REVIEW OF CADIA VALLEY OPERATIONS ENVIRONMENTAL MONITORING PROGRAM DESIGN AND DATA

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PREPARED FOR THE NSW EPA

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EXECUTIVE SUMMARY

This report presents the findings of a comprehensive review of the groundwater, surface water, and aquatic ecosystem monitoring programs at Cadia Valley Operations (CVO), undertaken on behalf of the NSW Environment Protection Authority (EPA). The review assessed the design, implementation, data quality, and overall effectiveness of these monitoring programs in detecting, characterising, and managing potential environmental impacts associated with mining activities. The aim was to determine whether these programs are fit-for-purpose and provide reliable information to support compliance, risk assessment, and environmental decision-making.

SURFACE WATER

Scope of the review:

This component assessed the effectiveness of the surface water monitoring program at CVO in detecting mine-related impacts and supporting compliance and environmental management. The review examined the spatial distribution of sites, sampling frequency, parameter coverage, trigger value application, data integrity, and analytical approaches used to evaluate trends and risks.

Key findings:

- The monitoring network includes a large number of sites, but their roles (e.g. control, reference, impact) are not clearly defined. This limits the ability to make valid comparisons and identify mine-related effects.
- Site-specific guideline values (SSGVs) are applied to water quality results, but their derivation, spatial applicability, and updates over time are not well documented, reducing transparency and confidence.

- No formal trend or statistical analysis is currently undertaken, despite the availability of long-term data. This reduces the program's ability to detect gradual changes or patterns over time.
- Limited integration between water quality and ecological monitoring outcomes restricts the ability to evaluate cause–effect relationships.
- Limited integration of flow data, which constrains the ability to calculate contaminant loads or assess mass fluxes across catchments.
- Duplicate and blank samples are collected, but the results are not always reported, limiting the ability to verify data reliability.

Recommendations:

- Clearly define the role of each site in the monitoring network and improve site selection to support impact assessment.
- Apply formal statistical techniques to assess long-term changes and identify spatial patterns.
- Improve the documentation and application of SSGVs, including their derivation and geographic relevance.
- Strengthen reporting of QA/QC outcomes to improve transparency and support data confidence.
- Combine streamflow and concentration data to calculate contaminant loads, facilitating better understanding of source contributions and impact magnitude.
- Develop mass balance models to evaluate cumulative contaminant fluxes across catchments and within hydrologically connected zones.
- Strengthen Integration of Water Quality Data with Ecological Outcomes

The surface water monitoring program has produced a valuable dataset, but its ability to detect and explain mine-related impacts is currently limited by design, documentation, and analysis gaps. Implementing the recommended improvements would increase transparency, analytical rigour, and the program's usefulness for regulatory reporting and environmental management.

GROUNDWATER

Scope of the review:

This component evaluated the adequacy and effectiveness of CVO's groundwater monitoring program, including bore network design, data quality, analytical techniques, and interpretation. Particular focus was given to infrastructure-adjacent areas such as the TSFs, pit voids, and potential receptor zones, as well as the consistency and defensibility of Site-Specific Guideline Values (SSGVs).

Key findings:

- The groundwater monitoring network broadly covers key mine infrastructure and regional areas but lacks adequate representation in some critical zones (e.g. downgradient of TSFs, sensitive receptors such as private bores and groundwater-dependent ecosystems).
- The functional roles and hydrogeological context of many bores are not formally defined, and up-to-date bore status and installation history are inconsistently documented.
- Long-term datasets are available, but formal time-series or multivariate statistical analyses (e.g., PCA, cluster analysis) are not currently applied to assess trends or contaminant groupings.
- QA/QC data (e.g., blanks, duplicates, RPDs, lab control) are collected but are not consistently integrated into data interpretation or publicly reported.
- SSGVs are applied inconsistently across the monitoring network, and in some cases, derivations are unclear or lack hydrogeological justification.

- Discrepancies were observed in the interpretation of groundwater trends across different reports (e.g., between operator and consultant conclusions), leading to inconsistent assessments of risk and impact.

Recommendations:

- Establish a comprehensive framework for bore network design, clearly defining each bore's purpose (e.g., compliance, observation, background) and hydrogeological context.
- Retrieve and compile legacy groundwater data (pre-2010) to extend baseline assessments and distinguish operational impacts.
- Standardise groundwater datasets, ensuring consistent use of units, qualifiers (e.g., <LOR), and centralised data management for QA/QC traceability.
- Apply statistical and trend analyses (e.g., Mann-Kendall, PCA) to long-term groundwater data to identify changes, detect contaminant sources, and assess spatial groupings.
- Strengthen QA/QC protocols, including regular reporting of duplicate precision, blank contamination, and laboratory control performance, and integrate QA/QC results into the core dataset.
- Refine the use of SSGVs by:
  - Clearly differentiating between guideline triggers and true SSGVs.
  - Developing SSGVs for both elevated and low-concentration bores to improve early detection of risk.
  - Implementing a two-tiered SSGV approach: observation bores for non-toxicants (e.g., TDS, sulfate), and compliance bores for toxicants.
  - Adopting dissolved molybdenum as a tracer of tailings seepage due to its elevated concentrations in TSF decant water.
- Align groundwater assessments with surface water monitoring to better understand interactions, especially in areas with known seepage or expressed groundwater.
- Ensure consistency in data interpretation and conclusions across all reporting documents to support robust, evidence-based environmental management.

The groundwater monitoring program is broadly established and provides useful baseline information. However, improvements are needed in model structure, site coverage, and data interpretation. Enhancing these areas will increase the program's reliability and its value in detecting and managing potential mining impacts.

AQUATIC ECOLOGY

This review assesses the adequacy of the aquatic ecology monitoring program at Cadia Valley Operations (CVO) in identifying and characterising potential environmental impacts from mining activities. The program has been in place since 2006 and involves monitoring of water and sediment quality, aquatic habitat condition, macroinvertebrates, fish, and platypus across multiple sites within and downstream of the mine, as well as at upstream and reference locations.

Scope of the review:

The review assessed whether the design and methods of the aquatic ecology monitoring program are appropriate for detecting ecological impacts associated with mining activities. It also evaluated the consistency and rigour of aquatic ecology data collection and analysis over time, the defensibility of conclusions presented in annual reports, and the program's alignment with regulatory expectations and current scientific best practice.

Key findings:

- Reference site limitations: All nominated reference or upstream sites are affected by land uses such as forestry, grazing, and past channel modification. These sites do not meet the criteria for minimally disturbed conditions and are ecologically distinct from mine-affected locations. This undermines the ability of the program to confirm whether observed impacts are caused by mining.
- Lack of formal control sites: While reference sites are included in the program, no control sites are explicitly defined or maintained in the experimental design. The lack of clearly designated control locations limits the strength of causal inference regarding mining impacts.
- Analytical limitations: Despite 18 years of data, no formal trend analysis or statistical power assessments have been undertaken. This severely constrains the program's capacity to proactively detect long-term or subtle changes in ecosystem condition.
- Incomplete quality assurance documentation: While recognised methods are employed, procedures for quality control, particularly in macroinvertebrate and fish sampling, are inconsistently documented. Verification of field and taxonomic procedures is lacking, which reduces confidence in the reliability and comparability of results over time.
- Interpretive gaps: Conclusions of "no mining impact" are frequently reported but are not supported by inferential statistical evidence or rigorous integration of chemical, biological, and habitat data. While exploratory tools (e.g. RELATE, BEST) are applied to macroinvertebrates and sediment chemistry, results are inconsistent and not extended to fish or platypus. Exceedances (e.g. copper) are rarely linked to biological outcomes using integrated analysis. The program lacks a holistic, statistically grounded framework to examine inter-relationships across datasets.

Recommendations:

To improve the scientific robustness and regulatory defensibility of the monitoring program, the following actions are recommended:

- Redesign the monitoring network to ensure inclusion of ecologically valid reference sites and clear definition of site roles.
- Apply formal statistical analysis, including trend detection and power analysis, to improve the sensitivity of impact detection.
- Strengthen QA/QC frameworks across all program components, including taxonomic verification and observer calibration.
- Integrate datasets (e.g. habitat, chemistry, and biology) to support more robust causal interpretations of ecological condition.
- Implement previous recommendations, including replicate sampling, improved species identification protocols, and consideration of environmental DNA (eDNA) methods.

