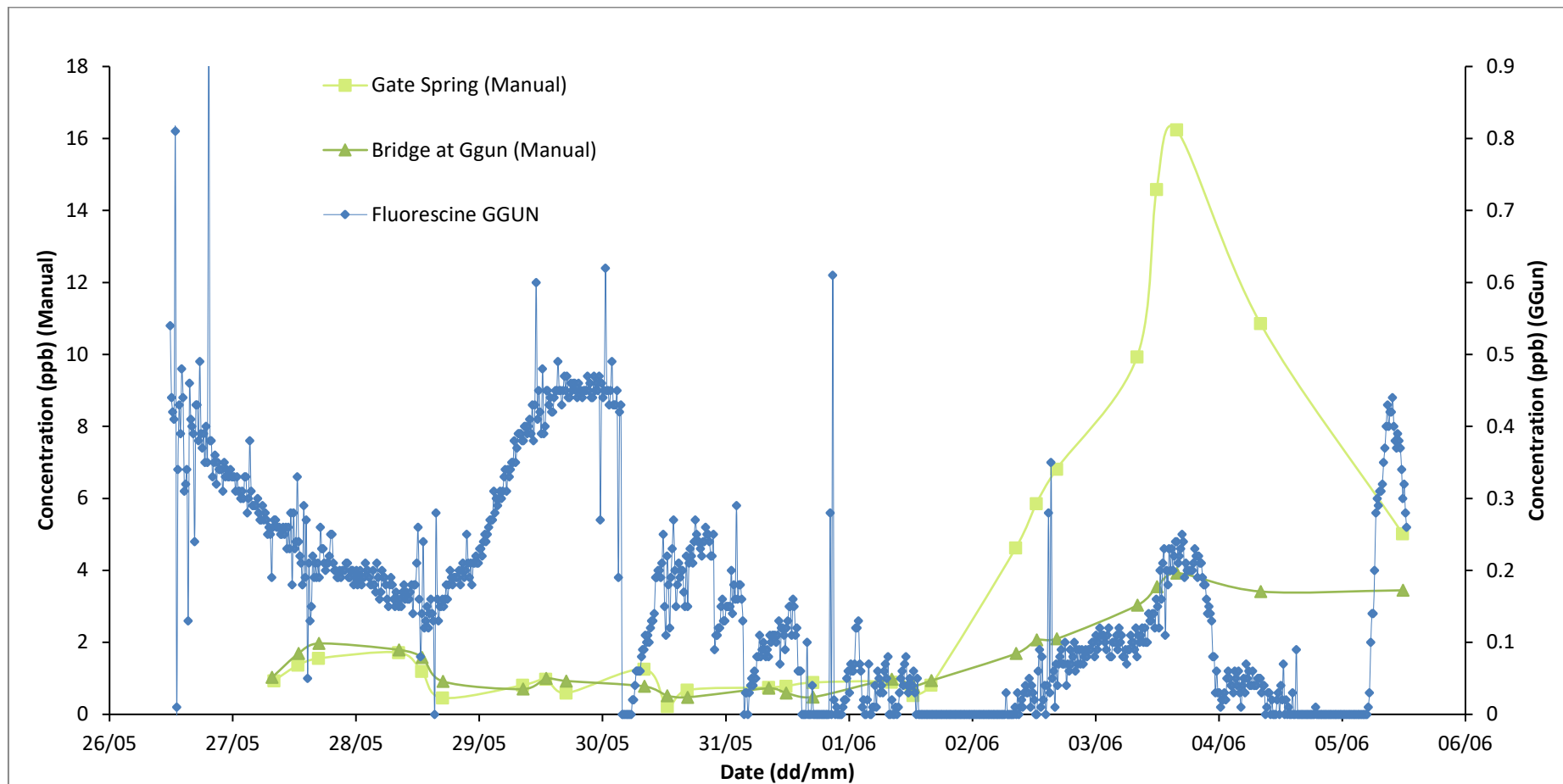


Figure 5: BTC (FLT) Comparison of Manual and G-Gun Measurements

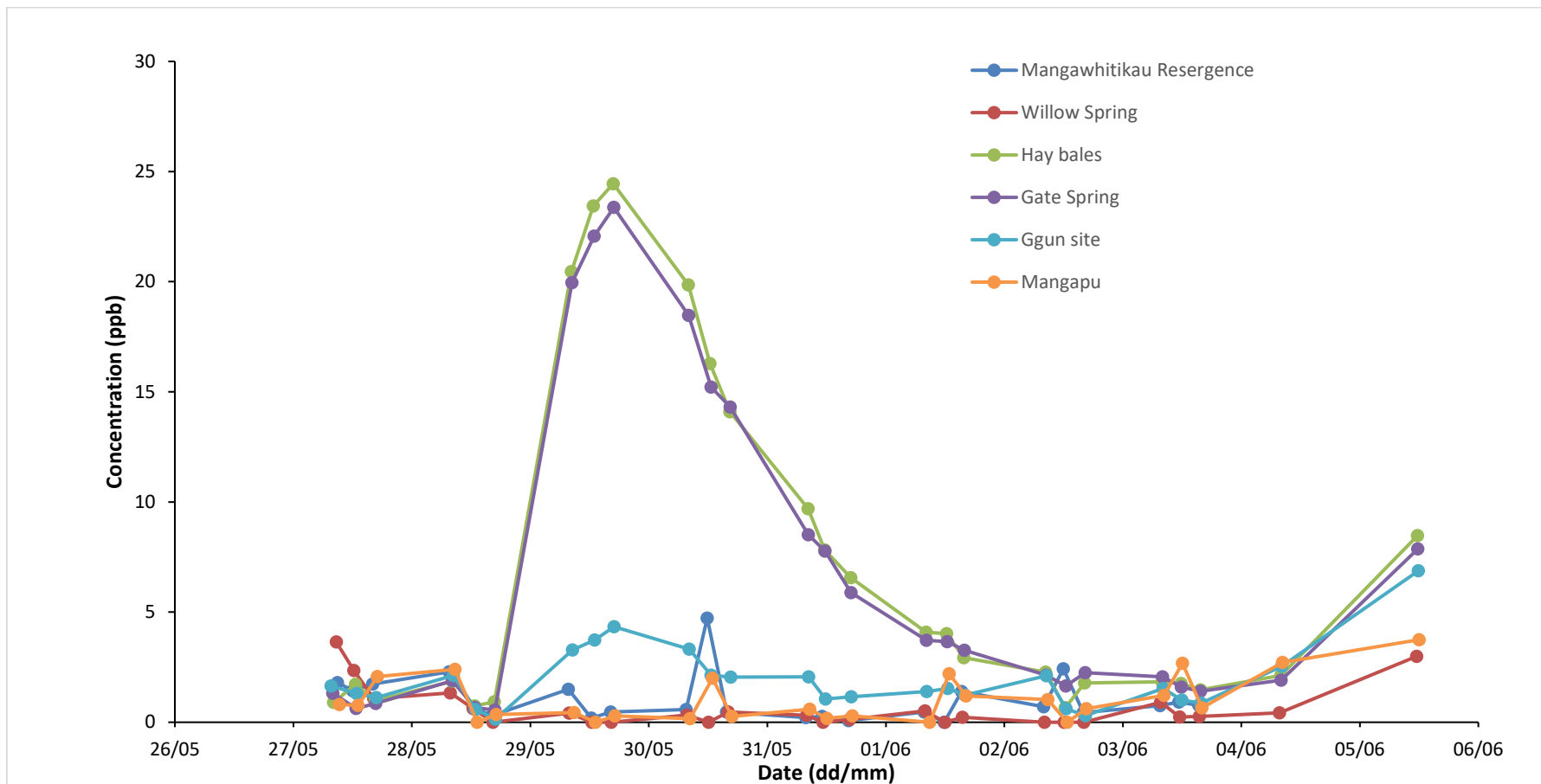


Figure 6: RWT BTC Manual Measurements comparison of springs in the Mangawhitikau Catchment and Mangapu Catchment

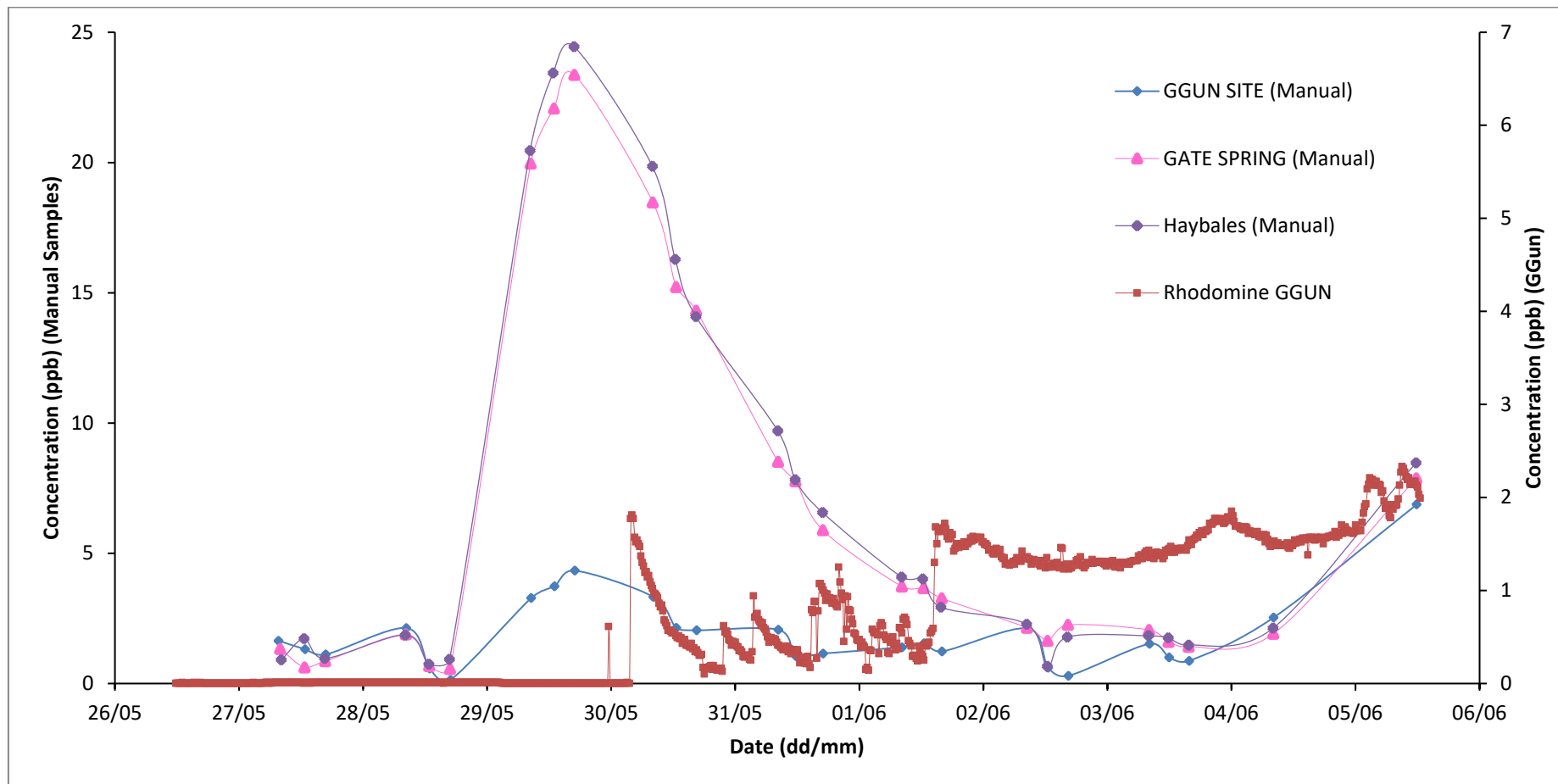
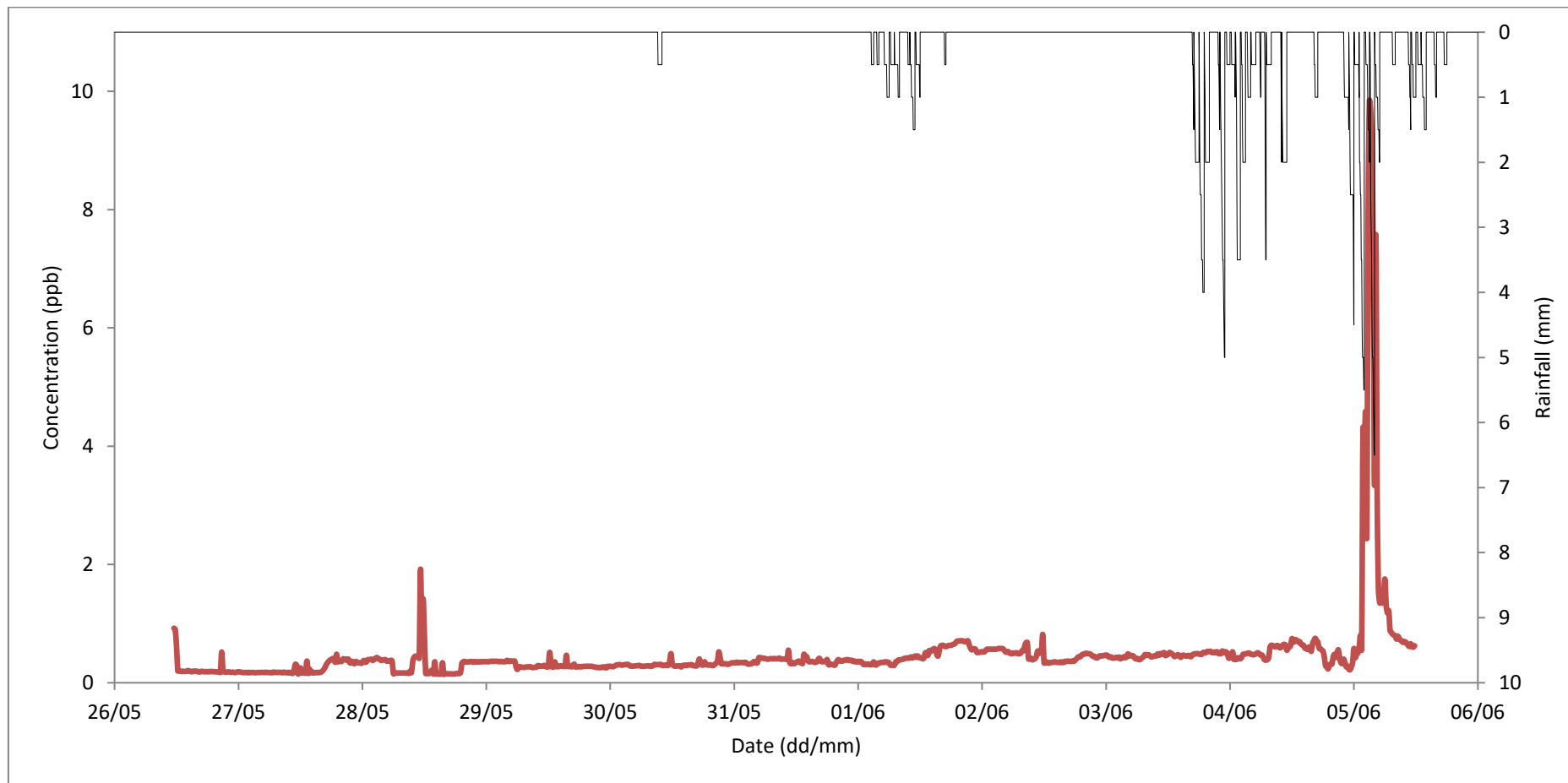


Figure 7: BTC (RWT) Comparison of Manual and G-Gun Measurements





**Figure 8: RWT recorded by the Cyclops logger in the Mangapu Catchment and Rainfall from the Waitanguru rain gauge**

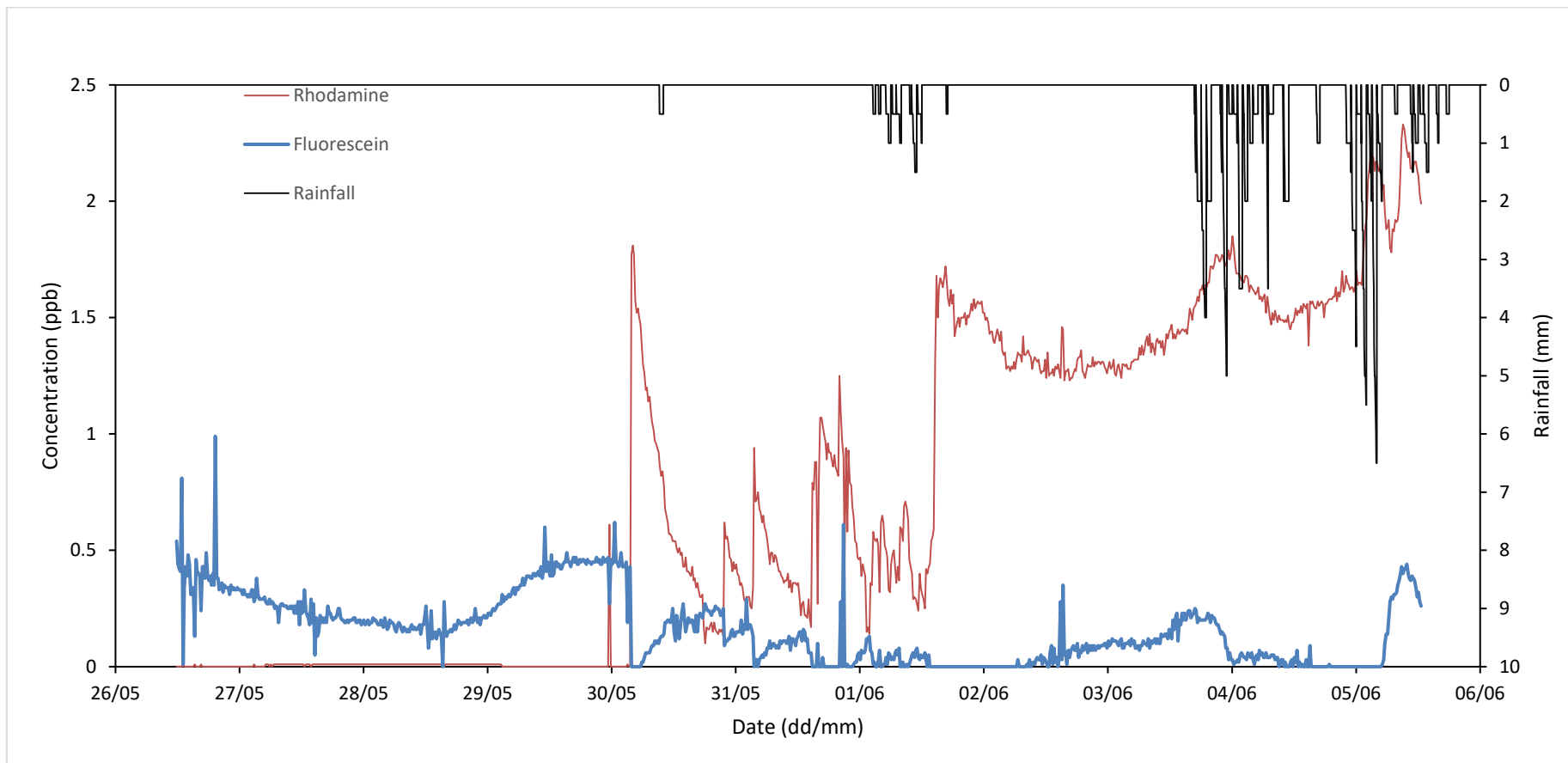


Figure 9: BTC (FLT & RWT) recorded by the G-Gun in the Mangawhitikau Catchment and Rainfall from the Waitanguru rain gauge

## 4.0 Discussion

The results of the dye tracer test matched the results of the previous study completed by Williams, 1979. Both the RWT and FLT dyes emerged at the same location in the Mangawhitikau Stream at the Gate Spring and were not present in the Mangapu catchment. The resulting BTCs give insight into the groundwater network by examining maximum concentration peaks and recovery times.

