WRS Assessment – Seepage Quality

Macraes Phase 4 Project

31 August 2026

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MINE WASTE MANAGEMENT
GREENROAD GROUP

OCEANAGOLD

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EXECUTIVE SUMMARY

Overview

OceanaGold (New Zealand) Limited (OGNZL) currently undertakes open pit and underground gold mining operations at the Macraes Operation located at Golden Point Road, Macraes Flat, East Otago. As part of their ongoing operations, OGNZL continually review the remaining life of the Macraes Operation in light of updated knowledge of the gold resource and the economics of mining.

Reflecting recent exploration success and optimisation work, together with higher gold prices, the Macraes Phase Four Project (MP4 or the Project) seeks to extend the life of mining at the Macraes Operation until at least 2039. The Project, which will enable ongoing gold production at a rate of approximately 130,000 ounces per annum, is identified as a Listed Project in Schedule 2 of the Fast-track Approvals Act 2024 (FTAA) as a project providing significant national or regional benefits.

To support the development of the substantive application for the Project, OGNZL has engaged Mine Waste Management Limited (MWM) to provide an assessment of the Project's effects on surface water and groundwater quality and, to the extent required, identify any necessary management and operation measures to address any such effects.

This scope of this report is to provide an updated evaluation of the MP4 specific waste rock stack (WRS) seepage water quality. It documents the methodology, consolidated data review outcomes, and updated geochemical model predictions.

The primary objective of this particular study was to derive WRS seepage source terms for five WRS associated with MP4, including Golden Bar (GB), Coronation (CO), Coronation North (CN), Trimbells (TR), and Frasers West (FW). These source terms will define the chemical inputs for the subsequent water quality modelling for the Project including pit lake modelling undertaken by MWM (2026a) and surface water and groundwater quality modelling by GHD (2026a).

Methodology

The assessment utilised a reference dataset comprising consolidated long-term water quality monitoring data and updated physical geometries for eight key WRS (Figure ES-1) across the Macraes site to understand the water quality expected from the five WRS associated with the Project. To estimate post-closure WRS seepage, a predictive model was developed utilising the established empirical correlation between peak sulfate (SO_4) concentrations and average WRS height (Navarro-Valdivia et al., 2024). This relationship was refined using the latest monitoring data and updated volumetric calculations for the Project WRS configurations. This approach ensures that the predicted WRS seepage reflects final landform geometries and incorporates a conservative upper-bound for SO_4 concentrations based on latest WRS water quality data. The resulting predictions serve as the source terms for the subsequent pit lake water quality modelling and other surface water and groundwater quality models being undertaken by OGNZL.

Key Findings

The correlation between SO_4 concentration and average WRS height remains the most robust predictor for long-term water quality for the Project. To ensure a conservative assessment, an updated linear upper-bound relationship was derived:

$$[SO_4\ (mg/L)]\text{max} = 87 \times \text{Average WRS height (m)}$$

This equation envelopes the maximum observed concentrations across the site (i.e., Northern Gully East (NGE) WRS, which appears to have reached geochemical maturity), providing a conservative basis for predicting long-term, post-closure SO_4 concentrations.

- Major cations (calcium, magnesium, sodium, potassium) demonstrate strong linear correlations with SO_4 and were modelled via site-specific regression slopes.
- Parameters independent of SO_4 concentrations (typically trace metals and some nutrients) were defined using median values of the consolidated dataset to represent steady-state release rates.

Outcomes

Specific seepage source terms were derived for five MP4 WRS: GB, CO, CN, TR, and FW. These source terms, summarised in Table ES-1, incorporate the 'life-of-mine' geometric changes proposed by the Project.

Table ES-1: Summary of predicted WRS seepage quality at closure (Year 0).

PARAMETER	UNIT	GB	CO	CN	TR	FW
pH	pH units	6.9	7.1	7.6	6.8	8.2
Total Alkalinity	mg/L as $CaCO_3$	267	36	891	411	1,035
Ca	mg/L	586	597	1,281	1,081	198
Mg	mg/L	725	457	892	396	1,523
Na	mg/L	101	61.9	204	85.8	106
K	mg/L	13.1	10.6	14.4	24.7	31.1
SO_4	mg/L	4,481	3,706	6,081	4,193	6,125
Cl	mg/L	11	8	12	6	11
NO_x - N	mg/L	8.05	1.1	50.7	40.6	14
Amm - N	mg/L	0.005	0.245	0.017	0.92	0.05
As	mg/L	0.001	0.0005	0.00075	0.0005	0.003
Cu	mg/L	0.0011	0.0005	0.0006	0.1347	0.0015
Fe	mg/L	0.02	0.05	0.05	0.19	0.02
Pb	mg/L	0.0001	0.000075	0.00005	0.00005	0.00025
Zn	mg/L	0.049	0.36	0.0028	0.36	-

Note: NO_x = nitrate nitrogen + nitrite nitrogen; Amm-N = ammoniacal nitrogen.

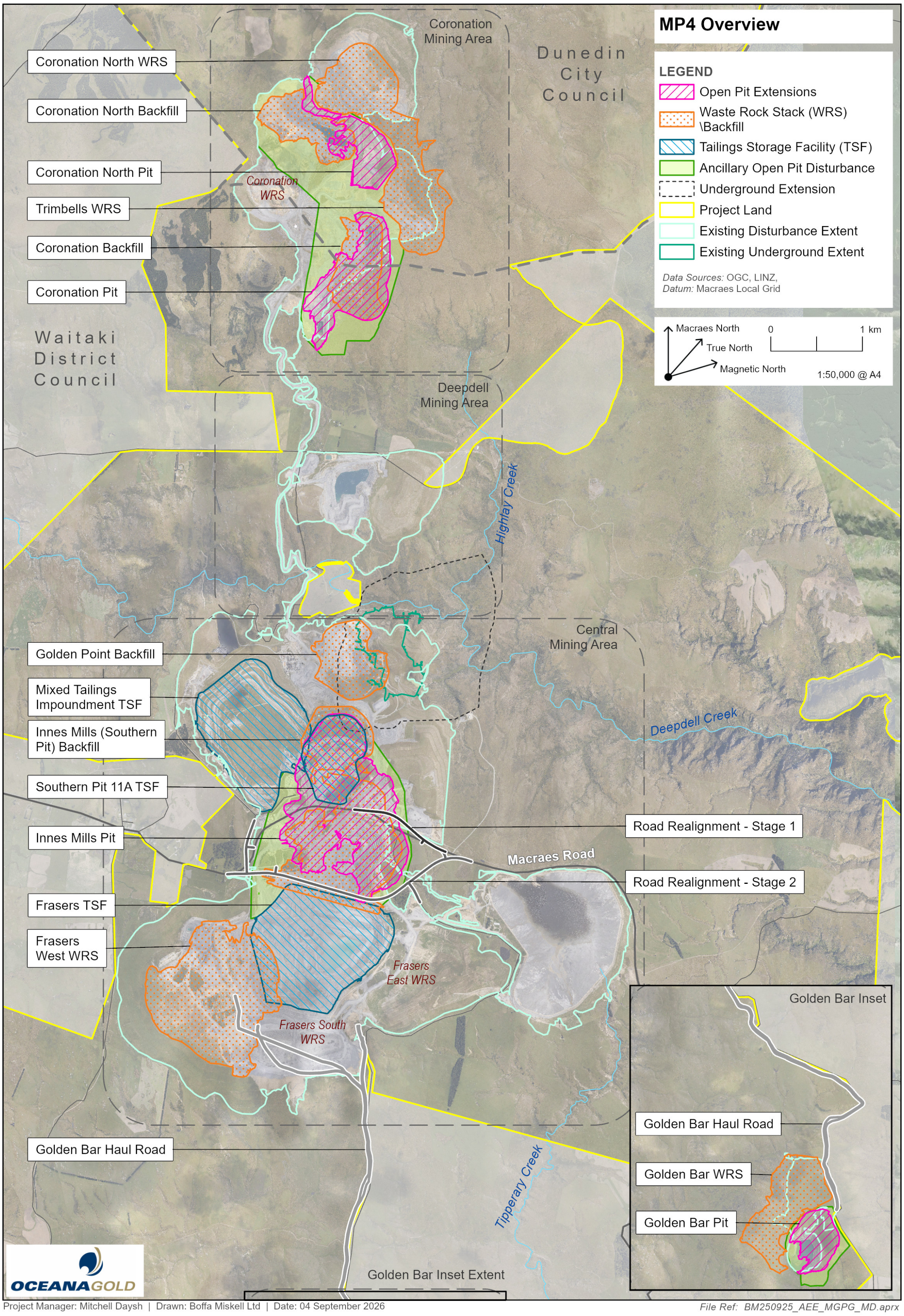

Figure ES-1: MP4 Overview Plan.

Source: OGNZL (2026).

Zinc and Nitrate in Seepage

Predicted zinc (Zn) concentrations for the CO and TR WRS seepages are defined by a historical median of 0.36 mg/L, which exceeds the proposed ecological compliance trigger value of 0.016 mg/L (Viridis, 2026). Geochemical studies confirm that dissolved Zn is independent of SO_4 trends. Instead, elevated Zn is likely controlled by localised mineralogical differences in the host rock that prevents the formation of alkaline drainage with a pH > 8. This may be driven by the abundance of carbonate minerals. Instead, these WRS have circumneutral seepage (pH ~7.0), which limits pH-dependent adsorption of dissolved Zn onto iron (Fe) oxyhydroxides.

Nitrate (NO_3) concentrations as NO_3-N vary significantly across the WRS domains, with lower median concentrations at the CO WRS (1.1 mg/L) contrasting with higher median concentrations at CN (8.3 mg mg/L) and TR (9.7 mg/L). Studies suggest the low NO_3 levels at CO may be driven by microbially mediated natural denitrification within the rock mass, sustained by buried organic matter incorporated during dump construction. To mitigate the elevated NO_3 concentrations predicted for future WRS developments, engineered passive treatment options, specifically gravel bed bioreactors (GBBRs) and enhanced passive treatment systems (E-PTS), were evaluated (MWM, 2026e). Site-specific pilot trials demonstrate that these carbon-amended systems can reliably achieve 85% to 99% NO_3 removal depending on the design hydraulic residence time (HRT).

Recommendations

The following recommendations are provided:

- Given the evolving nature of WRS seepage chemistry during active deposition of waste rock, review the empirical correlations between maximum SO_4 concentrations and average WRS heights every 12 months throughout the operational life of the facility and into closure. This annual statistical review should be utilised to update the WRS seepage source terms, including incorporating other solutes that may be elevated (such as B, Co, and Sb) as verified by column leach testing (MWM, 2026c).
- Following the completion of the final WRS landforms and the commencement of the closure phase, re-evaluate the frequency of the WRS water quality reviews, which should be based on the observed stability of seepage water quality and quantity trends, potentially transitioning to a biennial or event-based schedule.
- Complete focused investigations to:
    - Undertake continuous flow and EC measurements of WRS seepage to understand geochemical trends and loads as a function of waste rock mass and flow rates over time.
    - Characterise dilution effects (e.g., surface runoff and near-surface flows) at seepage monitoring locations to better understand seepage-rainfall dynamics.
    - Determine why CO WRS exhibits lower nitrogen concentrations compared to other WRS on site.

- Conduct targeted geochemical and mineralogical investigations of the waste rock within the CO and TR domains to understand what geochemical reactions are suppressing seepage pH and maintaining elevated Zn concentrations
- Whilst engineering controls are proposed to manage diffuse toe seepage at the CN and FW WRSs where seepage tends to be less confined, undertake further investigations to characterise the pathways and environmental effects of other diffuse seepage pathways to ensure best-practice management of mine-impacted water.
- For the preliminary design and conceptual modelling of the recommended passive nitrate treatment systems (such as GBBRs / E-PTS) for future WRS developments, adopt a conservative NO_3 removal efficiency of 85%, assuming a hydraulic residence time of approximately one day.

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1 INTRODUCTION

1.1 Project Context

OceanaGold (New Zealand) Limited (OGNZL) currently undertakes open pit and underground gold mining operations at the Macraes Operation located at Golden Point Road, Macraes Flat, East Otago. As part of their ongoing operations, OGNZL continually review the remaining life of the Macraes Operation in light of updated knowledge of the gold resource and the economics of mining.

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To support the development of the substantive application for the Project, OGNZL has engaged Mine Waste Management Limited (MWM) to provide an assessment of the Project's effects on surface water and groundwater quality and, to the extent required, identify any necessary management and operation measures to address any such effects.

The scope of this report is to provide an updated evaluation of the MP4 waste rock stack (WRS) seepage water quality and associated post-closure seepage quality predictions for selected WRSs. The report summarises the supporting data review, methodology, and updated empirical geochemical model predictions. The results provide the definitive source term inputs for subsequent hydrogeochemical pit lake modelling and other studies completed by GHD (2026a).

1.2 Technical Background

A previous assessment by Babbage (2019) identified a correlation between the physical dimensions of a WRS, its age, and the solute load in its toe seepage. Specifically, taller WRSs were observed to generate higher sulfate (SO_4) concentrations. While this suggests that SO_4 concentrations are positively correlated with both WRS age and average height, the hypothesis that concentrations increase indefinitely with age is geochemically unrealistic.

MWM (2023) reviewed site monitoring data and noted that SO_4 concentrations in some WRS seepage appeared to reach a maximum value before entering an oscillatory phase (e.g., Northern Gully East (NGE) WRS). This indicates that these WRSs have likely entered a geochemically mature, or semi-stable, stage.

Building on these findings, Navarro-Valdivia et al. (2024) developed a predictive model for WRS seepage quality. Using historical monitoring data, a linear relationship was established between maximum SO_4 concentrations and average WRS height, as shown in Equation 1.

Equation 1: $$[SO_4\ (mg/L)]max = 80.44 \times Average\ WRS\ height\ (m) + 74.64$$

This equation allows prediction of maximum post-closure SO_4 concentrations in WRS seepage based on the final average WRS height derived from the consented WRS design and topography. Other water quality parameters can subsequently be estimated from their empirical correlations with SO_4.

1.3 Objectives and Scope of Work

The primary objectives of this assessment are to:

- Review and update the empirical relationship between peak SO_4 concentrations and average WRS heights using current landform geometries and long-term water quality monitoring data.
- Predict post-closure WRS seepage quality to provide conservative source term inputs for subsequent pit lake and regional water quality models.

To achieve these objectives, the scope of work comprised:

- Consolidating and evaluating historical water quality datasets from representative WRS seepage monitoring locations.
- Calculating current average heights for the WRS within the scope of MP4.
- Re-evaluating the empirical scaling relationships between maximum SO_4 concentrations and average WRS height to predict landform-specific peak SO_4 source terms.
- Deriving post-closure seepage water quality profiles by estimating concentrations of other key geochemical constituents using regression models or historical median values.

1.4 Methodology and Procedures

Unlike previous assessments that applied site-wide dataset aggregation without differentiating between sampling locations (MWM, 2023), this assessment evaluates water quality and geometric parameters on an individual WRS basis. This approach accounts for localised differences in WRS geometry, age, and material composition, resulting in more representative source terms for subsequent modelling. Consequently, the predicted water quality outcomes are expected to better reflect landform-specific conditions than previous site-wide estimates.

This assessment was undertaken using the following procedure:

- Reviewed consolidated long-term water quality monitoring data to identify peak SO_4 concentrations for each individual WRS.
- Processed topographic files and GIS data to determine current and final footprints and volumes for each WRS (MWM, 2026b).
- Updated the empirical relationship between peak SO_4 concentrations and average WRS heights.
- Estimated post-closure SO_4 concentrations for WRS seepage.
- Derived other key water quality parameters based on their empirical correlations with SO_4 as follows:
    - Correlated parameters (R^2 >0.5): Estimated using linear regression (Equation 2):

Equation 2: $$y = a \times x + b$$

where *y* is the predicted parameter concentration (mg/L), *a* is the slope, *b* is the intercept, and *x* is the predicted post-closure SO_4 concentration (mg/L).

- Independent parameters (R^2 ≤0.5): Considered independent of SO_4, with post-closure values assigned using the median concentration from the historical dataset for the relevant WRS.

2 DATA REVIEW

2.1 Waste Rock Stacks

This assessment evaluates eight WRSs across the Macraes Operation (Figure 1) to ensure the predictive model is underpinned by a statistically robust site-wide dataset. The selected monitoring sites have been established to monitor the primary seepage pathways from each WRS. These facilities and their corresponding monitoring sites are summarised in Table 1.

Table 1: Summary of WRS and representative seepage monitoring sites.

WRS	MONITORING SITE	DATA PERIOD
Golden Bar	MAC-Clydesdale Creek Silt Pond MAC-Clydesdale WRS Seepage	Dec 2003 to Jul 2025 Aug 2016 to Oct 2025
Coronation	MAC-Coronation Silt Pond	Sep 2015 to Sep 2025
Coronation North	MAC-Maori Hen Gully Seepage	Aug 2017 to Aug 2025
Trimbells	MAC-Trimbells Gully Silt Pond MAC-Trimbells Gully Drain	Feb 2016 to Oct 2025 Jun 2020 to Oct 2025
Northern Gully East	MAC-N Gully Seep East	Aug 2009 to Oct 2025
Northern Gully West	MAC-N Gully Seep West	Apr 2011 to Oct 2025
Deepdell North	MAC-Deepdell North Silt Pond	Sep 2001 to Oct 2025
Frasers West	MAC-Murphy's Creek Silt Pond	Mar 2005 to Jul 2025

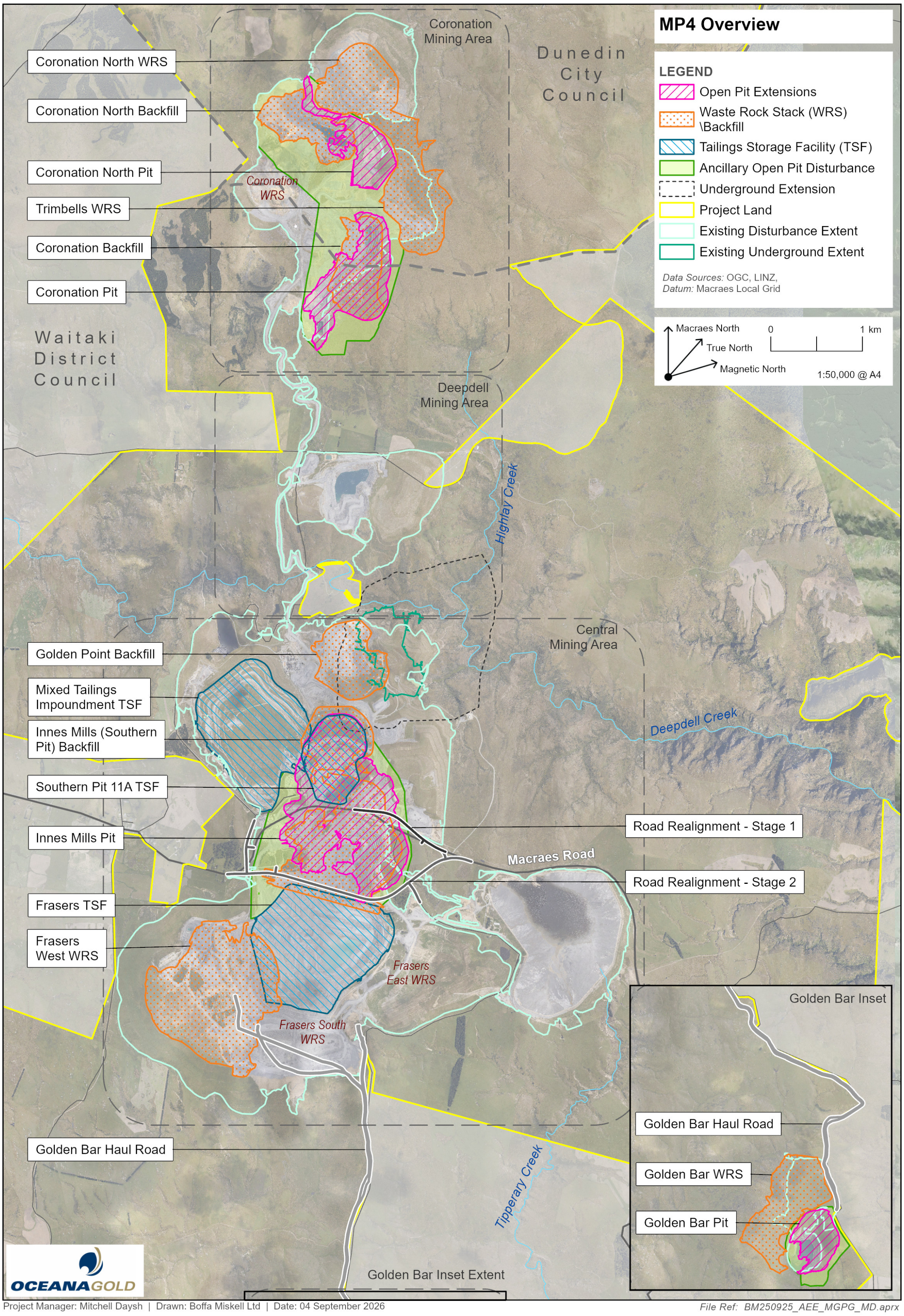

Figure 1: MP4 Overview Plan.

Source: OGNZL (2026).

2.2 WRS Seepage Quality Data Review

Consolidated long-term water quality data were reviewed to identify geochemical trends, with particular focus on the evolution of SO_4 concentrations over time.

2.2.1 Golden Bar

Seepage from the Golden Bar (GB) WRS is characterised using monitoring data from the MAC-Clydesdale Creek Silt Pond and MAC-Clydesdale WRS Seepage sites (Figure 2). Consolidated SO_4 concentration trends are presented in Figure 3, with the following observations:

- Sulfate concentrations in the Clydesdale Creek Silt Pond increased gradually from approximately 7 mg/L in 2003 to 2,400 mg/L in 2025. Although the rate of increase has slowed since 2016, concentrations remain highly variable, likely due to climatic influences (e.g., rainfall-driven dilution) and complex flow path dynamics within the WRS.
- Monitoring at the MAC-Clydesdale WRS Seepage site, which commenced in 2016, shows a concentration trend consistent with that observed in the Silt Pond.
- Since 2021, SO_4 concentrations have fluctuated between 1,200 and 2,400 mg/L. While notable variations are evident at both monitoring sites from 2023 onwards, no consistent seasonal pattern is apparent. Instead, the observed fluctuations are considered to reflect net percolation through the unsaturated waste rock mass and subsequent dilution by surface and near-surface flows.

Figure 2: Approximate locations of water quality monitoring sites for Golden Bar WRS.

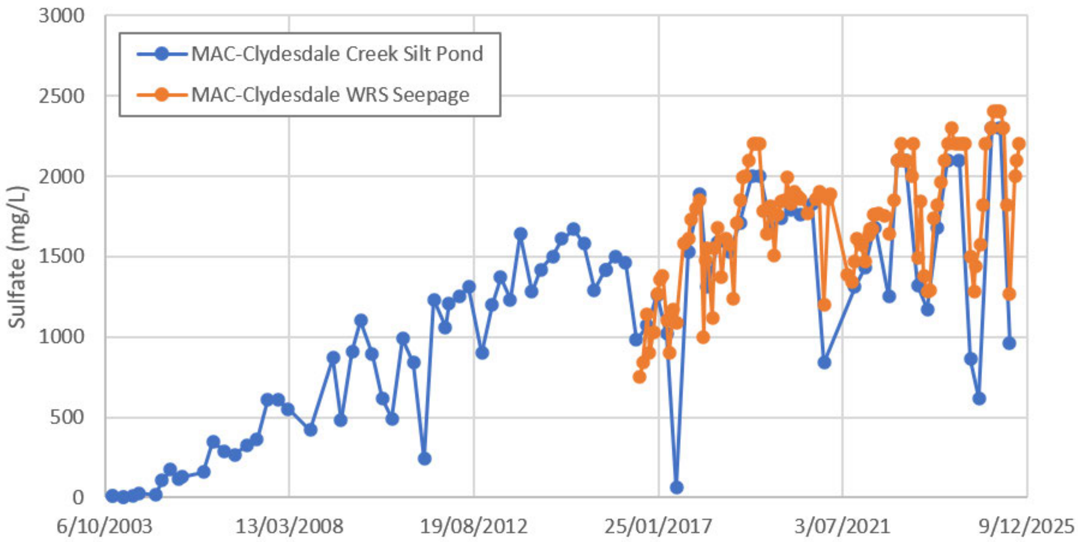

Figure 3: Time-series sulfate concentrations for Golden Bar WRS seepage (2003-2025).

2.2.2 Coronation

Seepage from the Coronation (CO) WRS has been monitored at MAC-Coronation Silt Pond (Figure 4) since 2015. The SO_4 concentration trends presented in Figure 5 exhibit two distinct stages:

- Stage 1 (2015-2019): Sulfate concentrations increased from less than 1 mg/L to approximately 1,300 mg/L in 2019.
- Stage 2 (2019-present): The rate of increase has slowed, with concentrations fluctuating over a range of approximately 750 mg/L and recent peak values reaching 2,100 mg/L.

Figure 4: Approximate location of water quality monitoring site for Coronation WRS.

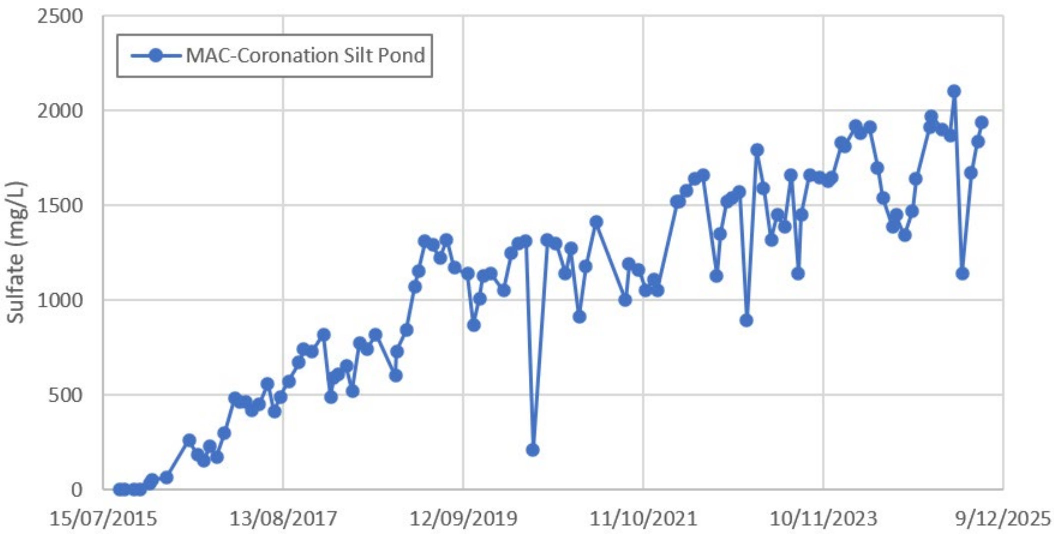

Figure 5: Time-series sulfate concentrations for Coronation WRS seepage (2015-2025).

2.2.3 Coronation North

The majority of seepage from the Coronation North (CN) WRS is monitored at the MAC-Maori Hen Gully Seepage site (Figure 6). The dataset presented in Figure 7 indicates:

- Sulfate concentrations increased from below 100 mg/L in 2017 to approximately 1,600 mg/L during several recent sampling events.
- Following a temporary period of stabilisation at approximately 400 mg/L (2020-2021; n = 17), SO_4 concentrations resumed an upward trend.
- Apparent seasonal patterns have emerged since 2023, with lower concentrations generally recorded during winter months. However, rather than reflecting a strict seasonal cycle, these variations are interpreted to be primarily driven by net percolation through the waste rock mass and subsequent dilution from surface and near-surface inflows.

Figure 6: Approximate location of water quality monitoring site for Coronation North WRS.

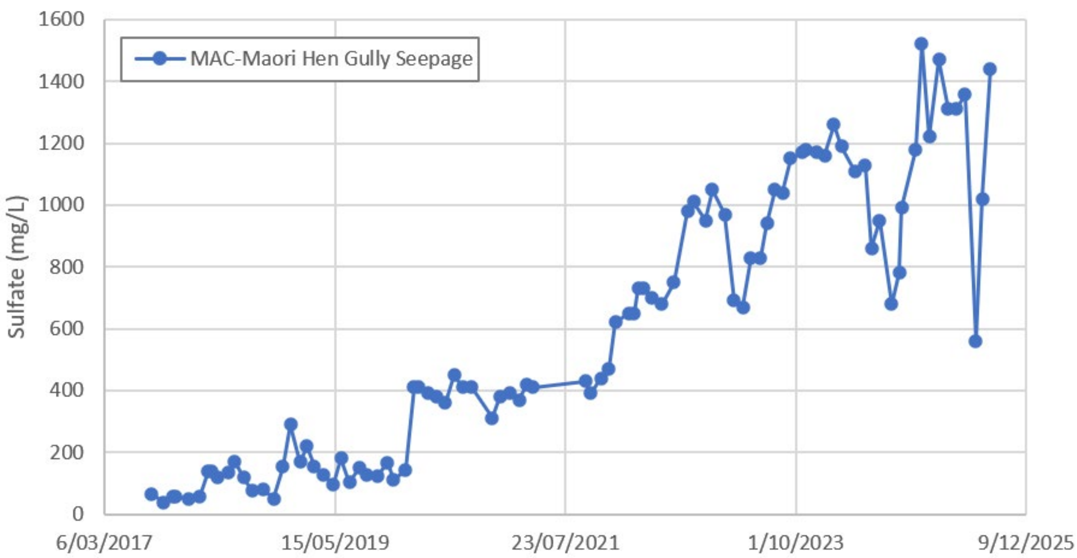

Figure 7: Time-series sulfate concentrations for Coronation North WRS seepage (2017-2025).

2.2.4 Trimbells

Seepage from the Trimbells (TR) WRS is characterised by monitoring data collected at the MAC-Trimbells Gully Silt Pond and MAC-Trimbells Gully Drain sites (Figure 8). Long-term SO_4 concentrations at these monitoring locations are illustrated in Figure 9, with the following observations:

- Sulfate concentrations at the Trimbells Gully Silt Pond were generally below 20 mg/L between 2016 and 2020, before increasing steadily to approximately 1,300 mg/L in 2025.

- This increasing trend is confirmed by monitoring data from the Trimbells Gully Drain, which exhibits a similar concentration trend. The drain is located less than 40 m upstream of the Trimbells Gully Silt Pond and represents a seepage expression at the toe of the WRS.
- Peak SO_4 concentrations at the Trimbells Gully Drain appear to have stabilised over the past 24 months.
- Fluctuations in SO_4 concentrations since 2024 are primarily attributed to hydrological influences, with lower concentrations associated with dilution by surface and near-surface flows. However, these fluctuations do not follow a consistent seasonal cycle.

Figure 8: Approximate location of water quality monitoring site for Trimbells WRS.

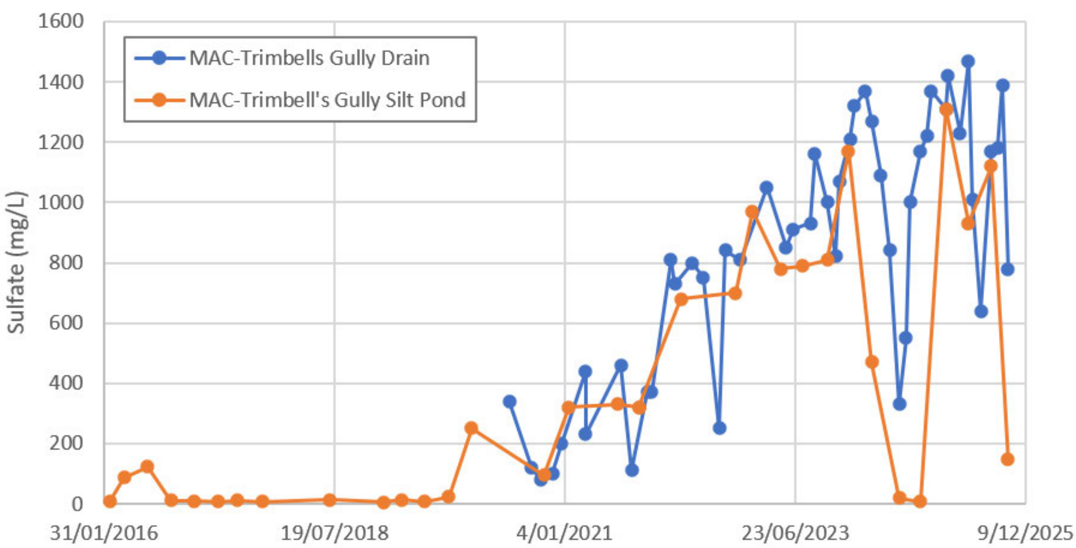

Figure 9: Time-series sulfate concentrations for Trimbells WRS seepage (2016-2025).

2.2.5 Frasers West

The MAC-Murphy's Creek Silt Pond (Figure 10) serves as the primary monitoring location for seepage from the Frasers West (FW) WRS. Long-term records from quarterly monitoring, presented in Figure 11, indicate the following:

- Sulfate concentrations increased consistently from less than 100 mg/L to 2,500 mg/L between 2005 and 2015. Since 2015, the rate of increase has moderated, suggesting that concentrations may be approaching a plateau.
- An apparent seasonal pattern in SO_4 concentrations has become evident since 2022. Concentrations have fluctuated between approximately 2,000 and 3,500 mg/L, with the lowest values typically observed during winter and peak concentrations generally recorded during summer.
- These fluctuations are likely associated with variations in net percolation and dilution by seasonal surface and near-surface flows. However, the timing and magnitude of observed changes indicate that near-surface recharge and seepage processes also contribute to the variability.

Figure 10: Approximate location of water quality monitoring site for Frasers West WRS.

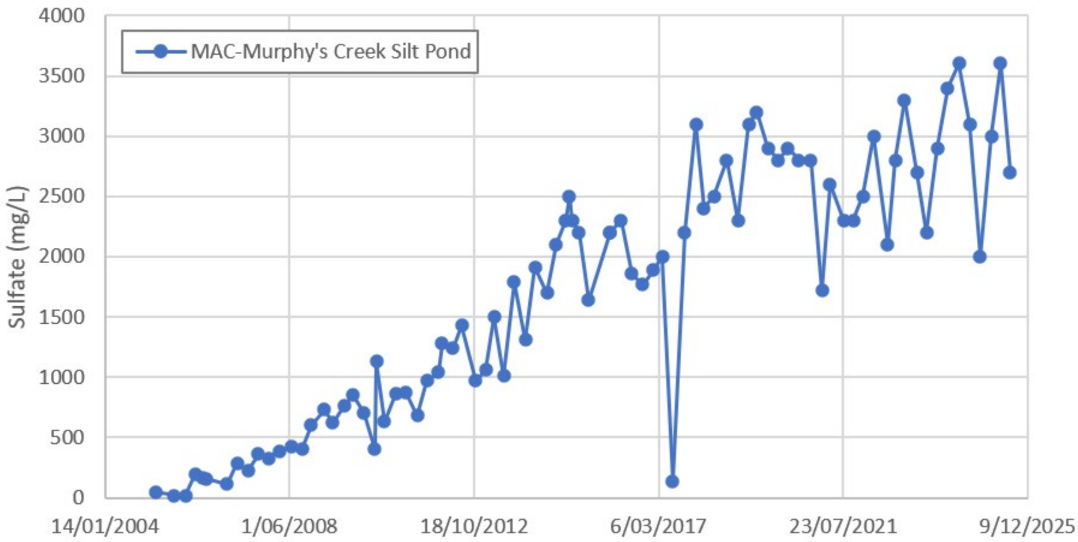

Figure 11: Time-series sulfate concentrations for Frasers West WRS seepage (2005-2025).