The CVO aquatic ecology monitoring program has generated a substantial long-term dataset. However, without critical improvements to monitoring design, data analysis, and quality assurance, the program cannot currently provide reliable evidence to assess or attribute mine-related ecological impacts. A shift towards a more statistically rigorous and ecologically grounded framework is necessary to ensure the program meets regulatory expectations and effectively supports environmental risk management.

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1. INTRODUCTION

1.1 SCOPE

At the request of the New South Wales Environment Protection Authority (NSW EPA), Hydrobiology has undertaken a comprehensive review of the Cadia Valley Operations (CVO) groundwater, surface water, and aquatic ecosystem monitoring programs and associated data. The purpose of this review is to conduct a comprehensive and independent assessment of the effectiveness and suitability of the existing monitoring programs. Specifically, the review evaluates whether the programs are fit-for-purpose in identifying and characterising potential impacts on local and regional groundwater and surface water systems. It also assesses the extent and nature of any identified impacts, and provides clear, evidence-based recommendations for potential enhancements to the monitoring framework. The scope is defined by the following objectives:

- evaluate the effectiveness and suitability of the groundwater, surface water and aquatic ecosystem monitoring programs for detecting and characterising potential risks to and impacts on local and regional groundwater and waterways from CVO, including but not limited to spatial coverage, temporal frequency, knowledge gaps and inconsistencies.
- consider whether the monitoring programs are consistent with the practices and principles of relevant guidelines and standards, including, for example, the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018)
- assess the potential risks and impacts of CVO on the environmental values (e.g. aquatic ecosystem health, stock water, irrigation) of local and regional groundwater (including private bores) and waterways consistent with relevant guidelines.
- assess the containment performance and potential groundwater risks from key infrastructure, including the Pit TSF and Northern/Southern TSFs

- identify any impacts on surface water quality associated with expression of groundwater potentially contaminated by CVO.
- develop a conceptual site model that identifies, and estimates the magnitude of, any pollutant pathways from CVO to groundwater and waterways.
- review the derivation and application of any site-specific guideline values developed by CVO for consistency with ANZG (2018).
- consider how the natural geological properties of the Cadia Valley area could influence water quality and aquatic ecosystem observations.
- include comprehensive and robust statistical analysis of historical and current data to identify any temporal and spatial patterns and trends in water quality parameters and aquatic ecosystem impacts, identifying any knowledge gaps and data inconsistencies.
- review the trigger action response plan in CVO water management plan and advise on its suitability for managing potential water pollution risks.
- provide clear, concise recommendations for any enhancements to the monitoring programs (e.g. changes to monitoring frequency and/or timing of sampling, additional or alternative monitoring sites, inclusion of reference sites, the analytes and ecological indicators monitored etc.) and the trigger action response plan and any potential revisions to site-specific guideline values.
- provide a detailed, robust justification for all conclusions.
- include a separate plain English summary of the findings, including any relevant diagrams, figures and recommendations.

1.2 BACKGROUND OF CADIA VALLEY OPERATIONS (CVO)

Cadia Valley Operations (CVO) is a large-scale gold and copper mining and processing operation located approximately 25 km southwest of the city of Orange, in the Central Tablelands region of New South Wales (NSW), and about 250 km west of Sydney. CVO is shown in a regional context in Figure 1-1. CVO is owned and operated by Cadia Holdings Pty Limited (CHPL), a wholly owned subsidiary of Newmont Corporation (formerly Newcrest Mining Limited) (GHD, 2016). CVO operates under six Mining Leases (ML): ML1405, ML1449, ML1472, ML1481, ML1689 and ML1690 (GHD, 2016). CVO comprises two underground mines (Cadia East and Ridgeway), a completed open-cut pit (Cadia Hill Pit), and associated infrastructure including ore processing facilities, tailings storage facilities (TSFs), waste rock dumps, and various water storages. The site is positioned within the upper catchments of several waterways, including Cadiangullong Creek, Rodds Creek, Swallow Creek, and Flyers Creek, all of which are tributaries of the Belubula River. Land use in the vicinity of Cadia is dominated by sheep and cattle grazing in the more gently undulating areas, and private and state forestry operations to the north and east (GHD, 2016).

Mining activities at CVO have evolved significantly over the past two decades. Open-cut mining at Cadia Hill commenced in 1998 and concluded in 2012, with the pit now serving as a passive tailings storage facility (PTSF). The Ridgeway underground mine operated from 2002 until its closure in 2010 and is now in care and maintenance, while Cadia East underground mine has been the main operational focus since 2012. Cadia East is a panel cave mining operation to extract approximately 450 million tonnes (Mt) of ore over a period of 21 years, with current approvals taking the project through to June 2031 (GHD, 2020). The ore body contains gold, copper and other metals. The tailings from these operations are managed through the Northern and Southern TSFs, with seepage capture systems in place. Both TSF embankments were constructed across the former Rodds Creek valley, the NTSF being at the upstream location and the STSF at the downstream location. The site also maintains two waste rock emplacements (the rehabilitated North Waste Rock Dump (NWRD) and the active South Waste Rock Dump (SWRD)) [AGE, 2023; GHD, 2020].

Given the scale and complexity of the mining operations and the proximity to sensitive receiving environments, an extensive environmental monitoring framework has been implemented as part of their regulatory obligations under project approval (06_0295) and Environment Protection Licence (EPL) No. 5590 to assess potential impacts on local and regional groundwater systems, surface waters, and aquatic ecosystems. These monitoring programs are documented and reported through the Annual Environmental Management Reviews (AEMRs), groundwater and surface water technical assessments, and targeted environmental studies. Multiple independent consultancies including Australasian Groundwater and Environmental Consultants Pty Ltd (AGE), GHD Pty Ltd, and Golder Associates have been engaged over the years to support data evaluation and program design [Golder, 2011; GHD, 2016b; AGE, 2023].

Monitoring efforts span a wide range of parameters and environmental compartments:

- **Groundwater monitoring** covers over 120 bores, targeting hydrostratigraphic units including the Tertiary Basalt, Silurian sediments, and Ordovician volcanics. These systems range in productivity and connectivity, with the basalt aquifers generally more transmissive and used for local water supply [GHD, 2016b; AGE, 2023].
- **Surface water monitoring** includes upstream reference sites and downstream compliance sites across key catchments. These programs assess water quality trends, flow data, and compliance with ANZG (2018) guidelines and more recently adopted site-specific guideline values (SSGVs) [GHD, 2016a; GHD, 2022].
- **Aquatic ecosystem assessments** evaluate ecological condition, habitat quality, and biological indicators such as macroinvertebrate community structure. These are supported by complementary physical and chemical monitoring to assess potential stressors [GHD, 2021].

The NSW Environment Protection Authority (EPA), as the environmental regulator, has commissioned an independent review of the CVO groundwater, surface water, and aquatic ecosystem monitoring programs and associated data to assess the effectiveness, adequacy, and fit-for-purpose nature of these monitoring programs. The primary objectives of this review are to:

- Determine whether the groundwater, surface water, and aquatic ecosystem monitoring programs are suitable for identifying and assessing potential risks and impacts associated with mining activities;
- Identify any current or potential risks to local and regional water resources, including both quality and quantity parameters; and
- Recommend improvements or enhancements to monitoring design, data analysis approaches, and program implementation.

This review is based on an extensive body of documentation spanning more than a decade and it aims to provide an evidence-based assessment to support environmental decision-making and ensure that the monitoring programs are adequate to protecting water resources and ecological values within and surrounding the CVO area.