### 4.1 Flow Paths

#### 4.1.1 Catchment Scale (Mangapu vs Mangawhitikau)

The focus of this tracer test was to determine the groundwater flows paths from the areas of recharge (dolines) to discharge (springs). It was evident in the concentration measurements from the logger and manual fluorometer that there was no dye present within the Mangapu catchment. When the RWT dye was present in the Mangawhitikau Stream on 29/06/2020, there was no indication of RWT recorded by either the manual or Cyclops fluorometers shown by comparing Figure 6 and Figure 8. An increase shown by the Cyclops logger on 5/06/2020 correlated with elevated turbidity from rainfall in the catchment. This increase was likely not resultant from dye detection due to this correlation and timing not matching with presence in the Mangawhitikau Stream. Both dyes were present in the Mangawhitikau catchment as shown from the BTCs by the increase in dye concentration and a decrease from the maximum to baseline concentrations after a few days (Figure 4 & 6).

#### 4.1.2 Mangawhitikau Catchment

The emergence of both dyes was at the Gate Spring, which then flows to the Hay bales monitoring site and from there to the mainstem of the Mangawhitikau where the G-Gun monitoring site is located. The manual measurements (Figure 4 & 6) shows no dye detection (FLT or RWT) upstream of the Gate Spring at the Resurgence and Willow spring. Therefore, it is not likely that water from the Pit Doline reaches the Resurgence and Willow Springs.

The size and shape of the BTCs are summarised in Table 1.

| Table 1: Characteristics of Breakthrough Curve                               |                 |                                                |                                                  |                                                |                                |                          |                                 |
|------------------------------------------------------------------------------|-----------------|------------------------------------------------|--------------------------------------------------|------------------------------------------------|--------------------------------|--------------------------|---------------------------------|
| Tracer                                                                       | Monitoring Site | Straight-line distance to monitoring site (km) | Time from seeding to start of rising limb (days) | Time from seeding to peak concentration (days) | Duration of rising limb (days) | Peak Concentration (ppb) | Duration of falling limb (days) |
| FLT                                                                          | Gate spring     | 2.20                                           | 7                                                | 9                                              | 2                              | 16.24                    | 2                               |
|                                                                              | Hay bales       | 2.15                                           | 7                                                | 9                                              | 2                              | 16.03                    | 2                               |
|                                                                              | G-Gun           | 2.25                                           | 7                                                | 9                                              | 2                              | 3.926                    | 2                               |
| RWT                                                                          | Gate Spring     | 1.60                                           | 2.5                                              | 3.5                                            | 1                              | 23.37                    | 3                               |
|                                                                              | Hay bales       | 1.60                                           | 2.5                                              | 3.5                                            | 1                              | 24.45                    | 3                               |
|                                                                              | G-Gun           | 1.70                                           | 2.5                                              | 3.5                                            | 1                              | 4.336                    | 1                               |
| Notes:<br>1. Days are rounded to nearest half days<br>2. FLT end was unknown |                 |                                                |                                                  |                                                |                                |                          |                                 |

Both the Gate spring and Hay bales site show very similar characteristics whereas the G-Gun site shows significantly more dilution occurring in the mainstem of the Mangawhitikau Stream. River flow data collected from the Waikato Regional Council at the Mangapu River displayed an hourly averaged river flow of 1.45 m<sup>3</sup>/s throughout the duration of the tracer test (29/05/2020-06/06/2020). The flow at the upper Mangawhitikau at the Resurgence was estimated to be 249 L/s and the lower Mangawhitikau Stream had an estimated flow of 266 L/s. The springs (Willow Spring, Gate Spring, and possible other springs), therefore, contribute approximately 17 L/s. These flow estimations are calculated within the Hydrological analysis which is presented in the water report for the re-consenting of the quarry activities at Oparure pit.

At Gate spring, the FLT dye had a rising limb of around two days and a falling limb of at least two days, although the true recovery time for FLT was unknown due to an increase in turbidity due to rainfall and the manual measurements ceasing.

The RWT dye had a much steeper rising limb of one day and a falling limb of around three days. This longer falling limb for the RWT dye to return to baseline could be representative of the dye taking longer more convoluted pathways to the emergence location or large voids or pools of water within the subsurface network.

The RWT data collected from the G-Gun displays pulses of dye after the initial increase which are shown in Figure 7 and Figure 9. These measurements do not coincide with rainfall events, so the pulses were not likely due to increases in turbidity. If they do represent the actual emergence of the tracer, the pulses



could indicate the dye taking different flow paths through the karst network. However, they may also be an artefact of the accuracy of the measuring device and the low concentrations of the dye such they do not represent the actual tracer behaviour, particularly given that the measurements were not above baseline concentrations.

Increases in RWT measured by the G-Gun on 1/06/2020, 3/06/2020 and 5/06/2020 shown in Figure 9, coincided with increased rainfall events in the upper reaches of the catchment. This rainfall likely increased turbidity levels which caused increased measurement concentrations that were not related to the tracer test. These increased RWT measurements resulting from increased turbidity were evident at all the manual sampling locations within the Mangawhitikau Stream and also within the Mangapu River (Figure 6, 7 and 8). FLT concentrations were also observed to increase resulting from increased rainfall which may have caused an increase in turbidity at the Mangawhitikau Resurgence and Mangapu monitoring sites (Figure 4).

The RWT dye was also visually observed at Spring 5 shown in Appendix A, (Figure 10) however, due to accessibility, the concentration was not able to be measured.

## 4.2 Travel Times and Velocity

Flow times from the two different seed locations are summarised in Table 2 below.

| Table 2: Travel Times                                                                                                                             |                 |                                                |                                                        |                               |
|---------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|------------------------------------------------|--------------------------------------------------------|-------------------------------|
| Tracer                                                                                                                                            | Monitoring site | Straight-line distance to monitoring site (km) | Travel duration to measured peak concentration (hours) | Straight-line velocity (m/hr) |
| FLT                                                                                                                                               | Gate Spring     | 2.20                                           | 196                                                    | 11.2                          |
|                                                                                                                                                   | Hay bales       | 2.15                                           | 196                                                    | 10.8                          |
|                                                                                                                                                   | G-Gun           | 2.25                                           | 196                                                    | 11.5                          |
| RWT                                                                                                                                               | Gate Spring     | 1.60                                           | 74                                                     | 21.6                          |
|                                                                                                                                                   | Hay bales       | 1.60                                           | 74                                                     | 21.6                          |
|                                                                                                                                                   | G-Gun           | 1.70                                           | 74                                                     | 23.0                          |
| Notes:<br>1. The minimum straight-line distance from doline to monitoring site however, it was not likely that the flow path was a straight line. |                 |                                                |                                                        |                               |

The RWT dye injected into the Woods Doline (closest to the Mangawhitikau Stream) took approximately two and half days to reach the spring, whereas the Pit Doline, further away from the Mangawhitikau Stream seeded with the FLT dye, took approximately seven days to reach the spring. The FLT dye tracer reached peak concentrations 8 days after injection and the RWT dye tracer reached peak concentrations after 3 days.

Transit times from recharge zones are also dependent on the initial flow state of the system. Flow state is determined by weather and climate conditions which can change on many different timescales. For example, after storm/high rainfall events, it is expected that due to the volume of water flowing through the network flow times may be faster and the dye may become more diluted. Hydrographic data is needed to show the effect of changes to the weather and climate.

It is likely that a variety of different flow speeds were achieved owing to the karst network with different sized conduits and caves. The straight-line distance reported in Table 2 above indicates a broad scale approximation of travel times. The FLT tracer had an average travel time of approximately 11.2 m/hr and the RWT tracer had an average travel time of approximately 22.0 m/hr, double the velocity of the FLT tracer. However, it is likely that the real flow path from the doline to the spring would have been more tortuous (and therefore longer). The real velocities are then likely to have been faster than those calculated, due to the longer flow path.

These velocities can be compared to the equivalent velocities from 27 m/hr to 62 m/hr determined from the Paul Williams tracer test. The average travel time compared to Williams, 1979 was slower which may have been due to the initial flow state of the system, resulting in faster water flow velocities than those reported above. In the Williams 1979 tracer test, the dye took 55 hours (time estimated till dye was first present and not peak concentrations) and the velocity calculation used an approximate 2 km straight-line distance which may also account for the difference in velocities.

### 4.3 Rainfall

Rainfall from the Waitanguru rain gauge in the Mangaotaki Catchment (located approximately 20 m to the South West of the monitoring locations) displays a cumulative rainfall of 65.5 mm over the period 26/05/2020 to 6/06/2020. The rainfall gauge at Waitanguru captures the rainfall from the upper reaches of the catchment that feeds into the watercourses that were monitored in this tracer test. From the rainfall observed, there was likely to have been natural recharge occurring during the test period. Rainfall occurrences are generally correlated with an increase in turbidity causing false increased concentration measurements on the recording equipment. This was shown at the end of the RWT dataset recorded by the G-Gun after sufficient rainfall was recorded on 1/06/2020,

3/06/2020 and 5/06/2020 (Figure 9). FLT measurements were affected less than RWT, with an increased concentration displayed with the largest rainfall occurrence on 5/06/2020.

#### 4.4 Dilution

Table 3 summarises the dilution occurring at each site.

| Table 3: Dilution                                                                                                                                                    |                 |                                         |                                             |                |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-----------------------------------------|---------------------------------------------|----------------|
| Tracer                                                                                                                                                               | Monitoring site | Concentration of tracer at source (ppb) | Peak concentration at monitoring site (ppb) | Dilution ratio |
| FLT                                                                                                                                                                  | Gate Spring     | 91,000                                  | 16.24                                       | 1:5,600        |
|                                                                                                                                                                      | Hay bales       | 91,000                                  | 16.03                                       | 1:5,700        |
|                                                                                                                                                                      | G-Gun           | 91,000                                  | 3.926                                       | 1:23,000       |
| RWT                                                                                                                                                                  | Gate Spring     | 91,000                                  | 23.37                                       | 1:3,900        |
|                                                                                                                                                                      | Hay bales       | 91,000                                  | 24.45                                       | 1:3,700        |
|                                                                                                                                                                      | G-Gun           | 91,000                                  | 4.336                                       | 1:21,000       |
| Notes:<br>1. The conservative 91,000 ppb was used to calculate the dilution ratio however, it was likely the concentration was between 91,000 ppb and 45,360,000 ppb |                 |                                         |                                             |                |

Table 3 shows the dyes were highly diluted with large dilution ratios. The dilution ratio was calculated using the conservative dilution approach accounting for the 10,000 Litres of water that followed the 20 Litre dye injection. It was likely that not all the dye mixed with the 10,000 Litres and the real concentration was much larger (between 91,000 ppb and 45,360,000 ppb). The real dilution factor is likely to be much larger than those shown above.

Both dyes were highly diluted when they were measured present in the Mangawhitikau Stream. This dilution was shown by concentrations no greater than 25 ppb measured by the handheld fluorometer at the Gate Spring. The RWT dye was shown to reach a maximum concentration of 23.4 ppb at the spring and was five times more diluted to reach a maximum of 4.3 ppb in the main stem of the Mangawhitikau Stream at the G-Gun site. This result shows more dilution occurred when comparing concentrations from the Gate Spring to the main stem of the Mangawhitikau Stream. A similar dilution pattern was shown in the FLT measurements with a maximum of 16.2 ppb measured at the Gate Spring and a peak concentration of 3.9 ppb measured at the G-Gun site. The emerged FLT dye at the gate spring and hay bales was four times more diluted at the G-Gun monitoring site.

FLT was measured to be slightly more diluted than RWT. This dilution comparing a maximum of 16.2 ppb compared with 23.4 ppb was perhaps owing to the longer travel path from the Pit Doline to the emergence location or more dispersal through the network. Dilution can occur due to the dye parcel mixing with water within the karst system but also, some of the dye taking a different flow path or going underneath the spring in the groundwater network and not emerging to the surface flow. The dye may have also been filtered through the network and adhered to soils and substrates and therefore, did not reach the emergence location.

## 5.0 Conclusion

This tracer test provided information on the emergence of groundwater from dolines in the Oparure pit catchment, while providing some information of flow times through this network. The groundwater currently flows from the two dolines and emerges in the Mangawhitikau Stream at the Gate Spring. This emergence location was downstream of Resurgence and Willow springs and no dye was present within the Mangapu catchment. It was also evident in the results collected from the handheld measurements that there was a significant dilution of the dye measured at the emergence location of both dye tracers. Further dilution was also shown as the spring water entered the main stem of the Mangawhitikau Stream.

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**Appendix A**

Dye Tracer Study Williams, 1979

## Dye Tracer Study Williams, 1979

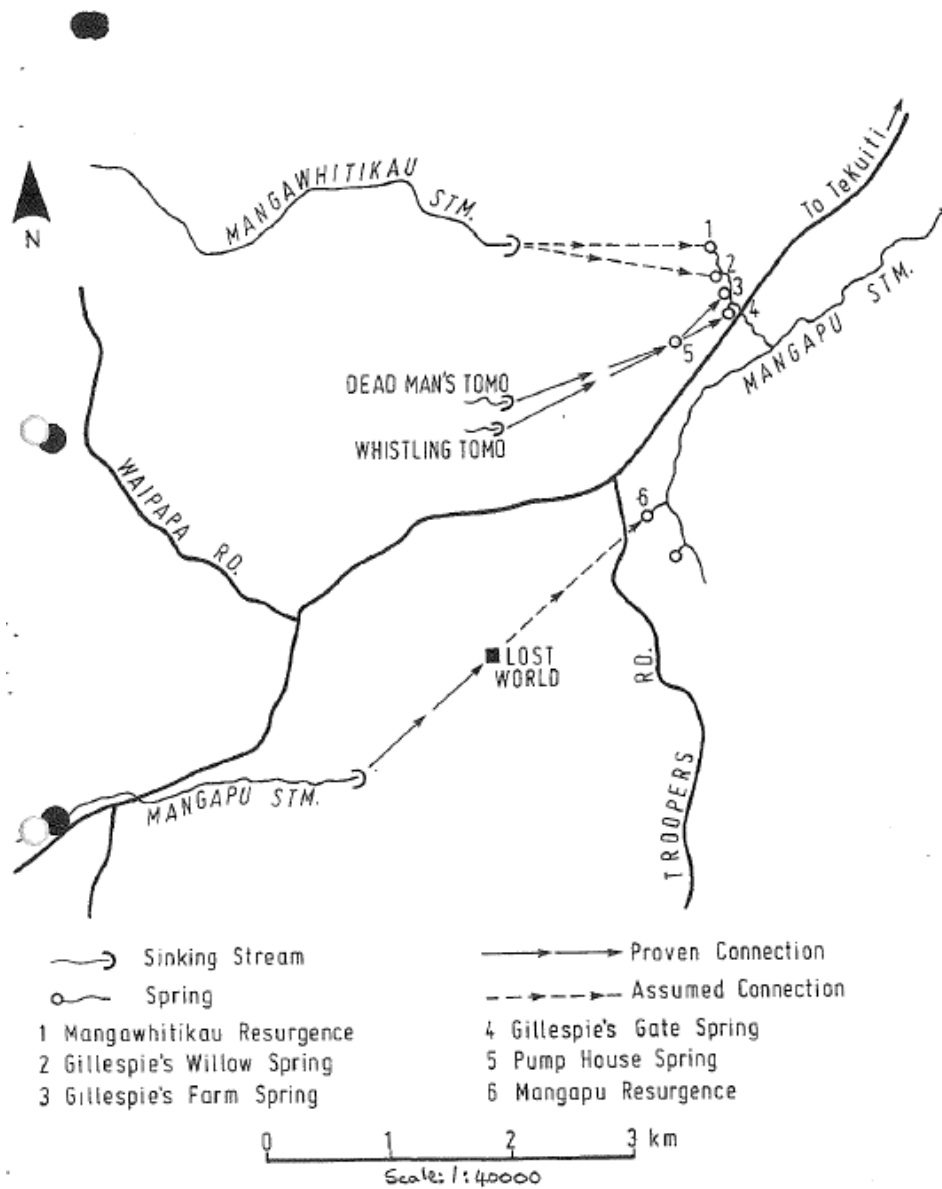


Figure 10: Map of previous dye tracer testing

# Additional Dye Tracer Groundwater Monitoring

✦ Prepared for

Graymont New Zealand Limited

✦ October 2023



PATTLE DELAMORE PARTNERS LTD  
Ground Floor, 233 Collingwood Street  
Hamilton Lake, Hamilton 3204  
PO Box 9528, Auckland 1149, New Zealand

Tel +64 7 949 7880  
Web [www.pdp.co.nz](http://www.pdp.co.nz)



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| 1                | 6/10/2023  | Final          | Morgan Harvie | Blair Thornburrow | Peter Callander |

### DOCUMENT CONTRIBUTORS

Prepared by

SIGNATURE



Morgan Harvie

Reviewed by

SIGNATURE



Blair Thornburrow

Approved by



Peter Callander

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## Executive Summary

An investigation into the subsurface migration of soakage discharges in the Northern extent of the Western pit was undertaken via four tracer tests using fluorescent dye, Rhodamine (RWT) at four recharge points. These points are cave entrances and dolines known as D29, C4, C13 and D2.19.

In the first tracer test, the RWT dye was introduced into D29 and measured present by the cyclops RWT sensor at the Mangawhitikau Stream Resurgence site 25 hours after injection. 8 hours later, the peak of the dye was measured (maximum 0.45 ppb) and took a further 15 hours to return to baseline concentrations.

In the second dye tracer test, RWT dye was introduced into C4, a cave entrance North of D29. RWT dye was measured present and visually seen at Upper Mangawhitikau Spring by the handheld sensor and measured present at the Resurgence logger with a peak concentration of 9.32 ppb. The dye was measured present 26 hours after injection similar to round one. 8 hours later the peak concentration was measured and took a further 17 hours to return to baseline concentrations.