2.2.6 Northern Gully East and West

Water quality monitoring sites for the Northern Gully (NG) WRS are located at the eastern and western extents of the Northern Gully Silt Pond (Figure 12). While sampling was sporadic during the early monitoring period, routine monitoring has been conducted since 2009. The SO_4 concentrations are presented in Figure 13, with the following observations:

- Sulfate concentrations at MAC-N Gully Seep East remained relatively stable at approximately 2,500 mg/L between 2009 and 2016, before increasing to 3,500 mg/L. Since 2019, the concentrations have generally fluctuated between 3,000 and 3,700 mg/L.
- Sulfate concentrations at MAC-N Gully Seep West show a similar but lower concentration trend, increasing from approximately 1,000 mg/L prior to 2016 to 1,500 mg/L by 2019. Recent data shows a continued gradual increase, reaching approximately 2,500 mg/L by 2025.
- Historical sample labelling errors between these two monitoring locations have been corrected in the current dataset.
- A low-grade ore stockpile is located on the NGE WRS and may influence seepage quality observed at these monitoring locations.

Figure 12: Approximate locations of water quality monitoring sites for Northern Gully WRS.

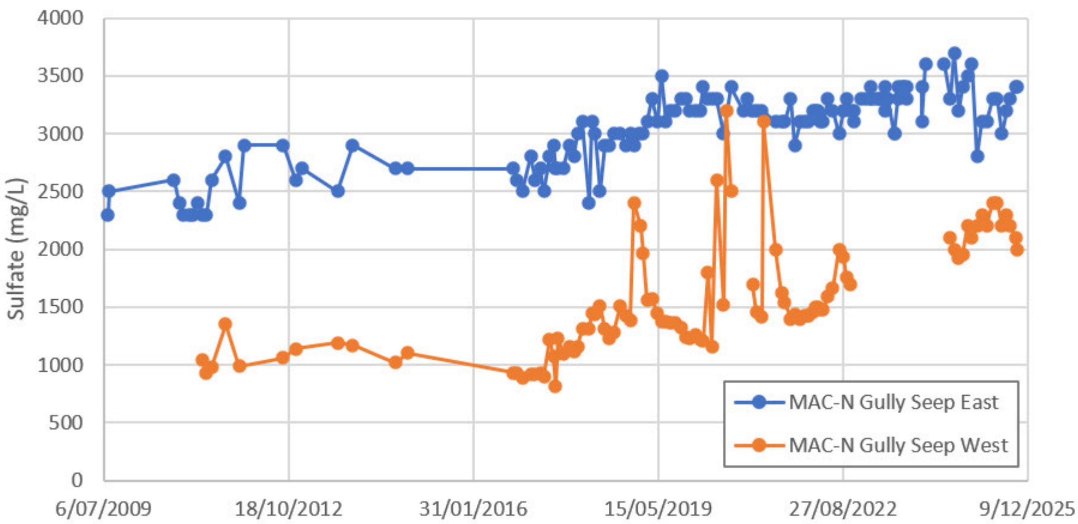

Figure 13: Time-series sulfate concentrations for Northern Gully WRS seepage (2009-2025).

2.2.7 Deepdell North

Seepage from the Deepdell North (DN) WRS reports to the Deepdell North Silt Pond (Figure 14). As this pond receives surface runoff in addition to seepage, the monitoring data represents a composite water quality rather than undiluted WRS seepage. Long-term SO_4 concentrations are presented in Figure 15, with the following observations:

- Sulfate concentrations remained relatively low (<300 mg/L) prior to 2010. These early concentrations are interpreted to reflect runoff water and water infiltrating the WRS batter slopes between the silt pond and the internal southern cut of the DN Pit, rather than seepage originating from the WRS.
- The SO_4 concentrations began to increase after 2019, when the backfilled pit volume reached the pit overflow and a sustained contribution of backfill seepage to the silt pond was established.

- Between 2015 and 2020, SO_4 concentrations typically fluctuated between 700 and 1,400 mg/L.
- Since 2021, peak SO_4 concentrations have increased markedly, reaching 2,100 mg/L during several recent sampling events.

Figure 14: Approximate location of water quality monitoring site for Deepdell North WRS.

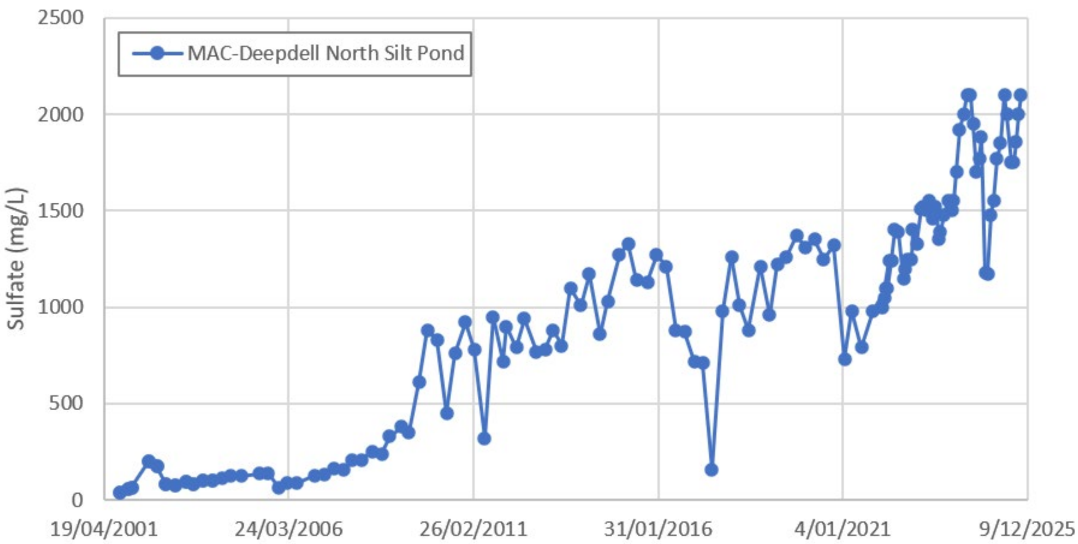

Figure 15: Time-series sulfate concentrations for Deepdell North WRS seepage (2001-2025).

2.2.8 Summary of Observed Maximum Sulfate Concentrations

Review of the consolidated long-term water quality dataset indicates that SO_4 concentrations have not yet reached a definitive peak at several monitoring locations. While SO_4 concentrations continue to increase at many sites, the observed rate of increase has generally reduced over time. Water quality at several locations also appears to be influenced by seasonal climatic conditions, with lower SO_4

concentrations commonly recorded during winter months. However, these fluctuations do not follow consistent seasonal cycles and are therefore interpreted to reflect an intermittent seasonal signature driven by net percolation through the unsaturated waste rock mass, followed by dilution from surface and near-surface flows.

Peak SO_4 concentrations recorded at each WRS seepage monitoring location are summarised in Table 2. It is assumed that peak SO_4 concentrations occur during periods of minimal surface runoff and near-surface flow, therefore reducing dilution effects and providing the most representative indication of WRS seepage water quality.

The highest SO_4 concentrations were recorded at the NGE WRS (Figure 13). This site exhibits the most stable SO_4 concentration trend among the monitored locations, with concentrations fluctuating between 3,000 and 3,700 mg/L since 2019 without evidence of a sustained upward trend. This apparent stabilisation provides confidence in the empirical relationship developed between maximum SO_4 concentrations and WRS height.

Table 2: Summary of peak observed SO_4 concentrations.

WRS	PEAK SO_4 CONCENTRATION (mg/L)	LOG DATE	SITE
Golden Bar	2,400	14/4/2025	MAC-Clydesdale Creek Silt Pond
Coronation	2,100	14/4/2025	MAC-Coronation Silt Pond
Coronation North	1,520	10/12/2024	MAC-Maori Hen Gully Seepage
Trimbells	1,470	28/4/2025	MAC-Trimbells Gully Drain
Frasers West	3,600	14/4/2025	MAC-Murphy's Creek Silt Pond
Northern Gully East	3,700	21/8/2024	MAC-N Gully Seep East
Northern Gully West	2,400	1/8/2020	MAC-N Gully Seep West
Deepdell North	2,100	1/10/2025	MAC-Deepdell North Silt Pond

Note: If a peak concentration was recorded multiple times, the most recent date is provided in the table.

2.3 Average WRS Heights

To calibrate the sulfate-to-average WRS height correlation, the physical geometry of the WRSs was recalculated using historical baseline topography and current GIS data (MWM, 2026b). A detailed technical description of the methodology is provided in the associated technical memorandum (Appendix A). The methodology and key results are summarised below.

2.3.1 Objectives

The primary objective was to convert the complex 3D geometry of each WRS into a representative ‘average height’ metric. The geometric analysis focused on three outcomes:

- Volume quantification: Calculating fill volumes by differencing pre-mining basal surfaces against current and design topographies.
- Hydrological delineation: Mapping sub-catchments beneath the WRS to identify specific seepage discharge locations, acknowledging that flow paths are often governed by basal (pre-mining) contours rather than the surface dumping profile.

- Model calibration: Updating the empirical relationship between maximum SO_4 concentration ($[SO_4]_{max}$) and average WRS height.

2.3.2 Methodology

Spatial analysis was conducted within the local mine coordinate system (MGPG). To ensure mathematical rigour during volumetric differencing, source data (TINs/DXFs) were converted to high-resolution rasters. This grid-based approach minimises volumetric estimation bias relative to conventional vector-based differencing methods. The calculation workflow involved:

- Surface alignment: The base (as mined) and current/design surfaces were aligned to a common grid resolution to eliminate interpolation drift during subtraction.
- Spatial masking: Analysis was clipped to specific WRS footprints, ensuring that the surrounding regional topography did not skew the volumetric or average height results.
- Volumetric differencing: A thickness raster was generated to define the vertical profile of the waste rock:

  Equation 3: $$\text{WRS Thickness} = \text{Current Elevation} - \text{Basal Elevation}$$

  The total volume was calculated by integrating thickness across the WRS footprint.
- Drainage modelling: Sub-catchments were delineated based on the basal (pre-mining) topography, assuming that the original natural ground contours control the contributing area and subsequent seepage flow paths.

2.3.3 Site-Specific Observations

- Frasers West & South: While these domains form a single continuous landform, the analysis focused specifically on the Frasers West drainage. It is important to note that any backfill within the Frasers Pit void was excluded from the height calculation.
- Northern Gully (East & West): Although these constitute a single physical landform, hydrological modelling partitioned the volume into two distinct sub-catchments, allowing for more precise correlation with their respective monitoring points.
- Trimbells & Coronation North: A minor spatial overlap exists between these design footprints. The overlapping volume is negligible and does not materially affect the sulfate-to-height correlations.

Consequently, sub-catchment average height, rather than the full facility average height, was used to develop the predictive sulfate concentration correlations.

2.3.4 Limitations and Assumptions

The following model limitations and assumptions are acknowledged:

- Temporal snapshot validity: Topography is dynamic in an active mine. The current results represent a point-in-time assessment; actual volumes may vary slightly due to active waste rock deposition and re-contouring schedules.

- Data precision and interpolation: Volumes are best estimates. Accuracy is limited by the resolution of source topography and minor interpolation uncertainties associated with the conversion from TIN to Raster formats.
- Flow path assumption: Catchment delineation assumes that seepage flow paths are predominantly controlled by gravity and the underlying basal topography.
- Landform compliance: While current deposition profiles may differ from the original plans, it is assumed that final landforms will conform to the consented design boundaries.

2.3.5 Updated Average WRS Heights

The geometric data for current and designed configurations are summarised in Table 3 and Table 4, respectively.

The geometries presented in the tables are reported for two distinct spatial boundaries: 'Full Extent' and 'Sub-Catchment' (see Figure 16).

- The 'Full Extent' values represent the total physical footprint and volume of the entire WRS.
- The 'Sub-Catchment' values represent the hydrologically delineated portion of the WRS from which infiltrating seepage is interpreted to drain towards a specific downstream measurement site (monitoring site).

These categories define spatial drainage areas for the seepage model and do not represent different design or consent stages.

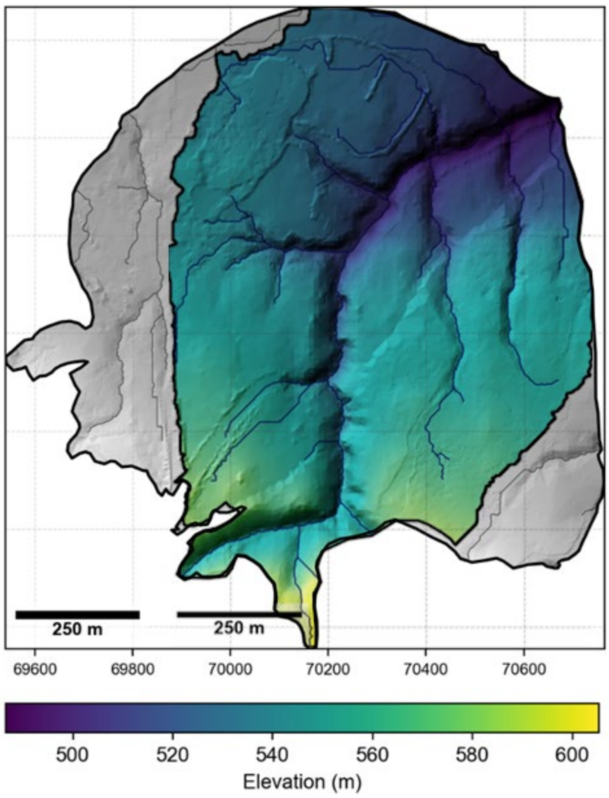

Figure 16: Spatial boundary classification example at Coronation North WRS.

Note: 'Full Extent' comprises the entire outlined footprint (grey and elevation-coloured regions combined); 'Sub-Catchment' denotes the hydrologically delineated area (elevation-coloured region) with internal drainage pathways.

Table 3: Summary of current WRS physical dimensions.

SITE NAME	TYPE	AREA (ha)	VOLUME (Mm^3)	AVERAGE HEIGHT (m)
Coronation	Full Extent	43.9	12.8	29.1
Coronation North	Full Extent	104.5	32.1	30.7
Trimbells	Full Extent	52.7	16.5	31.3
Deepdell North	Full Extent	12.7	3.0	23.6
Northern Gully West and East	Full Extent	138.7	51.6	37.2
Frasers West and South	Full Extent	332.9	133.3	40.0
Frasers East	Full Extent	114.1	44.8	39.3
Golden Bar #	Full Extent	24.4	7.3	29.9
Coronation	Sub-Catchment	27.2	9.7	35.7
Coronation North	Sub-Catchment	80.0	27.8	34.8
Trimbells	Sub-Catchment	46.6	15.5	33.3
Deepdell North	Sub-Catchment	8.1	2.2	27.2
Northern Gully West	Sub-Catchment	79.3	28.7	36.2
Northern Gully East	Sub-Catchment	42.7	18.2	42.6
Frasers West	Sub-Catchment	163.8	85.4	52.1
Frasers East	Sub-Catchment	81.9	37.1	45.3
Golden Bar #	Sub-Catchment	24.4	7.3	29.9

Note: #Golden Bar WRS is located exclusively within a single catchment where all surface drainage theoretically reports to a common downstream outlet. Therefore, Full Extent equals the Sub-catchment.

All values rounded to one decimal place. Average height calculated from unrounded raw data.

Table 4: Summary of consented and proposed MP4 WRS physical dimensions.

SITE NAME	TYPE	AREA (ha)	VOLUME (Mm^3)	AVERAGE HEIGHT (m)
Coronation*	Current + Consented	43.7	15.2	34.8
Coronation North	Consented + Design	139.1	84.0	60.4
Trimbells	Consented + Design	88.4	35.2	39.8
Frasers West	Consented + Design	287.5	160.4	55.8
Golden Bar	Consented + Design	55.8	21.9	39.3
Coronation	Sub-Catchment	26.8	11.4	42.6
Coronation North	Sub-Catchment	81.7	57.1	69.9
Trimbells	Sub-Catchment	61.8	29.8	48.2
Frasers West	Sub-Catchment	153.0	107.7	70.4
Golden Bar	Sub-Catchment	37.8	19.5	51.5

*Note: * Coronation WRS dimensions reflect current consented conditions without further MP4 modifications.*

All values rounded to one decimal place. Average height calculated from unrounded raw data.

3 WRS SEEPAGE ASSESSMENT

3.1 Geochemical Assessment of Waste Rock

WRS seepage chemistry is the product of complex geochemical processes influenced by several site-specific factors, including:

- The geochemical and physical characteristics of the waste rock deposited within a WRS.
- The internal arrangement and heterogeneity of waste rock within the WRS.
- Construction and closure methods, including final landform geometry and cover design.
- Water infiltration rates and preferential flow pathways through the WRS.

While detailed WRS construction and operational histories were not available for this assessment, the baseline geochemical characteristics of waste rock from selected mining domains were reviewed. Based on the historical acid base accounting (ABA) data summarised in Table 5, the following observations are noted:

- Total S values are consistently low across the assessed WRSs, with domain averages ranging from 0.10 wt% at CN to 0.17 wt% at Golden Point.
- These low total S values correspond to limited maximum potential acidity (MPA), with domain average values remaining below 6 kg H_2SO_4/t across all domains.
- The acid neutralising capacity (ANC) of the waste rock is moderate, with domain average values ranging from 31.9 to 64.0 kg H_2SO_4/t.
- The net acid production potential (NAPP), calculated as the difference between MPA and ANC, is negative for all domains, indicating that the waste rock is non-acid forming and does not present a risk of acid generation.

Overall, the geochemical characterisation results indicate that waste rock across the assessed WRSs exhibits similar ABA characteristics. This supports the application of a unified SO_4-height relationship for predicting WRS seepage quality across the MP4 area.

Table 5: Summary of acid-base accounting results for waste rock by WRS domain.

PIT DOMAIN	SAMPLES (n)	TOTAL S (wt%)	MPA (kg H_2SO_4/t)	ANC (kg H_2SO_4/t)	NAPP (kg H_2SO_4/t)
Coronation	39	0.16	4.90	40.59	-35.68
Coronation North	48	0.10	3.11	31.87	-28.76
Trimbells	8	0.12	3.73	33.39	-29.67
Frasers West	201	0.14	4.42	63.97	-59.62
Innes Mills	36	0.15	4.52	61.65	-57.13
Golden Point	36	0.17	5.25	56.53	-51.28

Note: The values presented for each pit domain are the averages of the respective sample set.

3.2 Updated Sulfate-Average WRS Height Correlation

The empirical relationship between seepage water quality and WRS geometry was updated to provide a basis for predicting post-closure seepage quality.

Seepage quality monitoring data can be influenced by external factors, particularly dilution from rainfall, surface runoff, and near-surface flows. Consequently, individual monitoring results may not always represent undiluted seepage chemistry. To minimise the influence of dilution and provide a conservative assessment of the source term, the highest recorded SO_4 concentrations at each monitoring location (Section 2.2.8) were adopted to update the correlation. These values are considered the most representative of undiluted WRS seepage conditions and provide an upper-bound estimate of seepage quality for use in environmental modelling and closure assessments.

Recent monitoring data indicate that while SO_4 concentrations continue to increase at some locations, several WRSs, such as the NGE WRS, appear to have stabilised with regard to SO_4 concentrations. Based on these observations, the original correlation between SO_4 concentration and average WRS height (Navarro-Valdivia et al., 2024) was revised as follows:

- The highest recorded SO_4 concentrations (Section 2.2.8), representing current 'peak' values, were paired with the updated average WRS heights for the corresponding sub-catchments (Section 2.3.5), as shown in Figure 17.
- An empirical upper-bound relationship was fitted to the dataset and anchored by the maximum SO_4 concentration recorded at the NGE WRS. This enveloping approach bounds the highest observed SO_4 concentrations across the range of WRS heights considered in this assessment.
- The selection of NGE to define the upper-bound is based on the following:
  - NGE records the highest SO_4 concentration observed across all reviewed MP4 WRSs.
  - NGE is among the tallest WRS landforms on site.
  - Time-series data (Figure 13) indicate that this WRS has reached an apparent plateau, suggesting a relatively mature geochemical condition.
- The slope of the upper-bound relationship is governed by the NGE dataset, which represents the highest sulfate-to-height ratio among the reviewed MP4 WRSs.
- The resulting slope of 87 mg/L/m (Equation 4) provides a conservative predictive basis for all sub-catchments as they progress towards geochemical maturity. This conservatism is intended to account for the inherent uncertainties associated with WRS construction, internal heterogeneity, and seepage evolution.

Equation 4: $$[SO_4\ (mg/L)]max = 87 \times Average\ WRS\ height\ (m)$$

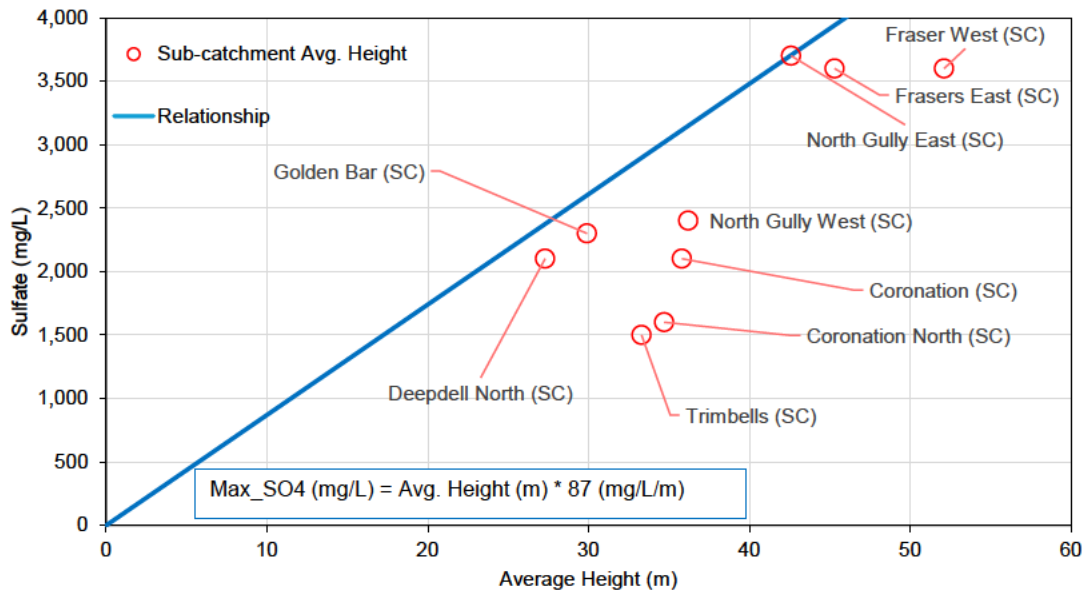

Figure 17: Updated correlation between maximum sulfate concentrations and average WRS height.

Note: The light blue circles represent sub-catchment areas draining to monitoring points where maximum SO_4 concentrations were identified. SC: Sub-catchment.

3.3 Predicted Sulfate Concentrations in Post-closure WRS Seepage

Sulfate concentrations in post-closure WRS seepage, representing conditions immediately following final landform completion, were predicted using Equation 4 and are summarised in Table 6.

Table 6: Summary of final average WRS height and predicted post-closure sulfate concentrations.

WRS	CURRENT AVERAGE HEIGHT (SUB-CATCHMENT) (m)	MAXIMUM OBSERVED (CURRENT) SO_4 CONCENTRATION (mg/L)	FINAL AVERAGE HEIGHT (SUB-CATCHMENT) (m)	PREDICTED POST-CLOSURE SO_4 CONCENTRATION (mg/L)
Golden Bar	29.9	2,400	51.5	4,481
Coronation	35.7	2,100	42.6	3,706
Coronation North	34.8	1,520	69.9	6,081
Trimbells	33.3	1,470	48.2	4,193
Frasers West	52.1	3,600	70.4	6,125

3.4 Correlations of Water Quality Parameters with Sulfate

Key water quality parameters in the consolidated WRS seepage dataset were reviewed to determine representative post-closure values for each MP4 WRS.

3.4.1 Golden Bar WRS

The correlations between key water quality parameters and SO_4 concentrations for the GB WRS are presented in Figure 18, with the corresponding slopes, intercepts, and median values summarised in Table 7. The following observations are noted:

- pH values ranged from 6.0 to 8.5, with a median of 6.9.
- Major cation concentrations show strong linear correlations with SO_4. In particular, calcium (Ca), magnesium (Mg), and sodium (Na) exhibit R^2 values near or exceeding 0.9. Post-closure concentrations for these elements were estimated using the linear regression equations derived from the slope and intercept values presented in Table 7.
- Total alkalinity initially showed poor correlation with SO_4 due to high variability at SO_4 concentrations below 500 mg/L during the pre-2009 monitoring period. As SO_4 concentrations increased, the relationship evolved into a linear trend. To reflect the current geochemical trajectory, the regression analysis was undertaken using the filtered dataset (2009 to present) for total alkalinity. Although the resulting R^2 value (0.487) is marginally below the nominal threshold of 0.5, due to a small number of outliers, a linear correlation was retained as it provides a more realistic representation of the observed relationship and future trend than a static median value.
- Other parameters exhibit weak correlations with SO_4 (R^2 <0.5). This lack of correlation is attributed to the circumneutral pH conditions, under which Fe released through pyrite oxidation precipitates as secondary Fe oxyhydroxide phases. These phases provide reactive surfaces for the adsorption and co-precipitation of trace elements. Consequently, median values derived from the historical monitoring dataset were adopted to represent post-closure WRS seepage chemistry for these parameters.

Table 7: Seepage chemistry regression statistics and median values for Golden Bar WRS (2003-2025).

PARAMETER	COUNT OF DATA POINTS	INTERCEPT	SLOPE	R^2	MEDIAN	PREDICTION METHOD
pH	188	-	-	0.062	6.9	Median
Total Alkalinity	169	52.6652	0.0479	0.485	130	Linear
Ca	188	36.4919	0.1227	0.952	230	Linear
Mg	188	1.5809	0.1615	0.948	240	Linear
Na	188	15.5713	0.0192	0.897	45	Linear
K	188	3.5047	0.0021	0.740	6.7	Linear
Cl	188	-	-	0.009	11	Median
NO_x - N	144	-	-	0.346	8.05	Median
Amm - N	141	-	-	0.053	0.005	Median
As	106	-	-	0.096	0.001	Median
Cu	47	-	-	0.260	0.0011	Median
Fe	105	-	-	0.079	0.02	Median
Pb	53	-	-	0.152	0.0001	Median
Zn	2	-	-	1.000	0.049	Median

Note: Regression parameters (slope, intercept, and R^2) for total alkalinity were derived from the filtered dataset (2019 to present). Green shading denotes a statistical relationship with SO_4. Zn only has two data points, so still uses the median value. NO_x-N = nitrate nitrogen + nitrite nitrogen; Amm-N = ammoniacal nitrogen.

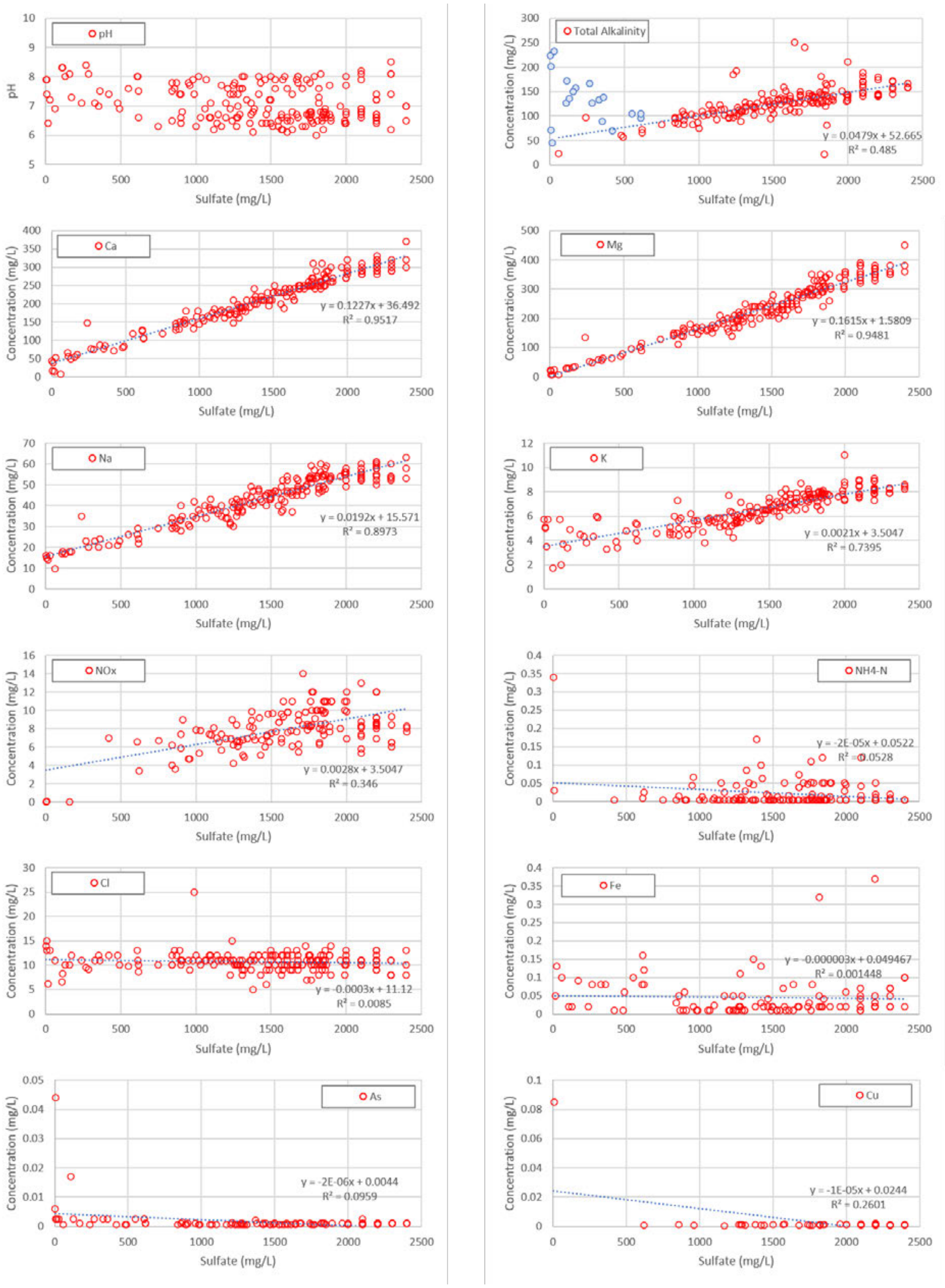

Figure 18: Correlation between water quality parameters and sulfate concentrations for Golden Bar WRS seepage.

Note: Pre-2009 total alkalinity data plotted in blue circles for differentiation.

3.4.2 Coronation WRS

The correlations between major water quality parameters and SO_4 concentrations for the CO WRS are presented in Figure 19, with the corresponding slopes, intercepts, and median values summarised in Table 8. The following observations are noted:

- Seepage pH declined from 8.5 to 7.0 between 2015 and mid-2016 and has since ranged between 6.5 and 7.5, with a median of 7.1.
- Concentrations of Ca, Mg, and Na exhibit strong correlations with SO_4 (R^2 >0.9). Post-closure concentrations for these major cations were estimated using the linear regression equations derived from the slope and intercept values presented in Table 8.
- A distinct cluster of potassium (K) data at approximately 6 mg/L was observed during the early monitoring period (2015 to mid-2016) and is associated with relatively low SO_4 concentrations. Excluding this subset, the two parameters display a strong correlation ($R^2 \approx 0.8$). Accordingly, the slope and intercept values derived from the filtered dataset (Table 8) were adopted to provide a more reliable prediction.
- Total alkalinity in the CO WRS seepage remains relatively stable and independent of SO_4 concentrations, excluding the initial low-sulfate monitoring period. Consequently, the median value derived from monitoring data collected since 2017 was adopted to represent long-term total alkalinity.
- Other parameters exhibit weak correlations with SO_4 and were often below the limit of reporting (LOR) (e.g., As). Accordingly, median values derived from the historical monitoring dataset were adopted to represent post-closure concentrations of these parameters in WRS seepage.

Table 8: Seepage chemistry regression statistics and median values for Coronation WRS (2015-2025).

PARAMETER	COUNT OF DATA POINTS	INTERCEPT	SLOPE	R^2	MEDIAN	PREDICTION METHOD
pH	115	-	-	0.353	7.1	Median
Total Alkalinity	115	-	-	0.473	36	Median
Ca	115	35.2635	0.1515	0.971	220	Linear
Mg	115	3.5348	0.1224	0.974	147	Linear
Na	115	14.0638	0.0129	0.929	29	Linear
K	108	3.2314	0.0020	0.774	5.7	Linear
Cl	115	-	-	0.137	8	Median
NO_x - N	96	-	-	0.117	1.1	Median
Amm - N	96	-	-	0.156	0.245	Median
As	81	-	-	0.106	0.0005	Median
Cu	58	-	-	0.004	0.0005	Median
Fe	81	-	-	0.008	0.05	Median
Pb	58	-	-	0.042	0.000075	Median
Zn	37	-	-	0.056	0.36	Median

Note: Regression parameters for K are derived from mid-2016 onwards. The median total alkalinity was calculated using data from 2017 onwards to represent stabilised geochemical conditions.

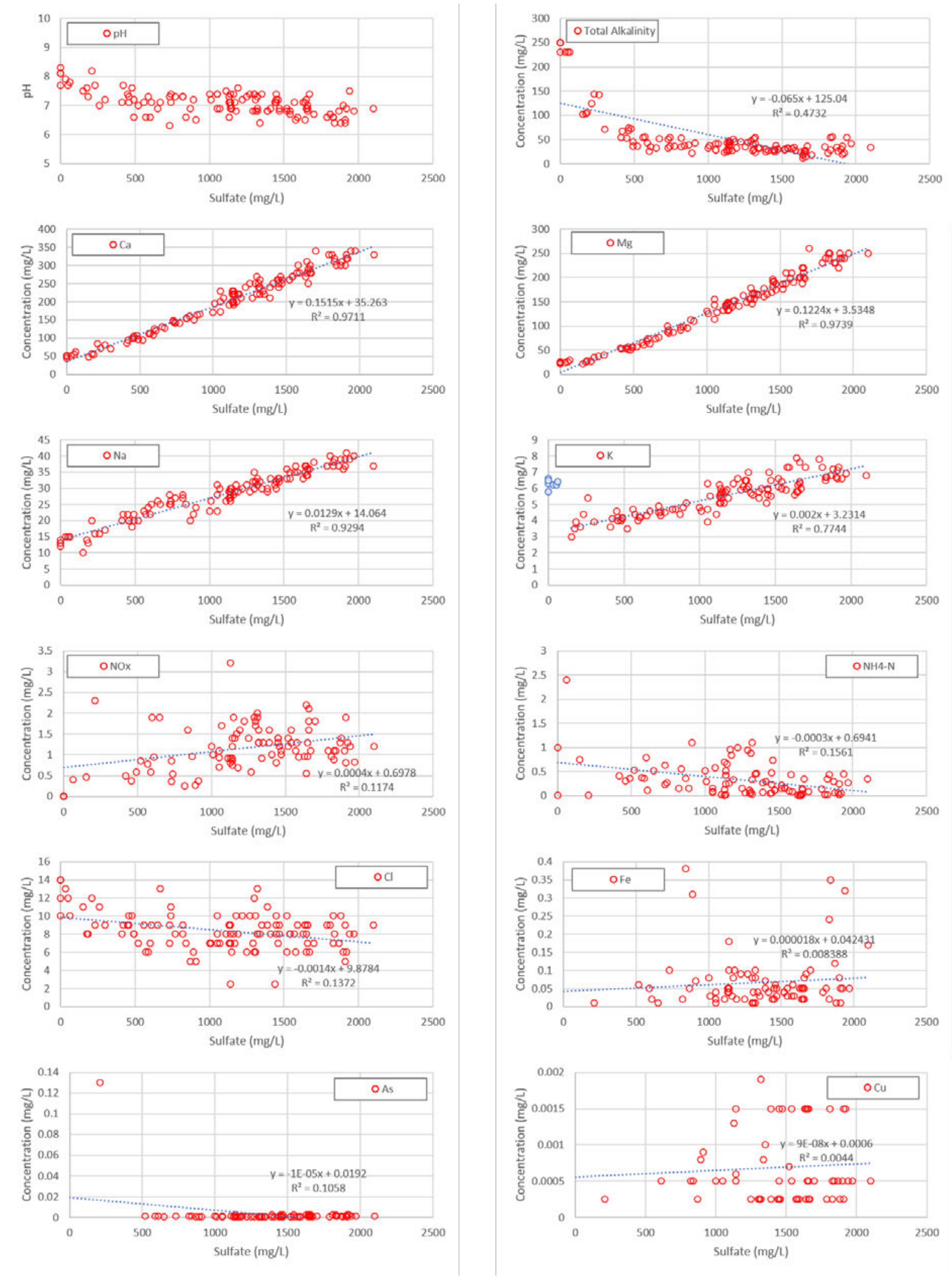

Figure 19: Correlation between water quality parameters and sulfate concentrations for Coronation WRS seepage.