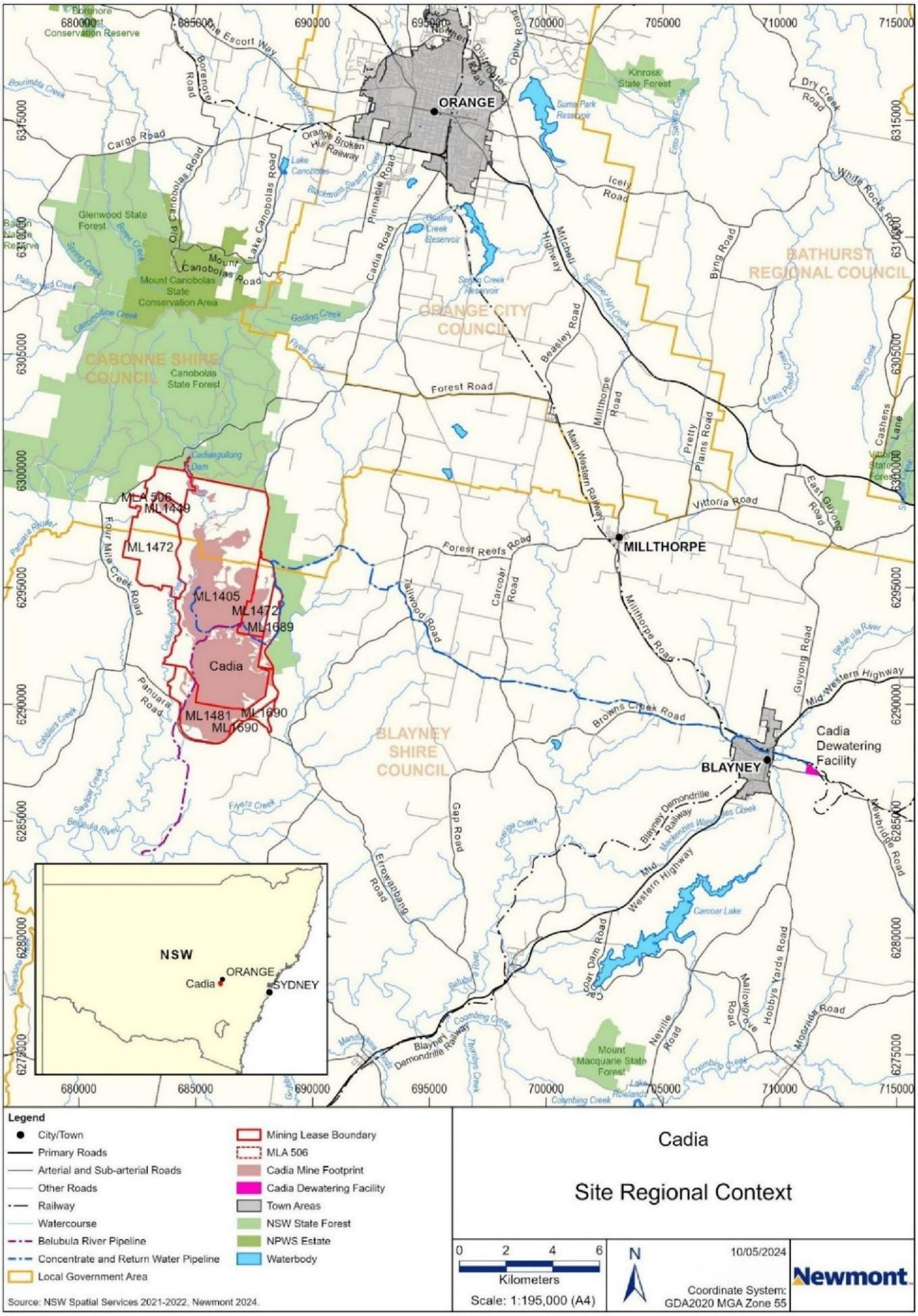

Figure 1-1 Location of Cadia in a regional context (Cadia 2024 Annual Review)

1.3 REGULATORY CONTEXT AND COMPLIANCE REQUIREMENTS

The assessment was framed using the following legislation/regulations:

- Environment Protection and Biodiversity Conservation Act 1999 (Cth)
- Protection of the Environment Operations Act 1997 (NSW)
- Water Management Act 2000 (NSW)
- Biodiversity Conservation Act 2016 (NSW)
- Environmental Planning and Assessment Act 1979 (NSW)
- NSW Aquifer Interference Policy (2012)
- NSW Groundwater Dependent Ecosystems Policy
- Australia and New Zealand Environment and Conservation Council/ Agriculture and Resource Management Council of Australia and New Zealand, Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000)
- *Australian and New Guidelines for Fresh and Marine Water Quality 2018* (WQGs)
- Australian Drinking Water Guidelines (ADWG, NHMRC, 2011, updated 2022)
- National Water Quality Management Strategy (NWQMS)
- National Environment Protection Measures (NEPMs) Sampling data relating to blue water reported in the Molonglo River (NSW EPA 2019)
- Environment Protection Licence (EPL 5590)

1.4 METHODOLOGY AND APPROACH USED FOR THE REVIEW

The review was undertaken using a structured, multi-stage approach to ensure a thorough evaluation of the groundwater, surface water, and aquatic ecosystem monitoring programs and associated data. The methodology was designed to align with relevant regulatory expectations, particularly those of the EPA, and to ensure consistency with national and international best practices, including the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018).

Document Review

As part of this independent review, a comprehensive assessment was undertaken of Cadia Valley Operations' (CVO) groundwater, surface water, and aquatic ecosystem monitoring programs. The review encompassed a detailed examination of a range of documents and associated technical appendices, including:

- Annual environmental management reports (AEMRs);
- Groundwater and surface water monitoring assessments;
- Aquatic ecosystem monitoring reports;
- Groundwater model updates;
- Dam management plans;
- Tailings Storage Facility (TSF) Seepage Mitigation and Management Studies; and
- Site Water Management Plans.

Each document was critically evaluated to assess the quality, scope, and methodology of the monitoring activities reported, with specific reference to their alignment with relevant regulatory requirements, project approval conditions, Environment Protection Licence (EPL 5590) obligations, and contemporary best practice monitoring frameworks. The review process placed emphasis on assessing the adequacy of monitoring program design, data collection and interpretation methods, and reporting transparency, with the aim of identifying strengths, deficiencies, and opportunities for improvement. This approach ensures that the findings and recommendations presented in this report are based on a thorough, evidence-based assessment of CVO's monitoring programs and their effectiveness in detecting and characterising potential environmental impacts.

Site Visit and Field Evaluation

As part of this review, a site visit was conducted to inspect key monitoring locations and gain direct insight into the operational and environmental context of Cadia Valley Operations. The visit enabled the review team to assess the practicality and suitability of surface water, groundwater, and ecological monitoring sites, observe the implementation of sampling protocols, and examine water management infrastructure in the field. Discussions with on-site personnel provided valuable clarification regarding site-specific monitoring practices and operational constraints. Findings from the site visit have been incorporated into this review to contextualise data interpretation and enhance the accuracy and relevance of the overall assessment.

Assessment Against Guidelines and Standards

Monitoring programs and site-specific guideline values were assessed for consistency with:

- ANZG (2018) water quality guidelines
- National and regional water monitoring and ecosystem health frameworks
- Guideline documents relevant to mining activities and water resource protection

The assessment considered principles such as adaptive management, ecosystem protection levels, and the derivation of site-specific guideline values.

Data Analysis and Evaluation

A detailed analysis of historical and current water quality and ecosystem data was conducted to evaluate:

- Spatial and temporal trends in key parameters
- The presence and magnitude of any environmental impacts
- Suitability of current analytes and ecological indicators
- Data quality, gaps, and inconsistencies

Statistical tools (e.g. trend analysis, comparison to reference sites, and significance testing) were used to support evidence-based findings. Visual tools such as time-series plots were also generated.

Conceptual Site Model Review and Development

The conceptual site model (CSM) was reviewed and updated based on available data and field conditions. The CSM was used to:

- Identify and map potential pollutant pathways
- Characterise source–receptor relationships
- Support risk assessment and management recommendations

Risk Assessment

The review included an evaluation of potential and actual risks to environmental values such as aquatic ecosystem health, stock water, irrigation, and human uses of ground water (e.g. private bores). Risks were assessed based on monitoring results, site-specific hydrogeology, and potential failure modes of mining infrastructure such as TSFs and the pit.

Review of the Trigger Action Response Plan (TARP)

The TARP was reviewed for clarity, responsiveness, and suitability in managing identified risks. This included assessing trigger levels, response timelines, and management actions.

Development of Recommendations

All findings from the review informed clear, practical, and evidence-based recommendations to:

- Improve monitoring program design and execution
- Address data gaps and inconsistencies
- Refine TARP and guideline value application
- Enhance the capacity to detect and manage risks to water resources

Where applicable, recommendations were prioritised and supported by justifications based on regulatory standards and site-specific data.