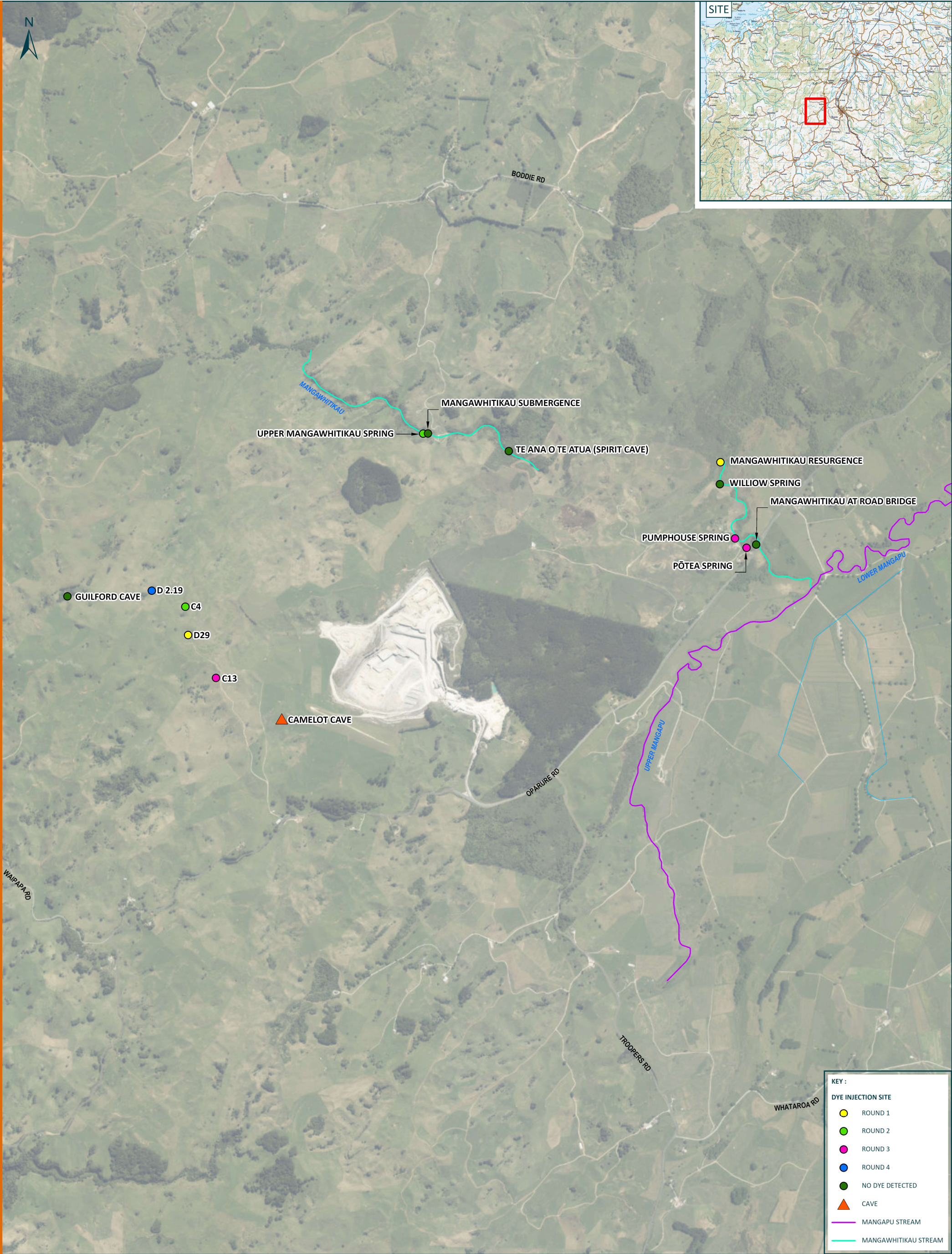
The third round of dye tracing saw dye introduced to the south of D29 and C4 at C13, another cave entrance. The dye emerged at Pōtea Spring and Pumphouse Spring which infers the divide between water that travels through to Pōtea Spring vs Upper Mangawhitikau Spring in the upper catchment. The dye was measured present by the handheld fluorometer and not measured by the sensor at the Resurgence. As the concentrations were measured with the handheld the actual emergence time and peak was unknown. The dye emerged between 29-46 hours after injection dye at Pōtea Spring. The peak concentration measured was 60.4 ppb.

Round four of the tracer tests was at the northern extent of the pit to identify whether water travelled towards the Guildford cave system. Dye was not detected present by the handheld fluorometer or cyclops sensor at any detection sites, indicating poor connectivity of the selected injection site to subsurface waterways.

Figure 1 shows the dye detection locations from all four tests within the Mangawhitikau stream catchment.

The RWT dye was released into the dolines and cave entrances at a source concentration of ~181,000 ppb (minimum dilution concentration). The dilution (from the doline and cave entrances) through the aquifer system was evident in comparing the high concentration of dye injected to the peak concentration measured in the springs and main stem of the Mangawhitikau Stream.





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FIGURE

FIG 1: DYE INJECTION AND DETECTION LOCATIONS

PROJECT

DYE TRACER GROUNDWATER MONITORING



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## 1.0 Introduction

Pattle Delamore Partners (PDP) were engaged by Graymont (NZ) Limited (Graymont) to complete an investigation into the subsurface migration pathway of soakage discharges at the proposed Western pit. This report aids in assessing the groundwater flow paths and provides an insight into transit times through the karst system.

### 1.1 Background

Dye tracing is being used as part of the water resource investigation for the proposed new limestone pit to the west of the current Oparure Quarry (to be referred to as the Western Pit). This involves introducing a dye solution into dolines and caves in the footprint of the proposed pit and monitoring for the dye in surrounding waterways.

- ✧ Dolines and caves in the footprint of the proposed pit, used for dye injection, represent the more permeable zones through which stormwater could infiltrate into the subsurface environment.
- ✧ Monitoring for the dye in the surrounding waterways identifies the presence of permeable pathways from the dye injection sites though to the monitoring sites.

If the dye is detected at some of the monitoring locations it indicates there is a permeable subsurface pathway between the injection site and the downstream monitoring location at which the detection occurred. The travel time for the detection to occur and the concentration at which the detection occurs both provide an indication of how direct and permeable the connecting flow path is, based on the subsurface flow conditions at the time of the tracer test. These travel times will be influenced by the amount of recharge into the subsurface flow systems via rainfall infiltration and river seepage.

If the dye is not detected at a monitoring location it indicates that there is not a permeable pathway between the injection site and that monitoring location and/or that the dye has been significantly diluted before it reaches the monitoring location.

Identification of drainage pathways is only one part of assessing the environmental effects of sediment generation in the proposed pit. Other factors that are taken into account include sediment volumes, intercepting controls such as sediment retention ponds, and any filtration of sediment before it enters the receiving environment.

## 1.2 Project Aims

The aim of the dye tracer project was to identify the emergence location(s) and flow directions of water entering subsurface waterways. Dolines and cave entrances within the proposed pit boundary were selected as entry points. Emergence zones were determined via specific springs within the Mangawhitikau catchment, which are the main points of concentrated inflow from the karst system. The emergence spring represents the location where downstream effects are most readily detected.

This project also aimed to characterise the transit times through the groundwater network and provide information about the concentrations of dye emerging in the surface water. This information was to be acquired by observing broad scale changes in concentrations and could likely be used in future to inform water quality monitoring requirements for the proposed pit.

## 2.0 Methodology

To trace the water through the karst system, one type of fluorescent dye powder Rhodamine-WT (RWT) was mixed through 20 Litres of water, resulting in source concentrations of 90,720,000 ppb. The 20 Litre solution was funnel fed into the dolines and cave entrances. Followed by the seeding of the dye, approximately 10,000 Litres of water was fed into the system for a total dye concentration of 181,000 ppb. It is not likely that all the dye mixed equally with the 10,000 Litres resulting in a seeding concentration of between 181,000 and 90,720,000 ppb. The conservative dilution approach and minimum injection concentration of 181,000 ppb is used to compare to the emerging concentrations, noting that the real concentration/ the actual dilution occurring within the karst system, may likely have been higher.

### 2.1 Seeding locations

Four dye injection locations were chosen in the northern extent of the proposed pit. The first of the locations was D29. This doline was seeded on 12<sup>th</sup> June 2023 at 11 am.

The second location was C4, a cave entrance located to the north of D29. The injection date was 20<sup>th</sup> June 2023 at 10:30 pm.

The third location was C13, another cave entrance located south of D29 and C4. The purpose of seeding at C13 was to determine the division between areas draining towards Pōtea Spring vs Upper Mangawhitikau Spring (or elsewhere upstream of the Mangawhitikau submergence). The C13 cave entrance was seeded on the 7<sup>th</sup> August 2023 at 11:30 pm.

The fourth and final location was doline D2.19 and located at the Northern boundary of the western pit. The final injection date was the 22<sup>nd</sup> August 2023 at 12 pm. Figure 1 shows the locations of these four injection locations.

## 2.2 Instrumentation

The Turner Cyclops-7F (Cyclops) Fluorometer with RWT optics was installed in the Mangawhitikau Stream at the Mangawhitikau Resurgence shown in Figure 1. This logger recorded rhodamine dye concentrations at regular 15-minute intervals (on the hour) during tracer testing to provide high temporal resolution of dye concentrations from the upper Mangawhitikau catchment.

A separate manual sampling regime using a Turner Designs AquaFluor Handheld Fluorometer was completed to provide data for specific locations of interest at a coarser temporal resolution. The AquaFluor was calibrated using known concentration standards using the recommended calibration method prescribed for the instrument.

## 2.3 Manual Sampling Locations

The Mangawhitikau Stream was determined as the receiving environment of other dolines and cave entrances located within the Western pit from previous dye tracer testing (Appendix A). Separate springs along the Mangawhitikau Stream were monitored using the handheld fluorometer. These points along the stream were named Upper Mangawhitikau Spring, Mangawhitikau Submergence and Resurgence, Willow Spring, Pumphouse Spring, Pōtea Spring (previously known as Gate Spring), Te ana o te atua (Spirit Cave), Guildford Cave and a manual sample taken at Mangawhitikau Stream at road bridge. The location of all these monitoring sites is shown in Figure 1. Monitoring all possible downstream locations increases the chance of successful dye detection.

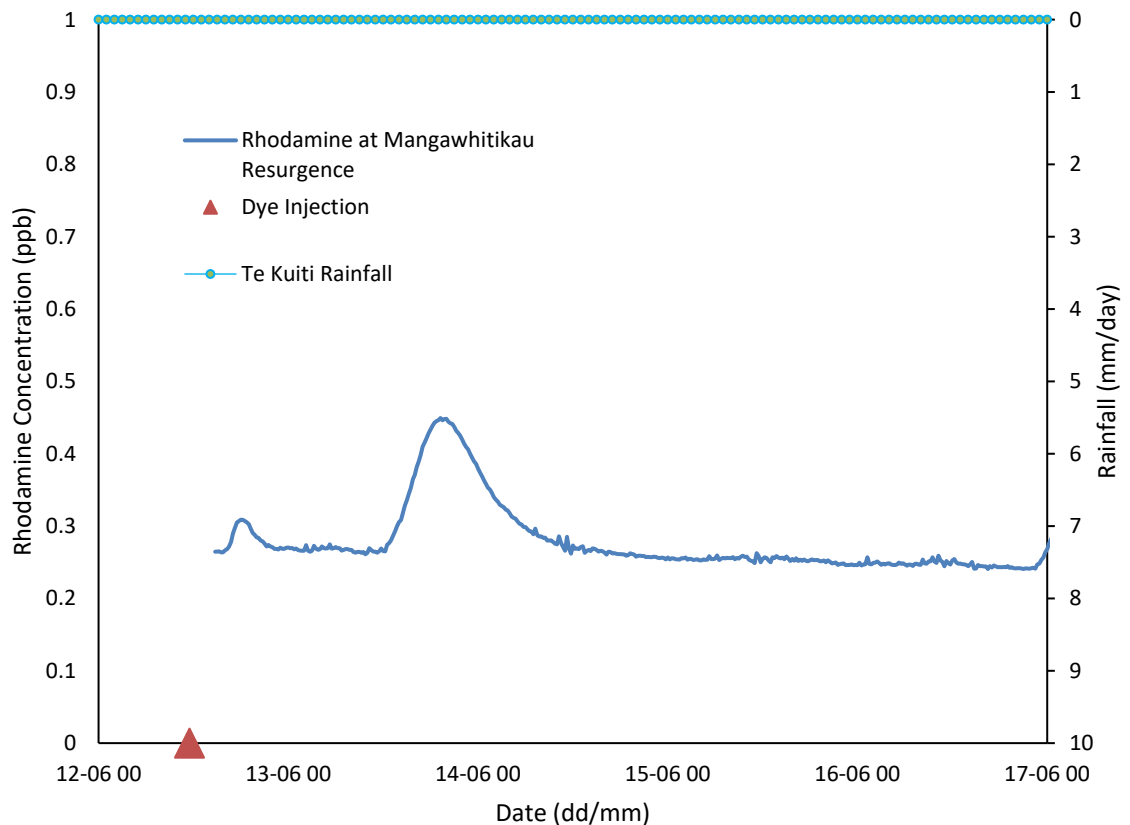
## 3.0 Results

The four dye tracer tests indicated the underground drainage system pathways. Positive signals indicate a connection between the injection location and emergence location. Strong signals indicate a direct conduit whereas a subdued response indicates more dilution or a less direct path to the emergence location.

### 3.1 Round One

In the first round of dye tracer testing, dye was seeded into doline D29 on the 12<sup>th</sup> June 2023 at 11 am. Dye emerged on the 13<sup>th</sup> June at 12pm and reached peak concentrations at 8pm. 15 hours later the dye returned to baseline levels. Dye concentrations did not exceed 0.45 ppb measured by the logger and not measured present by the handheld sensor as 0.45 ppb is below detection limits. Figure 2 shows the results from the logger. There was no rainfall during this

initial round and antecedent hydrological conditions were on a gradually receding river flow.

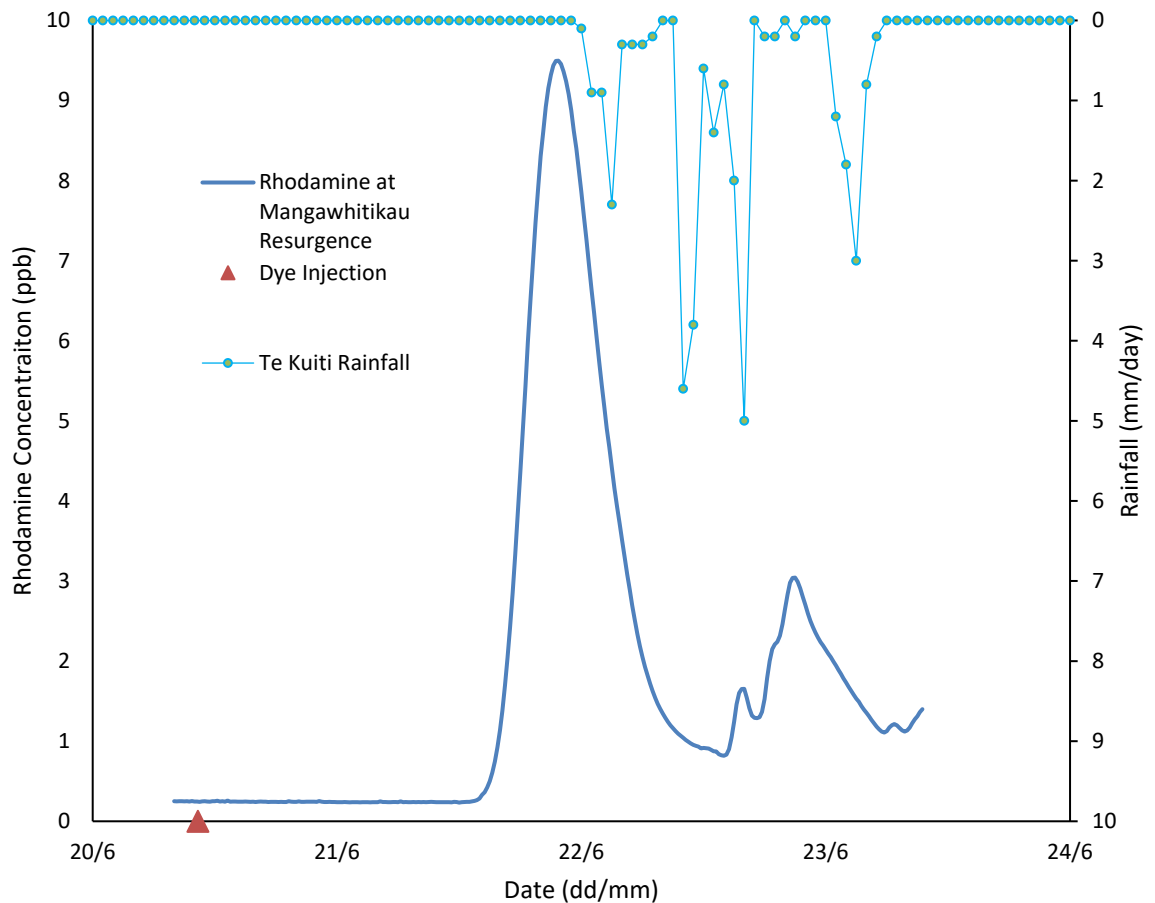


**Figure 2: Round One Dye Tracer Results from the Cyclops Sensor**

### 3.2 Round Two

In the second round of dye tracing, the RWT dye was injected into the C4 cave entrance on 20<sup>th</sup> June 2023 at 10:30 pm and measured by the Cyclops sensor at the Mangawhitikau Resurgence. Dye could also be seen visually and was measured present at Upper Mangawhitikau Spring by the handheld sensor. The peak concentration recorded by the handheld meter at Upper Mangawhitikau Spring was 86.1 ppb. The results from the sensor from Round Two are shown in Figure 3. Dye emerged at 2pm and reached peak concentrations at 9pm on the day after the injection occurred. Baseline concentrations returned 17 hours later. Rainfall was observed later in the week which is shown in the second peak after the initial dye tracer pulse. A strong tracer response was noted with a much greater peak of 9.32 ppb compared to 0.45 ppb in round one. No dye was detected upstream of Upper Mangawhitikau Spring with the handheld sensor in Round Two. Rainfall was recorded during the dye tracer test after the initial peak of the tracer and is shown by the second peak in Figure 3.