Note: K concentrations before mid-2016 plotted in blue circles for differentiation.

3.4.3 Coronation North WRS

The correlations between major water quality parameters and SO_4 concentrations for the CN WRS are presented in Figure 20, with the corresponding slopes, intercepts, and median values summarised in Table 9. The following observations are noted:

- Seepage pH ranged between approximately 6.8 and 8.5, with a median of 7.6, and appears to be independent of SO_4 concentrations.
- Consistent with the other WRS datasets, major cation concentrations correlate strongly with SO_4. In particular, Ca, Mg, and Na exhibit R^2 values exceeding 0.9. Post-closure concentrations for these elements were estimated using the linear regression equations derived from the slope and intercept values presented in Table 9.
- Total alkalinity and nitrogen oxides (NO_x-N) show moderate correlations with SO_4 concentrations (R^2 >0.5). Long-term concentrations for these parameters were therefore estimated using the derived linear regression equations. However, this approach may overestimate future NO_x concentrations if ammonium-nitrate fuel oil (ANFO) residues are progressively flushed from the WRS over time.
- Other parameters exhibit weak correlations with SO_4. Accordingly, median values derived from the historical monitoring dataset were adopted to represent post-closure concentrations for these parameters in WRS seepage.

Table 9: Seepage chemistry regression statistics and median values for Coronation North WRS (2017-2025).

PARAMETER	COUNT OF DATA POINTS	INTERCEPT	SLOPE	R^2	MEDIAN	PREDICTION METHOD
pH	95	-	-	0.069	7.6	Median
Total Alkalinity	95	145.4293	0.1226	0.687	230	Linear
Ca	95	42.0267	0.2038	0.962	147	Linear
Mg	95	7.7707	0.1454	0.981	73	Linear
Na	95	15.8168	0.0310	0.919	34	Linear
K	95	3.0297	0.0019	0.649	4.2	Linear
Cl	95	-	-	0.223	12	Median
NO_x - N	95	3.9260	0.0077	0.583	8.3	Linear
Amm - N	95	-	-	0.058	0.017	Median
As	90	-	-	0.003	0.00075	Median
Cu	90	-	-	0.002	0.0006	Median
Fe	90	-	-	0.088	0.05	Median
Pb	90	-	-	0.092	0.00005	Median
Zn	2	-	-	1.000	0.0028	Median

Note: Zn only has two data points, hence the median value is used.

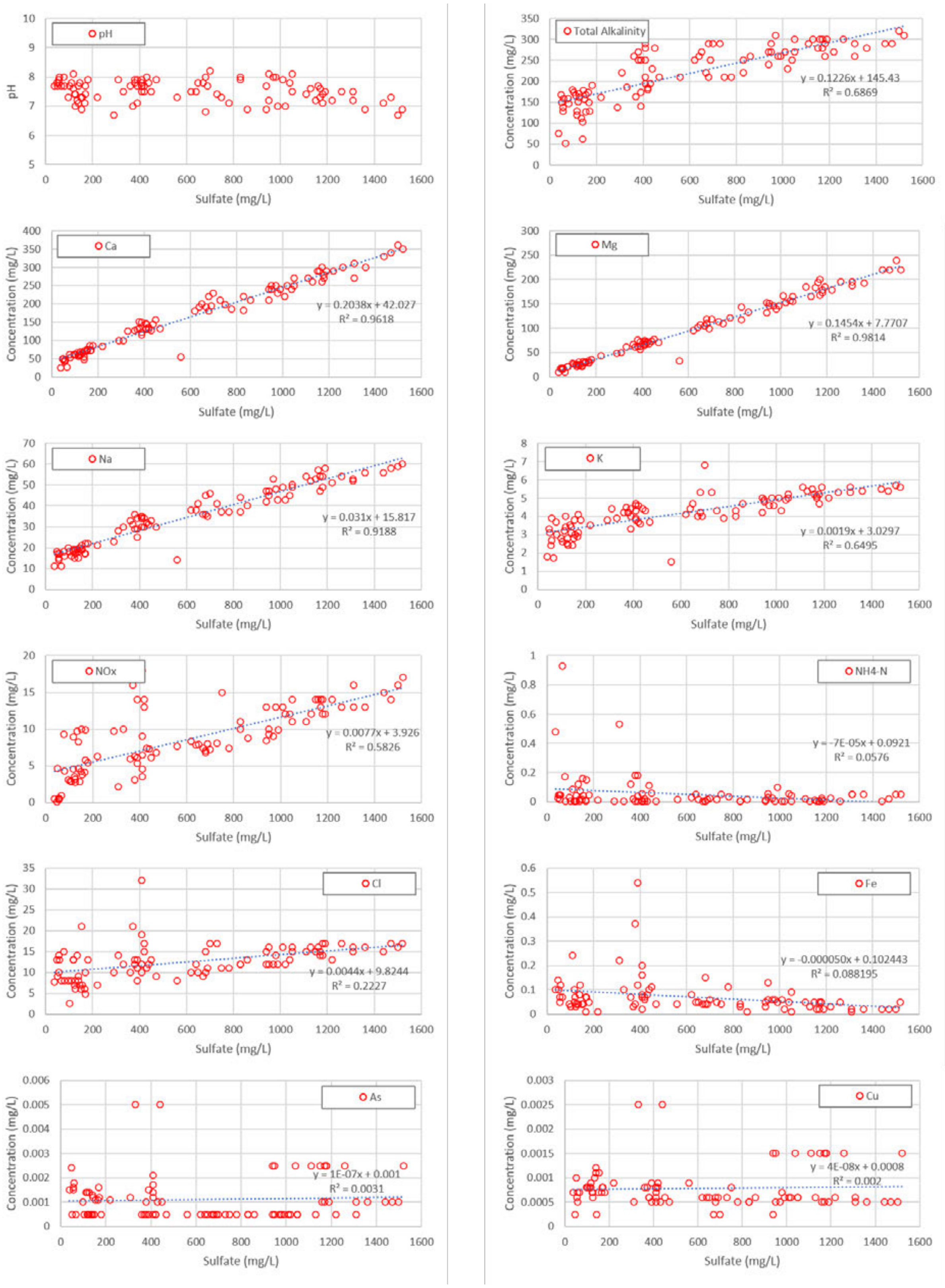

Figure 20: Correlation between water quality parameters and sulfate concentrations for Coronation North WRS seepage.

3.4.4 Trimbells WRS

The correlations between major water quality parameters and SO_4 concentrations for the TR WRS are presented in Figure 21, with the corresponding slopes, intercepts, and median values summarised in Table 10. The following observations are noted:

- Seepage pH generally ranged around 7, with a median value of 6.8.
- Major cation concentrations exhibit strong correlations with SO_4. Post-closure concentrations for these elements were estimated using the linear regression equations presented in Table 10.
- Total alkalinity and NO_x-N both exhibit positive correlations with SO_4 concentrations, despite variability within the datasets. Consequently, linear regression equations were adopted to represent the observed relationships and estimate long-term concentrations for these parameters.
- The initial correlation between Cu and SO_4 was weak due to two apparent outliers with elevated Cu concentrations. Excluding these data points increases the R^2 value to greater than 0.6, indicating a moderate correlation. Consequently, the post-closure Cu concentration was estimated using the regression equation derived from the filtered dataset.
- Other parameters exhibit weak correlations with SO_4. Accordingly, median values derived from the historical monitoring dataset were adopted to represent post-closure concentrations for these parameters in WRS seepage.

Table 10: Seepage chemistry regression statistics and median values for Trimbells WRS (2016-2025).

PARAMETER	COUNT OF DATA POINTS	INTERCEPT	SLOPE	R^2	MEDIAN	PREDICTION METHOD
pH	80	-	-	0.250	6.8	Median
Total Alkalinity	80	61.7815	0.0833	0.559	122	Linear
Ca	80	24.5810	0.2518	0.978	210	Linear
Mg	80	2.0725	0.0939	0.981	70.5	Linear
Na	80	8.7571	0.0184	0.913	23	Linear
K	80	2.4753	0.0053	0.702	6.3	Linear
Cl	80	-	-	0.081	6	Median
NO_x - N	73	2.4290	0.0091	0.583	9.7	Linear
Amm - N	73	-	-	0.183	0.92	Median
As	57	-	-	0.191	0.0005	Median
Cu	48	0.0027	0.00003	0.616	0.031	Linear
Fe	57	-	-	0.191	0.19	Median
Pb	50	-	-	0.158	0.00005	Median
Zn	2	-	-	1.000	0.36	Median

Note: Regression parameters for Cu are derived by excluding two outliers sampled on 22/2/2022 and 9/3/2022. Zn only has two data points, hence the median value is used.

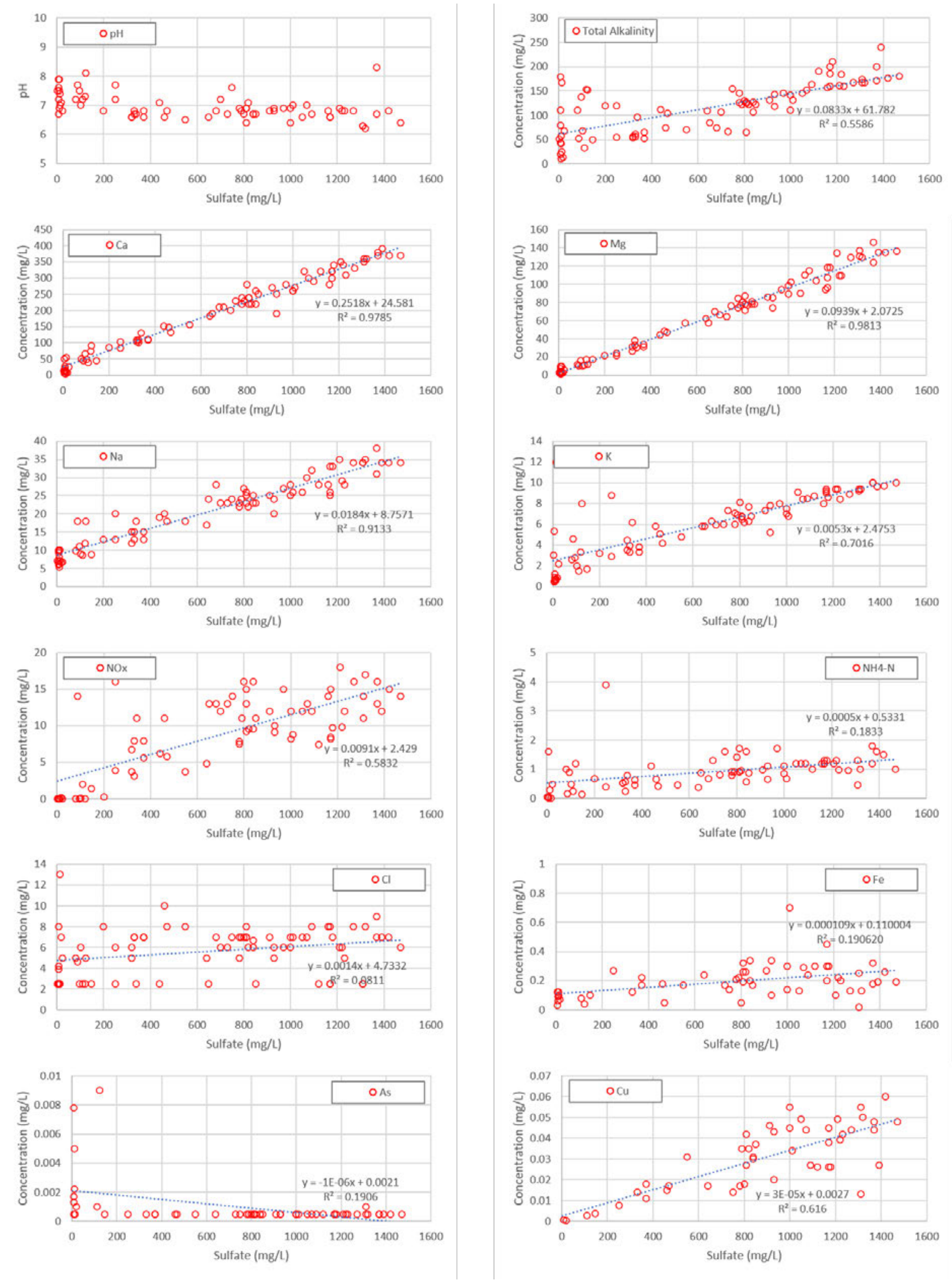

Figure 21: Correlation between water quality parameters and sulfate concentrations for Trimbells WRS seepage.

3.4.5 Frasers West WRS

The correlations between primary water quality parameters and SO_4 concentrations for the FW WRS seepage are presented in Figure 22, with the corresponding slopes, intercepts, and median values summarised in Table 11. The following observations are noted:

- Seepage pH remains relatively stable, ranging between 8.0 and 8.5, with a median of 8.2. The only exception occurred during the early monitoring period, when SO_4 concentrations were relatively low.
- Concentrations of Mg, Na, and K show strong correlations with SO_4. Post-closure concentrations for these elements were estimated using the linear regression equations presented in Table 11.
- Calcium exhibits a distinct decoupling from SO_4 concentrations once SO_4 exceeds approximately 500 mg/L, plateauing at concentrations between approximately 120 and 310 mg/L. This observation suggests that Ca concentrations are constrained by mineral solubility within the WRS, most likely through calcite precipitation. This interpretation is supported by the median pH value of 8.2 and elevated alkalinity. Consequently, a median Ca concentration of 198 mg/L, derived from the post-2009 dataset, was adopted to represent post-closure Ca concentrations.
- Other parameters exhibit weak correlations with SO_4. Accordingly, median values derived from the historical monitoring dataset were adopted to represent post-closure concentrations for these parameters in WRS seepage.

Table 11: Seepage chemistry regression statistics and median values for Frasers West WRS (2005-2025).

PARAMETER	COUNT OF DATA POINTS	INTERCEPT	SLOPE	R^2	MEDIAN	PREDICTION METHOD
pH	84	-	-	0.165	8.2	Median
Total Alkalinity	83	291.2434	0.1215	0.711	520	Linear
Ca	69	-	-	0.001	198	Median
Mg	84	-21.3962	0.2522	0.973	440	Linear
Na	84	15.7103	0.0148	0.930	44.5	Linear
K	84	5.6580	0.0042	0.915	14	Linear
Cl	84	-	-	0.005	11	Median
NO_x - N	44	-	-	0.392	14	Median
Amm - N	43	-	-	0.003	0.05	Median
As	60	-	-	0.181	0.003	Median
Cu	22	-	-	0.000	0.0015	Median
Fe	61	-	-	0.104	0.02	Median
Pb	22	-	-	0.017	0.00025	Median
Zn	0	-	-	-	-	-

Note: The median value for Ca is derived from the post-2009 dataset to reflect the solubility-controlled plateau phase. No Zn data is available for review. The monitoring data point for 24/07/2017 is excluded from the analysis as an anomaly.

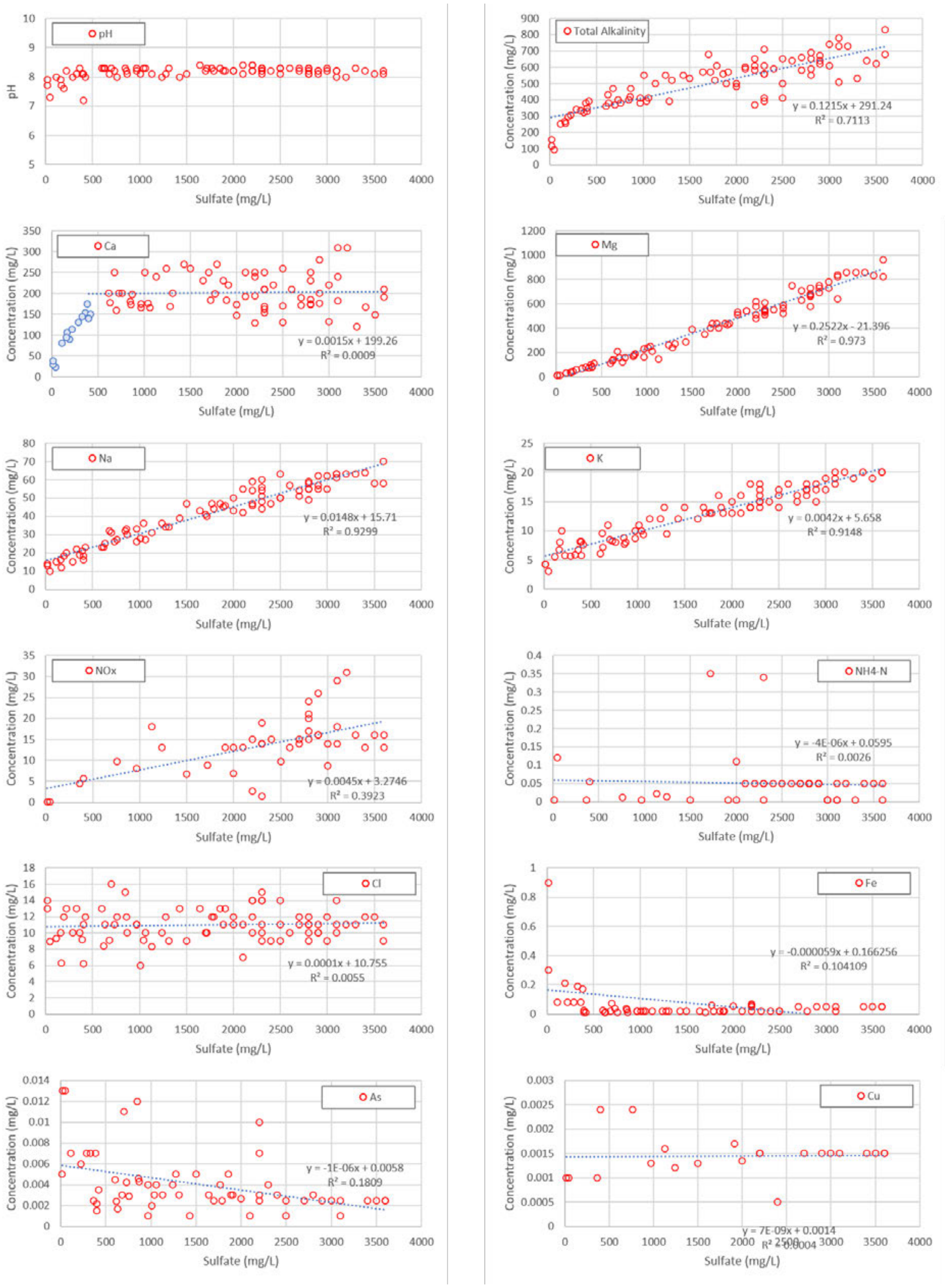

Figure 22: Correlation between water quality parameters and sulfate concentrations for Frasers West WRS seepage.

Note: The pre-2009 Ca concentrations are plotted in blue circles for differentiation.

3.5 Derived WRS Seepage Source Terms

The WRS seepage source terms derived in the previous sections are consolidated and presented in Table 12.

Table 12: Summary of predicted WRS seepage quality post-closure (Year 0).

PARAMETER	UNIT	GB	CO	CN	TR	FW
pH	pH units	6.9	7.1	7.6	6.8	8.2
Total Alkalinity	mg/L as $CaCO_3$	267	36	891	411	1,035
Ca	mg/L	586	597	1,281	1,081	198
Mg	mg/L	725	457	892	396	1,523
Na	mg/L	101	61.9	204	85.8	106
K	mg/L	13.1	10.6	14.4	24.7	31.1
SO_4	mg/L	4,481	3,706	6,081	4,193	6,125
Cl	mg/L	11	8	12	6	11
NO_x - N	mg/L	8.05	1.1	50.7	40.6	14
Amm - N	mg/L	0.005	0.245	0.017	0.92	0.05
As	mg/L	0.001	0.0005	0.00075	0.0005	0.003
Cu	mg/L	0.0011	0.0005	0.0006	0.1347	0.0015
Fe	mg/L	0.02	0.05	0.05	0.19	0.02
Pb	mg/L	0.0001	0.000075	0.00005	0.00005	0.00025
Zn	mg/L	0.049	0.36	0.0028	0.36	-

3.6 Investigation on Zinc in WRS Seepage

As discussed in Section 3.4.2, Zn concentrations in the CO WRS seepage do not correlate with SO_4. Consequently, the median value of 0.36 mg/L, derived from the historical monitoring record, was adopted to represent the post-closure Zn concentration. This concentration exceeds the recommended ecological compliance trigger value of 0.016 mg/L (Viridis, 2026).

Available Zn datasets for other WRS seepage monitoring locations are limited. The number of Zn datapoints and corresponding monitoring periods for each WRS domain are summarised in Table 13. This section presents the investigations undertaken to characterise elevated Zn concentrations and identify the mechanisms that may be contributing to the elevated Zn in CO WRS seepage.

Table 13: Summary of seepage sample datasets analysed for Zn.

WRS DOMAIN	MONITORING LOCATION	MONITORING PERIOD	NUMBER OF Zn DATAPOINTS
Coronation	MAC-Coronation Silt Pond	17/5/2022 – 1/10/2025	37
Deepdell North	MAC-Deepdell North Silt Pond	18/2/2022 – 1/10/2025	39
Golden Bar	MAC-Clydesdale WRS Seepage	27/2/2023 – 10/6/2024	2
Coronation North	MAC-Maori Hen Gully Seepage	7/12/2020 – 21/12/2021	2
Trimbells	MAC-Trimbells Gully Drain	9/12/2021 – 31/8/2022	2

3.6.1 Zinc in CO WRS seepage

The temporal trends in Zn concentrations and their relationships with SO_4 within the CO WRS seepage are presented in Figure 23. For comparison, the corresponding Zn dataset for the DN WRS seepage is shown in Figure 24. The following are noted:

- Consistent with the findings presented in Section 3.4.2, Zn concentrations display no linear correlation with SO_4. Over time, Zn concentrations followed a downward trend between 2022 and 2024. Recent data indicates fluctuations between 0.2 and 0.4 mg/L. Based on the available data it cannot be concluded whether the long-term downward trend will resume.
- Dissolved Zn concentrations are significantly lower in the DN WRS seepage than those observed in the CO WRS seepage. However, the DN WRS exhibits a gradual increase in Zn concentrations over time. Zinc also shows a weak positive correlation with SO_4 concentration, though the statistical strength of the correlation remains low (R^2 <0.5).

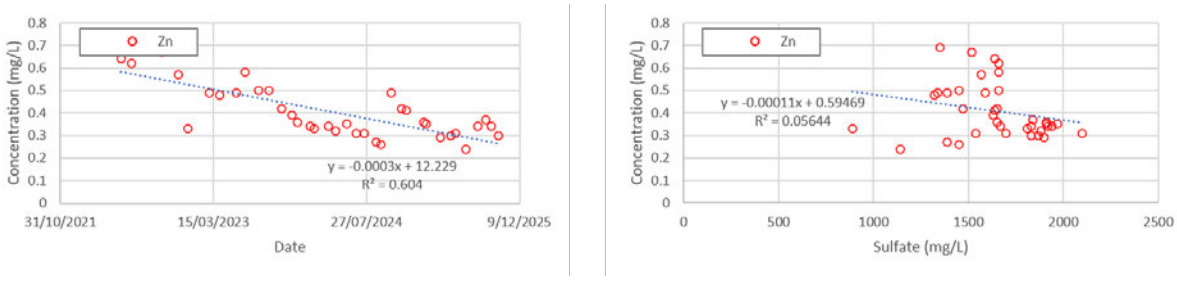

Figure 23: Zn concentrations and temporal trends in CO WRS seepage.

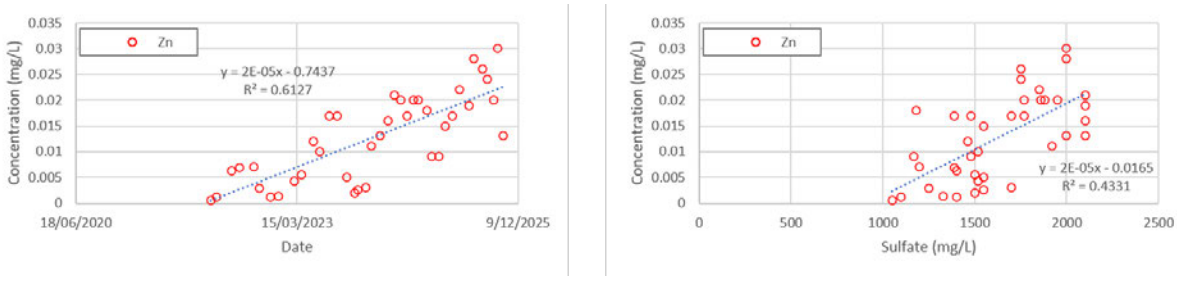

Figure 24: Zn concentrations and temporal trends in DN WRS seepage.

3.6.2 Mechanisms Controlling Elevated Zinc Concentrations in CO WRS Seepage

Based on the available data, the elevated Zn concentrations observed in the CO WRS seepage are interpreted to result from a combination of seepage pH conditions and the bulk geochemical characteristics of the waste rock.

<u>Influence of Solution pH</u>

Evaluation of dissolved Zn concentrations relative to seepage pH across all available datasets (Figure 25 and Figure 26) indicates that Zn solubility is highly sensitive to pH conditions. Dissolved Zn concentrations are up to three orders of magnitude higher in circumneutral seepage (approximately pH 7.0), including the CO, TR, and GB domains, than in more alkaline drainage near pH 8.0, such as that observed in the DN and CN domains. Within the pH range of 7.0 to 8.0, dissolved Zn concentrations are likely controlled by two key geochemical mechanisms:

- pH-dependent adsorption: Adsorption of dissolved Zn onto Fe (and Al and Mn) oxyhydroxide surfaces is strongly pH dependent. At the lower pH conditions (~ pH 7.0) characteristic of the CO WRS seepage, adsorption efficiency is reduced relative to the more alkaline environments (pH 8.0), allowing a greater proportion of Zn to remain in the dissolved phase.
- Secondary mineral solubility: In carbonate-buffered systems operating between pH 7.0 and 9.0, dissolved Zn concentrations may be constrained by the precipitation of secondary Zn carbonate, such as smithsonite ($ZnCO_3$) and hydrozincite ($Zn_5(CO_3)_2(OH)_6$). These processes become increasingly important at higher pH (>~pH 8) .

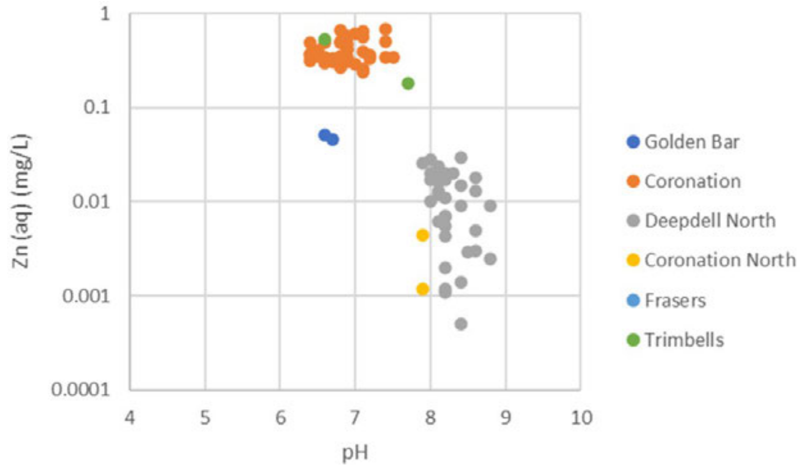

Figure 25: Correlation between dissolved Zn and solution pH across WRS seepage monitoring sites.

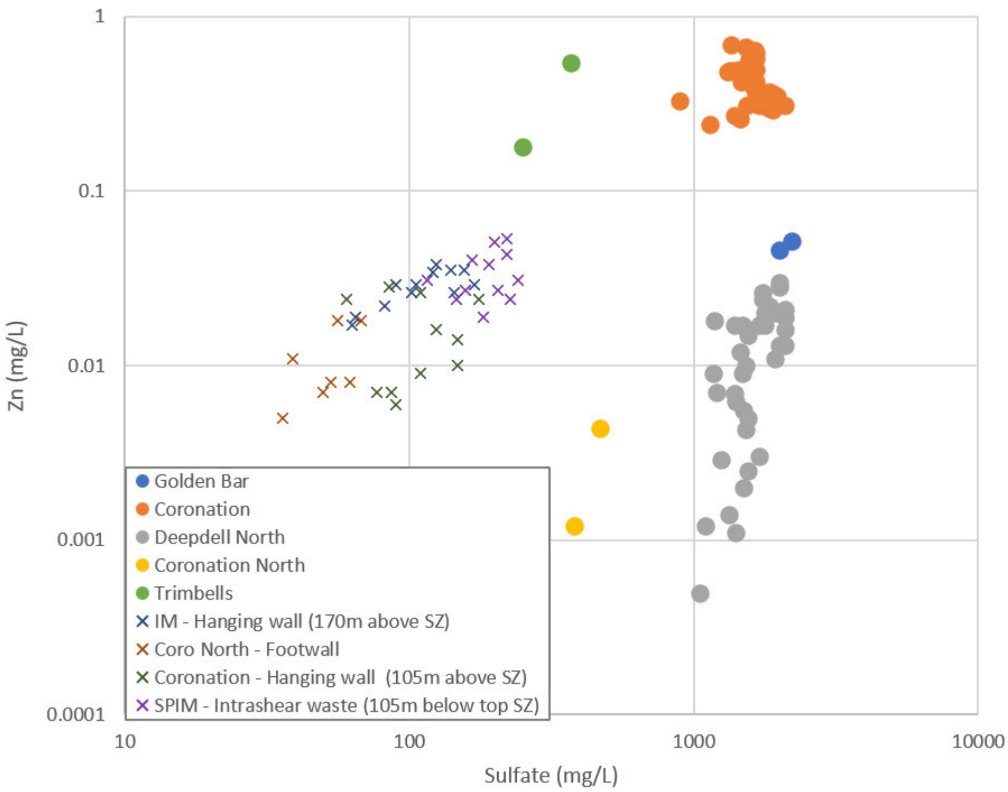

Figure 26: Correlation between dissolved Zn and SO_4 concentrations across WRS seepage monitoring sites.

Variance in Waste Rock Bulk Geochemistry

An evaluation of the ABA dataset by MWM (2026d) indicates that the waste rock within the CO and CN domains exhibits slightly different bulk geochemical characteristics compared to the historical Macraes Gold Project (MGP) database average (Table 14).

Statistically, the CO and CN waste rock is characterised by lower total S (and consequently lower MPA), lower ANC, and a higher proportion of samples with a neutralisation potential ratio (NPR) below 3. These differences suggest a degree of localised mineralogical variability within the host rock.

Despite these differences, waste rock from the CO and CN domains remains overwhelmingly non-acid forming (with a median NPR of 8.3). Consequently, the observed geochemical variance does not indicate a deficiency in neutralising capacity. Rather, the lower bulk ANC suggests a difference in the dominant acid buffering mineral assemblage.

Relative to other WRS domains, the CO and CN waste rock may contain lower abundances of reactive Ca carbonates (e.g., calcite) and potentially a higher proportion of Fe-carbonates (e.g., siderite and ankerite), which may be contributing to a slightly lower pH compared to other WRS domains.

Table 14: Geochemical parameter summary for Coronation and Coronation North waste rock compared to the regional MGP ABA database.

PARAMETER	UNIT	CO & CN DOMAINS	MGP DATABASE
Sample count (n)	-	101	982
Samples with NPR <3	-	16	37
Total S	wt%	0.103	0.143
ANC	kg H_2SO_4/t	26.2	52.1
MPA	kg H_2SO_4/t	3.15	4.38
NAPP	kg H_2SO_4/t	-24.4	-46.7
NPR	-	8.3	11.3

Note: Values presented for Total S, ANC, MPA, NAPP and NPR represent dataset medians; NPR is calculated as the ratio of ANC to MPA.

3.7 Nitrate Removal

Nitrate (NO_3), derived from ANFO explosive residues, is a key solute in WRS seepage at the Macraes Operation. Long-term water quality monitoring at the CO WRS indicates that natural NO_3 attenuation may be occurring within the rock mass. This is supported by monitoring data showing that NO_3 concentrations have remained stable and relatively low (typically <2 mg/L) and decoupled from the rising trends observed in SO_4 and electrical conductivity (EC), whereas other WRSs have strong relations for SO_4 versus NO_3 concentrations.

This subdued NO_3 response in CO WRS seepage is attributed to the presence of buried vegetation and organic matter incorporated during WRS construction. This material provides a bioavailable carbon source that promotes microbial denitrification under sub-oxic conditions within the dump interior (MWM, 2026e).

To proactively manage NO_3 loads in future WRS developments (such as the GB and TR WRSs), a range of engineered passive treatment systems have been evaluated (MWM, 2026e). These include:

- In-dump carbon amendments: engineered reactive zones incorporated within the waste rock matrix.

- Gravel bed bioreactors (GBBRs) / Enhanced passive treatment systems (E-PTS): engineered bioreactors installed within downstream WRS drainage networks.

Literature data indicate that the performance of these passive systems is primarily governed by hydraulic residence time (HRT), operating temperature, and carbon availability, with carbon-amended systems consistently achieving high rates of NO_3 removal.

Site-specific laboratory and pilot-scale E-PTS trials conducted by Verum Group using WRS seepage water from the Macraes Operation have demonstrated the effectiveness of this mechanism under representative operating conditions (MWM, 2026e). These trials achieved near-complete to complete NO_3 removal, reducing influent NO_3-N concentrations of up to 20 mg/L to below the limit of reporting at an HRT of approximately one day.