2. SITE AND ENVIRONMENTAL SETTING

2.1 DESCRIPTION OF THE MINING OPERATION AND KEY INFRASTRUCTURE

CVO is a large-scale, integrated gold, copper, and molybdenum mining operation located in Central West New South Wales, comprising a suite of mining areas, mineral processing facilities, and associated infrastructure (Figure 2-1). The site includes both active underground operations and legacy open-cut areas, supported by extensive ore processing and water management systems. Cadia's operations span multiple mining leases and cover a broad area that encompasses both current and historical infrastructure developed since mining commenced in 1998. The location of key features at Cadia is shown spatially in Figure 2-1.

2.1.1 MINING OPERATIONS

CVO currently consists of the following primary mining components:

- **Cadia East Underground Mine**: This is the primary production centre for CVO and has been operational since 2012. Cadia East is a large-scale panel cave mine that extracts up to 32 million tonnes per annum (Mtpa) of ore under current project approvals (valid until June 2031). The mine targets copper-gold porphyry deposits hosted in Ordovician volcanic rocks and contributes the majority of tailings and process water inputs to the site's storage facilities.
- **Ridgeway Underground Mine**: Commissioned in 2002, Ridgeway was a block cave operation that ceased production in March 2016 and has since been placed in care and maintenance. Historical dewatering and inflows from Ridgeway still influence groundwater monitoring and require ongoing water quality management.
- **Cadia Hill Open Cut Pit**: Mining at this open cut ceased in 2013. The pit is now used as a passive tailings storage facility (PTSF), receiving thickened tailings from the Cadia processing plant. Its use as a containment structure has introduced interactions between tailings decant water and local groundwater, as evidenced by elevated salinity and dissolved metal concentrations in pit water and adjacent monitoring bores.

2.1.2 ORE PROCESSING AND WATER MANAGEMENT

Ore extracted from Cadia East is processed at a central processing plant, which includes a conventional flotation circuit. The site has multiple associated water management features, including:

- **Site Runoff Pond (SROP)**: A zero-discharge stormwater containment structure located near the ore processing area. Elevated concentrations of dissolved ions, nitrogen species, and metals are frequently reported due to accumulation from site runoff. Groundwater levels in this area have shown increasing trends.
- **Dewatering Facilities**: Water extracted during underground mining and from pit dewatering is directed to surface containment structures or reused in processing.

2.1.3 TAILINGS STORAGE FACILITIES (TSFS)

The Cadia site manages its tailings through three main structures:

- **Northern Tailings Storage Facility (NTSF):** Constructed in 1998, the NTSF is used for tailings storage and includes a decant pond and leachate dams. It is bounded by embankments constructed from waste rock and is located over the former Roods Creek. On March 9, 2018, a slump occurred in the southern wall of the NTSF, causing it to partially lose containment of tailings.
- **Southern Tailings Storage Facility (STSF):** Commissioned in 2002, the STSF is the principal structure for active tailings deposition. It has associated leachate management systems, including Southern Leachate Dam (SLD) and collection ponds.
- **Cadia Hill Pit (PTSF):** Cadia Hill Pit is a legacy open-cut mining area within Cadia Valley Operations, where large-scale surface mining was conducted from the commencement of operations in 1998 until its completion in 2013. Since the cessation of mining, the pit has been repurposed as a Passive Tailings Storage Facility (PTSF). It now serves as a key containment structure for thickened tailings generated by the processing of ore from the Cadia East underground mine.

2.1.4 WASTE ROCK DUMPS

Two main waste rock dumps are located on site:

- **North Waste Rock Dump (NWRD)**: This is a rehabilitated structure associated with the early stages of Cadia Hill development.
- **South Waste Rock Dump (SWRD)**: Actively used and monitored, the SWRD has associated leachate collection infrastructure, including the Northern and Southern Leachate Dams. While elevated levels of EC and metals are frequently observed in the leachate, there is little evidence of impact to deeper

groundwater systems. Seasonal variations and flushing following wet periods account for much of the observed trends.

2.1.5 WATER HOLDING DAMS

Water holding dams at CVO are critical components of the site's water management system. They are used for the temporary storage, regulation, and redistribution of stormwater, seepage, dewatering inflows, and process water. These dams play a key role in maintaining operational water supply while minimising the risk of uncontrolled discharges to the environment.

The major water holding dams within the CVO footprint include:

- **Cadiangullong Dam:** Cadiangullong Dam is an in-stream water storage asset located on Cadiangullong Creek, upstream of the main Cadia Valley Operations (CVO) mining footprint. With a storage capacity of approximately 4,200 ML, the dam captures runoff from a 38 km² catchment primarily comprising Monterey Pine plantations and patches of native and rural land. It also receives piped inflows from Cadia Creek, a tributary to the north, via a small weir constructed in 1998. Cadiangullong Dam plays a critical role in environmental flow regulation, serving as the primary source for riparian flow releases into Cadiangullong Creek. These releases are carried out in accordance with the Cadia Project Approval (PA06_0295, Schedule 3 Conditions 27–28), to maintain minimum flow conditions at GS412702, a gauging station approximately 22 km downstream. Flow is monitored upstream at GS412168 and downstream at GS412702, and environmental releases are adjusted based on a 7-day rolling average of flow volumes. The riparian release system is designed to discharge up to 8 ML/day and ensures continuity of flow in the creek system during dry periods, supporting downstream aquatic ecosystems. Additionally, water is discharged via a spillway during high rainfall when inflows exceed dam storage capacity.
- **Rodds Creek Water Holding Dam**: The largest on-site water storage, with a capacity of approximately 14,500 ML, designed to store decant and process water recovered from the tailings facilities and mine infrastructure. It supports water supply to the process plant and acts as a key reservoir for internal recycling. Located downstream of key operational areas, this dam receives site runoff and seepage water, particularly from the vicinity of the Southern Tailings Storage Facility (STSF). It acts as a containment structure prior to reuse or controlled release and is regularly monitored for water quality parameters including EC, pH, turbidity, and trace metals.
- **Hoares Creek Dam:** Positioned within the Hoares Creek catchment, this dam collects runoff from the northern parts of the site, including waste rock dumps and haul roads. It supports internal water recycling and assists in managing flow volumes to downstream areas. The dam, with a storage capacity of 56 ML, is located at the northern end of the Passive Tailings Storage Facility (PTSF) and is designed to manage runoff and water collected from a tributary of Cadiangullong Creek. Water is discharged via an underflow pipe to either the Site Runoff Pond (SROP) or directly to the PTSF, depending on operational requirements.

2.1.6 CADIA DEWATERING FACILITY

The Cadia Dewatering Facility (CDF) is located on the eastern edge of Blayney (Newbridge Road) and was commissioned in June 2016. Concentrate is piped from the Cadia mine to the CDF for dewatering, prior to being railed (in sealed containers) to the eastern seaboard and shipped overseas for smelting and refinement.

2.1.7 MOLYBDENUM PLANT

The Molybdenum Plant recovers molybdenum from the bulk concentrate that is currently produced at the Cadia process plant. All process water is contained within the bunded Molybdenum Plant footprint. Excess process water is pumped to the NTSF where it is recovered for use in ore processing. Stormwater runoff is captured via two perimeter drains which divert runoff to Rodds Creek Dam.