**Figure 3: Round Two Dye Tracer Results from the Cyclops Sensor**

### 3.3 Round Three

Round three involved seeding cave entrance C13 to determine the division between areas draining towards Pōtea Spring (as identified in previous dye tracer testing rounds) vs Upper Mangawhitikau Spring (or elsewhere upstream of the Mangawhitikau submergence). C13 was an intermediate location between the injection test at doline D29 (which emerged at the Upper Mangawhitikau Spring) and the injection at Camelot Cave (which emerged at Pōtea spring). Dye was seeded on 7<sup>th</sup> August 2023 at 11:30 pm

The result from the manual monitoring regime in Round Three shows dye present at Pumphouse Spring, Pōtea Spring and the Mangawhitikau at road bridge sites. No dye was present at any upstream sites or detected by the logger at the Mangawhitikau resurgence. Dye was first detected at 9am on 9<sup>th</sup> August 2023 on the falling limb of the tracer. The falling limb (or recession limb as it is sometimes known) is when dye concentrations have already reached their peak concentrations and are decreasing. Due to the nature of the manual monitoring regime, the exact timing of dye emergence and peak concentration is unknown.

The dye emerged and reached peak concentrations sometime between 8<sup>th</sup> August at 4pm and 9am on 9<sup>th</sup> August. The results from the manual regime are shown in Figure 4. Little to no rain was recorded during Round Three as shown in Figure 4.

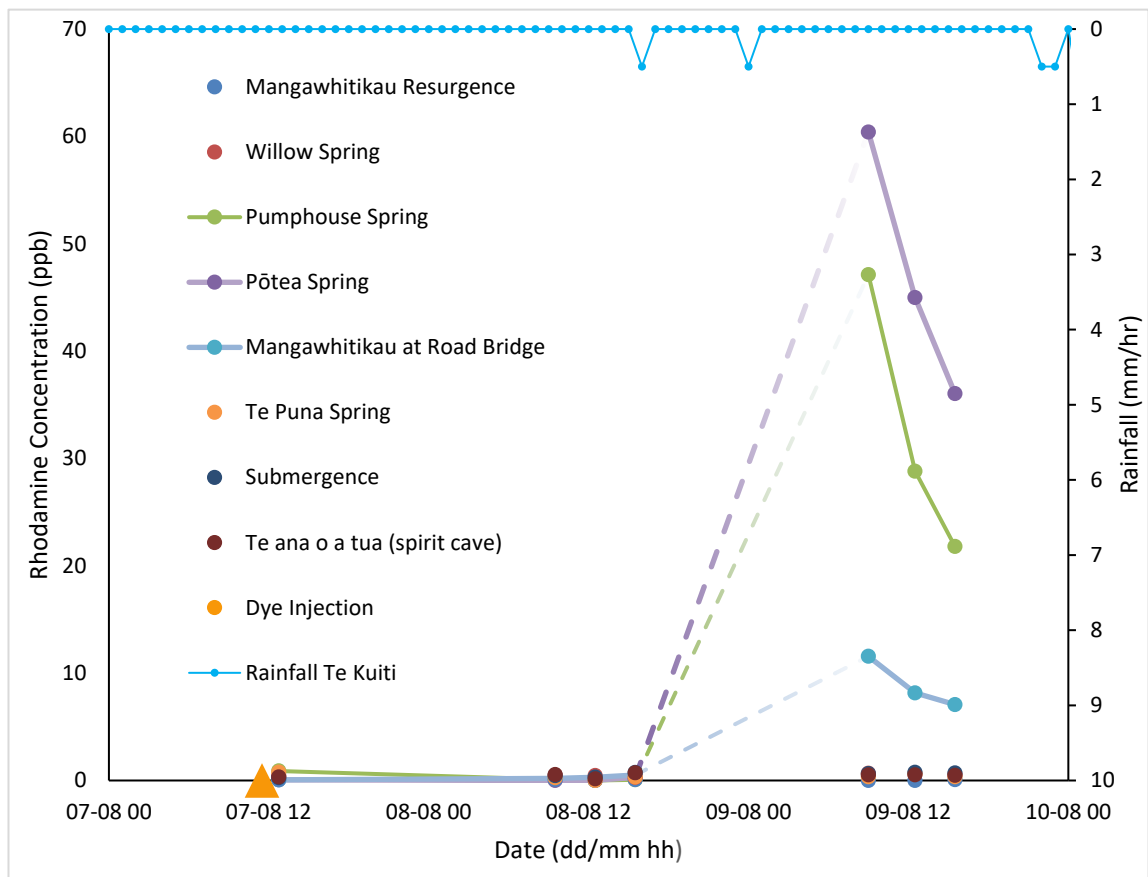


Figure 4: Round Three Dye Tracer Manual Monitoring Results

### 3.4 Round Four

The purpose of the fourth round was to determine whether water flowed north of Upper Mangawhitikau Spring into the Guildford cave system and the doline at the most Northern extent of the proposed pit D2.19 was therefore selected.

No dye presence was recorded during this monitoring round. This may have been due to one of three possibilities:

- ✧ There is poor connectivity to allow dye to pass from the dye injection locations to a receptor;
- ✧ There are large dispersion and dilution processes occurring, thereby causing monitoring sensors to not be able to detect dye presence i.e. below detection levels;

- ✧ Dye emerged at a location where monitoring was not occurring, or at a time when monitoring was not occurring. This was the least likely possibility.

No dye was detected at the Guildford Cave outlet which indicates there is not a connection between D2.19 and the Guildford Cave.

## 4.0 Discussion

The result of the dye tracer tests confirmed the exact emergence location for two of the dye injection locations and subsequently, gave an insight into flow paths within the cave system and information to broadly characterise travel times and velocities.

### 4.1 Flow Paths

Exact emergence locations were confirmed for two rounds of dye tracer testing, these were Upper Mangawhitikau Spring in Round Two and Pōtea Spring and Pumphouse Spring in Round Three. The exact emergence locations for Rounds One and Four were unknown, dye was detected at the downstream resurgence within the Mangawhitikau catchment in Round One and not detected in Round Four.

**Table 1: Characteristics of Breakthrough Curves for the RWT tracer**

| Tracer test              | Monitoring Site            | Straight-line distance to monitoring site (km) | Time to start of rising limb (hours) | Time to peak concentration (hours) | Duration of rising limb (hours) | Peak Concentration (ppb) | Duration of falling limb (hours) |
|--------------------------|----------------------------|------------------------------------------------|--------------------------------------|------------------------------------|---------------------------------|--------------------------|----------------------------------|
| Round One <sup>2</sup>   | Resurgence                 | 3.25                                           | 25                                   | 33                                 | 8                               | 0.45                     | 15                               |
| Round Two <sup>2</sup>   | Resurgence                 | 3.22                                           | 26                                   | 34                                 | 8                               | 9.32                     | 17                               |
| Round Two <sup>3</sup>   | Upper Mangawhitikau Spring | 1.7                                            | <22                                  | 0-22                               | -                               | >86.1 <sup>4</sup>       | >7 <sup>4</sup>                  |
| Round Three <sup>3</sup> | Pōtea Spring               | 3.17                                           | 29-46 <sup>4</sup>                   | 29-46 <sup>4</sup>                 | <17 <sup>4</sup>                | >60.4 <sup>4</sup>       | >7 <sup>4</sup>                  |
| Round Four               | No detection               | -                                              | -                                    | -                                  | -                               | -                        | -                                |

**Notes:**

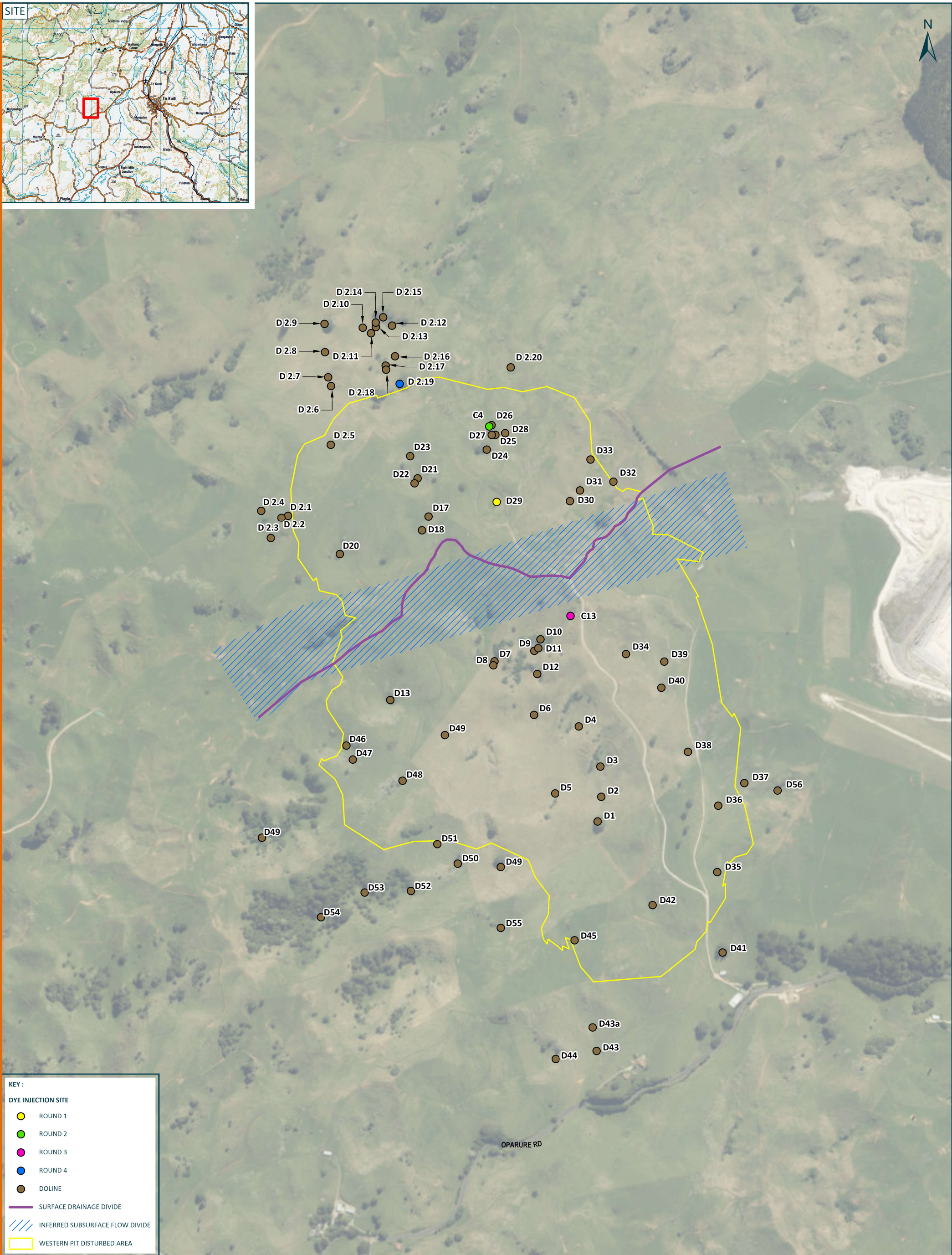
- Hours are rounded to nearest hour
- Measurements taken from cyclops sensor
- Measurements determined from handheld fluorometer
- Exact peak time and concentration are unknown

The four tracer tests determined the pathways from each of the sites. There is a direct conduit from C13 to Pōtea Spring and Pumphouse Spring and a direct conduit from C4 to Upper Mangawhitikau Spring. There is a partial connection from D29 to the Mangawhitikau resurgence similar to C4. From the fourth dye tracer test we can determine no direct conduit to the Guildford cave system from doline D2.19.

## **4.2 Catchment Delineation**

The results of this dye tracer study and the results from previous studies indicate a divide between water that travels to Pōtea Spring versus dye that emerges in the Upper Mangawhitikau Catchment. The estimate of the division between the two emergence locations is based on the overland topography, locations and positioning of dolines and results from the dye tracer tests to date. Figure 5 shows that water conceptually flows towards the Upper Mangawhitikau in the North of the proposed pit extent and flows to Pōtea Spring in the Middle and South of the proposed pit extent.







### 4.3 Travel Times and Velocity

Flow times from the dye injection locations are summarised in Table 2 below.

The RWT dye injected into the cave and doline in the upper catchment took approximately 26 hours to be first detected at the Mangawhitikau resurgence site.

| Table 2: Travel Times                                                                                                                                                                                                              |                 |                                                             |                                             |                               |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|-------------------------------------------------------------|---------------------------------------------|-------------------------------|
| Tracer test                                                                                                                                                                                                                        | Monitoring site | Straight-line distance to monitoring site (km) <sup>1</sup> | Time to measured peak concentration (hours) | Straight-line velocity (m/hr) |
| Round One                                                                                                                                                                                                                          | Resurgence      | 3.25                                                        | 33                                          | 98.4                          |
| Round Two                                                                                                                                                                                                                          | Resurgence      | 3.22                                                        | 34                                          | 94.7                          |
| Round Three                                                                                                                                                                                                                        | Pōtea Spring    | 3.17                                                        | 29-46                                       | 68.9-109 <sup>2</sup>         |
| Notes:<br>1. The minimum straight-line distance is determined from doline to monitoring site however, it was not likely that the flow path was a straight line.<br>2. The actual velocity will be somewhere between these 2 values |                 |                                                             |                                             |                               |

### 4.4 Dilution

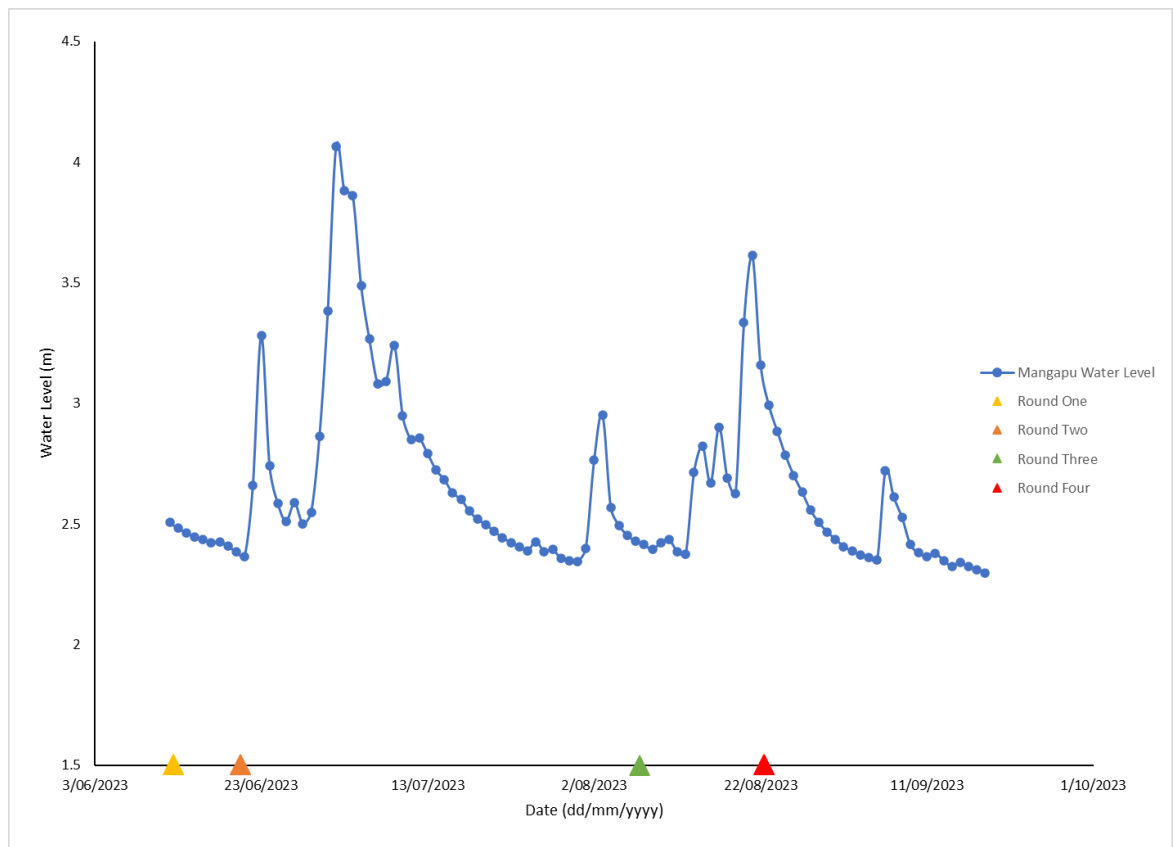
Table 3 shows large dilution ratios. The dilution ratio was calculated using the conservative dilution approach accounting for the 10,000 L of water that followed the 20 L dye injection. It was likely that not all the dye mixed with the 10,000 L and the real source concentration may be much larger (between 181,000 ppb and 90,720,000 ppb).

| Table 3: Dilution |        |                            |                                         |                                             |                |
|-------------------|--------|----------------------------|-----------------------------------------|---------------------------------------------|----------------|
| Tracer test       | Tracer | Monitoring site            | Concentration of tracer at source (ppb) | Peak concentration at monitoring site (ppb) | Dilution ratio |
| Round One         | RWT    | Resurgence                 | 181,000                                 | 0.45                                        | 1:402,000      |
| Round Two         | RWT    | Resurgence                 | 181,000                                 | 9.32                                        | 1:19,000       |
| Round Two         | RWT    | Upper Mangawhitikau Spring | 181,000                                 | 86.1                                        | 1:2,100        |

| Table 3: Dilution                                                                                                                                                                                                                                                                                                                                   |        |                 |                                         |                                             |                |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|-----------------|-----------------------------------------|---------------------------------------------|----------------|
| Tracer test                                                                                                                                                                                                                                                                                                                                         | Tracer | Monitoring site | Concentration of tracer at source (ppb) | Peak concentration at monitoring site (ppb) | Dilution ratio |
| Round Three                                                                                                                                                                                                                                                                                                                                         | RWT    | Pōtea Spring    | 181,000                                 | 60.4                                        | 1:3,000        |
| Round Four                                                                                                                                                                                                                                                                                                                                          | RWT    | Resurgence      | 181,000                                 | <0.4                                        | >1:453,000     |
| <b>Notes:</b> <ol style="list-style-type: none"> <li>The conservative 181,000 ppb was used to calculate the dilution ratio however, it was likely the concentration was between 181,000 ppb and 90,720,000 ppb</li> <li>Round One, Two and Four measurements are from the logger and Round Three measurement is from the handheld sensor</li> </ol> |        |                 |                                         |                                             |                |

## 4.5 Water Levels

The downstream Mangapu River water level throughout the duration of the dye tracer tests is shown in Figure 6. Dye tracer injections are marked. When water levels were higher, baseline sediment concentrations are higher which reduced the ability for the equipment to identify the dye tracer.



**Figure 6: Downstream Mangapu Water Level throughout the Dye Tracer Tests accessed from Waikato Regional Council Environmental Data Hub**  
<https://www.waikatoregion.govt.nz/environment/envirohub/environmental-maps-and-data/station/38164/WL?dt=Level>

#### 4.6 Result Implications

The dye breakthrough curves (BTC) for Rounds One and Two show a sharp fast short-lived pulse of dye with low concentrations (compared to injection concentrations) in the receiving environment. The total time of the pulse was 23-25 hours from first detection back to baseline levels measured with the cyclops logger. For the third round, the duration of the pulse lasted longer than 12 hours, however the total time is unknown.