These findings provide a high level of confidence that carbon-driven NO_3 removal is technically viable under the climatic and hydrogeochemical conditions at the Macraes Operation. For predictive hydrogeochemical modelling and adaptive management planning of future WRS configurations, implementation of these passive treatment systems (such as GBBRs or engineered in-dump treatment zones) can be represented using a defensible range of NO_3 removal efficiencies based on design HRT:

- Conservative baseline of 85% removal (optimised at ~1 day HRT).
- Expected performance of 95% removal (optimised at 1–2 days HRT).
- Upper-bound efficiency of 99% removal (optimised at >2 days HRT).

3.8 Limitations and Assumptions

The empirical WRS seepage predictive model developed in this assessment is subject to the following limitations and assumptions, reflecting the availability and quality of the current dataset:

- While the empirical relationship between maximum SO_4 concentrations and average WRS height was developed using a broad, site-wide dataset to establish a robust numerical basis, the derivation of seepage source terms is limited to the five WRSs associated with MP4 (GB, CO, CN, TR, and FW), consistent with the scope of this assessment.
- Seepage monitoring data can be influenced by rainfall, surface runoff, and near-surface flow, meaning individual samples may not represent undiluted WRS seepage. The historical dataset indicates that some monitoring locations are more strongly affected by surface water inputs than others. For example, the DN Silt Pond explicitly receives surface runoff, resulting in a composite water quality signature. Furthermore, sites such as TR, GB, and CN exhibit substantial temporal variability in concentrations, likely driven by high rainfall induced dilution and near-surface runoff. As dilution ratios cannot be quantified from the available dataset, the model assumes that use of the maximum recorded SO_4 concentrations mitigates these dilution effects, providing a conservative upper-bound basis for seepage quality predictions (i.e., when surface flows are minimal/negligible).
- Parameters exhibiting little or no correlation with SO_4 concentrations (typically trace metals and, in some instances, NO_3-N) were represented using median values derived from the consolidated historical monitoring dataset. While this approach may not capture short-term upper bound concentrations associated with operational conditions, it reduces the influence of

analytical outliers and sampling errors within the long-term monitoring records and avoids unnecessary compounding of conservatism within the predictive model. As the model is developed specifically to predict long-term post-closure WRS seepage chemistry, the use of median values for these parameters is considered appropriate and consistent with the assessment objectives.

4 CONCLUSION AND RECOMMENDATIONS

MWM has completed a seepage quality assessment for the WRS associated with the Project. By integrating updated 2025 topographic data with consolidated long-term water quality monitoring records, this assessment has refined the predictive model used to forecast post-closure WRS seepage chemistry.

4.1 Consolidated Predictive Approach

To derive representative source terms for WRS seepage, a predictive approach was developed to account for both the physical geometry of the WRS and their geochemical evolution.

The empirical relationship between maximum SO_4 concentration and average WRS height serves as the primary predictor for long-term seepage quality. To ensure the model is sufficiently robust for the Project application, this assessment adopted a conservative "upper-bound" approach. This was achieved by anchoring the correlation to the Northern Gully East dataset, which exhibits the highest observed SO_4 concentration from WRS seepage across the Project site, and has reached a semi-stable state (Figure 13). The resulting equation envelops the maximum observed concentrations across all WRS heights (see Equation 4).

Once the peak SO_4 concentration is established, the remaining chemical parameters are derived based on their observed geochemical relationship with SO_4:

- For parameters demonstrating a strong linear relationship with SO_4 (typically Ca, Mg, Na, and K), peak predicted concentrations are calculated using site-specific linear regression slopes and intercepts. This approach ensures that the projected major cation concentrations are consistent with the observed geochemical trends in WRS seepage.
- For parameters that remain independent of SO_4 concentrations (typically trace metals), median values from the historical monitoring dataset were adopted. This approach assumes that these elements have reached a steady-state release rate governed by mineral solubility controls (e.g., oxyhydroxide scavenging at circumneutral pH), adsorption processes, and other local geochemical controls rather than the rate of sulfide oxidation. The use of median values also reduces the influence of analytical outliers, concentrations reported near the limit of reporting, and short-term variability that are not representative of long-term post-closure seepage chemistry.

4.2 Study Findings

This assessment highlights the following key geochemical trends and outcomes:

- WRS seepage water quality is driven primarily by ongoing sulfide mineral oxidation, subsequent acid-neutralising reactions (e.g., carbonate mineral dissolution), and the precipitation of secondary minerals that will contribute to a reduction in metals and metalloids. However, the measured concentrations at monitoring locations are influenced by WRS geometry, age, rehabilitation status, water management practices (run-on and runoff), rainfall, materials placement schedules, geochemical reactions within the WRS, and catchment dilution (surface and near-surface).

- Individual source terms were derived for the GB, CO, CN, TR, and FW WRS. These source terms account for observed variations in waste rock geochemistry, WRS geometry, and seepage water quality behaviour:
  - Major cations, including Ca, Mg, and Na, exhibit a strong linear relationship with SO_4 and are predicted to increase proportionally with SO_4 concentrations.
  - Nitrate concentrations generally show weak to moderate correlations with SO_4 and are modelled accordingly.
  - Trace metal concentrations (excluding Zn) remain largely independent of SO_4 concentrations and are predicted to maintain low, steady-state concentrations.
  - Dissolved Zn concentrations in the CO and TR WRS seepage are elevated and independent of SO_4. As detailed in this assessment, this is interpreted to be associated with localised variability in waste rock geochemistry (lower bulk ANC). This variance is interpreted to result in circumneutral drainage conditions (pH ~7.0) which reduce the adsorption of Zn onto Fe oxyhydroxides and maintain higher Zn solubility relative to the more alkaline drainage conditions (pH ~8.0) observed in other WRS domains.
  - Natural attenuation of NO_3 appears to be occurring within specific WRS domains (such as CO) due to microbial denitrification driven by buried organic matter. For future WRS developments, this process can be replicated via engineered passive treatment systems (such as GBBRs / E-PTS) to effectively manage nitrogenous loads prior to discharge.

4.3 Source Terms

The predicted post-closure WRS seepage quality for selected Project WRS is presented in Table 12 (Section 3.5). These values represent the predicted seepage quality immediately following closure (Year 0) and constitute the definitive source term inputs for the pit lake water quality models.

4.4 Recommendations

Given the evolving nature of WRS seepage chemistry, the empirical relationship between SO_4 concentration and average WRS height should be reviewed annually throughout the operations and into closure using the monitoring locations identified in Section 2. The purpose of these reviews should be to:

- Confirm that predicted post-closure SO_4 concentrations remain appropriately conservative as WRSs evolve.
- Update seepage source terms and recalibrate the sulfate-height relationship where monitoring data indicate material changes in seepage quality.
- Incorporate additional constituents of concern (e.g., B, Co, Sb) determined from column leach testing (MWM, 2026c) and/or future consent requirements.

To support these ongoing refinements of the predictive model and reduce the uncertainties identified in Section 3.8, the following actions are recommended:

- Undertake continuous flow and EC measurements of WRS seepage to understand geochemical trends and loads as a function of waste rock mass and flow rates over time.
- Characterise dilution effects (e.g., surface runoff and near-surface flows) at seepage monitoring locations to better understanding seepage-rainfall dynamics.
- Determine why the CO WRS exhibits lower N concentrations compared to other WRSs on site.
- Conduct targeted geochemical and mineralogical investigations of the waste rock within the CO and TR domains to understand what geochemical reactions are suppressing seepage pH and maintaining elevated Zn concentrations
- Whilst engineering controls are proposed to manage diffuse toe seepage at the CN and FW WRSs where seepage tends to be less confined, undertake further investigations to characterise the pathways and environmental effects of other diffuse seepage pathways to ensure best-practice management of mine-impacted water.
- For the preliminary design and conceptual modelling of the recommended passive NO_3 treatment systems (such as GBBRs / E-PTS) for future WRS developments, adopt a conservative NO_3 removal efficiency of 85%, assuming a hydraulic residence time of approximately one day.

5 REFERENCES

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Mine Waste Management (MWM), 2026e. Macraes Phase 4 Project: Adaptive Management of Elevated Nitrate in WRS Seepage. MWM Document No. J-NZ0498-025-M-FINAL.

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Viridis, 2026. Recommended Surface Water Quality Compliance Framework. Document No. 10023-010-E.

6 LIMITATIONS

Attention is drawn to the document "Limitations", which is included in Appendix C of this report. The statements presented in this document are intended to provide advice on what the realistic expectations of this report should be, and to present recommendations on how to minimise the risks associated with this project. The document is not intended to reduce the level of responsibility accepted by Mine Waste Management, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in doing so.

APPENDIX A WRS TOPOGRAPHY ASSESSMENT

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MEMORANDUM

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From:	Paul Weber – Mine Waste Management Limited (MWM)
Date:	31 August 2026
Cc:	[redacted] – OceanaGold Leo Navarro – MWM; Eric Chen – MWM
Document Number:	J-NZ0498-005-M-FINAL
Document Title:	Waste Rock Stack Topography Assessment
Disclaimer:	This document has been produced for New Zealand consenting purposes only. Information contained herein must not be relied on for investment purposes.

Mine Waste Management Limited (MWM) has been engaged by OceanaGold (New Zealand) Limited (OGNZL) to assess environmental geochemistry hazards and potential effects for the proposed Macraes Phase Four Project (MP4 or the Project). This assessment supports the application as a Listed Project in Schedule 2 of the Fast-track Approvals Act 2024 (FTAA) as a project providing significant national or regional benefits.

As part of the broader environmental geochemistry hazard assessment, this memorandum documents the methodology and presents the volumes and surface areas of the ex-pit waste rock stacks (WRSs) for both the current and future MP4 mine plan designs. These outputs support the assessment of WRS seepage (MWM, 2026), which subsequently provides source term water quality data for pit lake water quality modelling.

OBJECTIVES

The objectives of this memorandum are to:

- Quantify the approximate current waste rock volumes within the WRSs. This is achieved by comparing 'as-mined'[1] surfaces against current topography, as well as consented and future MP4 design surfaces, to calculate total fill volumes within specific containment basins and WRS footprints.
- Delineate the sub-catchments beneath the WRS footprints that drain to specific monitoring points. While WRSs are often managed as singular entities, the underlying drainage frequently segregates flow to different locations.

[1] *The 'as-mined' surface represents the topography at its maximum point of excavation, prior to any waste rock placement. It provides the necessary baseline to differentiate backfill volumes versus waste rock stacks, ensuring that waste rock deposited within excavated voids (i.e., in-pit backfill) can be quantified and discounted from the volume of the Waste Rock Stack situated on the natural ground surface, as seen at Frasers West. But for the purpose of this memo, a 'pre-mine' surface is interchangeable with the 'as-mined' surface.*

- Update current volume and area estimates, which are used to determine average WRS heights for current conditions.
- Estimate designed volumes, areas, and average WRS heights for future landforms that are proposed as part of MP4.

METHODOLOGY

The spatial analysis utilised geospatial data within the Macraes Gold Project Grid (MGPG) coordinate reference system.

Data Inputs

The following data inputs were used:

- **Topographic Surfaces**: Source data consisted of triangulated irregular networks (TINs) provided in DXF format, which were rasterised for volumetric analysis:
    - **As-Mined Base (or Pre-Mined)**: The baseline surface representing the topography prior to any waste rock placement (e.g., Macraes_coro as-mined). For most WRSs analysed in this report, this surface is identical to the historical 'pre-mined' (pre-disturbance) topography. However, the 'as-mined' terminology is necessary to account for Frasers West (or any other pits that have been partially backfilled), where the surface includes excavated pit voids, allowing in-pit backfill to be isolated and discounted from the above-ground WRS volume.
    - **Most Recent Surface**: Current survey data representing the existing WRS geometry (e.g., CNWD2, FWWD2, TWRS2).
- **Spatial Boundaries**: Vector polygons defining the specific extent of individual basins and WRS footprints.

The following topography files were provided in DXF format:

- **Macraes Central Area**
    - **Macraes_Site As-mine_251130**: Reconstruction of the as-mined topography generated on 30-11-2025.
    - **Site_Surface_250702**: Topographical survey representing site conditions on 02-07-2025.
- **Macraes Coronation and Coronation North area:**
    - **Macraes_coro as mined 220301**: Reconstruction of the as-mined topography generated on 01-03-2022.
    - **Macraes_Coro_Site_Surface_241001**: Topographical survey representing site conditions on 01-10-2024.
- **Macraes Golden Bar Area:**
    - **Original Topo - FR-GB**: Pre-mined topography.

- **GB_topo_2017_without_water_Asbuilt**: 2017 topographical survey representing as-mined conditions.

Processing Steps

- **Surface Alignment:** The Base raster was aligned to the exact grid resolution and extent of the Current/Design raster to ensure geographic parity at the pixel level.
- **Spatial Masking:** The surfaces were clipped to the specific WRS footprints, or WRS basal sub-catchment polygons beneath the WRS footprints, to isolate the analysis to the relevant drainage paths and prevent the surrounding regional topography from influencing volume calculations.
- **Volumetric Calculation:** A difference model was generated by subtracting the Base elevation from the Current elevation for each pixel (*Waste Rock Volume = Current Elevation – Base Elevation*).
- **Total Volume:** This was calculated by summing the volume of all pixels where the elevation difference was positive.
- **Average Height:** The mean vertical thickness of the waste rock across the deposition area was calculated as the ratio of total volume to total area (*Average Height = Total Volume / Total Area*).
- **Sub-catchment Definition**: It was assumed that the base topography controls the flow at the bottom of the WRS once rainfall infiltration reaches the natural ground level. Therefore, drainage pathways were estimated based on this basal topography. This allowed for the definition of sub-catchments draining to the main seepage points, facilitating target calculations for area, volume, and average height of those specific basal sub-catchments.

Note: The same methodology was applied to MP4 designs using currently consented topographies.

LIMITATIONS AND SITE-SPECIFIC OBSERVATIONS

Analysis Limitations

The following limitations apply to the volumetric estimates and spatial analyses presented in this memorandum:

- **Topographic Resolution and Data Quality:** Source topographic resolution varies across the project area. Regions with lower data density or interpolation artefacts (visible in specific figures) exhibit a higher margin of error for elevation differencing. Consequently, all reported volumes should be considered best estimates rather than absolute values.
- **Temporal Validity (Snapshot versus Dynamic Operation):** The ‘Current’ surface represents a discrete snapshot in time. As the mining operation is active and ongoing, actual volumes fluctuate daily due to continuous material placement.
- **Interpolation Errors:** The conversion of TINs to raster grids inherently introduces minor smoothing and interpolation errors, particularly along sharp break lines such as bench crests and toes.

- **Future Compliance Assumption:** Discrepancies between current topography and consented designs are possible. However, as this is an ongoing operation, it is assumed that the final landform at the end of the mine life will comply with the consented design boundaries.
- It is also assumed that seepage through each WRS is vertically downward until the As-Mined surface is reached. This is a simplification due to lateral flow across running surfaces that may influence flow paths.

Site-Specific Observations

Specific geometric and hydrological conditions were identified for the key mining domains:

- **Frasers West and South Continuity**: The Frasers West and South WRSs effectively function as a single contiguous volume. For this analysis, the sub-catchment was delineated to focus primarily on the Frasers West WRS drainage. Note that backfill material within the Frasers Pit void was excluded from the full extent calculation, as the 'as-mined' pit shell was used as the base surface and the backfill material was accounted for as a separate volume.
- **Northern Gully Separation**: Similarly, the North Gully East and North Gully West WRSs present as a single physical volume that cannot be easily separated by current surface topography alone. By applying hydrological catchment analysis to the pre-mine surface, the mass was partitioned into two distinct sub-catchments draining to their respective East and West seepage monitoring points.
- **Trimbells and Coronation North Overlap**: A minor spatial overlap exists between the Trimbells and Coronation North WRS design footprints for MP4. While this theoretically introduces a double counting of volume in the overlap zone, a review of the area indicates this overlap is minor[2] and does not materially affect the total reporting figures.
- **Coronation Constraint**: The volumetric analysis for the Coronation WRS was constrained to the current operational footprint plus the remaining consented capacity, as residual volume exists within the permitted design limits. The updated mine plan involves depositing additional material within the existing Coronation WRS extent.

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[2] *While the Trimbells and Coronation North WRS designs overlap by approximately 4 ha (2% of their ~200 ha combined footprint), this is not considered material for the geochemical analysis (MWM, 2026). The overlapping areas are situated outside the hydrologically delineated sub-catchments that report to the current monitoring sites.*

RESULTS

Tabulated Data

The results of the volumetric analysis are presented in Table 1 for the ‘current’ WRSs, and Table 2 for the proposed WRS designs under MP4.

The geometries presented in the tables are categorised by two distinct spatial boundaries: 'Full Extent' and 'Sub-Catchment' (see Figure 1):

- The 'Full Extent' values represent the total physical footprint and volume of the entire WRS.
- The 'Sub-Catchment' values represent only the hydrologically delineated portion of the stack, where infiltrating seepage theoretically drains and reports to a designated downstream monitoring site.

These categories define spatial drainage areas for the seepage model and do not represent different design or consent requirements. Topographic and volumetric details for smaller, peripheral sub-catchments that drain outside the primary catchment area are excluded from the seepage chemistry model. Such effects are assessed by GHD (2026).

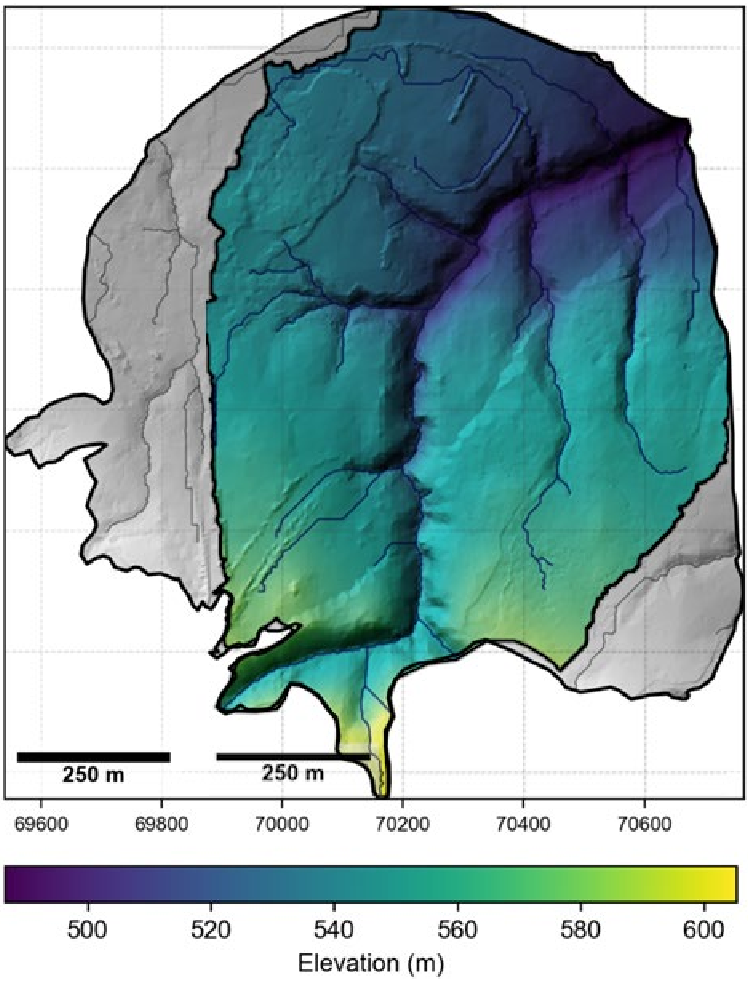

Figure 1: Spatial boundary classification example at Coronation North WRS.

The 'Full Extent' encompasses the entire outlined footprint (grey and elevation-coloured regions combined), while the 'Sub-Catchment' is restricted to the hydrologically delineated area (elevation-coloured region) showing internal drainage pathways.

Table 1: Current WRS area, volume, and average height.

SITE NAME	TYPE	AREA (ha)	VOLUME (Mm^3)	AVERAGE HEIGHT (m)
Coronation	Full Extent	43.9	12.8	29.1
Coronation North	Full Extent	104.5	32.1	30.7
Trimbells	Full Extent	52.7	16.5	31.3
Deepdell North	Full Extent	12.7	3.0	23.6
Northern Gully West and East	Full Extent	138.7	51.6	37.2
Frasers West and South	Full Extent	332.9	133.3	40.0
Frasers East	Full Extent	114.1	44.8	39.3
Golden Bar#	Full Extent	24.4	7.3	29.9
Coronation	Sub-Catchment	27.2	9.7	35.7
Coronation North	Sub-Catchment	80.0	27.8	34.7
Trimbells	Sub-Catchment	46.6	15.5	33.3
Deepdell North	Sub-Catchment	8.1	2.2	27.2
Northern Gully West	Sub-Catchment	79.3	28.7	36.2
Northern Gully East	Sub-Catchment	42.7	18.2	42.6
Frasers West	Sub-Catchment	163.8	85.4	52.1
Frasers East	Sub-Catchment	81.9	37.1	45.3
Golden Bar#	Sub-Catchment	24.4	7.3	29.9

 # The Golden Bar WRS is located exclusively within a single catchment where all surface drainage theoretically reports to a common downstream outlet. Therefore, the Full Extent equals the Sub-catchment that reports to the seepage point.

Area, Volume, and Average Height are rounded to one decimal place. Average Height is calculated using unrounded data, so manually dividing the displayed Volume by the displayed Area may result in minor discrepancies.

Table 2: Consented plus proposed MP4 design WRS area, volume, and average height.

SITE NAME	TYPE	AREA (ha)	VOLUME (Mm^3)	AVERAGE HEIGHT (m)
Coronation*	Current + Consented	43.7	15.2	34.8
Coronation North	Consented + Design	139.1	84.0	60.4
Trimbells	Consented + Design	100.1	37.5	37.5
Frasers West	Consented + Design	287.5	160.4	55.8
Golden Bar	Consented + Design	55.8	21.9	39.3
Coronation	Sub-Catchment	26.8	11.4	42.6
Coronation North	Sub-Catchment	81.7	57.1	69.9
Trimbells	Sub-Catchment	61.8	29.8	48.2
Frasers West	Sub-Catchment	153.0	107.7	70.4
Golden Bar	Sub-Catchment	37.8	19.5	51.5

** Unlike the other WRSs, the Coronation WRS does not include any modifications to the current consented conditions.*

Area, Volume, and Average Height are rounded to one decimal place. Average Height is calculated using unrounded data, so manually dividing the displayed Volume by the displayed Area may result in minor discrepancies.

Graphic Results

The following figures present the geospatial results for each WRS, showing:

- As-mined and current topographies (current volumes).
- As-mined and currently consented plus MP4 designs.

A Table of Figures is provided below to facilitate navigation to specific results.

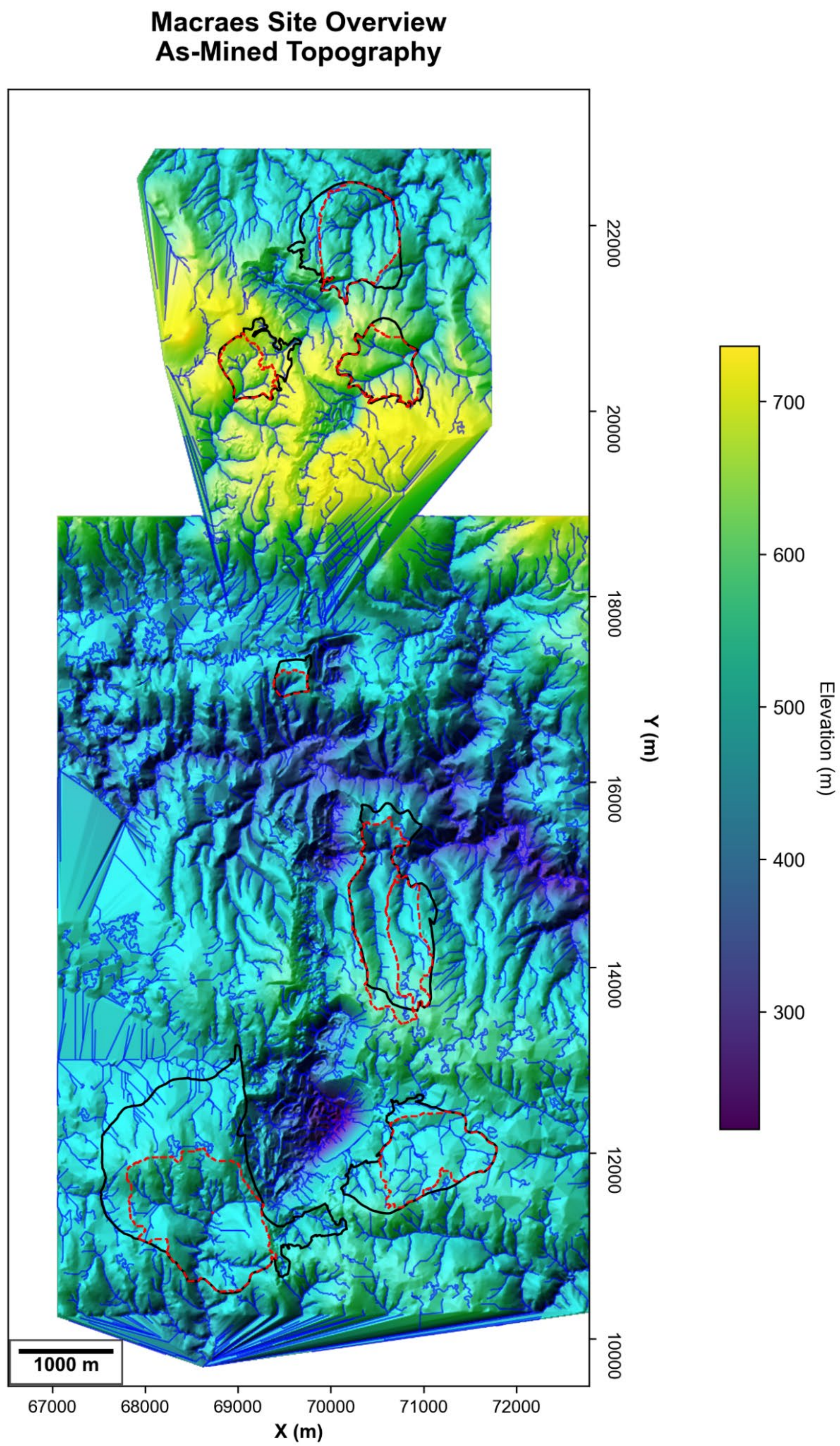

Figure 2: As-mined topography for the Macraes and Coronation area.

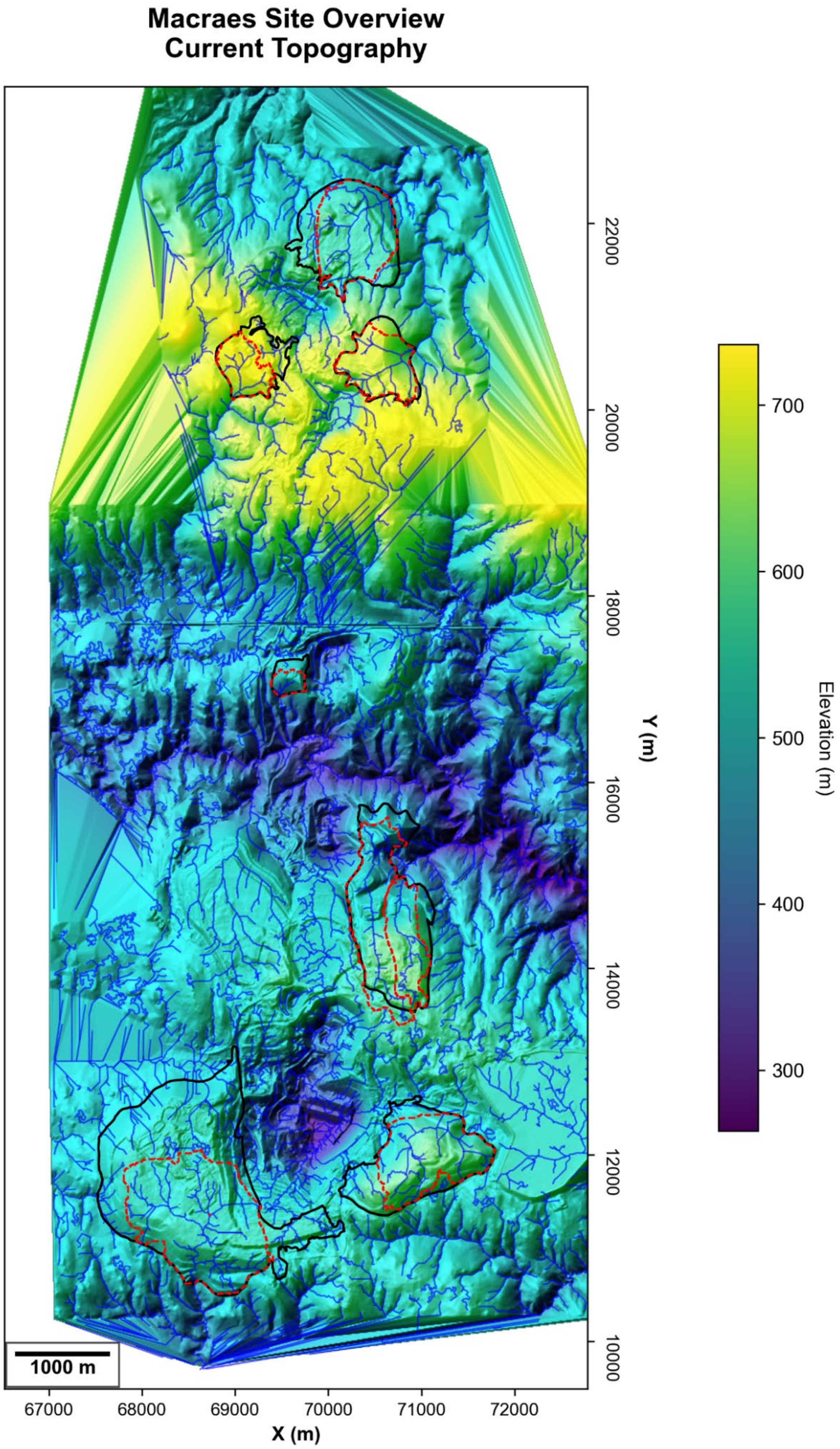

Figure 3: Current topography for the Macraes and Coronation area.

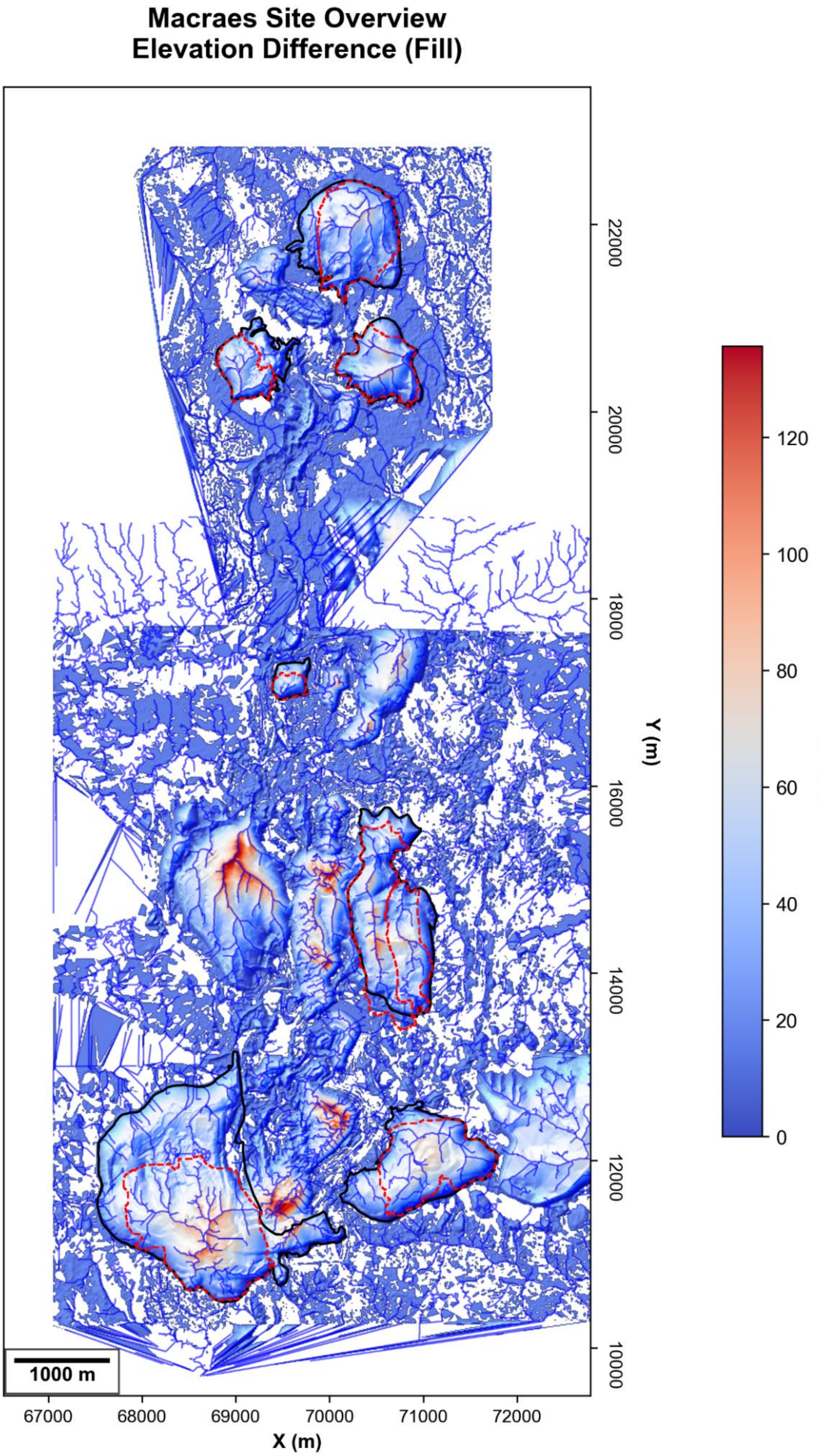

Figure 4: Elevation difference (difference >0) for the Macraes and Coronation area.