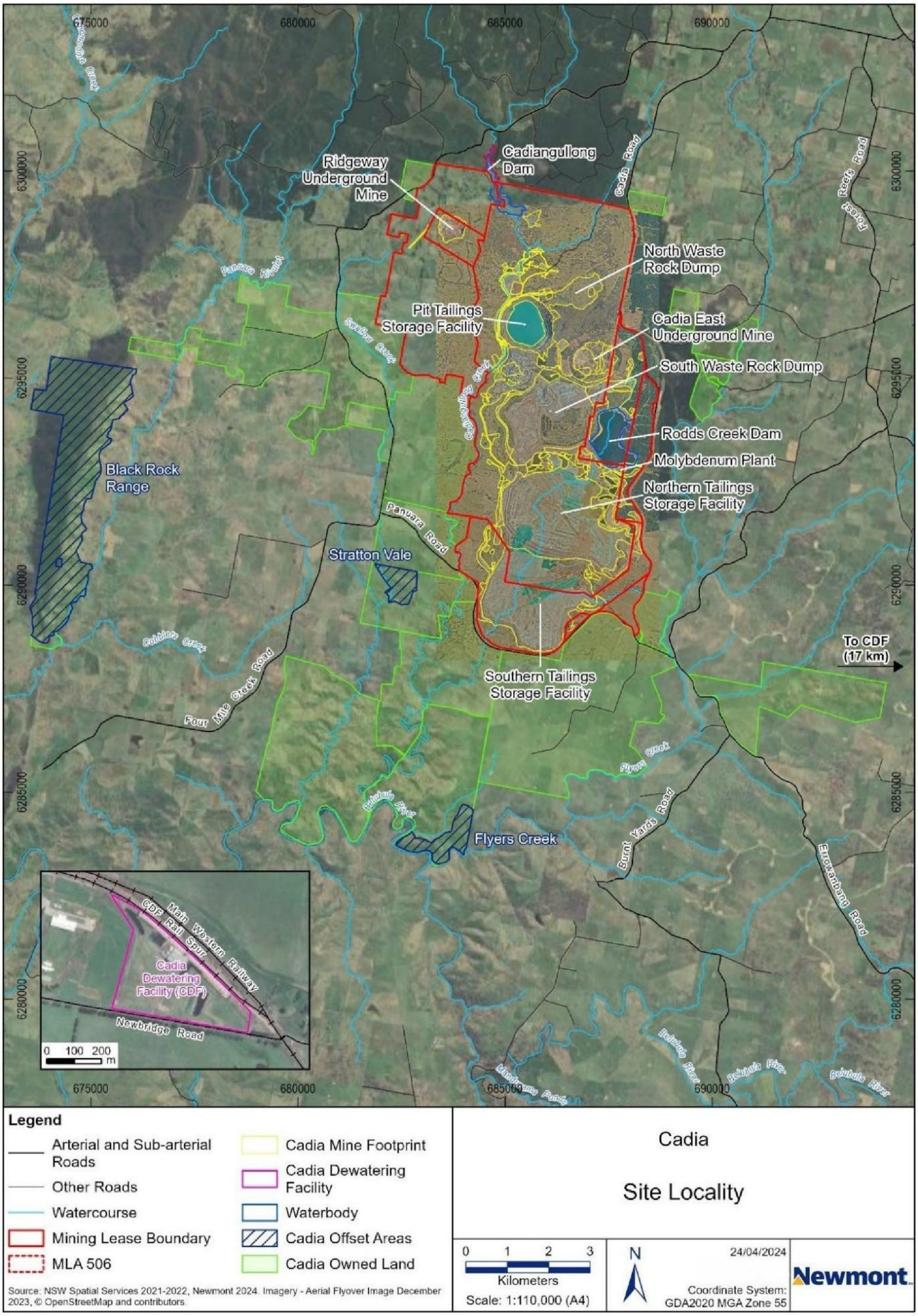

Figure 2-1 Cadia and key features in a local context (Cadia 2024 Annual Review)

2.2 ENVIRONMENTAL SETTING

2.2.1 CLIMATE

Cadiangullong Creek Valley has a temperate climate characterised by hot, dry summers and cold winters. Historical data from the Bureau of Meteorology (BOM) Orange Airport Automatic Weather Station (AWS) (station number 063303) indicates an average annual rainfall of approximately 946 mm for the period between January 1996 and December 2024. Monthly rainfall statistics are shown for the period 1996 to 2024 in Figure 2-2. Rainfall is generally evenly distributed throughout the year with April and May being the driest months on average (Figure 2-2).

Cadia operates two on-site weather stations (Ridgeway Weather Station [RW WS] and Southern Lease Boundary Weather Station [SLB WS]) and has access to data captured by rainfall recording stations both within and outside of the ML. The capture of meteorological data is a critical component of environmental monitoring, as it supports the interpretation of surface water, groundwater, and ecological trends by contextualising them within prevailing climatic conditions However, Hydrobiology was not provided access to this dataset and therefore could not analyse or interpret rainfall patterns or meteorological trends as part of this review.

Cadia receives an average of 740 mm per year of rainfall. Historical cumulative rainfall departure (CRD) curves show that the region has experienced extended periods of below-average rainfall (2001–2010, 2012–2014) interspersed with wetter conditions (e.g., 2010–2012). These climatic variations have a notable influence on streamflow behaviour and groundwater recharge patterns (CWMP, 2009; GHD, 2018b).

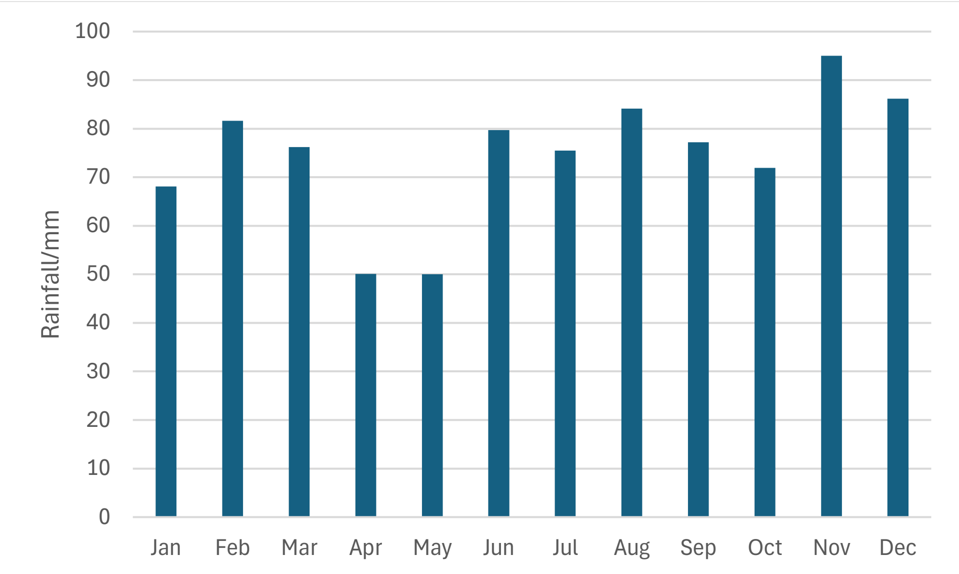

Figure 2-2 Monthly Rainfall Variability

2.2.2 WATERCOURSES AND CATCHMENT FEATURES

CVO is located within a complex network of catchments that ultimately contribute to the Belubula River, a significant tributary of the Lachlan River in the NSW section of the Murray–Darling Basin. The region's watercourses are largely intermittent and strongly influenced by seasonal rainfall and mining-related water management infrastructure. Historically, these creek systems have been disturbed by mining, agriculture, and forestry activities, and are classified as slightly to moderately or highly disturbed ecosystems (Gilbert & Associates, 2009).

CVO lies within the catchments of several important creeks, including Cadiangullong Creek, Rodds Creek, Flyers Creek, Swallow Creek, Cadia Creek, and Diggers Creek, each playing a distinct role in the site's hydrological connectivity and environmental context (Figure 2-3).

2.2.2.1 CADIANGULLONG CREEK

Cadiangullong Creek is the primary watercourse through the Cadia Valley and the main receiving water for many of the site's surface water pathways. It originates on the southern slopes of Mount Towac, within the Canobolas State Forest, and flows southward through the Cadia lease area before discharging into the Belubula River, approximately 12–14 km downstream of the Cadia southern boundary. A 2.4 km diversion, excavated from igneous rock, was created around open cut mining operations to allow for transport of water supply to downstream reaches of Cadiangullong Creek via the riparian releases. The total catchment area of Cadiangullong Creek is approximately 115 km^2, with much of the upstream catchment dominated by Monterey Pine plantations, native forest, and scattered rural land uses. Downstream areas are primarily cleared for pastoral grazing.

A major water storage, Cadiangullong Dam (capacity ~4,200 ML), is located upstream of the mine lease. It captures runoff from a 38 km^2 catchment and receives piped inflows from Cadia Creek. The dam plays a critical role in maintaining environmental flows in Cadiangullong Creek, with releases undertaken in accordance with Schedule 3, Conditions 27–28 of Project Approval PA06_0295. Approximately 1.5 km downstream of the dam, Cadiangullong Creek is diverted around the western perimeter of the PTSF for a distance of ~2 km.