As explained in the previous dye tracing report Appendix A, the antecedent hydrologic conditions affect the results of the study. The dilution, velocities, and therefore, total effect of the pulse on the receiving environment is dependent on the antecedent hydrological conditions. This includes both rainfall amount and intensity, and water levels. The initial conditions, therefore, will determine the resultant effect on the receiving environment.



## 5.0 Conclusion

These tracer tests provided information on the emergence of groundwater from dolines in the proposed Western pit disturbed area, while providing some information of flow times through this network.

Dye introduced to cave entrances were notably detected at both the Upper Mangawhitikau and Pōtea Spring. Dye introduced to cave entrance C4 in the northern section of the proposed western pit emerged at Upper Mangawhitikau Spring while dye injected into cave entrance C13 emerged at Pōtea Spring. These results helped to refine the location of an inferred subsurface flow divide crossing the proposed western pit disturbed area.

Low levels of detection were observed from the tracer injection into doline D29, which suggests large dilution and/or dispersion occurred.

Dye introduced at the most northern location of the proposed pit (doline D2.19) was not detected and is assumed to migrate through such a tortuous flow path that it causes no detectable effect in the Mangawhitikau Stream or nearby caves.

Successful dye detection was based on accessibility of upstream cave and doline entrances. The dolines decreased detection by dilution and possibly due to poor connections or significant mixing and dispersion over time.

## **Appendix D: Mangawhitikau Stream and Mangapu River Water Quality Results**

**Table D1: Mangapu (Upper) Water Quality Results**

| Parameter                     | Unit              | 02/04/2019 | 16/04/2019 | 14/08/2019 | 28/08/2019 | 19/09/2019 |
|-------------------------------|-------------------|------------|------------|------------|------------|------------|
| Discharge                     | m <sup>3</sup> /s | 0.017      | 0.013      | 1.908      | 0.675      | 0.503      |
| pH                            | pH units          | 8.1        | 8.0        | 7.8        | 7.8        | 7.0        |
| Electrical Conductivity       | μS/cm             | 294        | 287        | 215        | 234        | 231        |
| Total Alkalinity              | g/m <sup>3</sup>  | 144        | 148        | 99         | 102        | 88         |
| Chloride                      | g/m <sup>3</sup>  | 8.00       | 8.18       | 7.86       | 8.39       | 7.98       |
| Sulphate                      | g/m <sup>3</sup>  | 5.99       | 6.47       | 4.74       | 4.71       | 4.71       |
| Nitrate                       | g/m <sup>3</sup>  | 1.75       | 1.89       | 2.56       | 2.34       | 2.37       |
| Dissolved Reactive Phosphorus | g/m <sup>3</sup>  | 0.023      | 0.024      | 0.014      | 0.010      | 0.017      |
| Ammonia as N                  | g/m <sup>3</sup>  | < 0.005    | < 0.005    | < 0.005    | < 0.005    | < 0.005    |
| TSS                           | g/m <sup>3</sup>  | < 3        | < 3        | 107        | 28         | 24         |
| BOD                           | g/m <sup>3</sup>  | < 1.00     | < 1.00     | < 1.00     | < 1.00     | < 1.00     |
| Total N                       | g/m <sup>3</sup>  | 1.75       | 2.07       | 2.90       | 2.30       | 2.60       |
| Nitrite-N                     | g/m <sup>3</sup>  | < 0.0010   | < 0.0010   | 0.0012     | <0.0010    | < 0.0010   |
| TKN                           | g/m <sup>3</sup>  | 0.10       | 0.18       | 0.33       | 0.10       | 0.25       |
| TP                            | g/m <sup>3</sup>  | 0.048      | 0.030      | 0.140      | 0.034      | 0.051      |
| Sodium                        | g/m <sup>3</sup>  | 5.60       | 5.50       | 5.23       | 5.23       | 5.21       |
| Potassium                     | g/m <sup>3</sup>  | 1.0        | 1.1        | 1.0        | 1.0        | 1.1        |
| Calcium                       | g/m <sup>3</sup>  | 53.8       | 52.7       | 42.6       | 43.9       | 43.1       |
| Magnesium                     | g/m <sup>3</sup>  | 1.70       | 1.80       | 1.30       | 1.42       | 1.49       |

|                  |           |    |    |       |    |      |
|------------------|-----------|----|----|-------|----|------|
| E.coli           | MPN/100ml | 63 | 86 | > 200 | 77 | >200 |
| Faecal coliforms | MPN/100ml | 41 | 37 | 920   | 79 | -    |

**Table D2: Mangapu (Middle) Water Quality Results**

| Parameter                     | Unit              | 02/04/2019 | 16/04/2019 | 14/08/2019 | 28/08/2019 | 19/09/2019 |
|-------------------------------|-------------------|------------|------------|------------|------------|------------|
| Discharge                     | m <sup>3</sup> /s | 0.169      | 0.103      | 6.193      | 2.358      | 2.584      |
| pH                            | pH units          | 8.1        | 8.1        | 7.8        | 7.7        | 7.4        |
| Electrical Conductivity       | µS/cm             | 202        | 191        | 174        | 182        | 182        |
| Total Alkalinity              | g/m <sup>3</sup>  | 87.3       | 92.8       | 76.6       | 78.1       | 74.0       |
| Chloride                      | g/m <sup>3</sup>  | 7.20       | 7.47       | 6.72       | 7.65       | 7.34       |
| Sulphate                      | g/m <sup>3</sup>  | 4.57       | 5.41       | 4.08       | 4.48       | 4.02       |
| Nitrate                       | g/m <sup>3</sup>  | 0.88       | 0.94       | 1.91       | 1.65       | 1.93       |
| Dissolved Reactive Phosphorus | g/m <sup>3</sup>  | 0.022      | 0.018      | 0.013      | 0.014      | 0.013      |
| Ammonia as N                  | g/m <sup>3</sup>  | < 0.005    | < 0.005    | < 0.005    | < 0.005    | < 0.005    |
| TSS                           | g/m <sup>3</sup>  | < 3        | < 3        | 72         | 15         | 21         |
| BOD                           | g/m <sup>3</sup>  | 1.54       | < 1        | < 1        | < 1        | < 1        |
| Total N                       | g/m <sup>3</sup>  | 1.06       | 1.21       | 2.20       | 1.80       | 2.20       |
| Nitrite-N                     | g/m <sup>3</sup>  | 0.0023     | 0.0022     | 0.001      | < 0.001    | < 0.001    |
| TKN                           | g/m <sup>3</sup>  | 0.18       | 0.27       | 0.29       | 0.15       | 0.29       |
| TP                            | g/m <sup>3</sup>  | 0.059      | 0.060      | 0.100      | 0.034      | 0.055      |
| Sodium                        | g/m <sup>3</sup>  | 6.40       | 6.10       | 5.22       | 5.48       | 5.13       |



|                  |                  |      |      |       |      |      |
|------------------|------------------|------|------|-------|------|------|
| Potassium        | g/m <sup>3</sup> | 1.20 | 1.00 | 0.85  | 0.88 | 0.89 |
| Calcium          | g/m <sup>3</sup> | 31.1 | 31.4 | 32.2  | 32.5 | 31.7 |
| Magnesium        | g/m <sup>3</sup> | 1.60 | 1.60 | 1.11  | 1.26 | 1.25 |
| E.coli           | MPN/100ml        | 1236 | 171  | > 200 | 46   | 200  |
| Faecal coliforms | MPN/100ml        | 529  | 181  | 130   | 23   | -    |

| Table D3: Mangapu (Lower) Water Quality Results |                   |            |            |            |            |            |
|-------------------------------------------------|-------------------|------------|------------|------------|------------|------------|
| Parameter                                       | Unit              | 02/04/2019 | 16/04/2019 | 14/08/2019 | 28/08/2019 | 19/09/2019 |
| Discharge                                       | m <sup>3</sup> /s | 0.358      | 0.253      | 8.383      | 4.423      | 4.747      |
| pH                                              | pH units          | 8          | 7.8        | 7.7        | 7.7        | 7.5        |
| Electrical Conductivity                         | µS/cm             | 245        | 221        | 193        | 201        | 200        |
| Total Alkalinity                                | g/m <sup>3</sup>  | 101        | 104        | 77         | 80         | 76         |
| Chloride                                        | g/m <sup>3</sup>  | 7.38       | 7.83       | 7.25       | 7.43       | 6.92       |
| Sulphate                                        | g/m <sup>3</sup>  | 12.3       | 17.6       | 11.9       | 12.3       | 12.7       |
| Nitrate                                         | g/m <sup>3</sup>  | 0.96       | 1.04       | 1.88       | 1.61       | 1.79       |
| Dissolved Reactive Phosphorus                   | g/m <sup>3</sup>  | 0.019      | 0.013      | 0.012      | 0.012      | 0.012      |
| Ammonia as N                                    | g/m <sup>3</sup>  | < 0.005    | < 0.005    | < 0.005    | < 0.005    | < 0.005    |
| TSS                                             | g/m <sup>3</sup>  | 11         | < 3        | 82         | 17         | 25         |
| BOD                                             | g/m <sup>3</sup>  | < 1        | < 1        | < 1        | < 1        | < 1        |
| Total N                                         | g/m <sup>3</sup>  | 1.11       | 1.27       | 2.20       | 1.90       | 2.10       |
| Nitrite-N                                       | g/m <sup>3</sup>  | 0.0021     | 0.002      | 0.0019     | < 0.0010   | < 0.0010   |

|                  |                  |       |       |       |       |       |
|------------------|------------------|-------|-------|-------|-------|-------|
| TKN              | g/m <sup>3</sup> | 0.16  | 0.22  | 0.27  | 0.3   | 0.31  |
| TP               | g/m <sup>3</sup> | 0.060 | 0.041 | 0.095 | 0.026 | 0.048 |
| Sodium           | g/m <sup>3</sup> | 6.40  | 6.20  | 5.31  | 5.59  | 5.33  |
| Potassium        | g/m <sup>3</sup> | 1.2   | 1.1   | 1.0   | 0.9   | 1.0   |
| Calcium          | g/m <sup>3</sup> | 38.6  | 39.9  | 35.1  | 35.4  | 34.6  |
| Magnesium        | g/m <sup>3</sup> | 2.00  | 2.30  | 1.57  | 1.74  | 1.83  |
| E.coli           | MPN/100ml        | 1450  | 330   | 200   | 68    | > 200 |
| Faecal coliforms | MPN/100ml        | 631   | 237   | 170   | 33    | -     |

| Table D4: Mangawhitikau (Upper) Water Quality Results |                   |            |            |            |            |            |
|-------------------------------------------------------|-------------------|------------|------------|------------|------------|------------|
| Parameter                                             | Unit              | 02/04/2019 | 16/04/2019 | 14/08/2019 | 28/08/2019 | 19/09/2019 |
| Discharge                                             | m <sup>3</sup> /s | 0.109      | 0.056      | 1.931      | 0.813      | 1.09       |
| pH                                                    | pH units          | 7.9        | 8.1        | 7.5        | 7.1        | 7.6        |
| Electrical Conductivity                               | µS/cm             | 187        | 204        | 126        | 134        | 170        |
| Total Alkalinity                                      | g/m <sup>3</sup>  | 65.3       | 81.2       | 47.5       | 48.3       | 70.7       |
| Chloride                                              | g/m <sup>3</sup>  | 8.9        | 7.81       | 7.16       | 8.3        | 6.62       |
| Sulphate                                              | g/m <sup>3</sup>  | 10.4       | 6.63       | 4.3        | 4.8        | 5.53       |
| Nitrate                                               | g/m <sup>3</sup>  | 0.84       | 0.74       | 1.38       | 1.13       | 1.23       |
| Dissolved Reactive Phosphorus                         | g/m <sup>3</sup>  | 0.012      | 0.015      | 0.008      | 0.008      | 0.009      |
| Ammonia as N                                          | g/m <sup>3</sup>  | < 0.005    | < 0.005    | 0.01       | < 0.005    | < 0.005    |
| TSS                                                   | g/m <sup>3</sup>  | 4          | < 3        | 124        | 11         | 6          |

|                  |                  |        |       |        |          |         |
|------------------|------------------|--------|-------|--------|----------|---------|
| BOD              | g/m <sup>3</sup> | 1.56   | <1    | <1     | <1       | <1      |
| Total N          | g/m <sup>3</sup> | 1.06   | 0.85  | 1.7    | 1.3      | 1.2     |
| Nitrite-N        | g/m <sup>3</sup> | 0.0046 | 0.001 | 0.0013 | < 0.0010 | <0.0010 |
| TKN              | g/m <sup>3</sup> | 0.21   | 0.11  | 0.27   | 0.19     | 0.1     |
| TP               | g/m <sup>3</sup> | 0.045  | 0.044 | 0.14   | 0.024    | 0.037   |
| Sodium           | g/m <sup>3</sup> | 6.8    | 6.3   | 5.46   | 5.56     | 5.18    |
| Potassium        | g/m <sup>3</sup> | 1.7    | 1.2   | 0.91   | 0.88     | 0.89    |
| Calcium          | g/m <sup>3</sup> | 26     | 28.3  | 20.3   | 21.1     | 31.2    |
| Magnesium        | g/m <sup>3</sup> | 1.7    | 1.6   | 1.28   | 1.29     | 1.4     |
| E.coli           | MPN/100ml        | 1989   | 517   | 93     | 32       | > 200   |
| Faecal coliforms | MPN/100ml        | 958    | 461   | 240    | 49       | -       |

| Table D5: Mangawhitikau (Lower) Water Quality Results |                   |            |            |            |            |            |
|-------------------------------------------------------|-------------------|------------|------------|------------|------------|------------|
| Parameter                                             | Unit              | 02/04/2019 | 16/04/2019 | 14/08/2019 | 28/08/2019 | 19/09/2019 |
| Discharge                                             | m <sup>3</sup> /s | 0.177      | 0.123      | 5.459      | 1.587      | 1.563      |
| pH                                                    | pH units          | 8          | 8.3        | 7.7        | 7.5        | 7.6        |
| Electrical Conductivity                               | µS/cm             | 276        | 312        | 207        | 218        | 225        |
| Total Alkalinity                                      | g/m <sup>3</sup>  | 110        | 119        | 76.8       | 78.4       | 77.6       |
| Chloride                                              | g/m <sup>3</sup>  | 7.56       | 7.73       | 6.95       | 7.51       | 6.76       |
| Sulphate                                              | g/m <sup>3</sup>  | 20.8       | 31.3       | 20.1       | 20.9       | 21.9       |
| Nitrate                                               | g/m <sup>3</sup>  | 1.07       | 1.17       | 1.79       | 1.58       | 1.72       |

|                               |                  |         |          |          |          |          |
|-------------------------------|------------------|---------|----------|----------|----------|----------|
| Dissolved Reactive Phosphorus | g/m <sup>3</sup> | 0.031   | 0.013    | 0.01     | 0.007    | 0.01     |
| Ammonia as N                  | g/m <sup>3</sup> | < 0.005 | < 0.005  | < 0.005  | < 0.005  | < 0.005  |
| TSS                           | g/m <sup>3</sup> | < 3     | 4        | 134      | 10       | 13       |
| BOD                           | g/m <sup>3</sup> | <1      | <1       | <1       | <1       | <1       |
| Total N                       | g/m <sup>3</sup> | 1.2     | 1.29     | 2.1      | 1.7      | 2.1      |
| Nitrite-N                     | g/m <sup>3</sup> | 0.0012  | < 0.0010 | < 0.0010 | < 0.0010 | < 0.0010 |
| TKN                           | g/m <sup>3</sup> | 0.13    | 0.12     | 0.35     | 0.15     | 0.33     |
| TP                            | g/m <sup>3</sup> | 0.038   | 0.037    | 0.15     | 0.041    | 0.04     |
| Sodium                        | g/m <sup>3</sup> | 6.5     | 6.4      | 5.41     | 5.64     | 5.49     |
| Potassium                     | g/m <sup>3</sup> | 1.3     | 1.2      | 0.95     | 0.97     | 1        |
| Calcium                       | g/m <sup>3</sup> | 44.8    | 47.6     | 37.6     | 37.7     | 38.1     |
| Magnesium                     | g/m <sup>3</sup> | 2.5     | 3        | 2.07     | 2.24     | 2.44     |
| E.coli                        | MPN/100ml        | 2755    | 361      | 165      | 28       | > 200    |
| Faecal coliforms              | MPN/100ml        | 1450    | 248      | 350      | 49       | -        |



## **Appendix E: Continuous Water Quality SONDE Data**

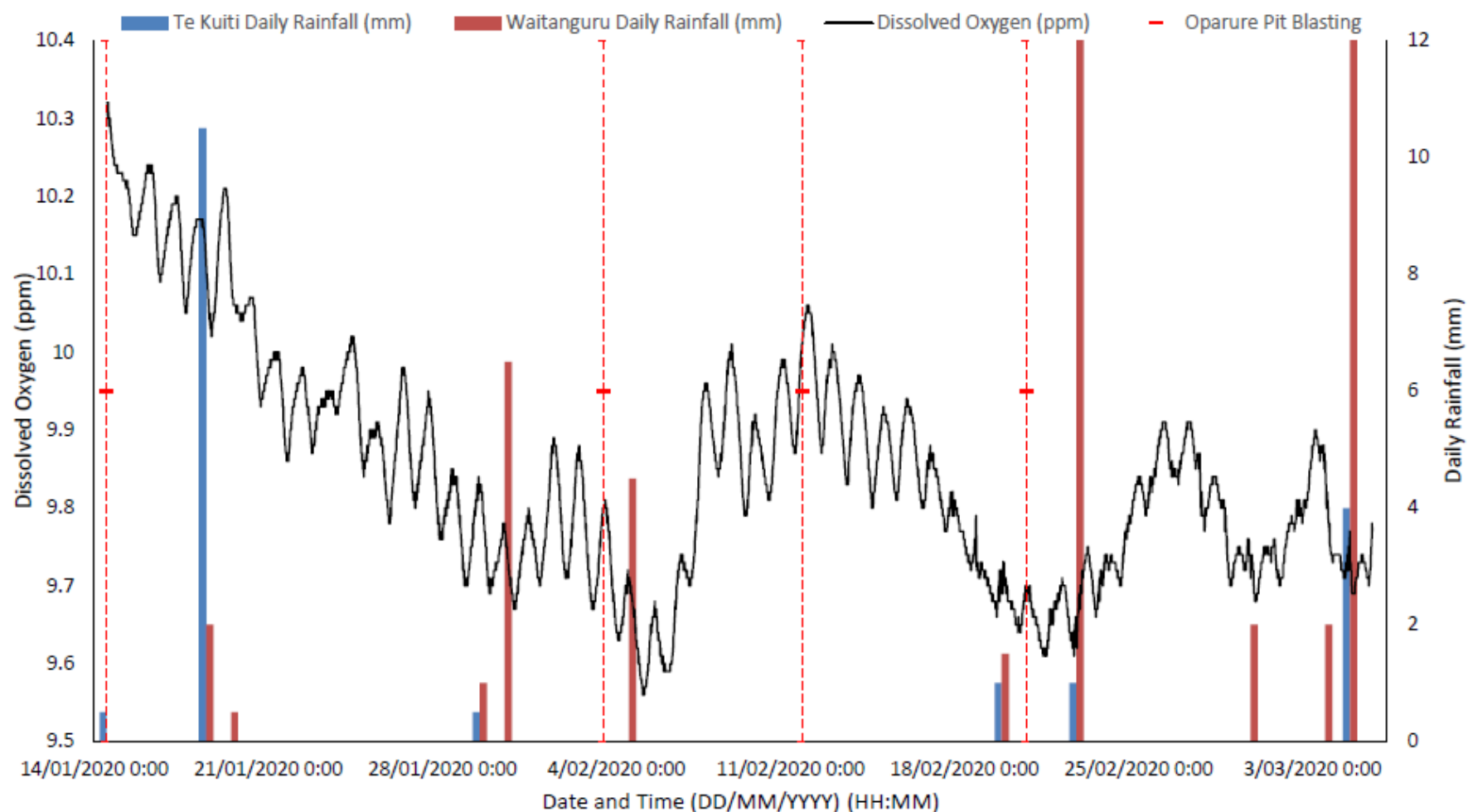


Figure E 1: Dissolved Oxygen (DO) concentration (ppm) in the Mangawhitikau Stream (Resurgence) with daily rainfall totals and timing of blasts within Oparure Pit