Current Volumes

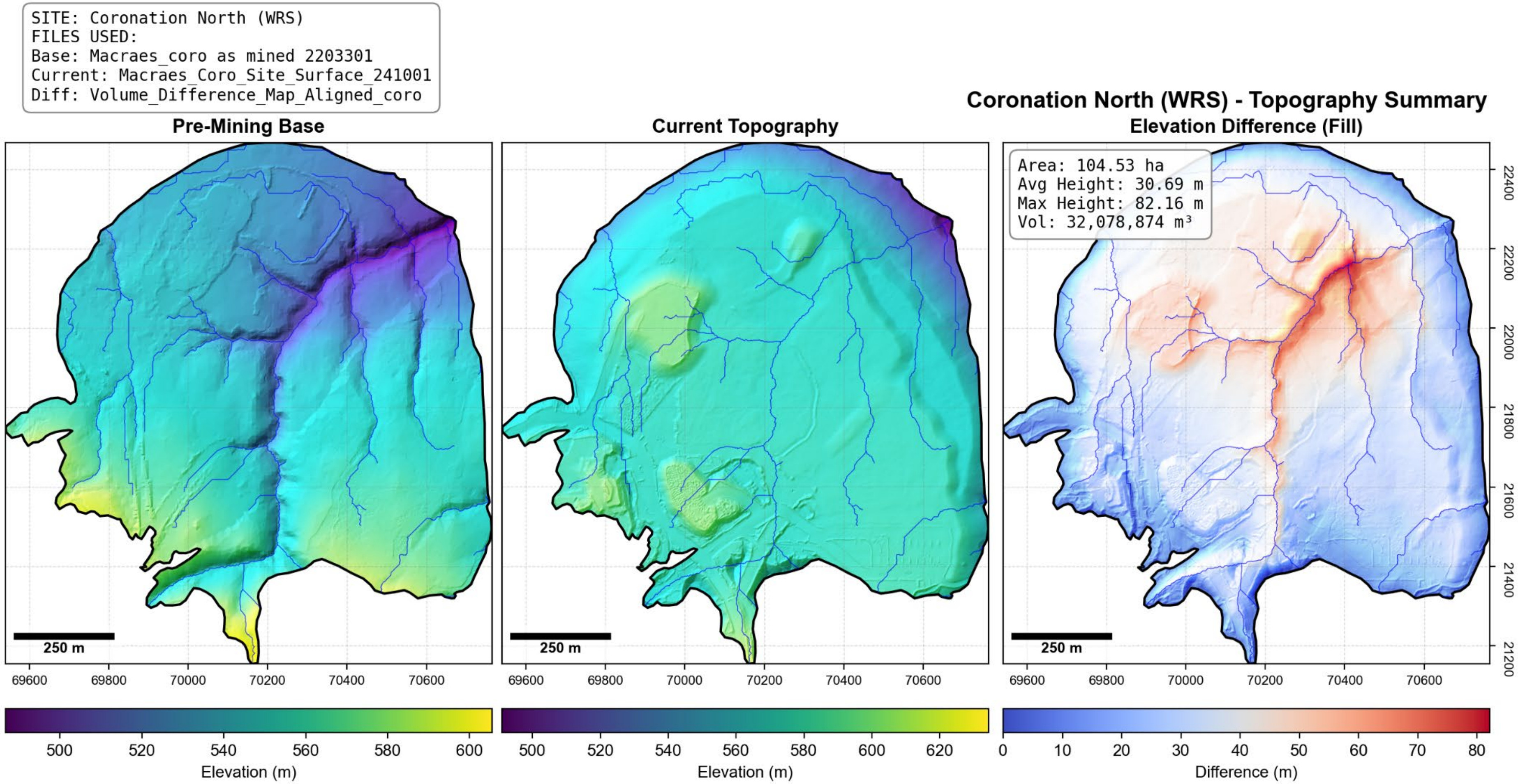

Figure 5: Coronation North – Current volume analysis for the full extent of the WRS.

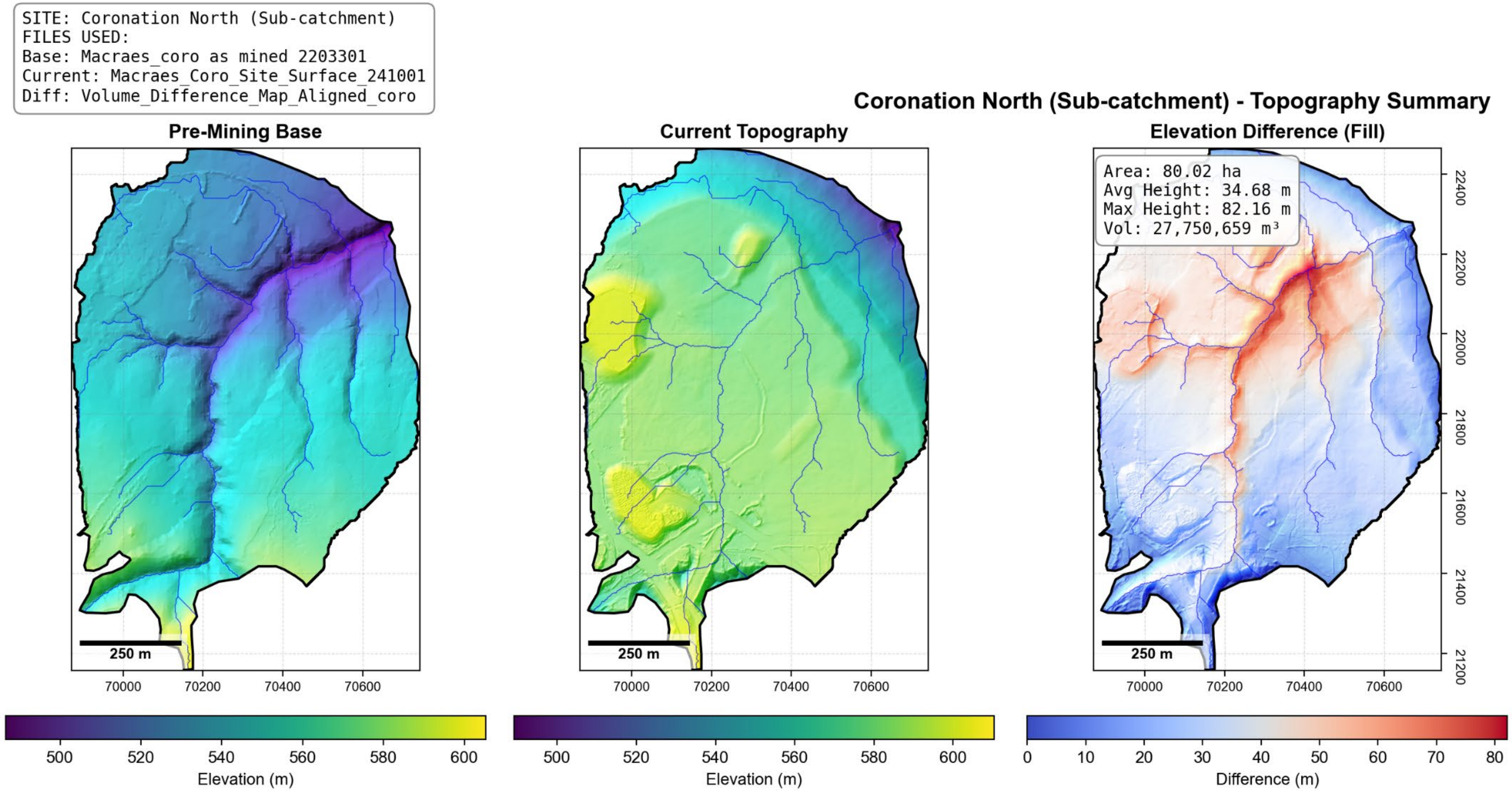

Figure 6: Coronation North volumetric distribution within the sub-catchment draining to the water monitoring location.

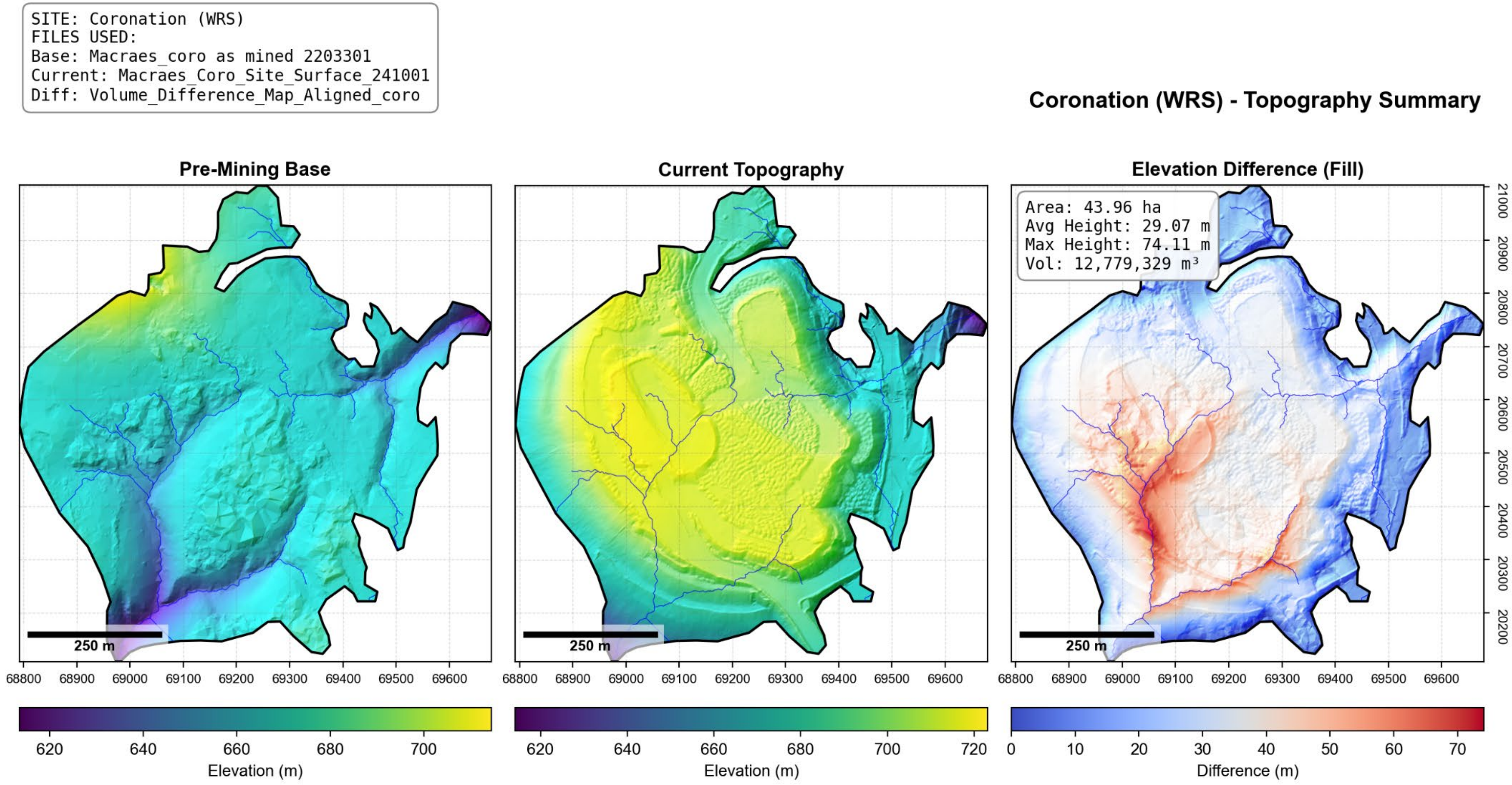

Figure 7: Coronation – Current volume analysis for the full extent of the WRS.

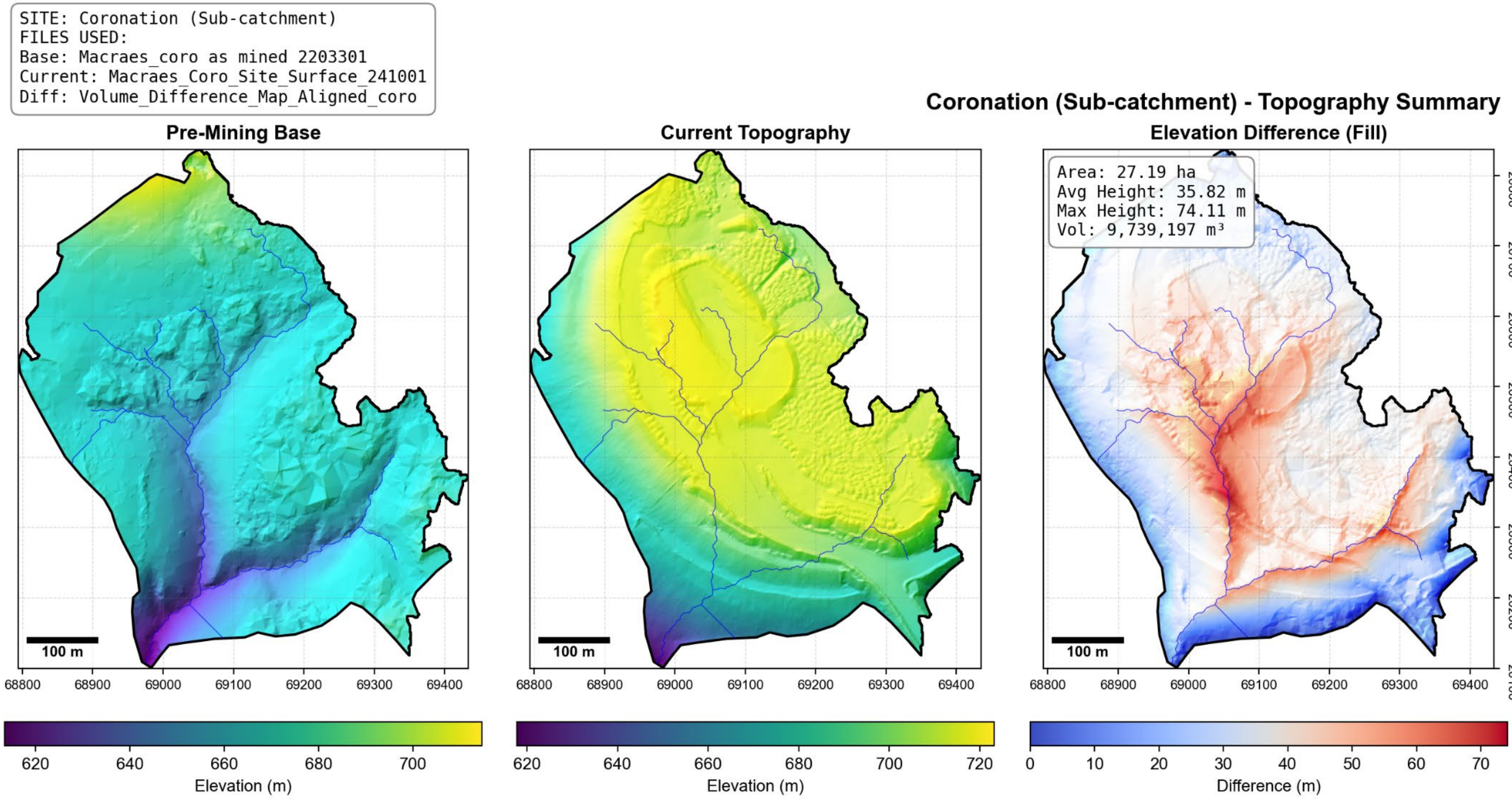

Figure 8: Coronation volumetric distribution within the sub-catchment draining to the water monitoring location.

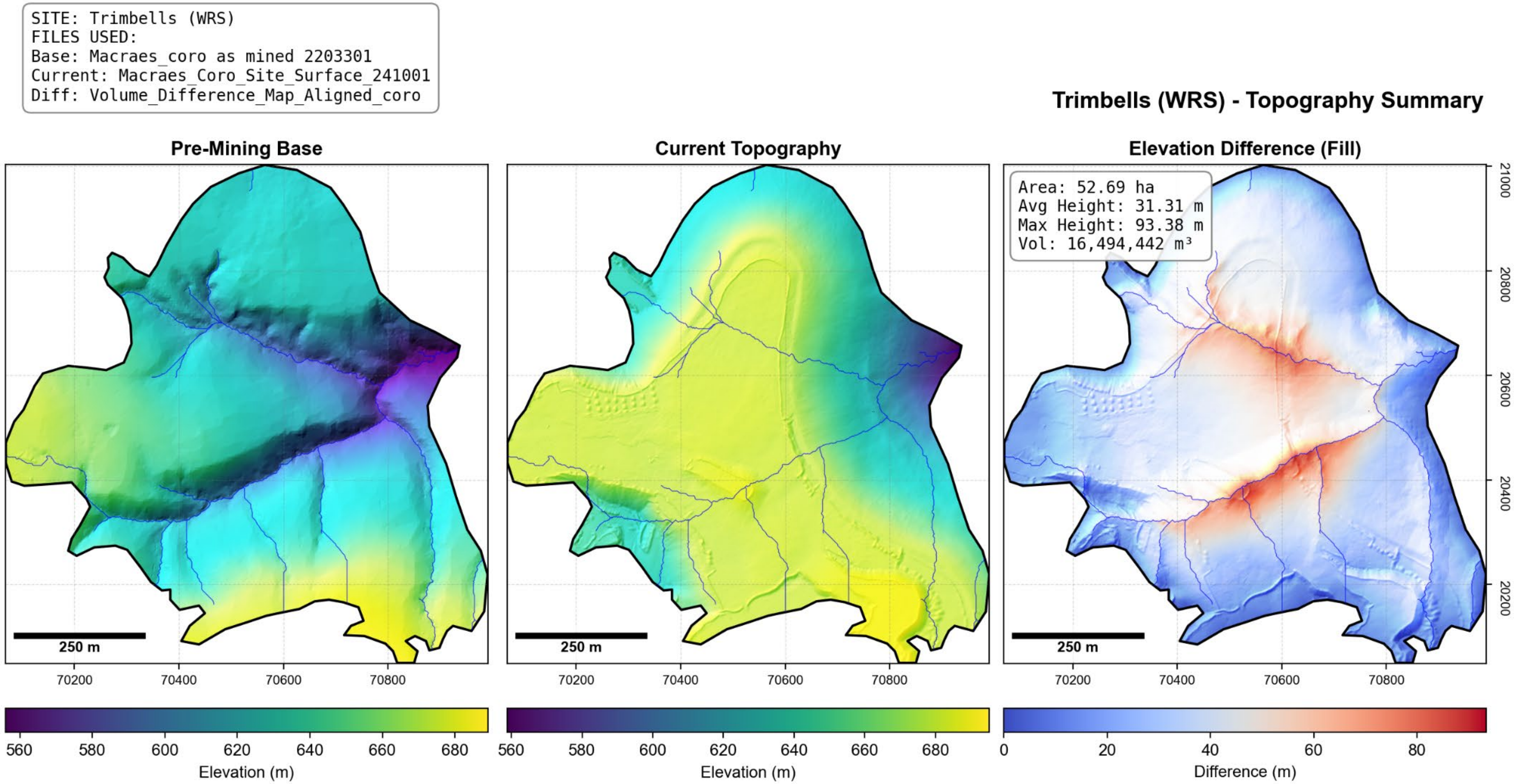

Figure 9: Trimbells – Current volume analysis for the full extent of the WRS.

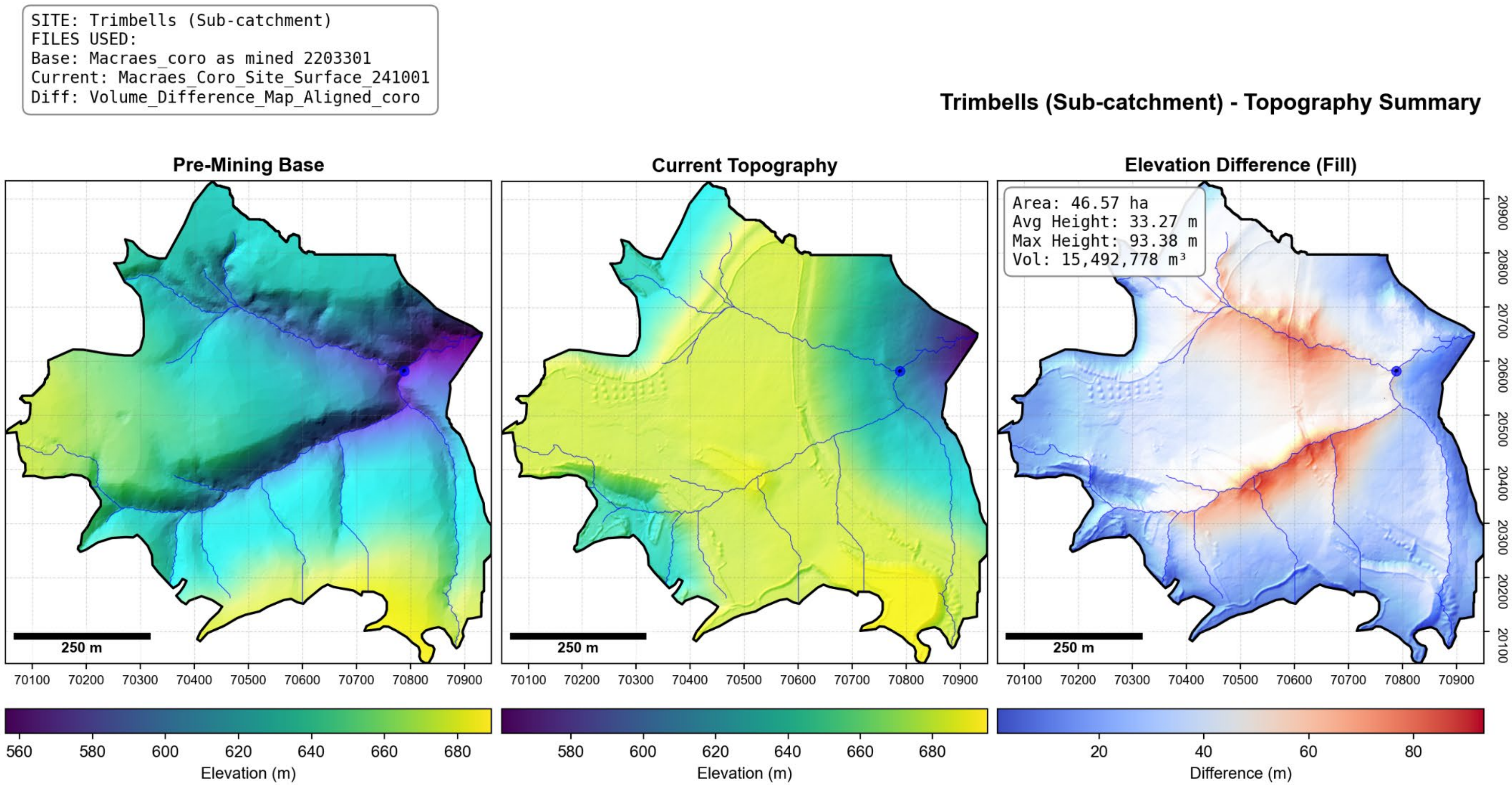

Figure 10: Trimbells volumetric distribution within the sub-catchment draining to the water monitoring location.

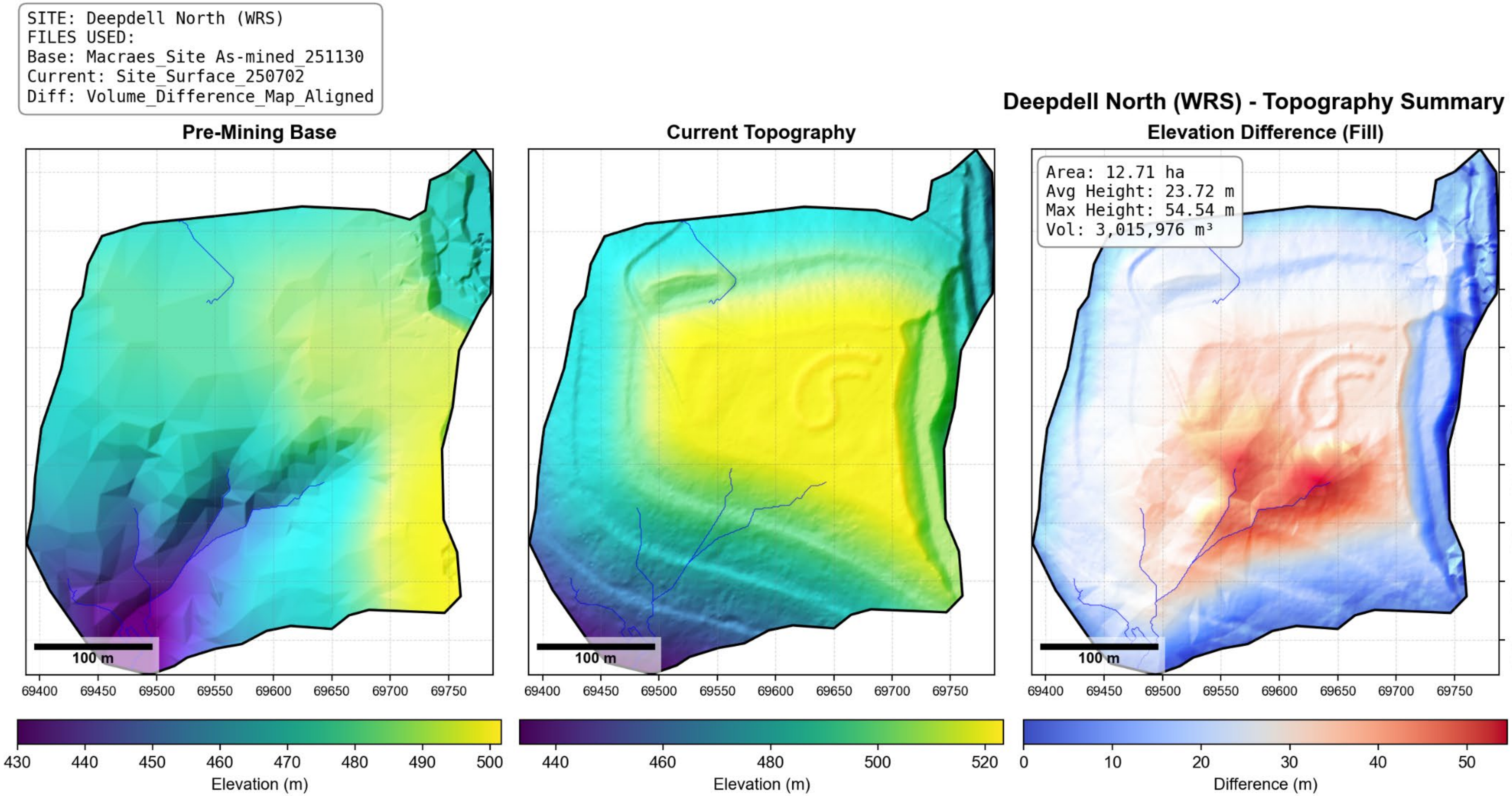

Figure 11: Deepdell North – Current volume analysis for the full extent of the WRS.

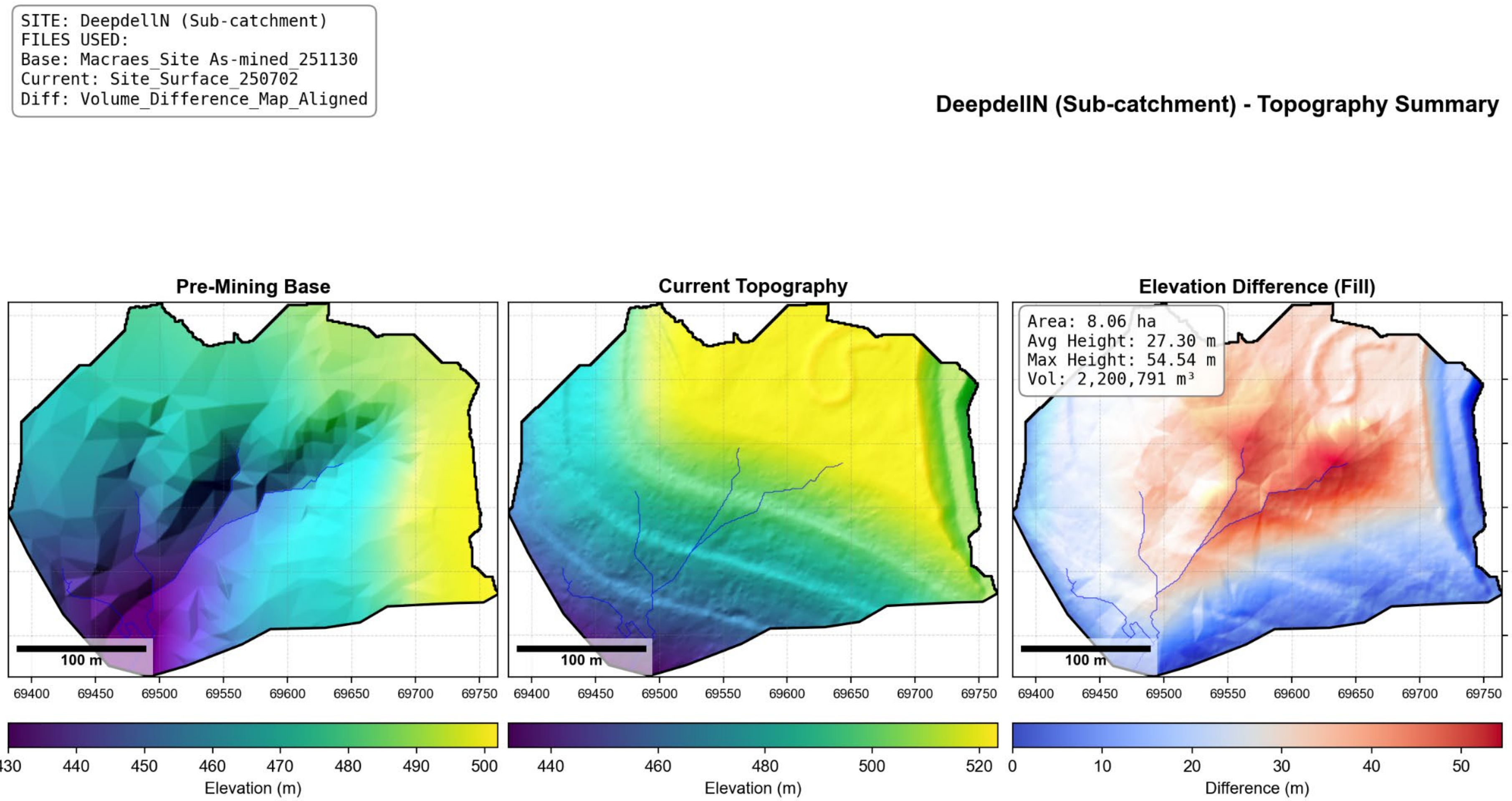

Figure 12: Deepdell North volumetric distribution within the sub-catchment draining to the water monitoring location.

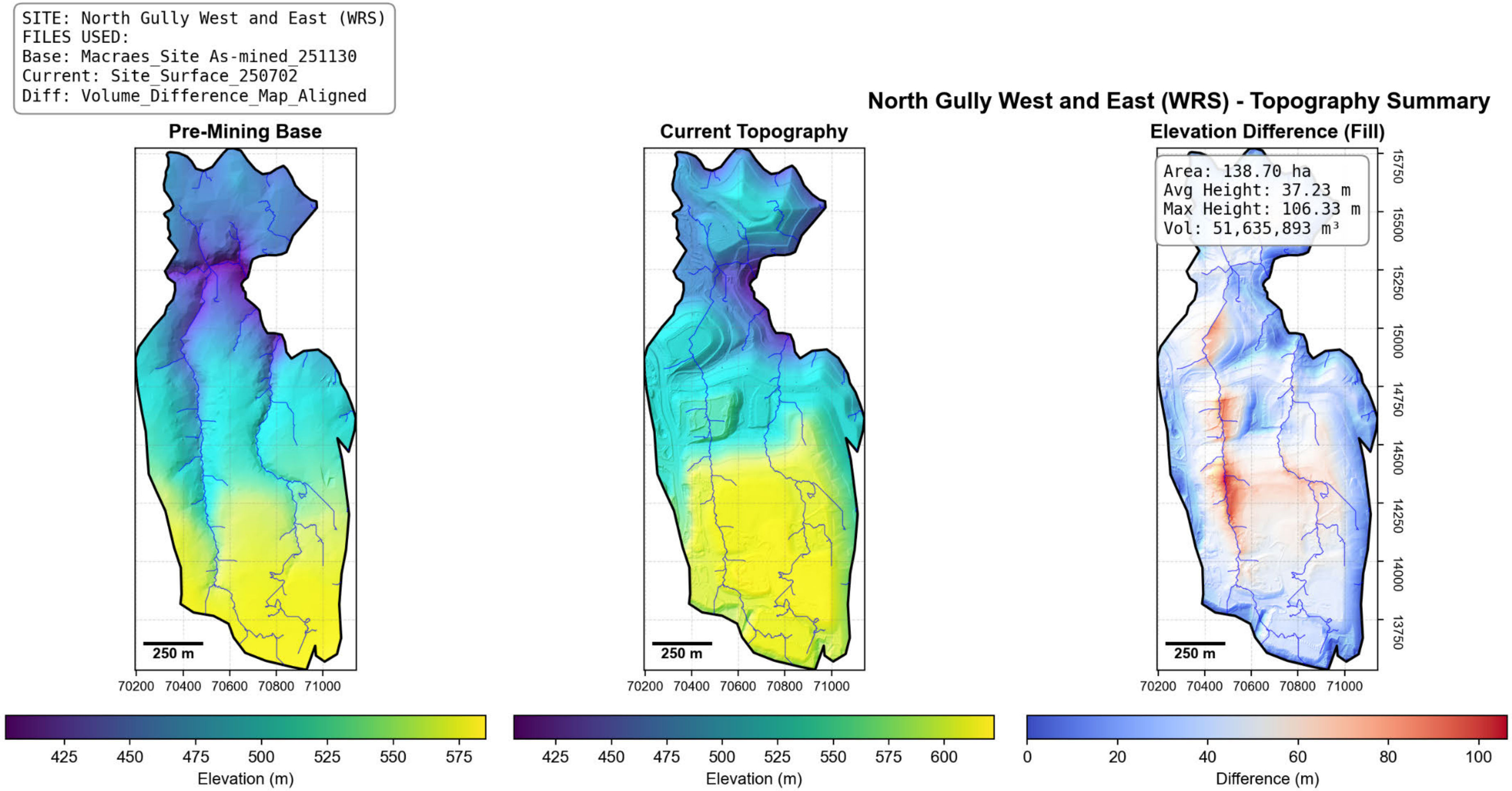

Figure 13: Northern Gully West and East – Current volume analysis for the full extent of the WRSs.

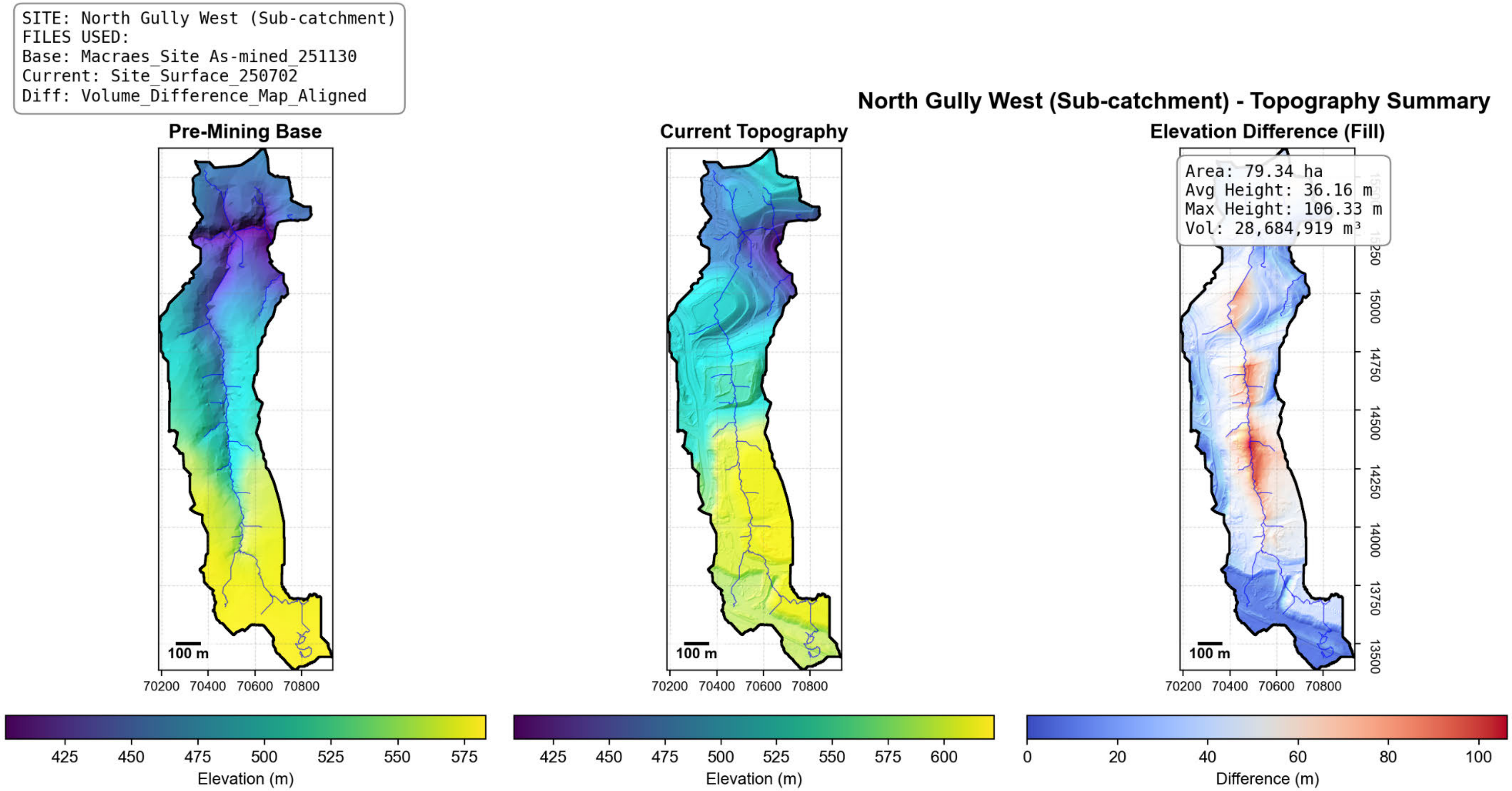

Figure 14: Northern Gully West volumetric distribution within the sub-catchment draining to the water monitoring location.