2.2.2.2 CADIA CREEK

Cadia Creek is a small eastern tributary of Cadiangullong Creek. It flows southward and joins Cadiangullong Creek approximately 800 metres downstream of Cadiangullong Dam. The creek drains an area of ~11.6 km^2, including parts of Canobolas State Forest and agricultural land within ML1405.

In 1998, a small weir was constructed on Cadia Creek to divert high flows via gravity-fed pipeline into Cadiangullong Dam. The creek is otherwise intermittent and primarily contributes to the system during wet conditions.

2.2.2.3 RODDS CREEK

Rodds Creek is an eastern tributary of Cadiangullong Creek and a key feature of Cadia's water management layout. The creek flows past or through several key infrastructure areas, including the Rodds Creek Dam, South Waste Rock Emplacement, NTSF and STSF.

The upper and mid sections of the Rodds Creek catchment have been extensively modified by mining operations, whereas the lower 13 km^2 of the catchment (below STSF) remains largely as cleared grazing land. Rodds Creek joins Cadiangullong Creek approximately 2.5 km downstream of the STSF embankment.

2.2.2.4 FLYERS CREEK

Flyers Creek is located east of the Cadia lease area, flowing south from an elevated plateau before joining the Belubula River. It has a catchment area of approximately 168 km^2. The creek is generally perennial downstream of Long Swamp Road, with baseflow supported by springs. Cadia holds a licence to extract water from Flyers Creek, and a weir constructed in 2004 enables intermittent transfer of water to Rodds Creek Dam via pipeline. Environmental flows are managed in accordance with Schedule 3, Condition 29 of the Project Approval. These flows are primarily maintained by limiting water extraction during low-flow conditions, thereby ensuring that baseflows and downstream ecological values are protected.

2.2.2.5 SWALLOW CREEK

Swallow Creek lies west of Cadiangullong Creek and flows from north to south, discharging into the Belubula River about 2 km downstream of the Cadiangullong-Belubula confluence. Its catchment area is approximately 39.5 km², and land use in its catchment is predominantly sheep and cattle grazing.

The Ridgeway underground mine, currently in care and maintenance, is located beneath the headwaters of Swallow Creek. While historical mine subsidence may have intercepted part of the headwaters, Swallow Creek is currently considered to lie outside the influence of ongoing mining operations.

2.2.2.6 PANUARA RIVULET

Panuara Rivulet serves as a right-bank tributary of the Belubula River. The rivulet originates near the locality of Panuara, west of Cadia, at an elevation of approximately 325 metres above sea level. Flowing generally westward, it traverses a rural landscape characterized by agricultural activities before joining the Belubula River.

Diggers Creek is a small tributary of the Panuara Rivulet, which eventually joins the Belubula River. Diggers Creek's catchment area is approximately 4.7 km² in area, mostly within the Canobolas State Forest, with minor areas used for grazing. Development of the Ridgeway Mine may have affected historical flow patterns in Diggers Creek; however, like Swallow Creek, it is considered to be outside the zone of influence of current operations.

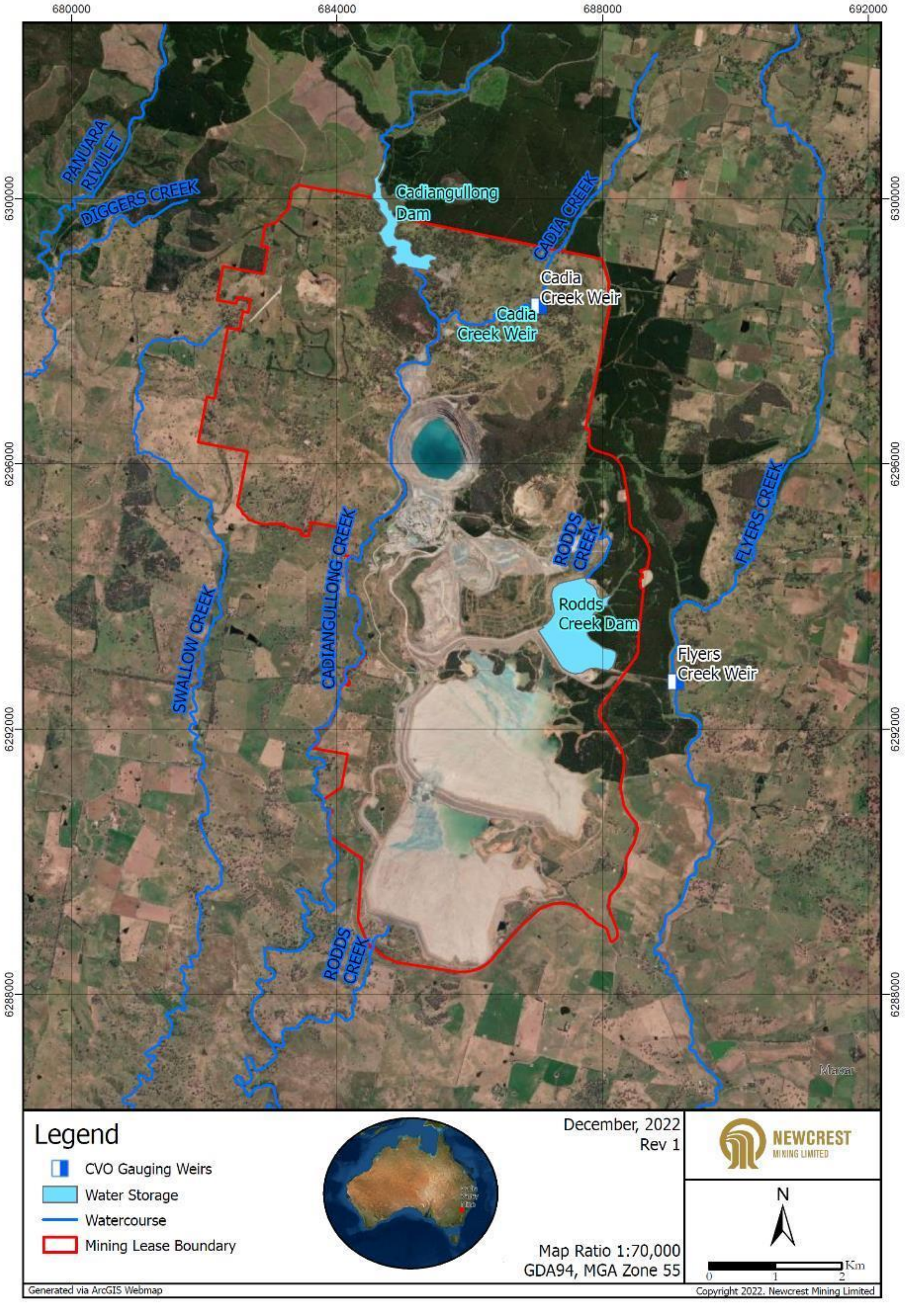

Figure 2-3 Surface water resources (Cadia Water Management Plan, 2023)

2.2.3 LOCAL HYDROGEOLOGY

The hydrogeology of the Cadia region is complex and consists of a multi-layered system of fractured rocks, volcanics, sediments, and basaltic cover. The groundwater system is structured around three main aquifer types:

1. Tertiary Basalt Aquifers

These are highly transmissive units with relatively shallow groundwater systems. They serve as important local aquifers and are often hydraulically connected to surface systems. Their porosity and recharge potential make them sensitive to mining-induced changes, such as compaction beneath TSFs

2. Silurian Sediments

These lower-permeability units include siltstones and sandstones that provide moderate confinement to groundwater flow. They generally show limited recharge potential and act more as flow pathways under pressure gradients than productive aquifers.

3. Ordovician Volcanics

Hosting the main ore bodies, these units have relatively low primary permeability but exhibit fracture-enhanced secondary porosity. Groundwater flow here is more constrained and locally affected by subsurface excavation and dewatering operations.

2.2.4 GROUNDWATER FLOW REGIME

Pre-mining groundwater flow in the Cadia region followed topographic gradients, generally flowing from the ridges toward the valleys. Since mining commenced, the flow regime has been significantly altered by excavation and storage structures:

- **Cadia East** and **Ridgeway** dewatering has created localised depressurisation zones, particularly in the deeper Ordovician units.
- **TSFs** (NTSF and STSF) have influenced local groundwater levels, particularly through consolidation of underlying aquifers, resulting in rising groundwater levels near their southern and western flanks.