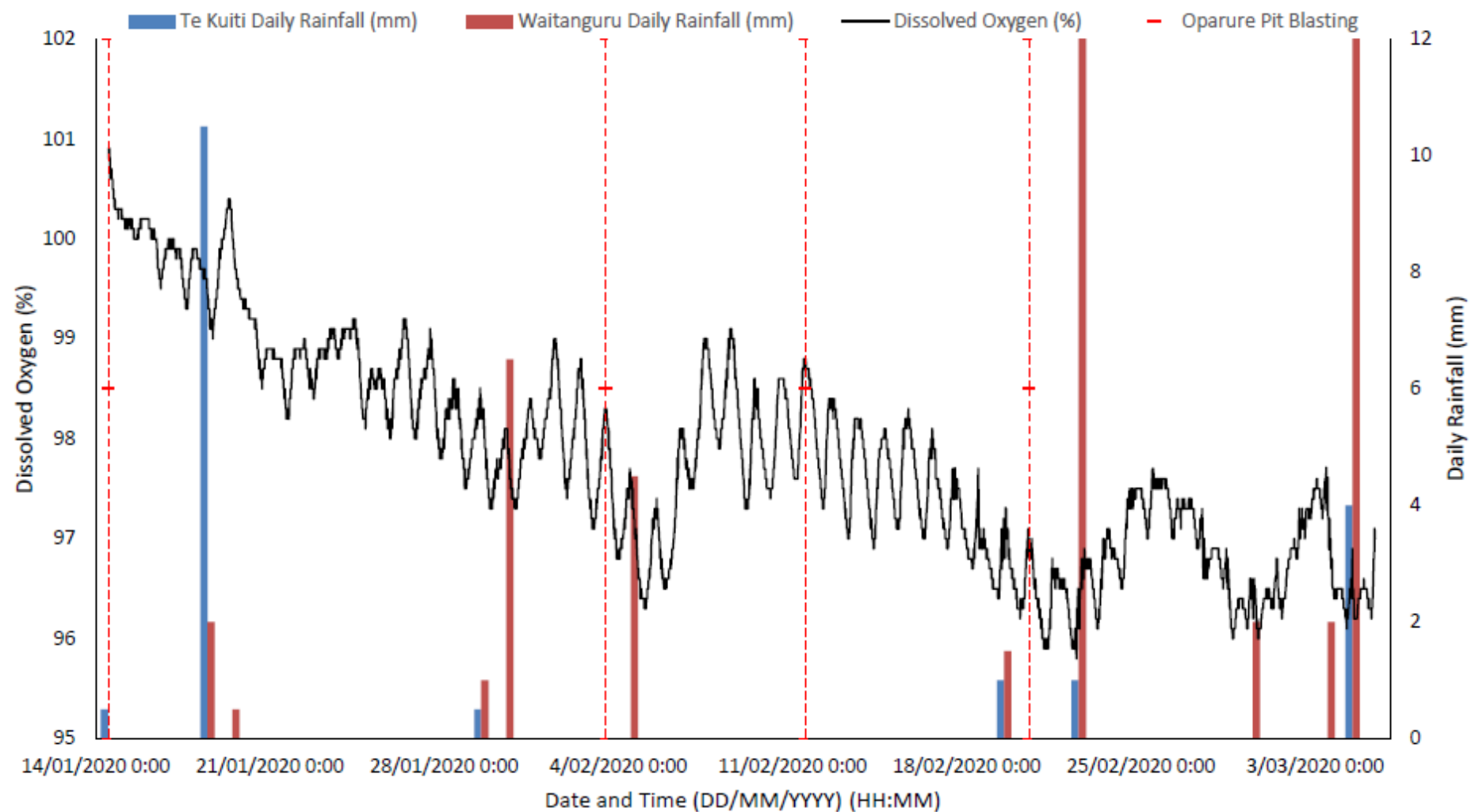


Figure E 2: Dissolved Oxygen (DO) concentration (% saturation) in the Mangawhitikau Stream (Resurgence) with daily rainfall totals and timing of blasts within Oparure Pit

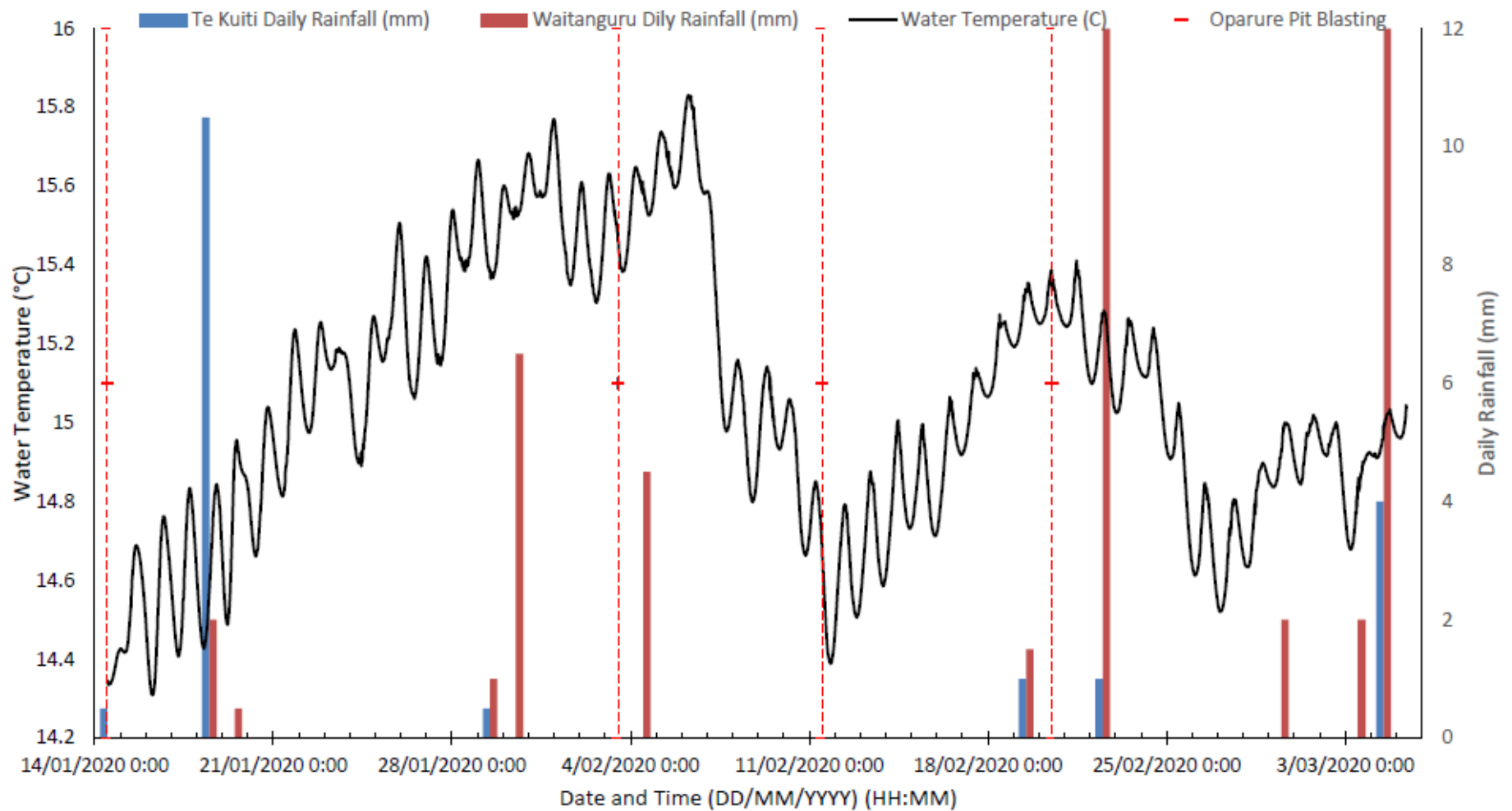


Figure E 3: Water temperature in the Mangawhitikau Stream (Resurgence) with daily rainfall totals and timing of blasts within Oparure Pit

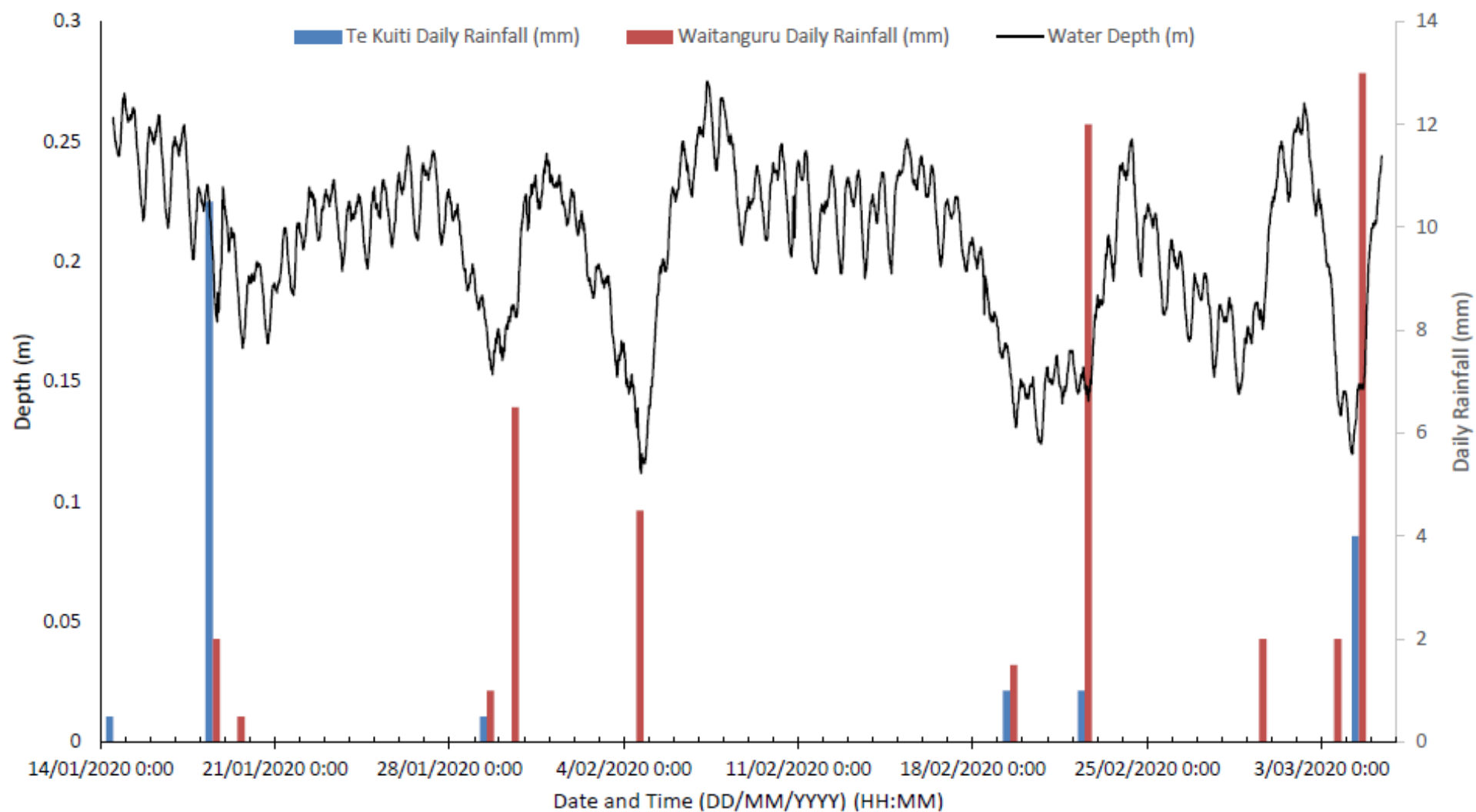
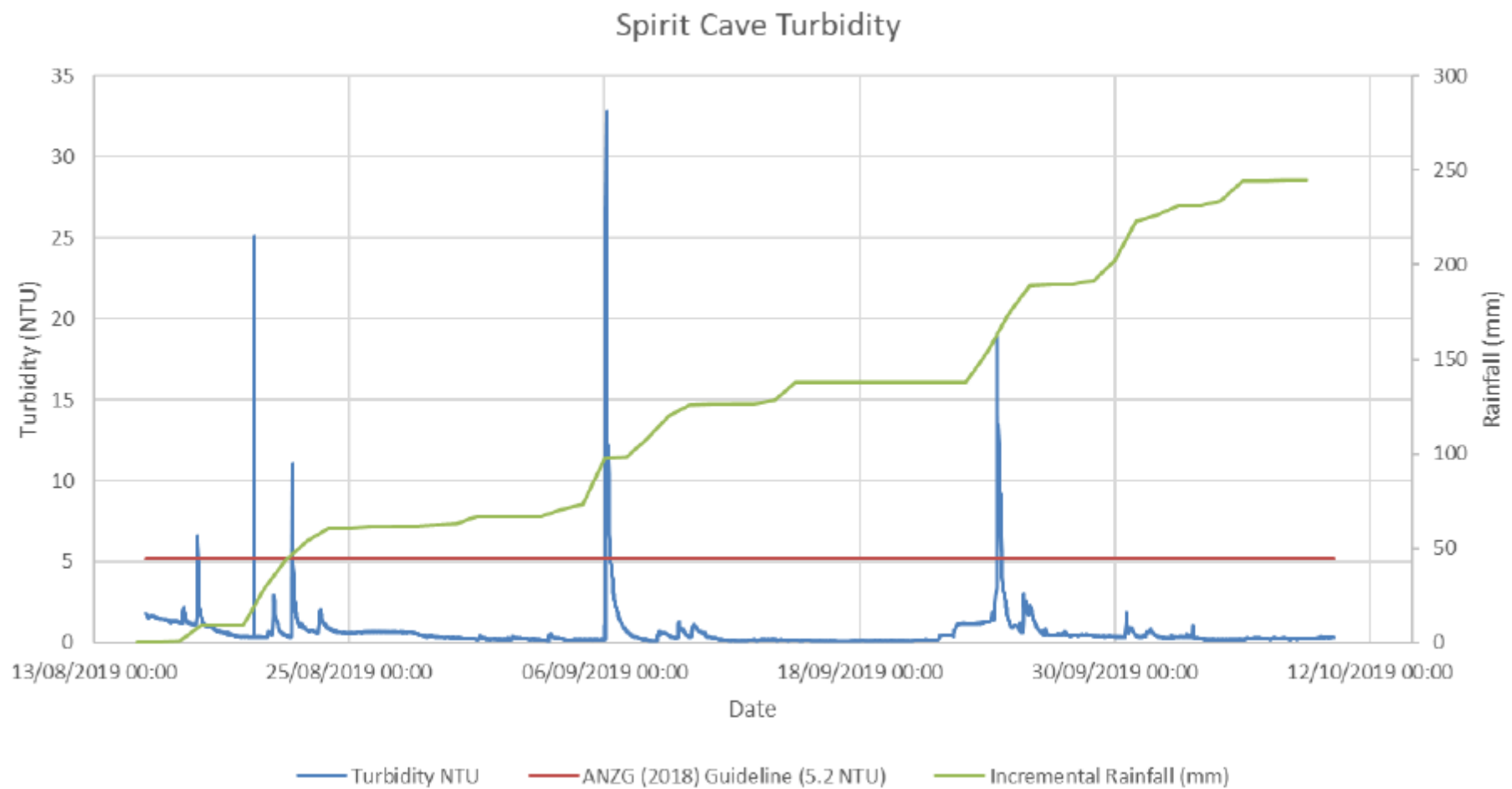
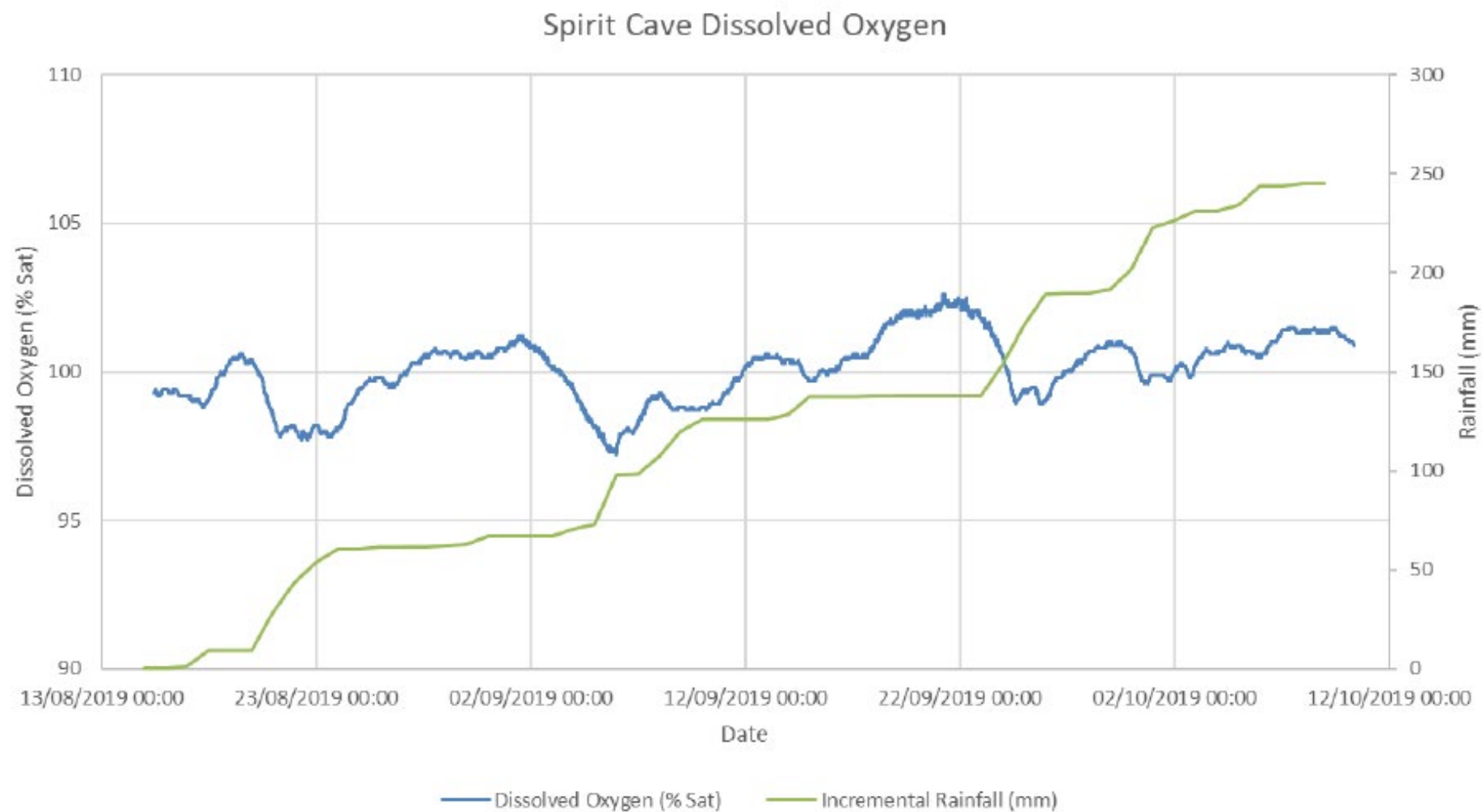