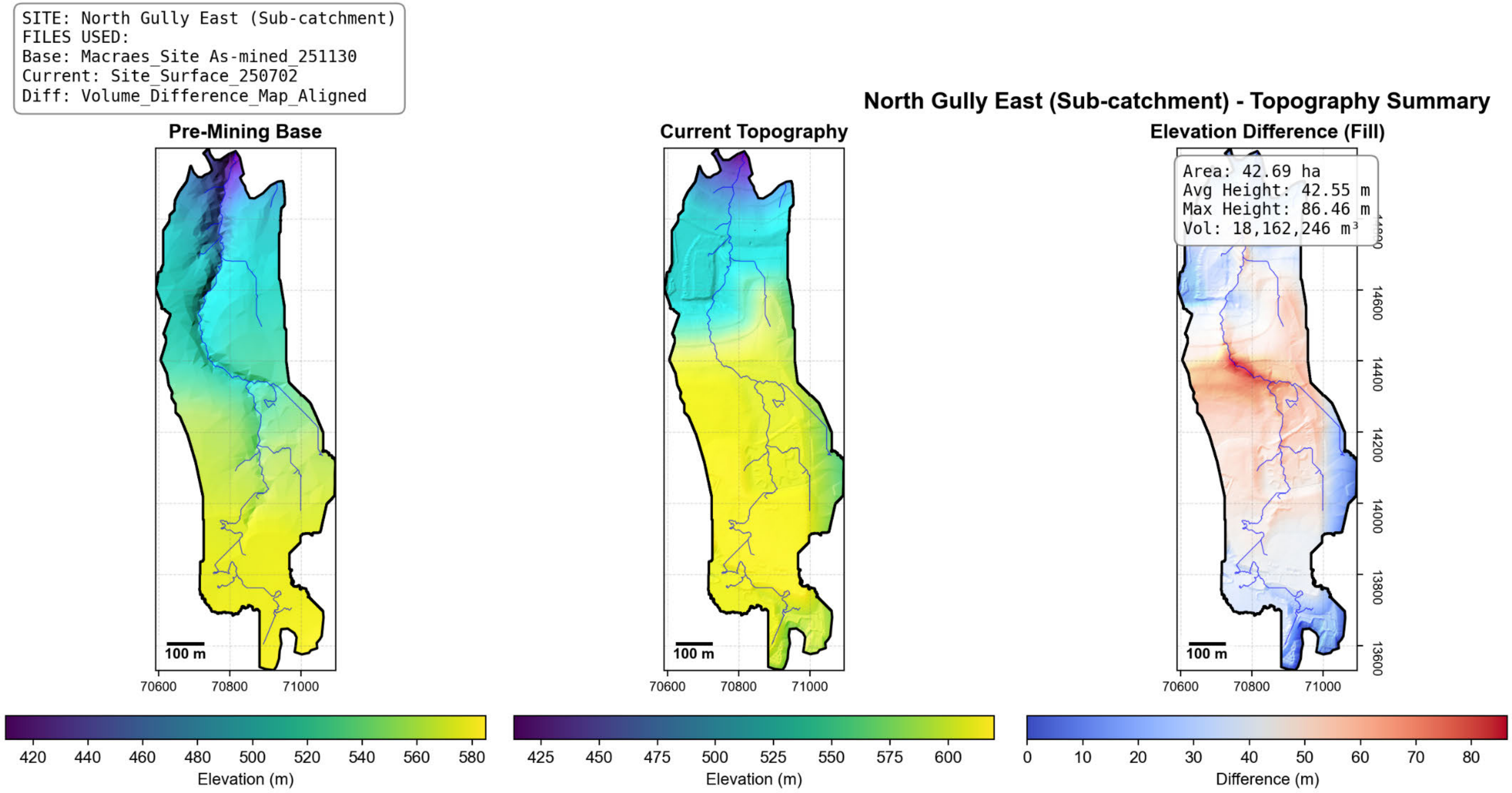

Figure 15: Northern Gully East volumetric distribution within the sub-catchment draining to the water monitoring location.

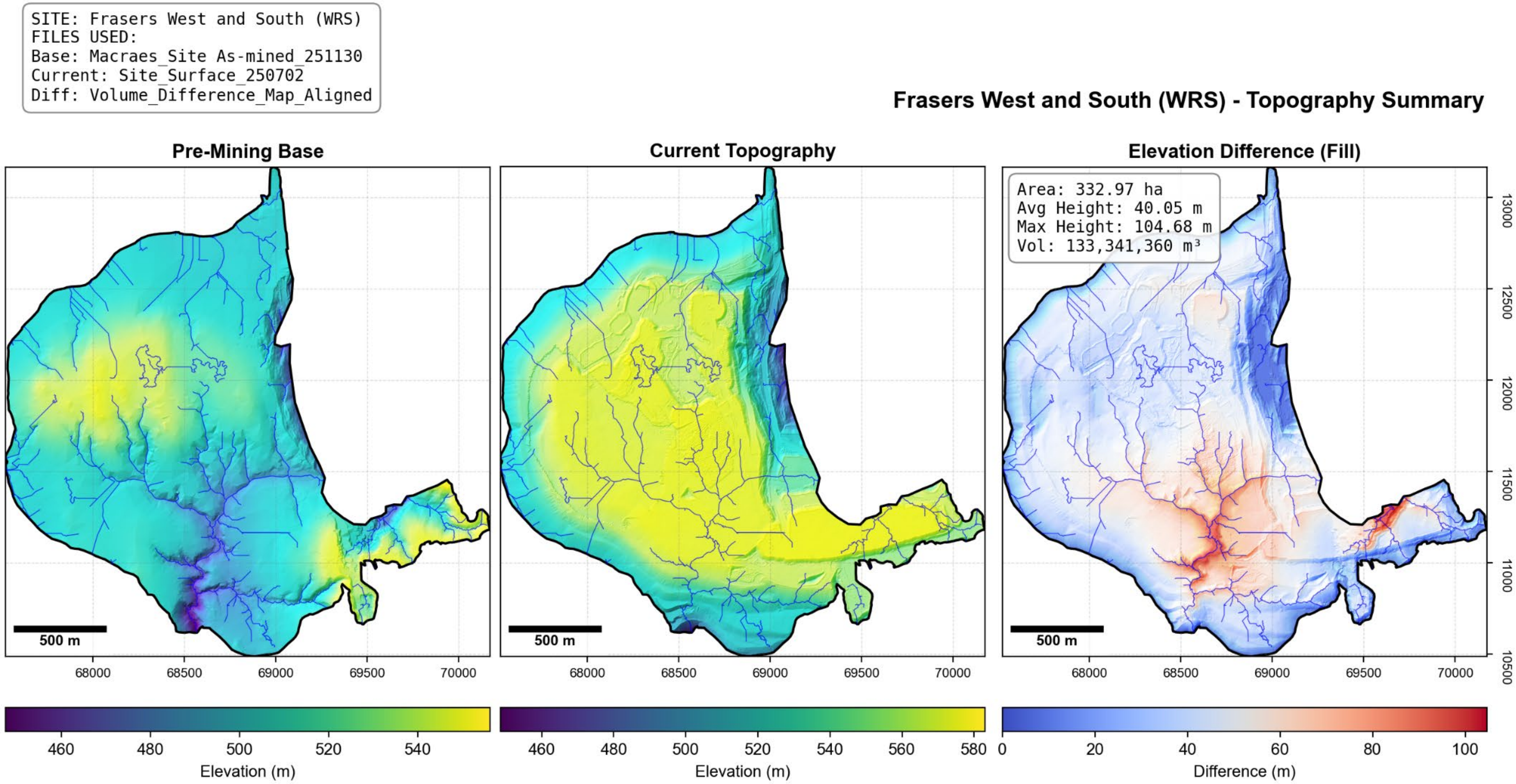

Figure 16: Frasers West and South – Current volume analysis for the full extent of the WRS.

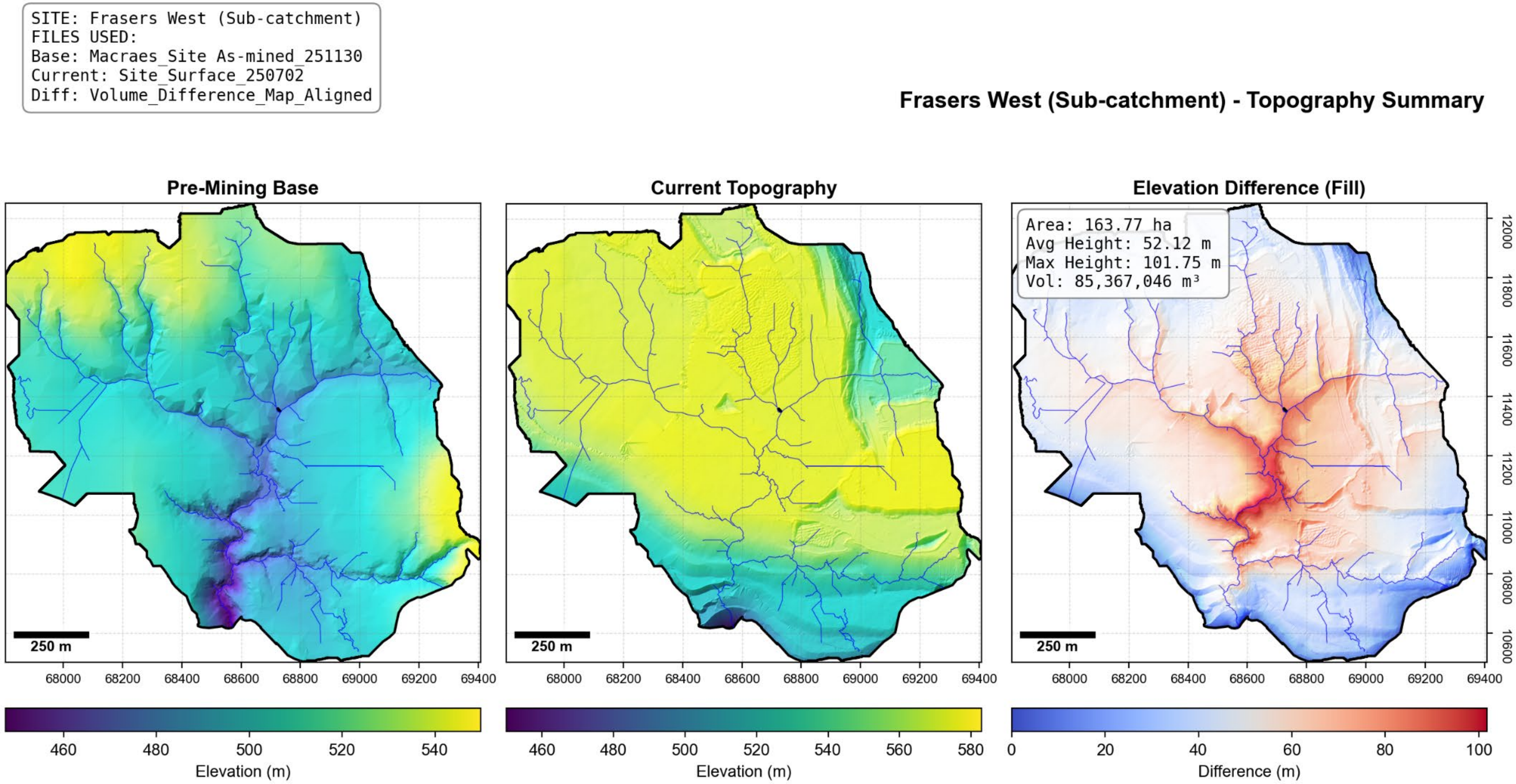

Figure 17: Frasers West volumetric distribution within the sub-catchment draining to the water monitoring location.

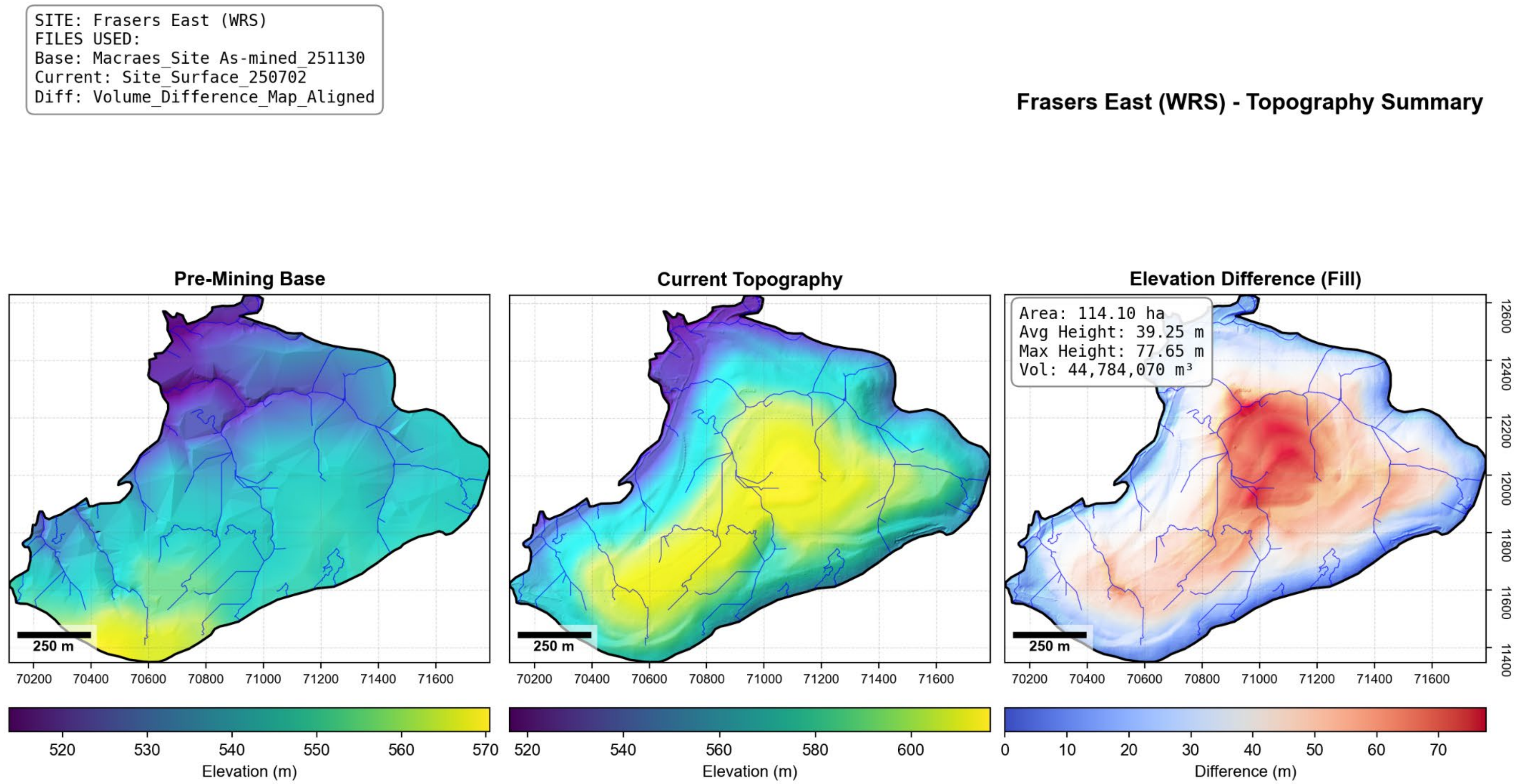

Figure 18: Frasers East – Current volume analysis for the full extent of the WRS.

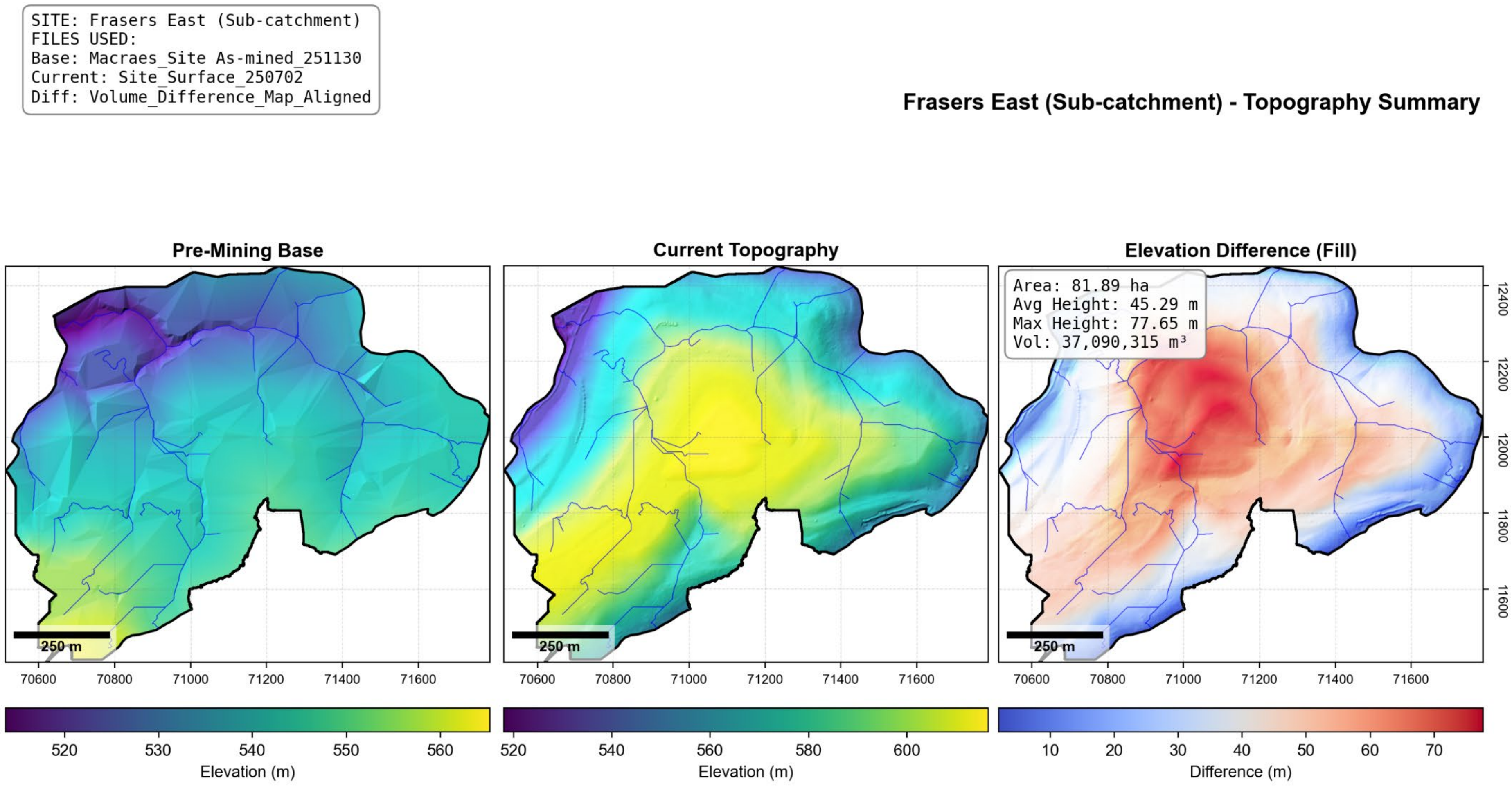

Figure 19: Frasers East volumetric distribution within the sub-catchment draining to the water monitoring location.

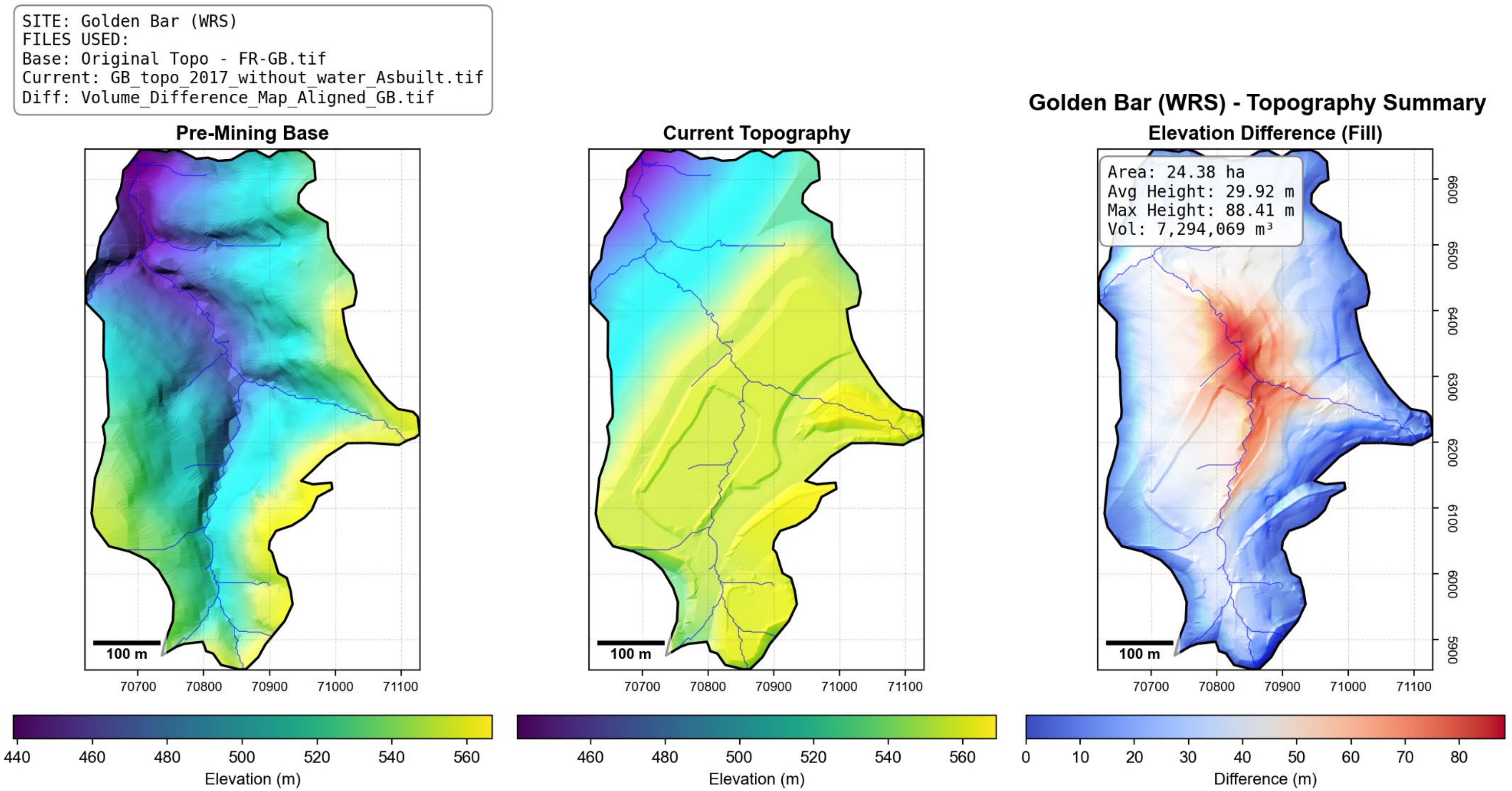

Figure 20: Golden Bar analysis of volume distributed over the full extent of the catchment (which drains completely to the water monitoring location).

Current Consented plus Mine Design (Future)

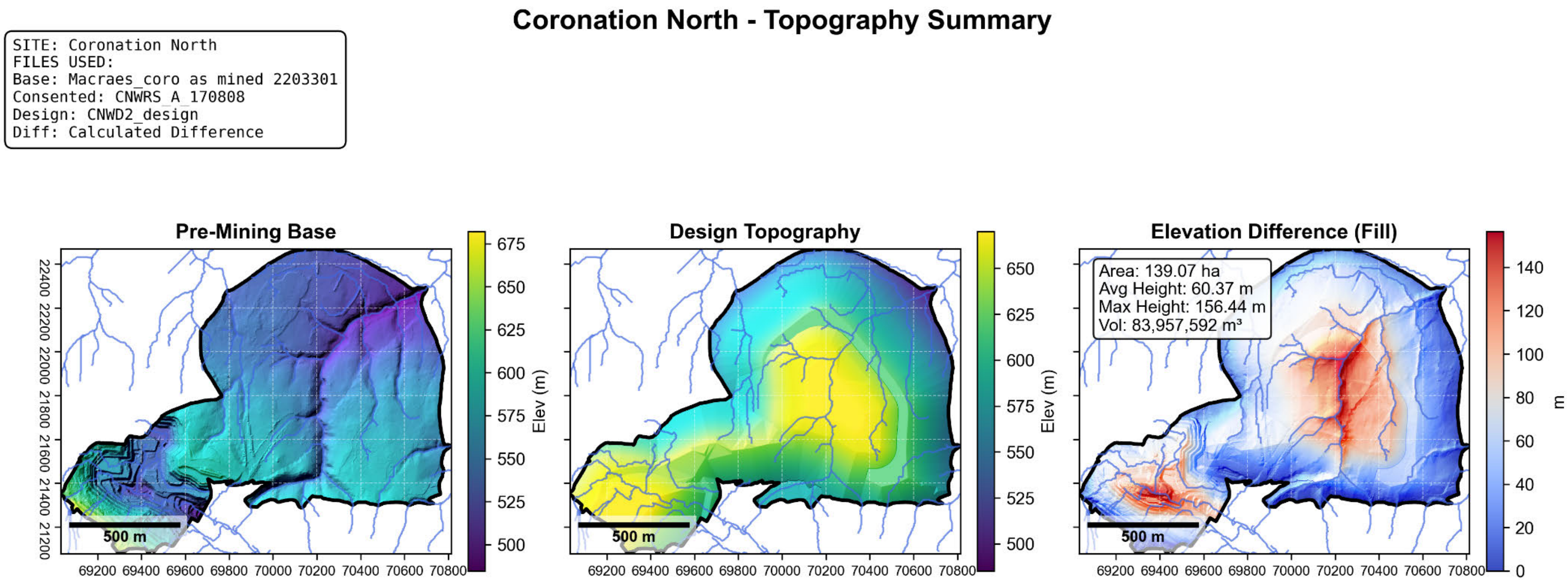

Figure 21: Coronation North – Design (MP4) volume analysis for the full extent of the WRS.

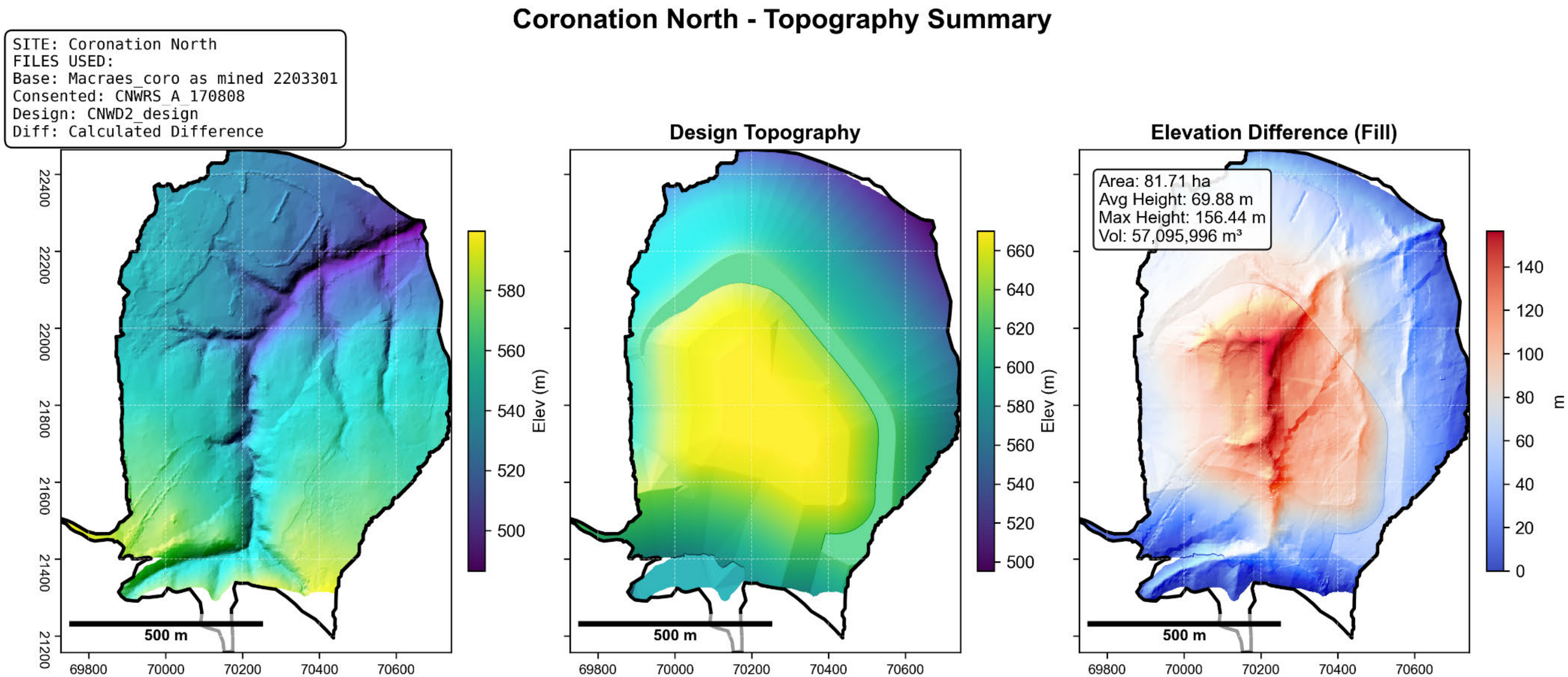

Figure 22: Coronation North – Design (MP4) analysis of volume distributed over the sub-catchment draining to the water monitoring location.

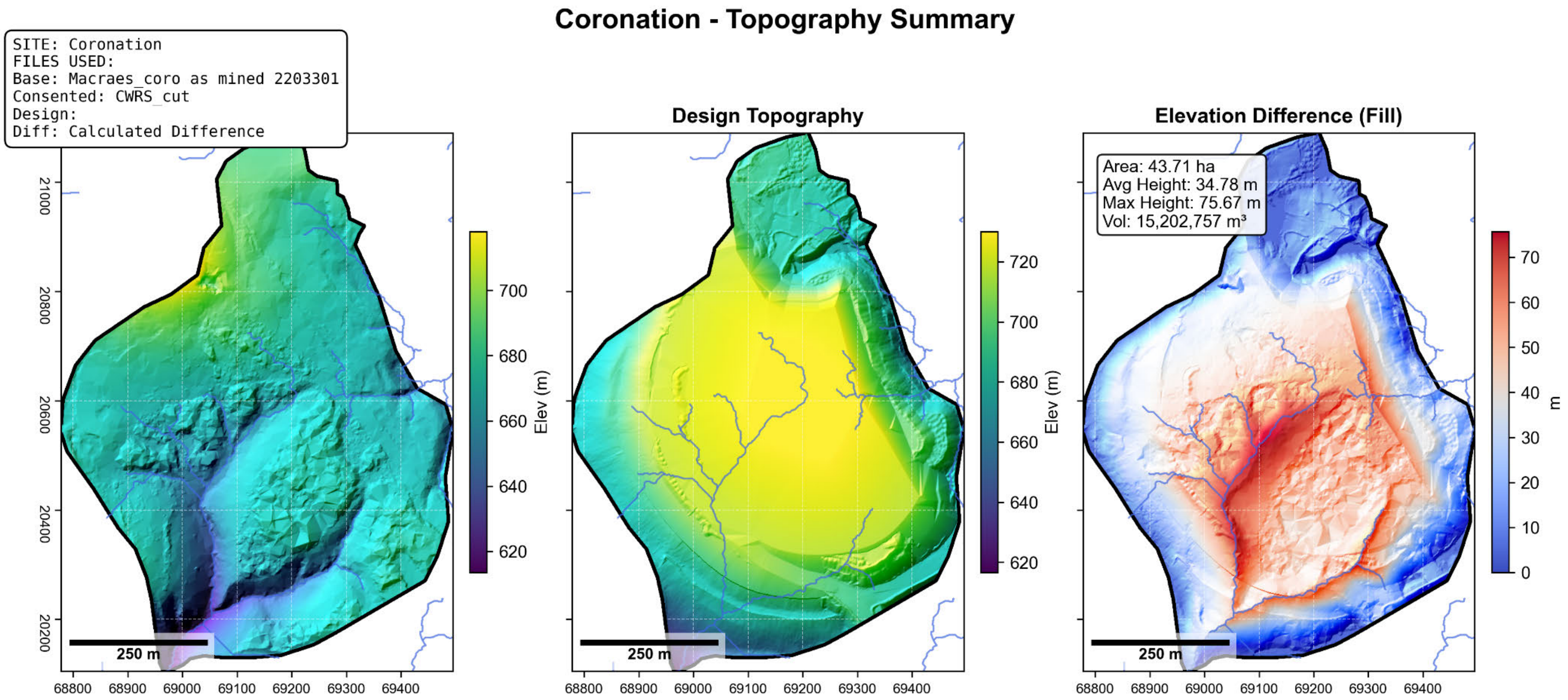

Figure 23: Coronation – Design (MP4) analysis of volume distributed over currently consented catchment (Full extent).