2.2.5 GROUNDWATER-DEPENDENT ECOSYSTEMS AND USERS

Cadia's groundwater system supports:

- Springs and seeps located mainly in the Tertiary Basalt zones.
- Private water supply bores in surrounding rural properties.
- Potential groundwater-dependent ecosystems (GDEs) in discharge zones around Rodds and Cadiangullong Creeks.

2.3 ENVIRONMENTAL VALUES OF CONCERN

The Cadia Valley region, located in the Central Tablelands of New South Wales, is an area of ecological, hydrological, and agricultural significance. CVO are situated within this region that includes a range of environmentally sensitive receptors and designated water-dependent ecosystems. While the site is heavily modified due to mining activities, both upstream and downstream areas support environmental values that require protection under relevant legislation, policies, and stakeholder expectations.

This section identifies the environmental values of concern based on monitoring data, ecological assessments, and regulatory commitments.

2.3.1 SURFACE WATER ECOSYSTEM HEALTH

Key intermittent and perennial watercourses including Cadiangullong Creek, Rodds Creek, and Flyers Creek provide aquatic habitat and ecological connectivity to the Belubula River. Environmental values associated with these systems include:

- Habitat for macroinvertebrates and native fish species.
- Riparian corridors supporting native vegetation, including *Eucalyptus* spp., *Casuarina*, and understory plants.

These values are explicitly recognised under both the NSW Water Sharing Plans—which identify and protect environmental water requirements—and the ANZG (2018) water quality framework, which defines ecosystem protection as a key water quality objective. The importance of these systems has also been reinforced through the derivation of site-specific guideline values (SSGVs) for relevant creeks within the CVO area.

2.3.2 GROUNDWATER-DEPENDENT ECOSYSTEMS (GDES)

Although groundwater systems at CVO are not associated with high-yield regional aquifers, several potential groundwater-dependent ecosystems (GDEs) have been identified in discharge zones along Rodds Creek, Cadiangullong Creek, and Flyers Creek. These GDEs are primarily supported by shallow basalt aquifers and include spring-fed wetlands, riparian vegetation, and native habitat patches. The groundwater model update (AGE, 2021) confirmed that these systems are located within or adjacent to zones of fluctuating groundwater levels, particularly around the periphery of the TSFs and dewatering influence zones.

2.3.3 AGRICULTURAL LAND AND WATER USE

The Cadia Valley supports grazing, viticulture, and mixed farming enterprises, which are dependent on access to clean surface water and productive groundwater. The Tertiary Basalt aquifers are particularly valued for their relatively high yields and have been historically used for stock and domestic purposes.

Protecting the quality and availability of ground water in these productive zones is a key environmental objective, particularly in relation to:

- Salinity intrusion.
- Drawdown associated with mining dewatering.
- Potential seepage from tailings or waste storage facilities.

2.3.4 CULTURAL AND SOCIAL VALUES

While no Aboriginal or non-Aboriginal heritage sites directly dependent on water resources have been identified in recent assessments, surface and groundwater systems in the Cadia region may contribute to broader cultural landscape values. These values are indirectly linked to ecosystem services such as water provisioning, healthy riparian zones, and land stability. Under NSW environmental planning frameworks, these are increasingly recognised as part of the broader environmental value network, particularly where intersecting with catchment-wide water planning.

3. REVIEW OF SURFACE WATER MONITORING PROGRAMS

This section provides a critical review of the surface water monitoring program at CVO, focusing on the design, implementation, and effectiveness of the program in detecting and characterising potential impacts on local and downstream watercourses. The review assesses the spatial and temporal adequacy of monitoring sites, parameter selection, exceedance management, and alignment with site-specific guideline values (SSGVs) and regulatory obligations.

The assessment is informed by a range of documents, including

- Cadia Water Management Plan (2023)
- Review of Surface Water and Groundwater Data - 2010/2011 AEMR
- CVO ANZECC Water Quality Assessment Review Report (GHD, 2016)
- CVO AEMR - Surface and Groundwater Assessment Report (GHD, 2019)
- CVO AEMR - Surface and Groundwater Assessment Report (GHD, 2020)

- CVO AEMR 2020-2021 Surface Water Assessment (GHD, 2021)
- CVO Annual Review 2021-2022 Surface Water Assessment (GHD, 2022)
- Cadia Valley AEMP Water quality trigger value review for Oaky Station (412702) (GHD, 2018)
- Annual Environmental Management Reports (AEMRs) from 2011–2024
- Section 4 of the Cadia East Project Approval Environmental Assessment (2009)

3.1 SUMMARY OF SURFACE WATER MONITORING PROGRAM

The surface water monitoring program at CVO is a long-established and integral component of the site's environmental management system. It is designed to detect and assess potential impacts from mining activities on the surrounding surface water environment, with a focus on water quality protection, regulatory compliance, and environmental risk mitigation.

All monitoring at Cadia is undertaken in accordance with industry guidelines as follows:

- Approved Methods for the Sampling and Analysis of Water pollutants in NSW (EPA, 2022)
- AS/NZS 5667.1:1998 Water Quality – Sampling
- Monitoring and Sampling Manual Environmental Protection Policy (Department of Environment and Science, 2018)

The program comprises a network of over 40 monitoring sites strategically located across key watercourses and operational zones. Monitoring sites are grouped based on function and hydrological connectivity such as upstream background sites, downstream receiving environments, and locations adjacent to critical infrastructure (e.g. tailings storage facilities, waste rock dumps, and ore processing areas).

Sampling is conducted at monthly to quarterly intervals. The range of monitored parameters includes electrical conductivity (EC), pH, turbidity, total suspended solids (TSS), nutrients, and a suite of dissolved metals such as molybdenum, arsenic, selenium, and antimony. These are assessed against both ANZG (2018) default guideline values and site-specific guideline values (SSGVs) derived from upstream reference conditions.

3.2 STREAMFLOW MONITORING

The hydrographic monitoring network at CVO consists of a series of water level sensors and streamflow gauging stations strategically distributed across the site. These installations typically comprise a flow control structure including V-notch weirs, concrete weirs, flumes, or rock-bar controls coupled with instrumentation to measure water levels (CWMP, 2009). Water levels are recorded at 10-minute intervals and converted to flow rates using verified rating relationships. Monitoring equipment maintenance and rating relationship verification are conducted quarterly by a Certified Practicing Hydrographer, ensuring data quality and system reliability. The distribution of the streamflow and baseflow monitoring sites is summarised in Table 3-1, with site locations illustrated in Figure 3-1. This hydrographic monitoring network forms a critical component of CVO's surface water assessment program, supporting compliance, impact assessment, and adaptive management across the broader catchment.

Table 3-1 Streamflow, Baseflow and Spring Monitoring Stations (CWMP, 2009)

Catchment	Gauging Station	Location / Description	Purpose
Cadiangullong Creek	412168	Upstream of Cadiangullong Dam	Streamflow reference, upstream of mining; informs dam release compliance
	412144	Downstream of Cadiangullong Dam	Streamflow reference; compliance for dam release
	412161	At southern lease boundary	Assess potential mining impacts at lease edge
	412702	Downstream extent of mining operations	Compliance site for cumulative mining effects
	CWRR	Cadia Creek Weir	Measures Cadia Creek contribution to Cadiangullong Creek
Flyers Creek	USFLY	Adjacent to Long Swamp Road	Upstream reference site
	WBW	Woodville Baseflow Weir	Assesses baseflow reduction from Cadia East
	412147	Adjacent to Rodds Creek Dam	Central reference for streamflow and Cadia East effects
	412080(1)	At Beneree	Downstream reference for Cadia East impacts
Swallow Creek	SCBW2	Baseflow Weir 2	Baseflow reduction assessment (Ridgeway)
	SCBW3	Baseflow Weir 3	Baseflow reduction assessment (Ridgeway)
	412167	General streamflow reference site	Unless Ridgeway effects are observed
Diggers Creek	DCBW1	Baseflow Weir	Baseflow reduction assessment (Ridgeway)
	412166	General streamflow reference site	Unless Ridgeway effects are observed
Belubula River	BRPS	Upstream of pumping station	Upstream reference site

Catchment	Gauging Station	Location / Description	Purpose
	412056(1)	At The Needles (downstream of BRPS)	Downstream flow assessment
Waste Rock Emplacement	NLEACH	Northern Leachate Dam	Characterisation of waste rock leachate
	SLEACH	Southern Leachate Dam	Characterisation of waste rock leachate
Rodds Creek	RUBW	Upstream of Rodds Creek Dam	Assessment of baseflow reporting to Rodds Creek Dam
	RCDBW	Downstream of ST14 (Rodds Creek downstream)	Assessment of baseflow downstream of the STSF
Private Land north-east of the mining area (Springs)(2)	SPR03	Redmore Property	Measurement of spring flow into small dam for private stock/domestic use

Notes:

1. Gauging station maintained by Water NSW.

2. SPR01 was decommissioned in 2017 at the request of the landholder. SPR02 and SPR04 are no longer monitored due to private pumping from an upstream dam (monitoring site no longer representative of the spring flow rate).