Figure E 4: Water depth in the Mangawhitikau Stream (Resurgence) with daily rainfall totals

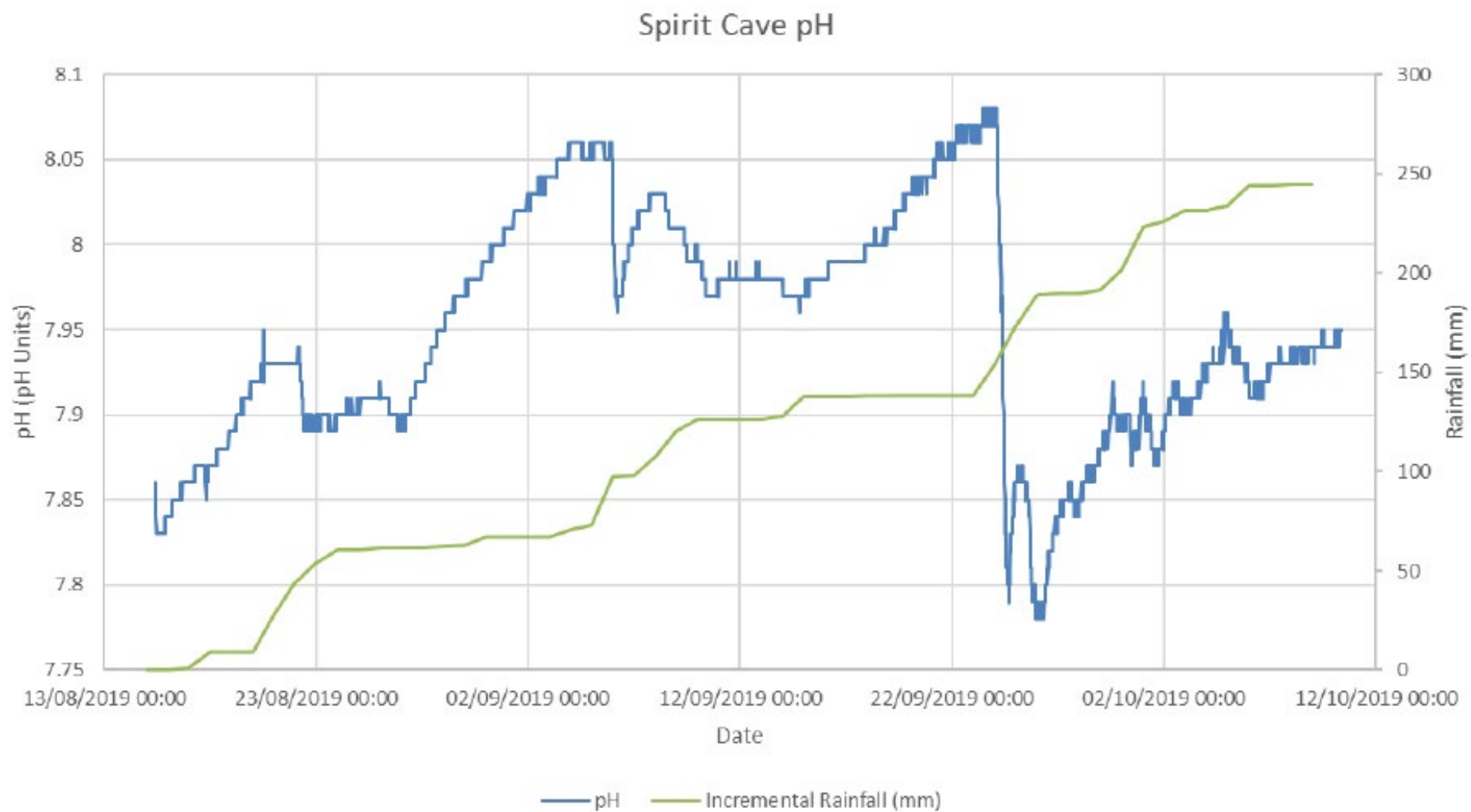




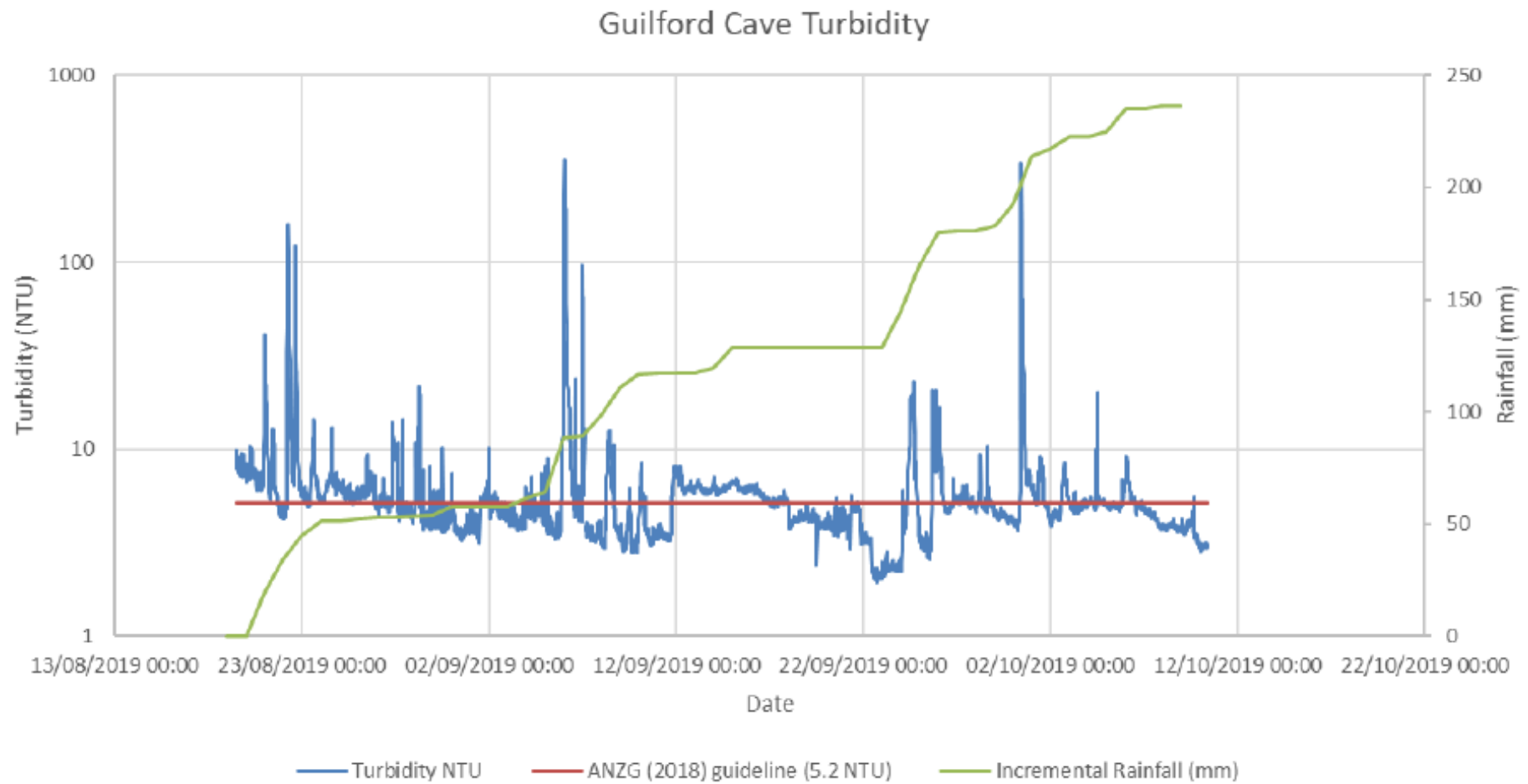
**Figure E 5: Turbidity (NTU) in Spirit Cave with cumulative rainfall**



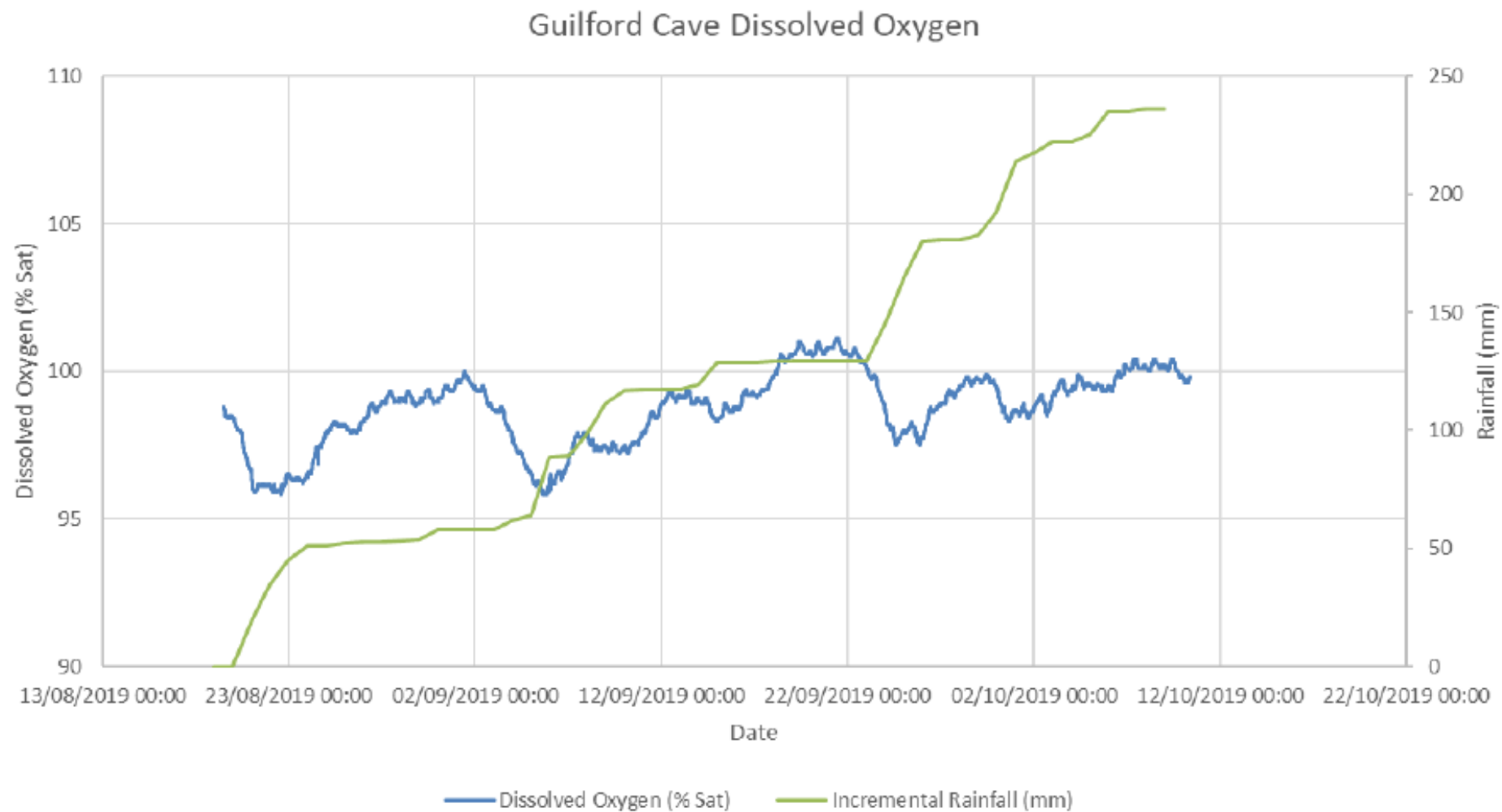
**Figure E 6: Dissolved Oxygen (ppm) in Spirit Cave with cumulative rainfall**



**Figure E 7: pH in Spirit Cave with cumulative rainfall**



**Figure E 8: Turbidity (NTU) in Guildford Cave with cumulative rainfall**



**Figure E 9: Dissolved Oxygen (% saturation) in Guildford Cave with cumulative rainfall**



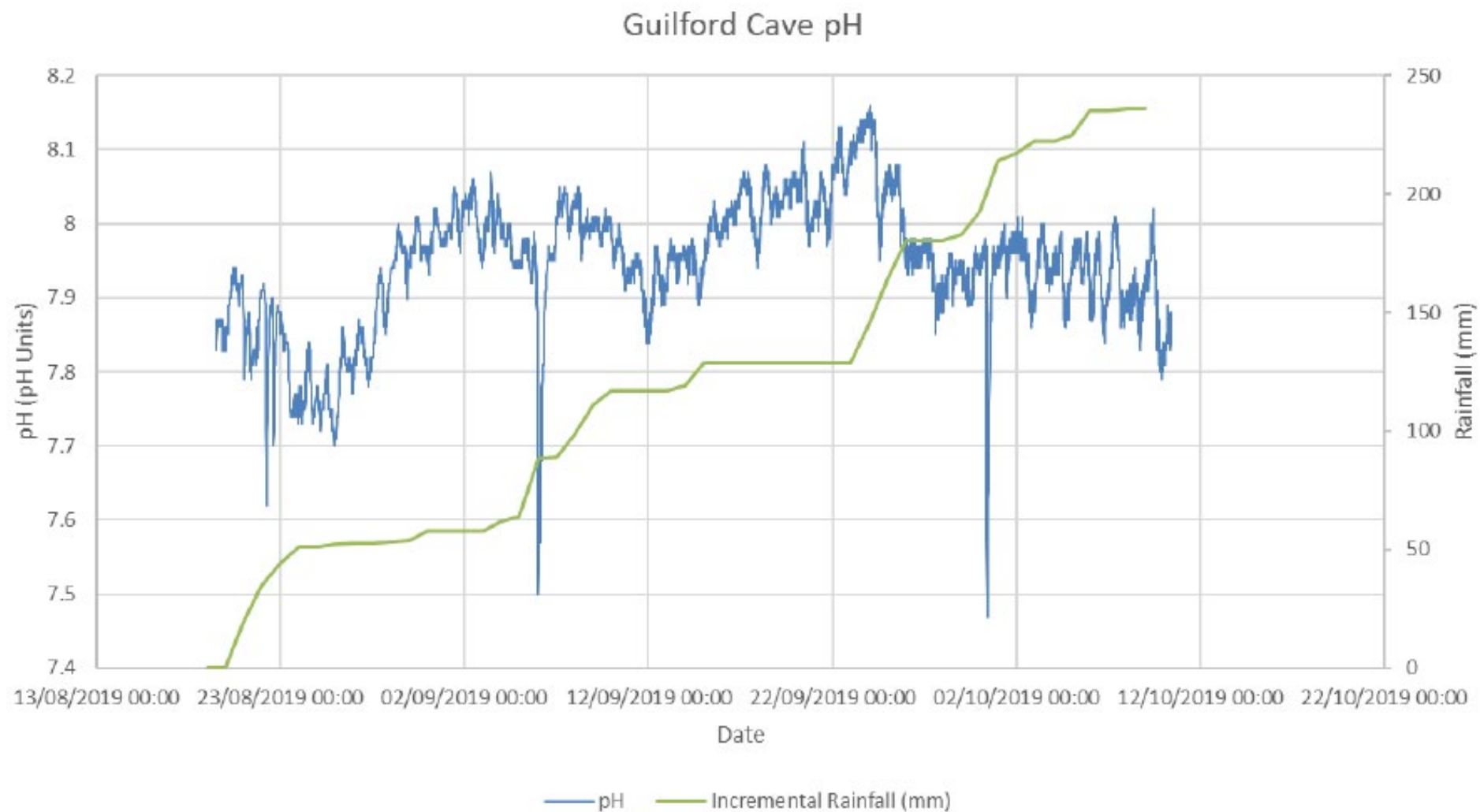


Figure E 10: pH in Guildford Cave with cumulative rainfall

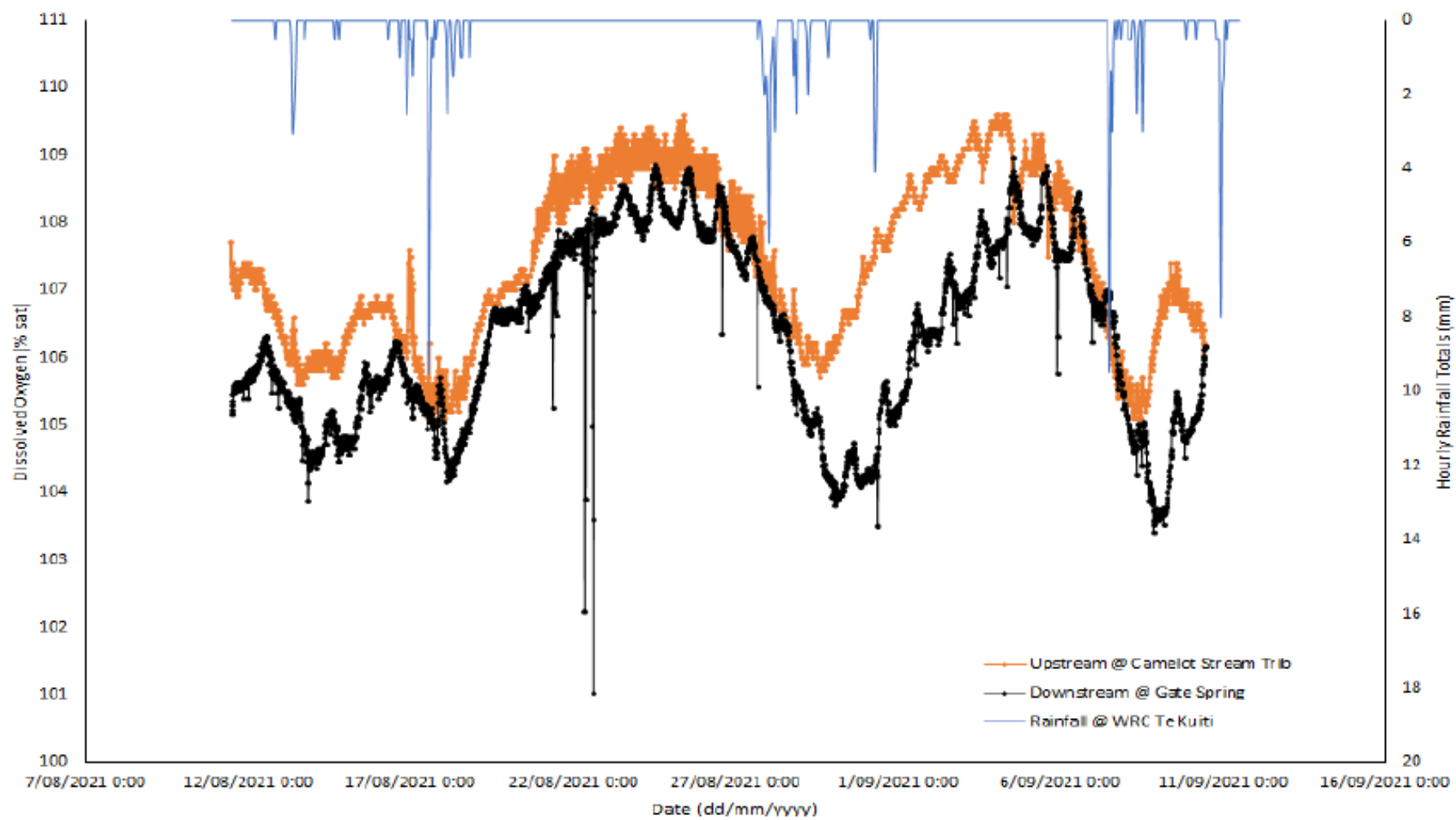


Figure E 11: Dissolved Oxygen (% saturation) in the Camelot Stream headwaters (orange) and Pōtea Spring (black) with daily rainfall