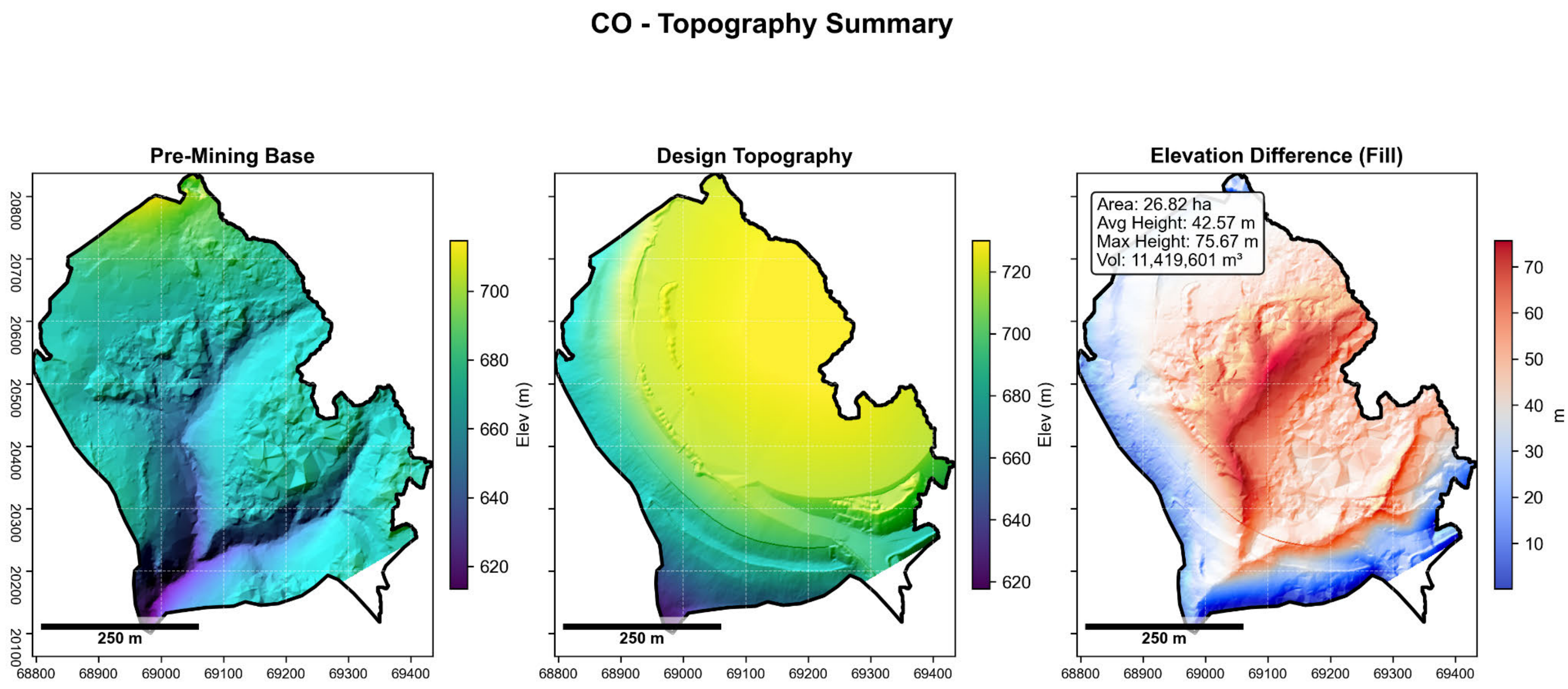

Figure 24: Coronation – Design (MP4) analysis of volume distributed over currently consented catchment draining to the water monitoring location.

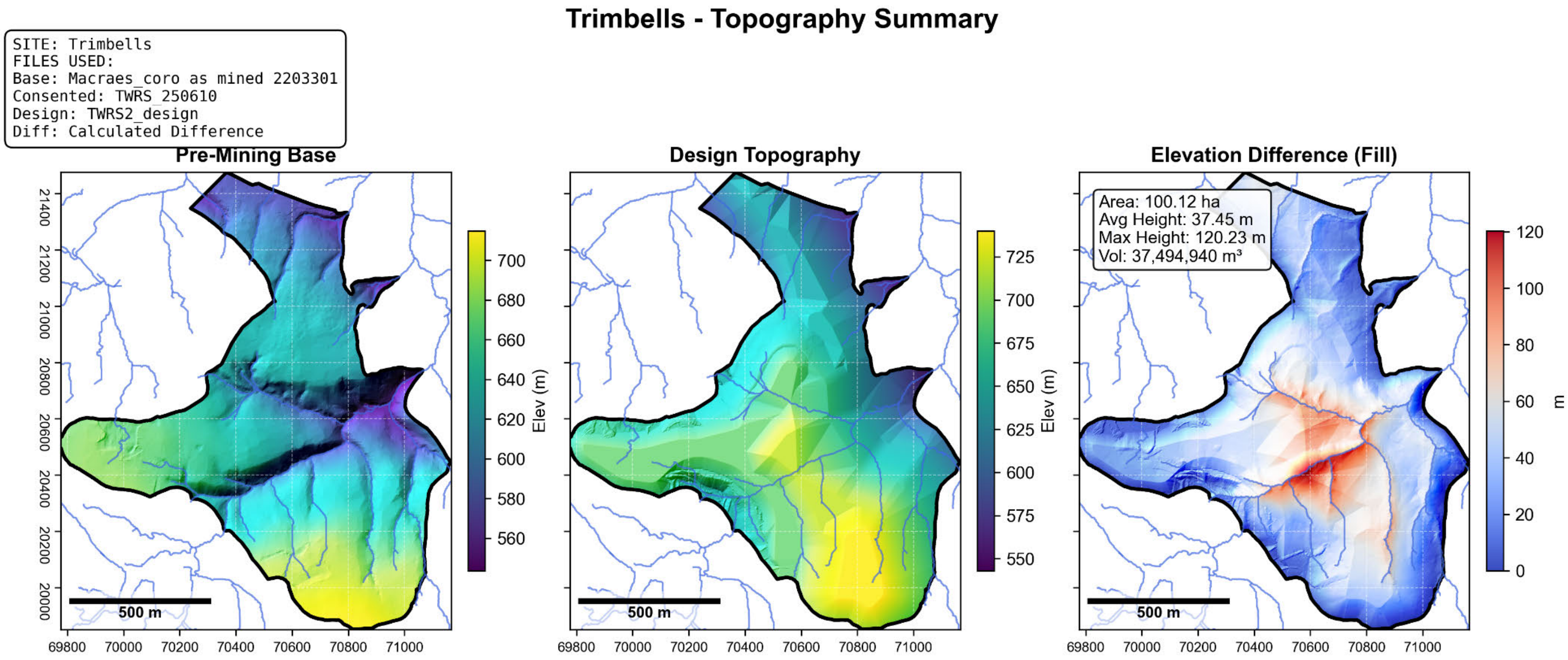

Figure 25: Trimbells – Design (MP4) volume analysis for the full extent of the WRS.

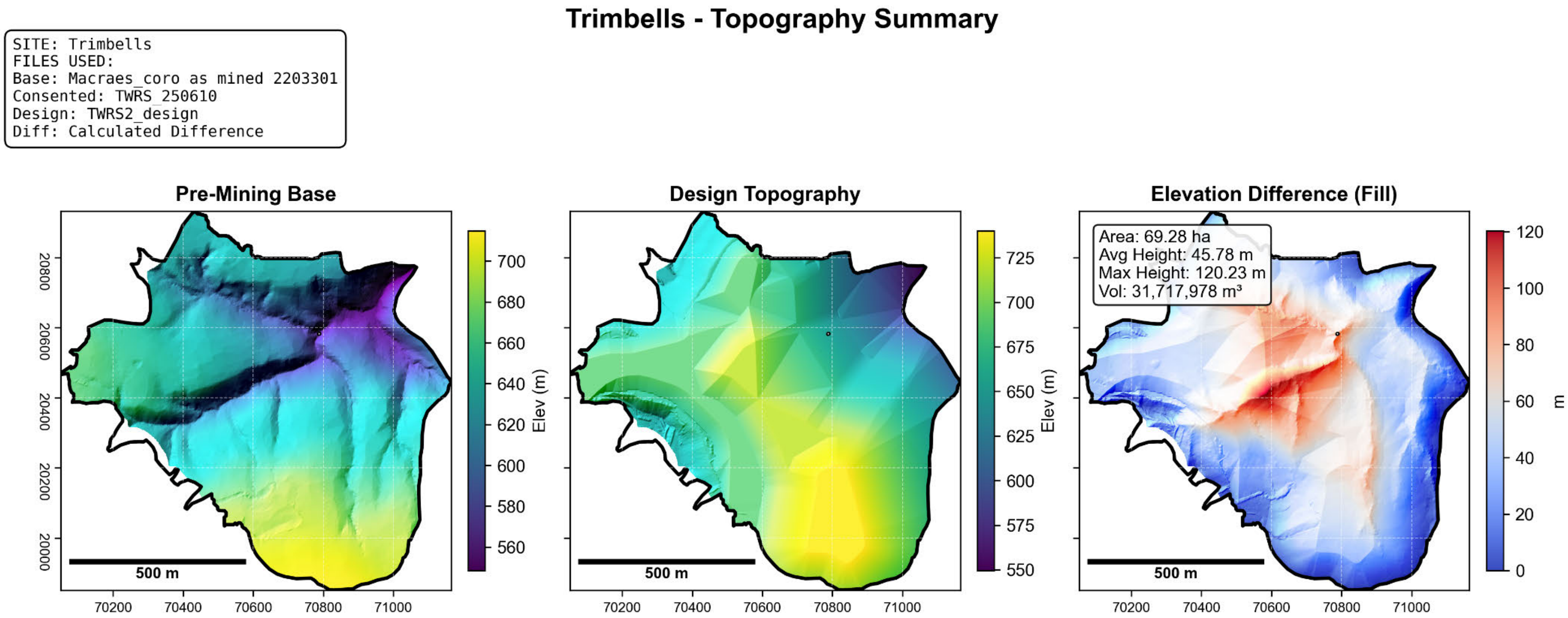

Figure 26: Trimbells – Design (MP4) analysis of volume distributed over the sub-catchment draining to the water monitoring location.

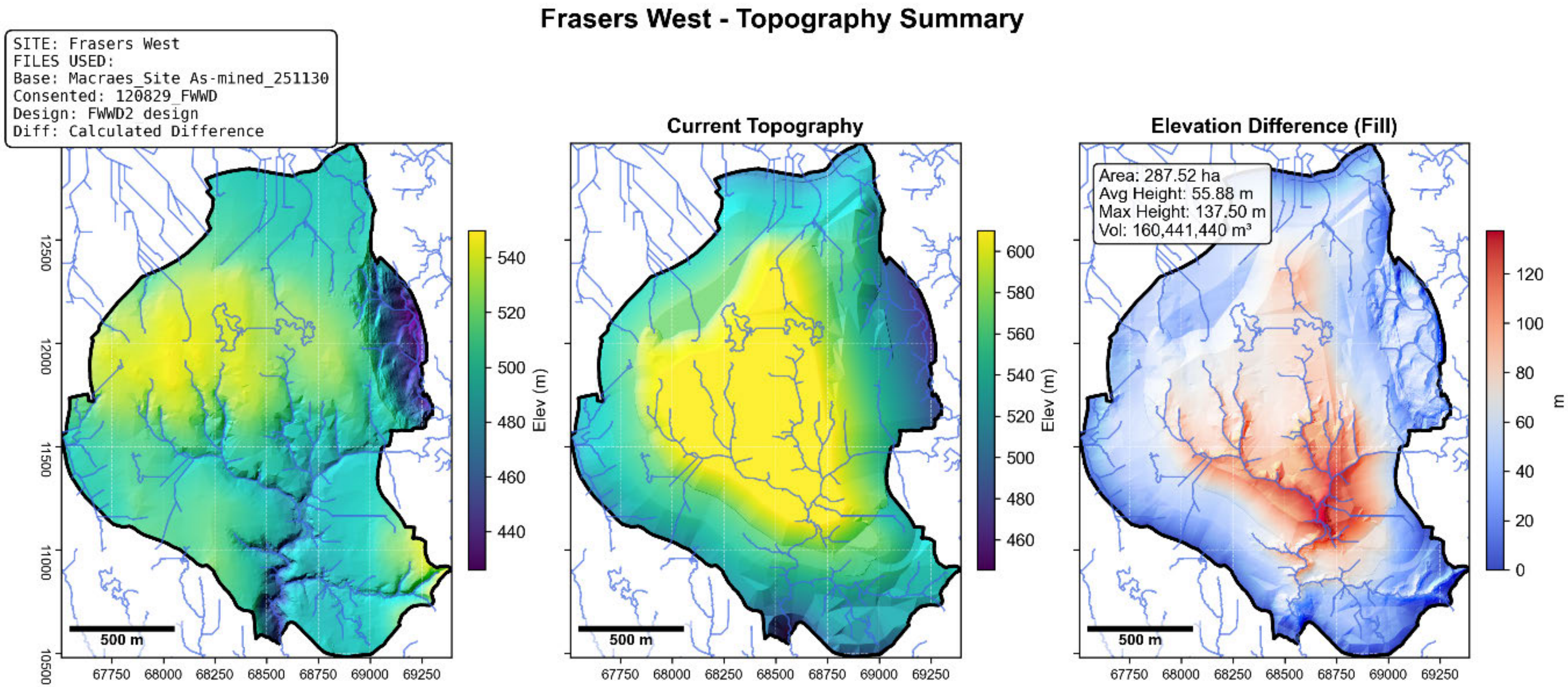

Figure 27: Frasers West – Design (MP4) volume analysis for the full extent of the WRS.

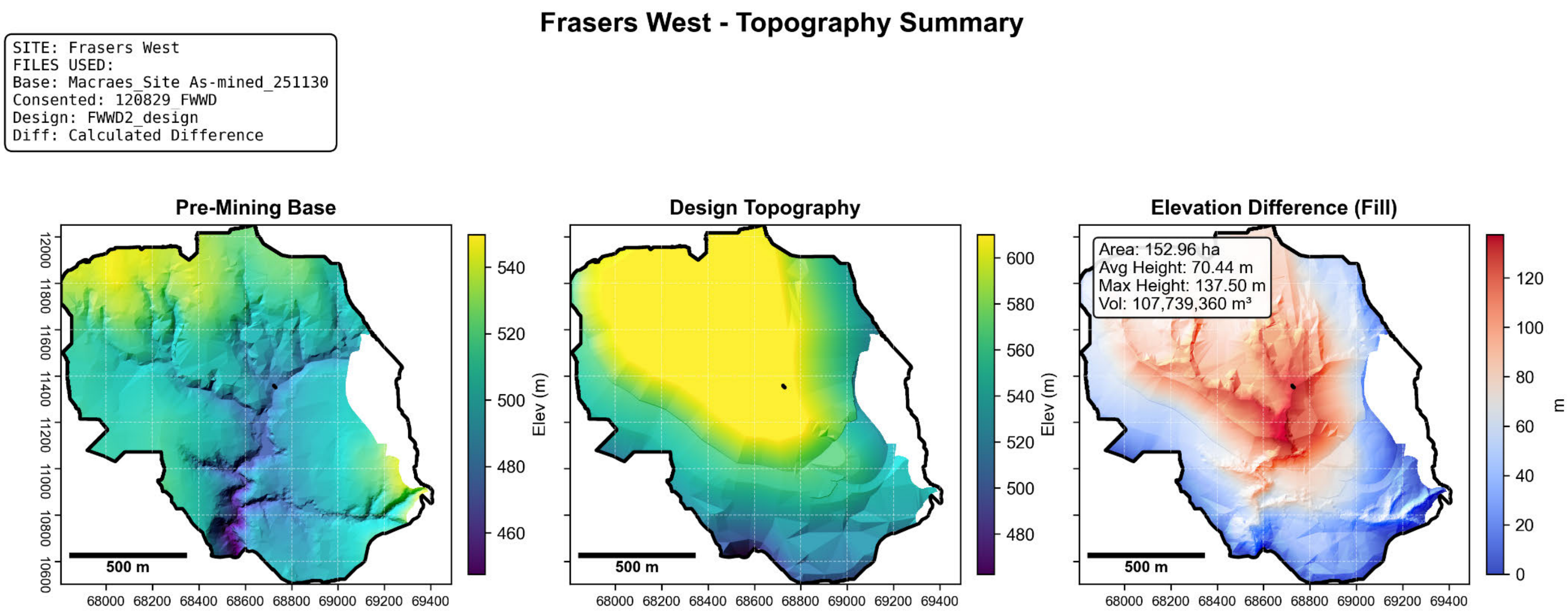

Figure 28: Frasers West – Design (MP4) analysis of volume distributed over the sub-catchment draining to the water monitoring location.

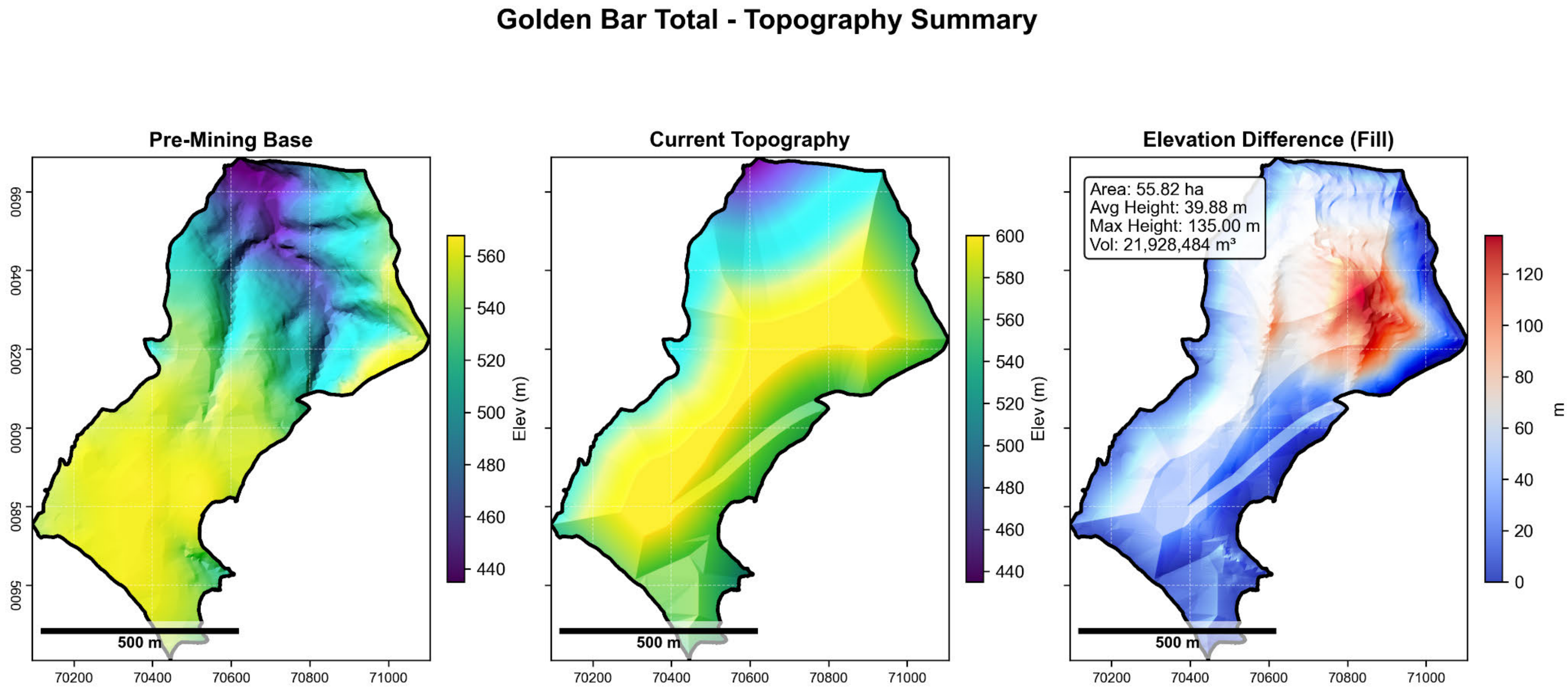

Figure 29: Golden Bar – Design (MP4) volume analysis for the full extent of the WRS.

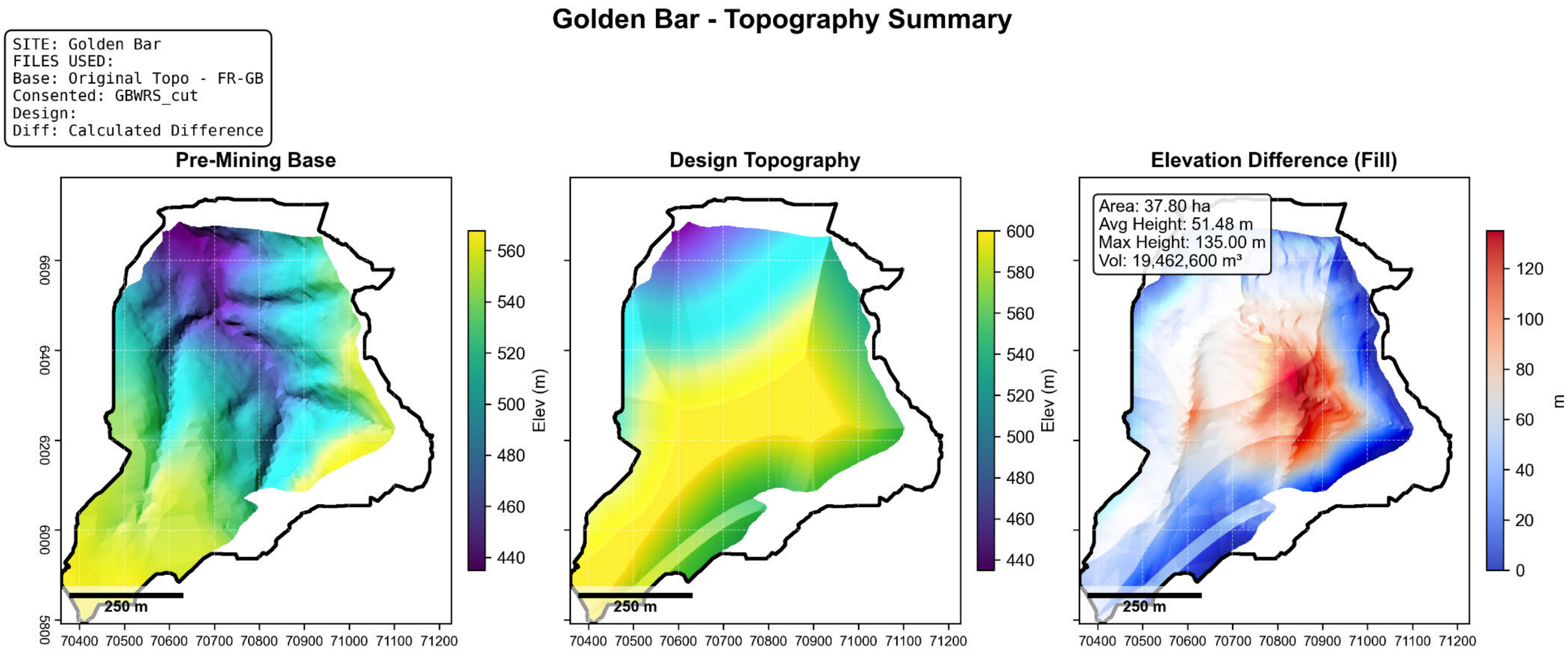

Figure 30: Golden Bar – Design (MP4) analysis of volume distributed over the sub-catchment draining to the water monitoring location.

CLOSING REMARKS

Please do not hesitate to contact Paul Weber at +[redacted] or [redacted] should you wish to discuss this memorandum in greater detail.

REFERENCES

GHD, 2026. Macraes Phase 4 FTA – Surface Water and Groundwater Assessment. 12682240-REP-REV0.

Mine Waste Management (MWM), 2026. Macraes Phase 4 Project: WRS Assessment Seepage Quality. MWM Document No: J-NZ0498-006-R-FINAL.

APPENDIX B ADAPTIVE MANAGEMENT OF ELEVATED NITRATE IN WRS SEEPAGE

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MEMORANDUM

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From:	Paul Weber – Mine Waste Management (MWM)
Date:	31 August 2026
Cc:	[redacted] – OceanaGold Carlos Hillman – Mine Closure Management; Dave Trumm – MWM
Document Number:	J-NZ0498-025-M-FINAL
Document Title:	Adaptive Management of Elevated Nitrate in WRS Seepage
Disclaimer:	This document has been produced for New Zealand consenting purposes only. Information contained herein must not be relied on for investment purposes.

Mine Waste Management Limited (MWM) has been engaged by OceanaGold (New Zealand) Limited (OGNZL) to assess environmental geochemistry hazards and potential effects for the proposed Macraes Phase Four Project (MP4 or the Project). This assessment supports the application as a Listed Project in Schedule 2 of the Fast-track Approvals Act 2024 (FTAA) a project providing significant national or regional benefits.

As part of the broader geoenvironmental hazard assessment undertaken by MWM, this memorandum provides a review of passive nitrate treatment technologies that may be applicable to nitrate management associated with existing and future waste rock stacks (WRSs) at the Macraes Operation. The review focuses on published laboratory, pilot-scale, and field-scale studies that investigate nitrate treatment performance and the factors influencing nitrate removal under a range of operating conditions. Consideration is given to treatment approaches that may be incorporated within WRSs or applied to seepage collected from WRSs.

The objectives of this review are to:

- Summarise literature on nitrate treatment performance.
- Assess the influence of hydraulic residence time (HRT), carbon availability, temperature, and other key design parameters on nitrate removal performance.
- Review the findings of previous Macraes-specific nitrate treatment studies completed by Verum Group (Verum).
- Evaluate the potential application of in-dump treatment systems and gravel bed bioreactors for nitrate treatment at the Macraes Operation.
- Develop a defensible range of nitrate treatment efficiencies for conceptual assessment and modelling of existing and future WRS developments.

BACKGROUND

Nitrate Occurrence in Waste Rock Stack Seepage

Nitrate is observed in WRS seepage at the Macraes Operation due to the use of ammonium nitrate-based explosives during mining operations. Residual nitrogen compounds are subsequently mobilised by infiltrating water to discharge as either basal or toe seepage from WRSs. As nitrate concentrations can exceed background concentrations, nitrate management has been identified as a key consideration for further WRS construction and future expansions.

Potential Natural Nitrate Attenuation at Coronation Waste Rock Stack

Coronation WRS was identified for further review as monitoring data suggested nitrate concentrations may be behaving differently to those observed at other monitored WRS at the Macraes Operation. Over 10 years of monitoring (23 September 2015 to 1 October 2025), NOx[1] concentrations remained relatively low and typically not greater than 2 mg/L over the monitoring period (Figure 1).

Relationships between NOx, sulfate, and electrical conductivity (EC) were subsequently evaluated to assess whether nitrate concentrations respond similarly to other key WRS water quality parameters (Figure 2). Weak positive relationships were observed between NOx and sulfate concentrations (R^2 = 0.117) and between NOx and EC (R^2 = 0.128) suggesting a different response for NOx in Coronation WRS compared to the other WRS at the Macraes Operation where there is a stronger relationship between NOx and sulfate or EC (e.g., Trimbells WRS, Figure 3).

Although the available data do not confirm the mechanism responsible, the comparatively low NOx concentrations and weak relationships between NOx and sulfate and EC, relative to those observed at other monitored WRS at the Macraes Operation, suggest that nitrate attenuation processes may be occurring. Site staff have indicated that vegetation and organic matter may have been buried beneath portions of Coronation WRS during construction (i.e., the clearing of wilding pines). The presence of buried organic carbon may provide conditions favourable for denitrification and could potentially be contributing to the comparatively low nitrate concentrations observed in seepage from the Coronation WRS.

This may have important implications for future WRS developments because it indicates that engineered systems designed to promote similar carbon-driven nitrate removal processes may provide an opportunity to reduce nitrate concentrations in seepage from future WRS expansions. The following sections review passive nitrate treatment technologies and previous Macraes-specific studies to assess the applicability of these concepts to future WRS developments, including Golden Bar and Trimbles WRSs.

[1] *NOx = NO_3 + NO_2*

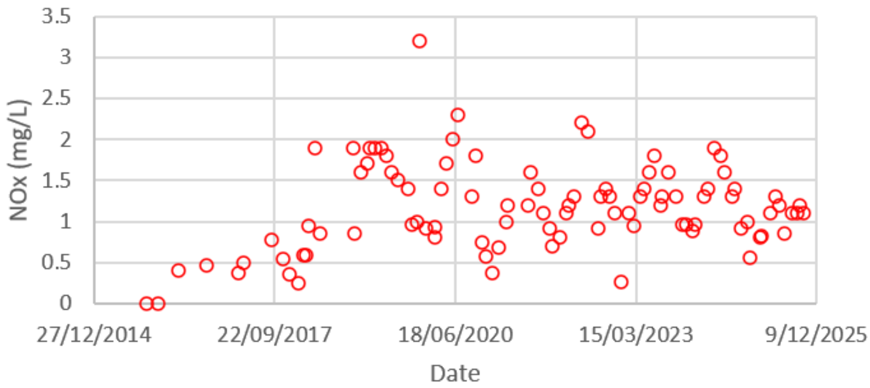
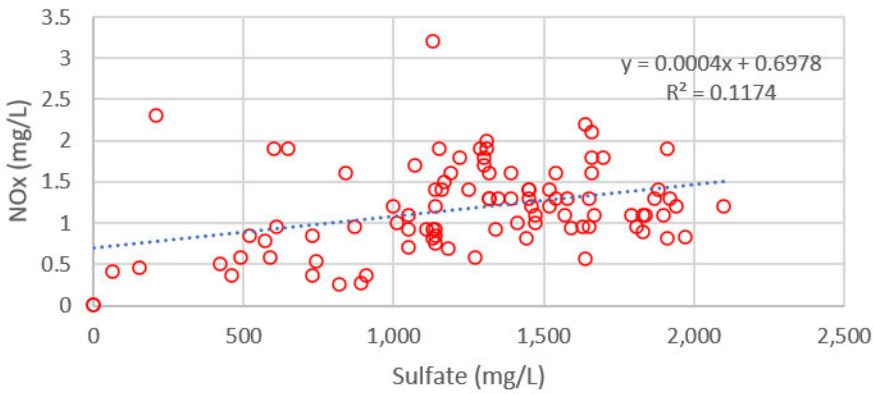


Figure 1: Coronation WRS NOx concentrations timeseries plots.



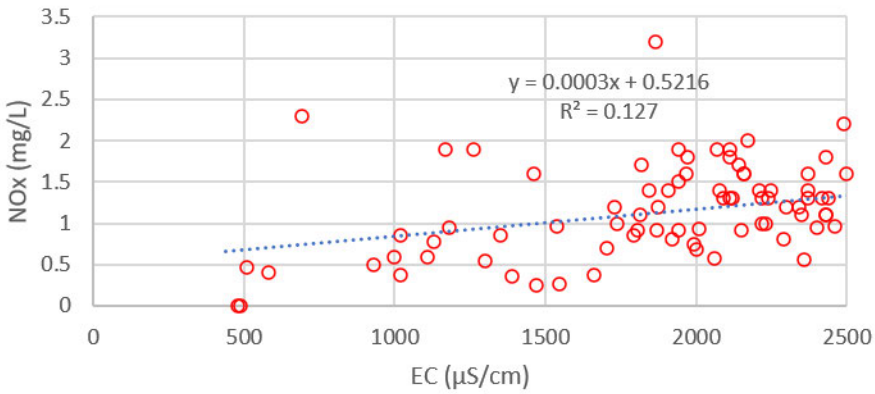


Figure 2: Coronation WRS NOx concentrations vs sulfate and EC.

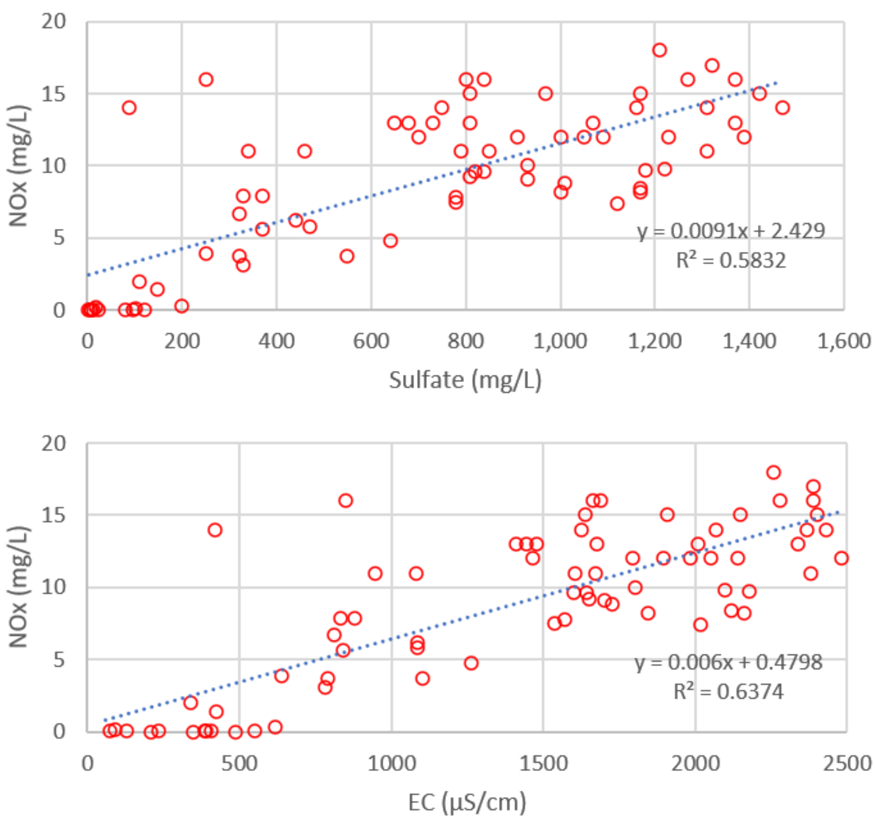


Figure 3: Trimbells WRS NOx concentrations vs sulfate and EC.

REVIEW OF APPLICABLE TREATMENT SYSTEMS

The following sections review passive nitrate treatment technologies that have been applied to agricultural, municipal, and mine-influenced waters and may be applicable for nitrate management at the Macraes Operation. The review includes woodchip bioreactors, carbon-amended treatment systems, enhanced passive treatment systems (E-PTS), and gravel bed bioreactors (GBBRs). Published laboratory, pilot-scale, and field-scale studies were reviewed to evaluate nitrate removal mechanisms, treatment performance, HRT requirements, and long-term operational considerations relevant to future WRS nitrate treatment applications.

Woodchip Bioreactors and Denitrification Walls

Burbery et al. (2020) evaluated a field-scale woodchip denitrification wall at Silverstream Reserve (North Canterbury, New Zealand) to assess nitrate treatment performance in a highly permeable gravel aquifer. The wall was constructed perpendicular to groundwater flow and comprised a 25 m long, 5 m wide, and 3 m deep trench backfilled with a 50:50 mixture of *Pinus radiata* woodchip and gravel. Key design and performance parameters included:

- Mean HRT of 41 to 49 hours (1.7 to 2.0 days).
- Groundwater flow through the wall of ~179 to 195 m^3/day.
- Influent nitrate (as N) concentrations ranging from 7.1 to 8.8 mg/L.
- Nitrate removal efficiencies ranging from 93 to 100%.

- Estimated removal of 458 to 575 kg N during the first year of operation.

Figure 4 shows groundwater chemistry measured up-gradient, within, and down-gradient of the denitrification wall. Key observations include:

- Elevated dissolved organic carbon (DOC) concentrations within the woodchip wall, indicating release of organic carbon from the woodchip substrate.
- Dissolved oxygen (DO) concentrations decreasing from 1 - 3 mg/L up-gradient to near-zero within the wall.
- Nitrate (as N) concentrations decreasing from 7 - 8 mg/L up-gradient to near-zero within and down-gradient of the wall.
- Nitrate removal remaining between 93 and 100% during the first year of operation.

The Silverstream study reported nitrate removal efficiencies of 93 to 100% at HRTs of approximately two days. The observed increase in DOC, reduction in DO, and near-complete removal of nitrate demonstrate the conditions required to support denitrification within woodchip-based treatment systems. The study also highlights the importance of achieving sufficient residence time, with high nitrate removal occurring at HRTs of approximately 1.7 to 2.0 days.