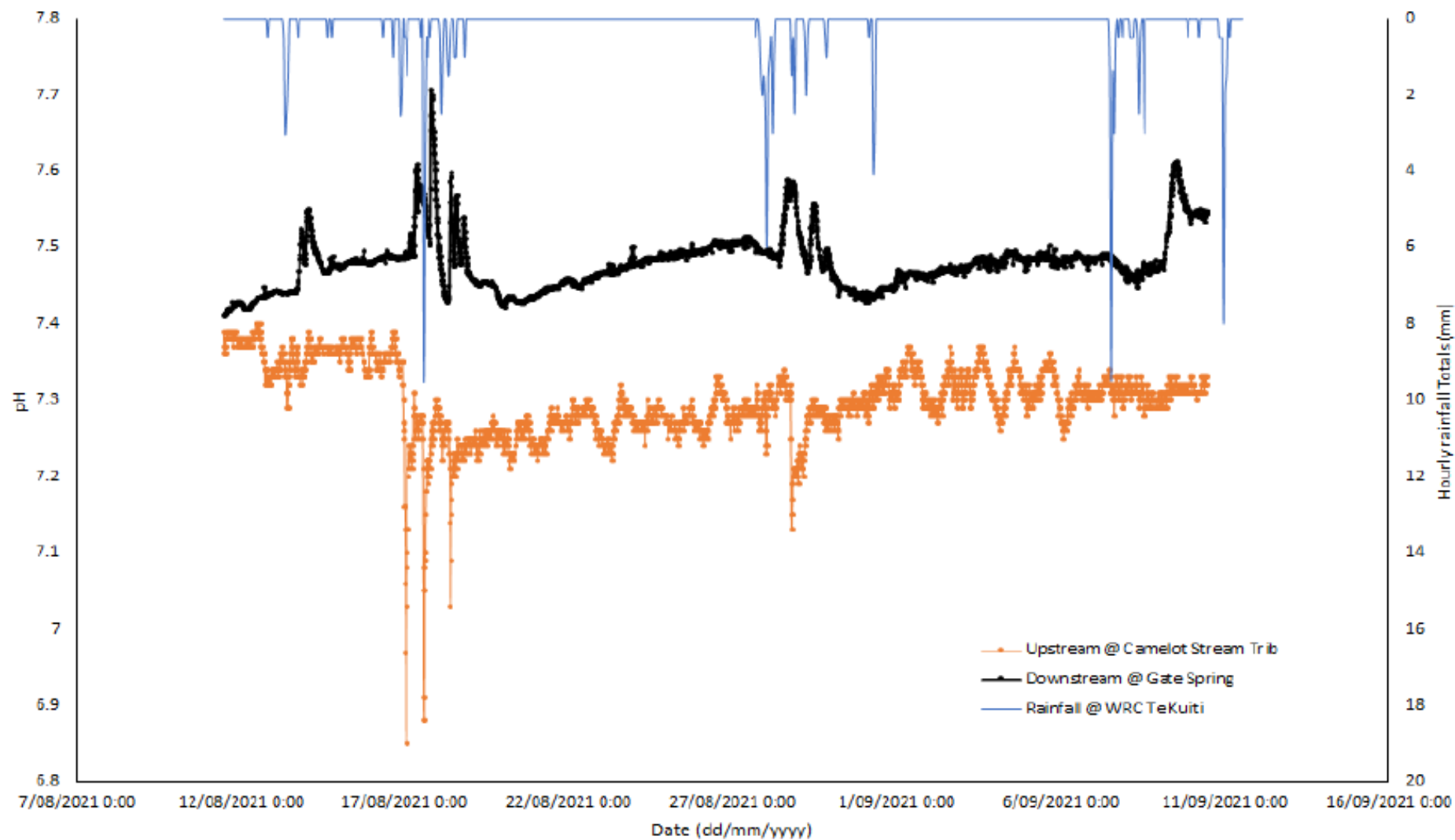


Figure E 12: pH in the Camelot Stream headwaters (orange) and Pōtea Spring (black) with daily rainfall





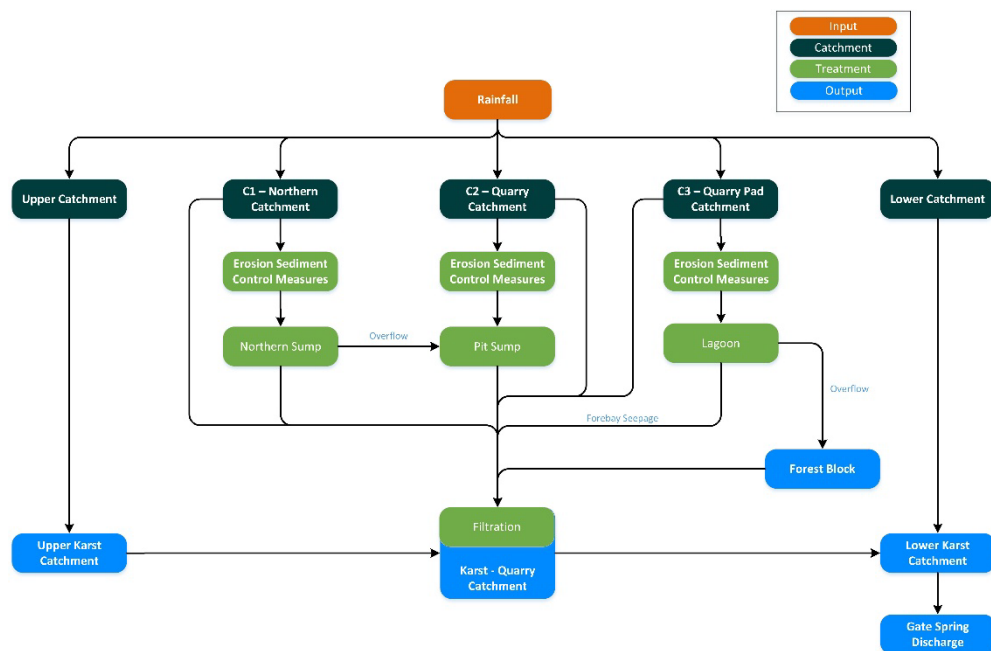


## Model Approach

### Water Management Model

A water management model (WMM) (Figure F1) has been developed to represent natural hydrological and geophysical systems at the SW Pit. The WMM incorporates two elements, a water balance model (WBM) and water quality model (WQM). The two model elements simulate the performance of the SW Pit to manage water and suspended solids over a range of quarry stages. Specifically, the WMM has been applied to optimise the operation of the erosion and sediment control structures to mitigate the mobilisation of entrained suspended solids and predict the likely discharge of quarry impacted water into the karst and groundwater system.

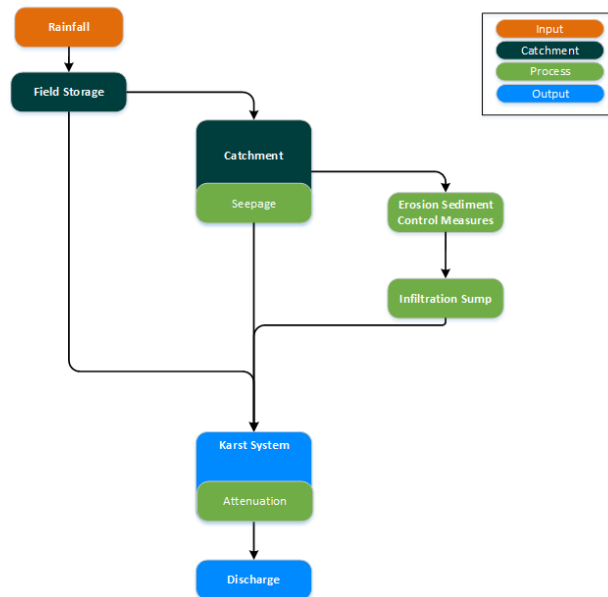
Model simulations are run on daily time steps over a 33-year rainfall dataset from 1 January 1985 to 31 December 2017.



**Figure F1. Conceptual model of the Water Management Model (WMM).**

### Water Balance Model

The WBM element of the WMM predicts stormwater runoff based on a rainfall time series. Figure F2 schematically shows the WBM process. The WBM calculates catchment runoff based on a relationship with rainfall. Soil storage and release, antecedent soil moisture and typical runoff coefficients are incorporated within the model.



**Figure F2. Schematic of the Water Balance Model Element of the Water Management Model**

### Water Quality Model Element

The Water Quality Model (WQM) element reconciles the mobilisation of entrained sediment in the stormwater within the quarry. The WQM applies the WBM to route the sediment through the various catchments and erosion sediment control measures to estimate the daily suspended solids entering the karst / groundwater system.

The mobilisation of TSS during rainfall events has predicted by applying the Universal Soil Loss Equation (USLE) and hence accounts for likely effectiveness of the ESC measures to minimise sediment entrainment, the performance of the sediment retention ponds to capture and retain solids is specially modelled in the WQM element.

### Model Limits and Assumptions

#### Modelled scenarios

The modelled catchment varies as the proposed SW Pit develops over the years. The model scenarios are shown in Table F1.

| <b>Table F1: Modelled Scenarios</b>                                                                                                |                      |                                         |
|------------------------------------------------------------------------------------------------------------------------------------|----------------------|-----------------------------------------|
| <b>Scenario</b>                                                                                                                    | <b>Modelled Year</b> | <b>Number of catchments<sup>1</sup></b> |
| Scenario 1                                                                                                                         | Year 0               | 1                                       |
| Scenario 2                                                                                                                         | Year 1               | 3                                       |
| Scenario 3                                                                                                                         | Year 5               | 2                                       |
| Scenario 4                                                                                                                         | Year 8               | 2                                       |
| Scenario 5                                                                                                                         | Year 13              | 2                                       |
| Scenario 6                                                                                                                         | Year 33              | 4                                       |
| Scenario 7                                                                                                                         | Year 53              | 3                                       |
| <b>Notes:</b><br><sup>1</sup> . The number of catchments indicated represent areas of the quarry which may contain multiple sumps. |                      |                                         |

Each scenario incorporates catchments which may include multiple sediment retention ponds and/or soak pits. The catchments are based on progression of the quarry site and the relative direction of overland flow paths. The catchments do not estimate sediment to individual retention ponds and rather, provide an estimate of TSS over the respective super-catchments.

Table F2 shows the total area breakdown based on land types over the progression of the quarry. The total catchment areas are reported, however, the calculations for sediment generation are based on sub-catchments within the quarry. The pasture catchments outside of the operational quarry represent the pre-existing conditions within the quarry permit area that generate sediment but are independent of the quarry operations. Pasture catchments into the operational quarry, are catchments which contribute runoff to a sump/detention pond within the quarry.

| <b>Table F2: Water Management Model – Quarry Catchments</b> |                                |             |           |             |             |             |             |
|-------------------------------------------------------------|--------------------------------|-------------|-----------|-------------|-------------|-------------|-------------|
| <b>Land Type</b>                                            | <b>Scenario # / Areas (ha)</b> |             |           |             |             |             |             |
|                                                             | <b>1</b>                       | <b>2</b>    | <b>3</b>  | <b>4</b>    | <b>5</b>    | <b>6</b>    | <b>7</b>    |
| Highwall                                                    | 0                              | 0.1         | 2.0       | 2.2         | 3.0         | 4.1         | 8.8         |
| Haul Road                                                   | 0.7                            | 1.1         | 2.1       | 3.9         | 6.4         | 2.3         | 2.1         |
| Stripped                                                    | 0.6                            | 0.7         | 1.0       | 2.2         | 2.0         | 1.7         | 0           |
| Overburden                                                  | 1.0                            | 2.0         | 2.9       | 3.6         | 3.8         | 10.3        | 9.7         |
| Quarry Floor                                                | 10                             | 8.5         | 9.0       | 11.3        | 13.2        | 14.9        | 1.1         |
| Backfill                                                    | 0                              | 0           | 0         | 0           | 0           | 13.5        | 37.7        |
| <b>Quarry Total</b>                                         | <b>13.3</b>                    | <b>14.4</b> | <b>20</b> | <b>27.2</b> | <b>33.4</b> | <b>52.8</b> | <b>66.4</b> |

## Rainfall

The WMM runs a daily time step to capture the influence of temporal variability in rainfall events on downstream structures (sediment retention ponds) and the influence on the receiving environment (karst or groundwater system). The rainfall series is based on rainfall observations at the Te Kuiti Electronic Weather Station (EWS) and Te Kuiti Pumping Station weather station operated by the Waikato Regional Council (Table F3).

| Table F3: Daily Rainfall Time Series |                        |                         |
|--------------------------------------|------------------------|-------------------------|
| Station Name                         | Coordinates            | Date Range              |
| Te Kuiti Pumping Station             | 175.170268, -38.338146 | 6/09/1983 – 31/12/2013  |
|                                      |                        | 1/01/2014 – 13/01/2017  |
| Te Kuiti EWS                         | 175.153630, -38.333019 | 14/01/2017 – 26/09/2018 |

Using the given time series, the model provides an estimate of the performance of the quarry erosion and sediment control infrastructure to manage runoff and entrained solids over a 33-year record of rainfall from 1 January 1985 to 31 December 2018.

## Catchment Runoff and Discharge to Ground Coefficients

The WBM recognises that during small rainfall events, up to 5 mm/day, little or no stormwater is generated, or if it is generated, it does not reach the sediment retention ponds. However, as expressed in Table F4, during larger rainfall events, the catchments will convert the rainfall into runoff, which will vary based on the nature or land use type of sub-catchment.

| Table F4: Sub-catchment Runoff and Discharge to Ground Coefficients |                         |        |             |
|---------------------------------------------------------------------|-------------------------|--------|-------------|
| Rainfall (mm)                                                       | Land use Type           | Runoff | Groundwater |
| 0 – 5                                                               | All                     | -      | 1           |
| > 5                                                                 | Pasture                 | 0.4    | 0.6         |
|                                                                     | Benches / highwalls     | 0.45   | 0.55        |
|                                                                     | Haul Road / quarry      | 0.65   | 0.35        |
|                                                                     | Stockpiles / overburden | 0.3    | 0.7         |
|                                                                     | Buildings               | 1      | -           |

### Cave System Antecedent Coefficients

In the previous assessment of the Oparure Quarry, a groundwater monitoring assessment was undertaken using tracer dye. The predicted discharge and concentration of solids leaving the cave system were based on the delay of peak dye concentrations observed. For the SW Pit, it was conservatively assumed that there was no delay between the generation of the sediment and the discharge to Pōtea Spring.

### Water Quality – Suspended Solids

The USLE was used previously to predict sediment yields for the Oparure Quarry WMM. The USLE provides a prediction of the typical annual sediment loss. This is attributed across the rainfall induced runoff of a typical year to estimate the average total suspended solids in the runoff, based on sub-catchment type and runoff depth.

Consequently, periods of heavier rainfall and more erodible soils will result in greater mass of suspended solids being entrained into the runoff and hence increase solids loading on the downstream erosion and sediment control infrastructure, as would be anticipated.

From the previous Oparure Quarry assessment, sediment yield predictions based on volume of rainfall were estimated for the different quarry land uses. These sediment yields are reproduced in Table F5.



| Table F5: Water Management Model Catchments – ULSE Prediction |              |                                    |
|---------------------------------------------------------------|--------------|------------------------------------|
| ID                                                            | Description  | Sediment Loss (kg/m <sup>3</sup> ) |
| 1                                                             | Pasture      | 0.02                               |
| 2                                                             | Highwall     | 4.03                               |
| 3                                                             | Haul Road    | 9.54                               |
| 4                                                             | Overburden   | 0.02                               |
| 5                                                             | Quarry Floor | 4.73                               |

### Water Quality – Treatment Efficiencies

The WQM recognises that infiltration sumps remove suspended solids in accordance with typical treatment efficiencies tabulated in Table F6. As these will be engineered structures, with imported sandfilter media as the base of the infiltration sump, the modelled treatment efficiency should be readily achievable.

| Table F6: Modelled Total Suspended Solid Treatment Efficiency |     |
|---------------------------------------------------------------|-----|
| Infiltration Sump                                             | 72% |

Within the karst system the treated stormwater from the SW Pit will form a matrix of solids within the upper portion of fractured karst, immediately below the engineered infiltration sump, which has the potential to remove additional the suspended solids passing through the karst system. To be conservative the model assumes this mechanism removes only a minor portion of the total suspended solids, assumed to be 5%.

It is anticipated that infiltration ponds and karst system filtration will collectively retain particles greater than silt size, hence it is anticipated that the proportion of solids entering the groundwater / cave system below the pit will predominantly be dissolved and/or be very small particles that will be readily mobilised and pass through the cave system and Pōtea Spring.