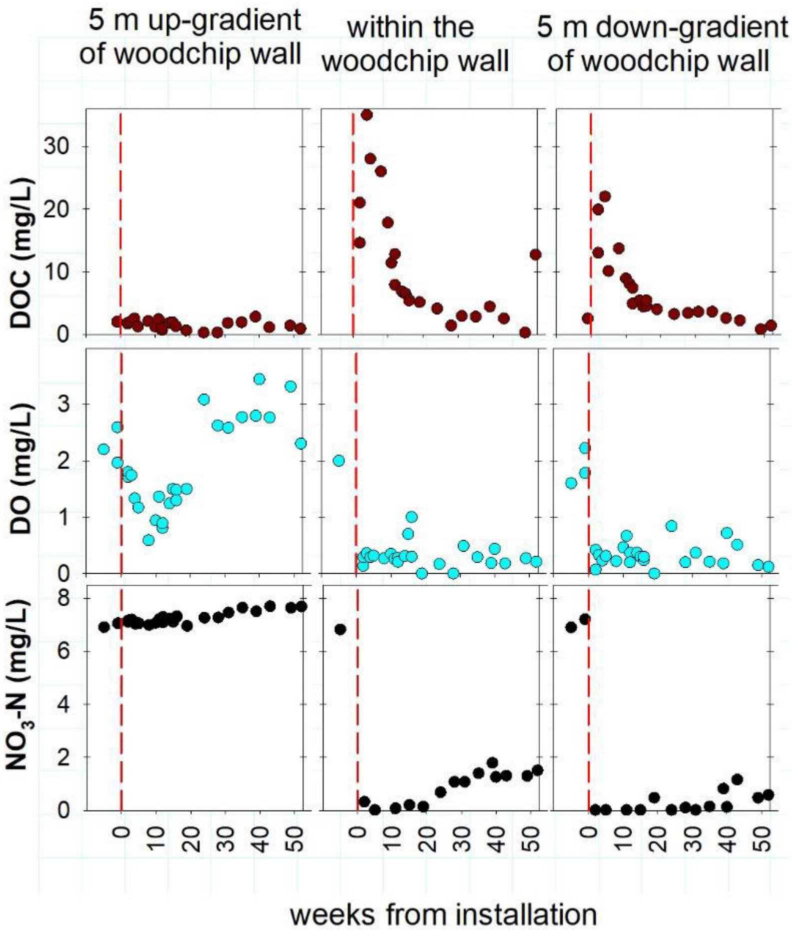


Figure 4: Time-series of groundwater chemistry parameters (DOC, DO, and nitrate) measured up-gradient, within, and down-gradient of the woodchip wall. The dashed red line marks the time of woodchip wall installation.

Source: Burbery et al. (2020).

Kohn et al. (2023) evaluated pilot-scale denitrifying bioreactors containing barley straw, hemp straw, and woodchip feedstocks under varying seasonal conditions in southern Alberta, Canada. The study assessed the influence of feedstock type, temperature, and HRT on nitrate removal performance. Key design and performance parameters reported by the authors included:

- HRTs ranged from 4 to 16 hours. Bioreactors operating at HRTs greater than ~10 hours generally achieved higher nitrate removal efficiencies than systems operating at less than 8 hours.
- Nitrate removal performance generally increased with rising water and air temperatures. Performance was more variable under colder conditions.
- Feedstock selection heavily influenced initial performance, but data shows a significant drop in efficiency by the second year:
    - Year 1: Annual mean nitrate removal efficiencies were 72% for barley straw, 55% for hemp straw, and 27% for woodchip feedstocks.
    - Year 2: Mean efficiencies declined to 34% for barley straw and 32% for hemp straw, while woodchips remained stable at 29%.

Figure 5 presents the relationship between nitrate removal efficiency and seasonal water and air temperatures. While higher nitrate removal efficiencies were generally associated with higher water and air temperatures, the magnitude of the response varied between feedstocks. Barley straw achieved the highest efficiencies but exhibited more performance variability at lower temperatures.

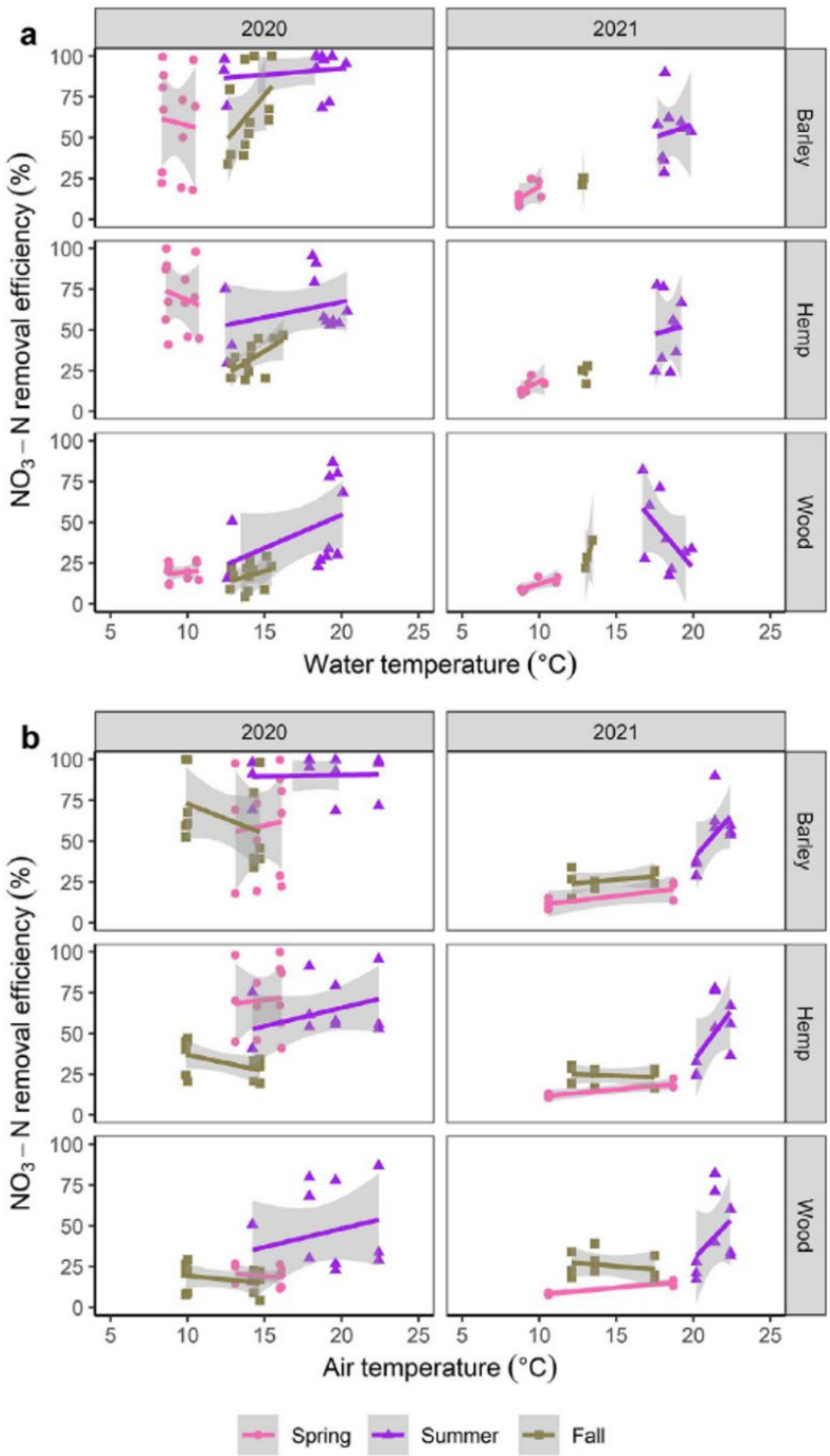


Figure 5: Nitrate removal efficiency as a function of (a) water temperature and (b) air temperature for barley straw, hemp straw, and woodchip denitrifying bioreactors.

Source: Kohn et al. (2023).

The available studies indicate that nitrate removal efficiencies ranging from 27% to 100% have been reported for woodchip-based and organic substrate denitrification systems. The reported performance suggests that HRT, feedstock selection, and operating temperature are important considerations during conceptual design of passive nitrate treatment systems.

Carbon-Amended Passive Treatment Systems

Gruyer et al. (2013) evaluated passive bioreactors containing a mixed organic substrate comprising maple woodchips, sawdust, poultry manure, compost, and sand for the treatment of greenhouse wastewater containing elevated nitrate and sulfate concentrations. The reactive substrate was specifically formulated to support denitrification and sulfate reduction. Key observations include:

- Hydraulic residence time of 5 days.
- Influent nitrate concentrations of 300 mg/L NO_3.
- Influent sulfate concentrations of 500 mg/L SO_4.
- Nitrate removal efficiencies of ~99%.

Nitrate removal was maintained throughout the monitoring period and nitrate reduction occurred preferentially to sulfate reduction. The study indicated preferential utilisation of nitrate, over sulfate, as an electron acceptor under reducing conditions.

Gruyer et al. (2014) subsequently evaluated the influence of supplementary carbon amendments on nitrate and sulfate removal performance under similar influent conditions. Carbon amendments included sucrose and compost-based substrates designed to increase carbon availability and support denitrification. Key observations included:

- Influent nitrate concentrations of 300 mg/L NO_3.
- Influent sulfate concentrations of 500 mg/L SO_4.
- Nitrate removal efficiencies of 95 to 99% in carbon-amended systems.
- Substantially lower nitrate removal in systems without supplementary carbon.

Figure 6 compares nitrate removal performance between systems with and without supplementary carbon amendments. The unamended wetland achieved little to no nitrate removal, whereas carbon-amended systems consistently approached 100% efficiency. These results demonstrate that carbon availability is a primary control on denitrification performance and highlight the importance of maintaining a sufficient carbon source within passive nitrate treatment systems.

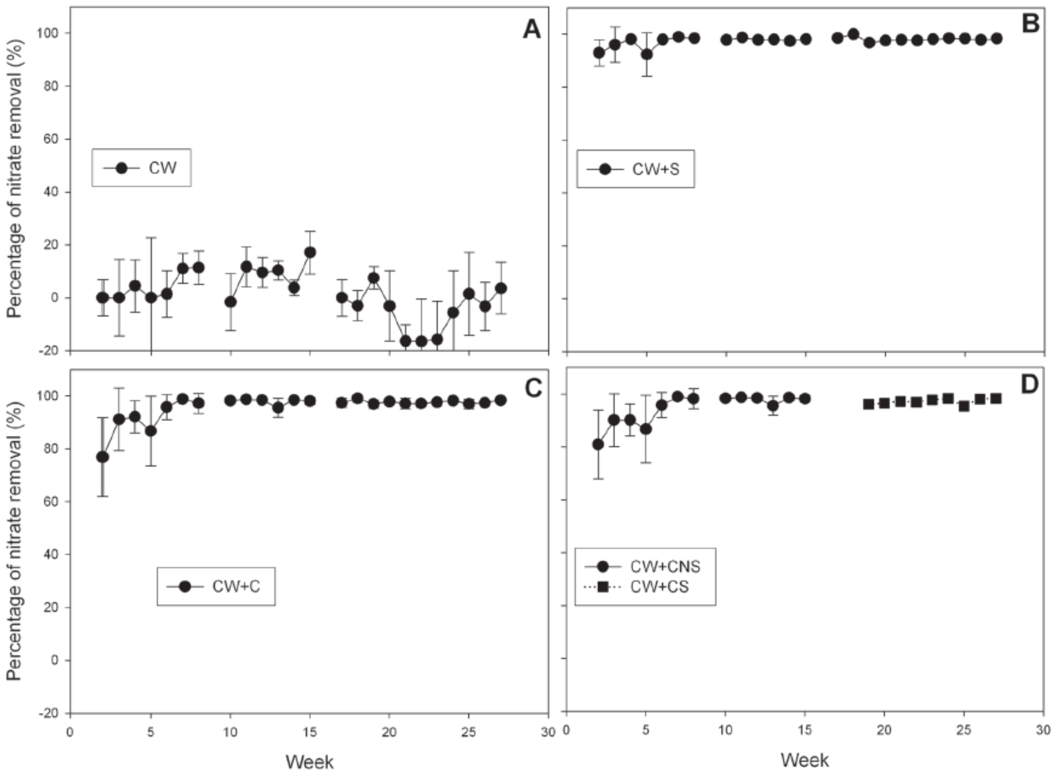


Figure 6: Nitrate removal performance for passive treatment systems with and without supplementary carbon amendments. CW = constructed wetland; CW+S = sucrose amended; CW+C = compost amended; CW+CNS and CW+CS = carbon-amended substrate systems.

Source: Gruyer et al. (2014).

Similar observations were reported by Chang et al. (2018), who evaluated nitrate removal in constructed wetland systems amended with macrophyte biomass. The study reported improved nitrate removal following biomass addition, with the additional organic matter providing a carbon source to support denitrification.

Gravel Bed Reactors

Gravel bed bioreactors (GBBRs) are engineered biological treatment systems developed for treatment of mine-impacted waters under controlled reducing conditions. For nitrate treatment, GBBRs promote microbial denitrification by supplying an external carbon source while maintaining an optimal environment for nitrate reduction. Treatment performance is influenced by HRT, carbon dosing, temperature, and reactor configuration. Depending on influent chemistry and operating conditions, GBBRs can simultaneously facilitate nitrate reduction, sulfate reduction, selenium reduction, and metal removal (e.g., Mancini et al., 2021).

Simair et al. (2023) reported on the performance of a full-scale GBBR installed at the Rainy River Mine in Ontario, Canada, for treatment of mine-impacted water. The system consisted of a fixed-bed vertical upflow reactor treating mine rock pond water during a 2022 operational flexibility trial. Key design and operating parameters included:

- Fixed-bed vertical upflow reactor configuration containing approximately 90% gravel and 10% peat or woodchips.

- Glycerol addition as the primary carbon source, monopotassium phosphate as a phosphorus nutrient, and ferrous iron as required.
- Treatment capacity of up to 10,000 m^3/day.
- Influent nitrate-N concentrations ranging from 15 to 36 mg/L, with an average concentration of 24 mg/L.
- Effluent nitrate-N concentrations ranging from 0.06 to 13 mg/L, with an average concentration of 3.4 mg/L.

Substantial nitrate reduction was achieved under full-scale high-flow operating conditions. Average influent nitrate-N concentrations decreased from 24 mg/L to 3.4 mg/L, corresponding to an average nitrate removal efficiency of 86%.

Simair et al. (2024) evaluated GBBR treatment for the Copper Mountain Mine in British Columbia, Canada, using a combination of on-site pilot testing and off-site column trials. The programme was developed to assess treatment of nitrate, selenium, molybdenum, copper, sulfate, and uranium under varying flow, temperature, and reagent dosing conditions. The GBBR columns were operated in a vertical upflow configuration and consisted of approximately 80 - 90% gravel mixed with woodchips.

Key design and operating parameters reported for the Copper Mountain GBBR trials included:

- Vertical upflow GBBR configuration.
- Substrate comprising ~80 - 90% gravel and 10 - 20% woodchips.
- Assessment of flow rate effects on treatment performance and residence time requirements.
- Assessment of temperature effects at 4°C, 10°C, and 20°C.
- Assessment of reagent dosing requirements under varying influent chemistry and flow conditions.
- Anticipated-case nitrate-N concentrations ranging from 3.8 to 20.1 mg/L.
- Worst-case nitrate-N concentrations ranging from 13.7 to 80.3 mg/L.
- On-site pilot feedwater nitrate-N concentrations ranging from 0.95 to 8.34 mg/L.
- Treatment objective of 3.0 mg/L nitrate-N in Wolfe Creek.

Figure 7 presents the results of column trials completed using synthetic SW67 water under varying HRT and temperature conditions. Nitrate concentrations decreased with increasing HRT across all test conditions, with nitrate concentrations reduced from 8 - 9 mg/L NO_3-N to near-zero within 1 to 2 days of HRT. Higher temperatures generally resulted in lower residual nitrate concentrations at equivalent residence times, indicating that both HRT and temperature influence treatment performance. Similar trends were observed for selenium, molybdenum, and copper, although the magnitude of removal varied between contaminants.

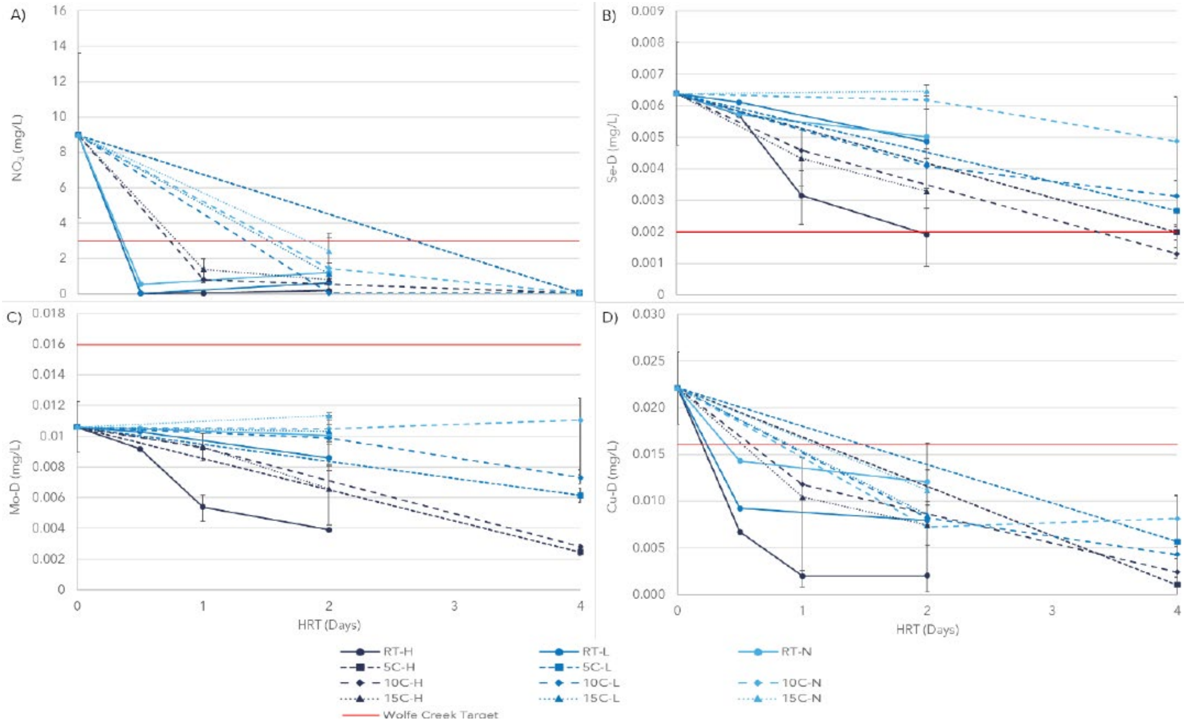


Figure 7: Effects of HRT and temperature on treatment of constituents of concern in the column trials with synthetic SW67 water.

Source: Simair et al. (2024).

Verum Nitrate Treatment Studies

Verum Group was engaged by OceanaGold to undertake laboratory-scale investigations into E-PTS for treatment of nitrate- and sulfate-rich WRS seepage at the Macraes Operation (Verum Group, 2021). E-PTS are passive bioreactors enhanced through the addition of soluble carbon sources to promote microbial activity and increase contaminant removal rates (e.g., Christenson et al., 2022). Laboratory bioreactors were operated under varying substrate compositions, temperatures, HRTs, and nutrient addition rates to optimise operating parameters prior to field-scale implementation (Verum Group, 2021).

The laboratory programme was designed to evaluate the influence of reactor media, carbon availability, temperature, and operating conditions on treatment performance. It consisted of seven continuously fed upflow bioreactors operated using the Macraes Operation seep water and inoculated with reduced sediment collected from the seep area (Christenson et al., 2022). Key design and performance parameters included:

- Influent mine water containing ~20 mg/L nitrate and 3,000 mg/L sulfate.
- Initial HRT of ~1 day.
- Four substrate matrices: standard mulch, bark and compost mixture; fresh pine chip; crushed schist; and a broom and silage matrix.
- Low temperature conditions (2 - 6°C).
- Reduced carbon dosing (50% of the standard dose – i.e., 50% of stoichiometric dose rate).
- Nitrogen sparging to evaluate the influence of gaseous metabolic products.

- Flow rate through the standard dose bioreactor was doubled after 220 days of operation to assess treatment performance under increased contaminant loading conditions.

Figure 8 presents nitrate and nitrite concentrations measured within the treatment reactors under varying testing conditions.

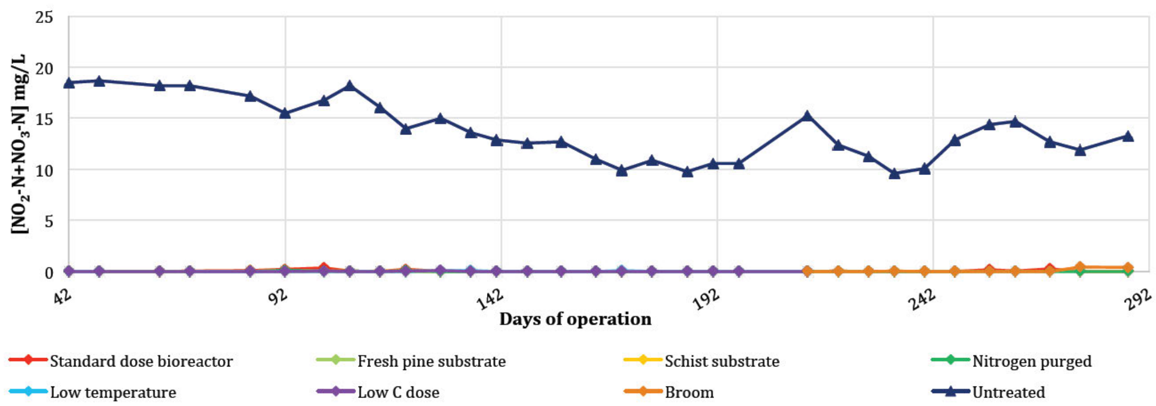


Figure 8: Nitrate and nitrite nitrogen concentrations in laboratory EPTS bioreactor effluents under varying substrate, temperature, carbon dosing, and nitrogen sparging conditions.

Source: Christenson et al. (2022).

Key findings from the laboratory programme included (Christenson et al., 2022):

- Near-complete nitrate removal across all reactor configurations.
- While untreated mine water contained approximately 17 mg/L nitrate-N, treated effluent concentrations of nitrate and nitrite remained below the limit of reporting (LOR) of 0.02 mg/L for the majority of the monitoring period, with a maximum combined concentration of 0.3 mg/L.
- The E-PTS trials were designed primarily for sulfate removal and were substantially overdosed with carbon relative to the requirements for nitrate removal. The observed nitrate removal performance therefore represents treatment under conditions where carbon availability was not expected to be limiting.

The laboratory programme subsequently led to the development of a pilot-scale E-PTS field trial at the Frasers East seep at the Macraes Operation. The field system comprised a nitrate reducing bioreactor (NRB), a sulfate reducing bioreactor (SRB), and a sulfide oxidising bioreactor (SOB-P) operated in series (Verum Group, 2025). Key field trial observations included:

- Influent nitrate-N concentrations ranging from 9.1 to 14.9 mg/L.
- Complete nitrate removal to below LOR.
- Simultaneous treatment of nitrate and sulfate within a passive treatment train.
- Successful replication of laboratory-scale nitrate treatment performance under field conditions.

Field monitoring undertaken during 2025 demonstrated complete nitrate removal from influent nitrate-N concentrations ranging from 9.1 to 14.9 mg/L to below the LOR. Although nitrate reduction was originally intended to occur within the nitrate reducing bioreactor, monitoring indicated that nitrate removal occurred predominantly within the sulfate reducing bioreactor due to lower-than-target glycerol dosing in the NRB. Despite this operational limitation, no oxidised nitrogen was detected leaving the treatment system (Verum Group, 2025).

The laboratory and field-scale studies demonstrate that E-PTS can achieve near-complete nitrate removal from mine-influenced waters containing ~10 - 20 mg/L nitrate-N. The laboratory programme achieved near-complete nitrate removal at a HRT of ~1 day, while the field trial subsequently demonstrated complete nitrate removal under operational conditions at the Macraes Operation.

Summary of Literature Findings

The following section summarises the key findings of the literature review. Table 1 provides a summary of nitrate treatment configuration and performance reported in the reviewed studies.

Where nitrate removal efficiencies were not explicitly stated by the authors, they were calculated from the reported average influent and effluent nitrate concentrations using the following removal efficiency calculation. Where average concentrations were unavailable, reported concentration ranges were used to estimate nitrate removal efficiency.

Equation 1: *Removal efficiency (%)* = $\frac{(Influent-Effluent)}{Influent} \times 100$

<u>Hydraulic Residence Time</u>

HRT was consistently identified as a primary factor controlling nitrate removal performance. Reported nitrate removal efficiencies generally increased with increasing residence time across a range of treatment systems (Burbery et al., 2020; Kohn et al., 2023; Simair et al., 2024; Vongsouthi, 2024). Efficiencies exceeding 90% were commonly reported at HRTs greater than 24 hours, with near-complete nitrate removal occurring at residence times of 2 to 5 days (Burbery et al., 2020; Gruyer et al., 2013; Gruyer et al., 2014). Conversely, lower nitrate removal efficiencies were generally associated with shorter residence times (Kohn et al., 2023).

<u>Carbon Availability</u>

Carbon availability is a key control on nitrate removal performance. Carbon-amended treatment systems consistently achieved higher nitrate removal efficiencies than unamended systems, with performance commonly ranging between 95% and 99% where supplementary carbon was provided (Gruyer et al., 2013; Gruyer et al., 2014). Christenson et al. (2022) and Verum Group (2025) similarly reported near-complete to complete nitrate removal in carbon-amended bioreactors treating mine-influenced water. Conversely, Vongsouthi (2024) reported declining nitrate removal rates as readily available carbon was depleted from aging woodchip substrates.

<u>Temperature</u>

Operating temperature significantly influences nitrate removal performance. Kohn et al. (2023) reported higher nitrate removal efficiencies at higher water and air temperatures across barley straw, hemp straw, and woodchip bioreactors. Simair et al. (2024) observed similar trends in GBBR column trials, where lower residual nitrate concentrations correlated with higher operating temperatures. Vongsouthi (2024) reviewed several studies that reported similar observations, though nitrate removal was still maintained under cold-climate conditions. The reviewed studies indicate that reduced treatment rates at lower temperatures can be accommodated by increasing HRT, allowing high nitrate removal efficiencies to be maintained under colder operating conditions.

Substrate and Reactor Configuration

Effective nitrate removal was reported across a range of treatment media and reactor configurations, including woodchips, barley straw, hemp straw, compost-amended substrates, E-PTS, and GBBRs (Kohn et al., 2023; Gruyer et al., 2013; Gruyer et al., 2014; Christenson et al., 2022; Simair et al., 2023; Simair et al., 2024). While treatment performance varied between configurations, the reviewed studies demonstrate that high nitrate removal efficiencies can be achieved across a range of configurations where sufficient residence time and carbon availability are maintained.

Long-Term Performance

Long-term performance data remain limited for passive nitrate treatment systems, particularly for mine-water treatment applications. Burbery et al. (2020) reported nitrate removal efficiencies of 93% to 100% during the first year of operation of a field-scale woodchip denitrification wall. Vongsouthi (2024) reported that woodchip bioreactors may remain operational for 5 to 15 years, though nitrate removal rates typically decline as readily available carbon sources are depleted.

Table 1: Summary of nitrate treatment performance reported in literature.

STUDY	TREATMENT SYSTEM	APPLICATION	SCALE / SIZE	INFLUENT NO_3-N (mg/L)	EFFLUENT NO_3-N (mg/L)	REMOVAL EFFICIENCY (%)	HRT RANGE
Burbery et al. (2020)	Woodchip Denitrification Wall	Field	25 m x 5 m x 3 m wall	7.1 - 8.8	~0 - 0.6	93 - 100	41 - 49 h
Kohn et al. (2023)	Denitrifying Bioreactors	Pilot	Pilot-scale bioreactors	Variable	Variable	Barley: 72 (2020), 34 (2021); Hemp: 55 (2020), 32 (2021); Woodchip: 27 (2020), 29 (2021)	4 - 16 h
Christenson et al. (2022)	EPTS	Laboratory	Seven continuously fed upflow bioreactors	~17	<0.5	97.1	~1 day
Verum Group (2025)	EPTS	Field	Pilot-scale NRB - SRB - SOB treatment train	9.1 - 14.9	<LOR	-	-
Gruyer et al. (2013)	Carbon-Amended Bioreactor	Laboratory	3.5 L columns (45 cm long x 10 cm diameter)	300 (NO_3^-)	-	99.9	5 days
Gruyer et al. (2014)	Carbon-Amended Constructed Wetland	Pilot-scale	0.6 m x 0.4 m x 0.35 m	300 (NO_3^-)	-	95 - 98	5 days
Simair et al. (2023)	GBBR	Field	2022 operation	15 - 36 (avg. 24)	0.06 - 13 (avg. 3.4)	85.8*	22 - 28 h
			2023 optimised operation	20 - 34 (avg. 27)	<0.01 - 0.64 (avg. 0.30)	98.9*	22 - 28 h
Simair et al. (2024)	GBBR	Pilot	Pilot and column-scale trials	~8	~0 - 1	88 - 99**	0.5 - 7 days

LOR = Limit of reporting.

A hyphen (-) infers no available data.

Reported nitrate concentrations are presented in the units reported by the original authors (NO_3-N or NO_3) and have not been converted.

**Calculated from reported average influent and effluent nitrate-N concentrations.*

***Estimated from Figure 5A presented by Simair et al. (2024). Nitrate concentrations decreased from approximately 8 mg/L NO_3-N to near-zero concentrations over HRTs of 1 to 4 days under multiple operating conditions.*

APPLICATION TO THE MACRAES OPERATION

Water quality data from Coronation WRS suggest that nitrate attenuation may already be occurring within the WRS. Although the mechanism has not been confirmed, site records indicate that vegetation and organic matter (i.e., pine trees, present before the WRS was constructed) may have been buried beneath portions of the WRS during construction. The buried organic carbon may create conditions favourable for denitrification and could contribute to the comparatively subdued nitrate response observed in seepage from Coronation WRS.

If confirmed, this provides evidence that carbon-driven nitrate attenuation can occur within a WRS environment and may represent a conceptual analogue for future in-dump treatment systems. Rather than treating nitrate after seepage has been generated, an in-dump treatment approach seeks to promote nitrate attenuation within the WRS itself through the incorporation of suitable carbon-rich materials into the base of the WRS to interact with seepage.

The Verum laboratory and field-scale investigations provide the most relevant line of evidence for application at Macraes. Unlike the majority of published studies, the Verum investigations were completed using the Macraes Operation seep water under site-specific conditions representative of those expected for future WRS seepage. The laboratory programme achieved approximately 97% nitrate removal at an HRT of approximately one day, while the field-scale E-PTS achieved complete nitrate removal under operational conditions, providing high confidence that carbon-driven nitrate removal is technically viable at the site.

For future WRS expansions, including Golden Bar and Trimbles, both in-dump treatment systems and GBBRs warrant further consideration:

- In-dump treatment systems offer the advantage of treating nitrate within the waste rock mass, thereby reducing nitrate concentrations before seepage reaches collection systems.
- GBBRs provide a highly controlled and easily monitored treatment system that can be installed within WRS drainage systems to treat collected seepage prior to discharge. GBBRs provide a highly controlled system that can be installed within WRS drainage systems to treat collected seepage prior to discharge. Full-scale GBBRs have been operated at:
    - Rainy River Mine for treatment of nitrate and metals (Simair et al., 2023), and
    - Copper Mountain evaluated Maven's mBio GBBR technology for treatment of nitrate, selenium, molybdenum, copper, sulfate, and uranium (Simair et al., 2024).

Both approaches rely on the same fundamental treatment mechanisms identified throughout this review, namely sufficient carbon availability and HRT to support denitrification. The reviewed GBBR studies reported nitrate removal efficiencies ranging from 85% to 99% under mine-site conditions, while the Verum investigations demonstrated near-complete nitrate removal.

Table 2 presents conceptual nitrate treatment scenarios for preliminary modelling of both in-dump treatment systems and GBBRs, based on the reviewed literature and Macraes-specific investigations.

Table 2: Conceptual nitrate treatment efficiencies for modelling of in-dump treatment systems and GBBRs.

SCENARIO	HRT	REMOVAL EFFICIENCY
Conservative	~1 day	85%
Expected	1–2 days	95%
Upper Bound	>2 days	99%

The conservative scenario is considered the most appropriate starting point for preliminary modelling. An assumed nitrate removal efficiency of 85% is supported by the lower range of treatment efficiencies reported for GBBRs and other passive treatment systems operating at 1-day HRT. The expected and upper-bound scenarios represent treatment systems operating at longer HRTs, achieving performance consistent with the Verum investigations and higher-performing treatment systems reported in the literature.

Monitoring Recommendations for Coronation WRS

Additional monitoring of Coronation WRS seepage is recommended to investigate whether the observed nitrate behaviour is associated with carbon-driven denitrification within the WRS. The recommended monitoring parameters and their relevance to assessing potential nitrate attenuation processes are presented in Table 3.

The monitoring results would improve understanding of the processes controlling nitrate concentrations within Coronation WRS and provide additional information to assess whether carbon-driven nitrate attenuation is occurring. This information would also support assessment of the potential applicability of engineered in-dump treatment systems at Golden Bar and Trimbles WRS.

Table 3: Recommended monitoring parameters for assessment of nitrate attenuation at Coronation WRS.

PARAMETER	RELEVANCE
Nitrate	Primary parameter for assessing nitrate concentrations and temporal trends.
Nitrite	Intermediate product of nitrate reduction and potential indicator of incomplete denitrification.
Ammonia	Reduced nitrogen species used to assess potential nitrogen transformation pathways.
Dissolved organic carbon (DOC)	Indicator of organic carbon availability to support microbial denitrification.
Dissolved oxygen (DO)	Indicator of aerobic or anaerobic conditions and suitability for denitrification.
Oxidation-reduction potential (ORP)	Indicator of redox conditions within WRS seepage.
Sulfide	Indicator of reducing conditions and potential sulfate reduction.
Sulfate	Indicator of WRS seepage evolution and potential sulfate reduction under reducing conditions.
pH	General indicator of geochemical conditions influencing microbial processes.
Electrical conductivity (EC)	Indicator of overall dissolved constituent concentrations and WRS seepage evolution

SUMMARY

The reviewed literature demonstrates that passive nitrate treatment systems can achieve high nitrate removal efficiencies where sufficient HRT and carbon availability are maintained. The Verum laboratory and field-scale investigations provide the most directly applicable line of evidence for the Macraes Operation and demonstrate that near-complete to complete nitrate removal is achievable under actual site conditions.

Observations from Coronation WRS suggest that nitrate attenuation may already be occurring within the rock mass, providing a potential analogue for future in-dump treatment concepts. The reviewed literature and Macraes-specific investigations indicate that both in-dump treatment systems and GBBRs represent technically viable, high-performance nitrate management approaches for future WRS developments at the Macraes Operation.

CLOSING REMARKS

Please do not hesitate to contact Paul Weber at +[redacted] or [redacted] should you wish to discuss this memorandum in greater detail.

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APPENDIX C LIMITATIONS

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