3.2.1 LIMITATIONS IN FLOW MONITORING AND HYDROLOGICAL INTERPRETATION

- Limited Streamflow Infrastructure and Data Gaps

During the site inspection, considerably low surface flows were observed in Cadiangullong Creek at the location where the diverted channel rejoins the natural creek. Notably, there is no gauging station installed at this hydrologically critical point, which limits the ability to verify flow continuity or detect baseflow inputs.

In contrast, at site 412161, located further downstream, a visibly higher flow was observed, suggesting the possible presence of an additional hydrological input between the two locations. As there are no known tributaries within this section of Cadiangullong Creek, one hypothesis is that groundwater discharge may be contributing to increased baseflow. However, in the absence of dedicated flow monitoring infrastructure or assessments of groundwater–surface water interactions within this reach, this contribution remains speculative.

- Load Estimation Constraints

While CVO has an established streamflow monitoring network with sufficient hydrological data coverage, these data have not been appropriately utilised in conjunction with water quality results to estimate contaminant loads. Most water quality assessments remain limited to concentration-based evaluations, without translating those concentrations into mass load estimates (e.g. kg/day or tonnes/year). This omission restricts the ability to undertake robust temporal and spatial comparisons of contaminant transport and accumulation. Without load estimates, it is difficult to differentiate between genuine water quality improvements and dilution effects during high-flow events, or to quantify pollutant contributions from various sources over time.

- Cumulative Impact and Catchment-Scale Analysis

Despite the availability of streamflow data, there is limited evidence that CVO's monitoring programs have applied these data to develop mass-balance models or conduct comprehensive catchment-scale water quality assessments. Flow data are essential for evaluating cumulative impacts—particularly where multiple discharge sources influence the same watercourses—and for supporting integrated catchment management. The lack of such modelling and analysis constrains the ability to understand broader ecological risks and undermines opportunities for proactive and adaptive management across the site and downstream environments.

3.2.2 RECOMMENDATIONS

To improve the robustness of flow-related assessments and reduce uncertainties in surface water impact evaluations, the following actions are recommended:

- Install additional gauging infrastructure at key hydrological transition points, particularly along diverted and rejoining creek segments.
- Conduct targeted hydrological studies to evaluate baseflow contributions and potential groundwater–surface water interactions.
- Integrate flow data with water quality results to enable contaminant load estimations, dilution assessments, and temporal comparisons.

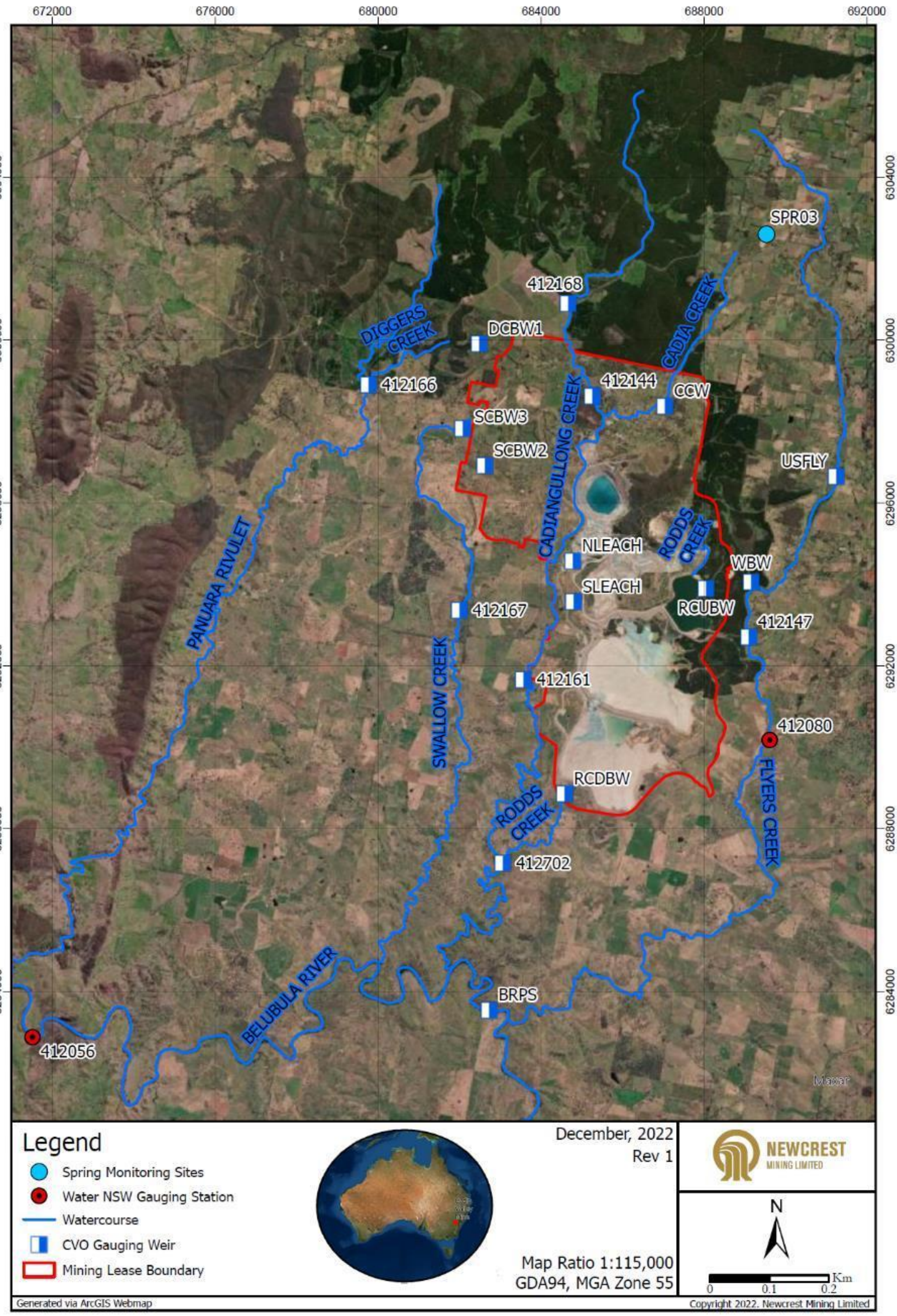

Figure 3-1Streamflow, Baseflow and Spring Monitoring Sites

3.3 SURFACE WATER QUALITY MONITORING

Water quality monitoring is a critical component of environmental management at CVO, ensuring that potential impacts from mining and associated activities on receiving water bodies are effectively identified, assessed, and controlled. The site operates under an Environment Protection Licence (EPL 5590), which outlines comprehensive requirements for surface water and groundwater monitoring to evaluate the influence of site activities on downstream ecosystems and protect environmental values.

Based on the review, it is noted that CVO's surface water quality monitoring program has evolved over more than two decades and is implemented in accordance with the Cadia Water Management Plan and the conditions of EPL 5590. Monitoring at CVO commenced in 1994 and the program has been continually expanded since then. Monitoring is undertaken across a network of upstream, operational, and downstream sites located on key watercourses including Cadiangullong Creek, Rodds Creek, Flyers Creek, and Swallow Creek. The assessments reference both the ANZG (2018) water quality guidelines and site-specific guideline values (SSGVs) developed through technical studies undertaken by GHD and other consultants.

Water quality monitoring is routinely conducted at these locations at either monthly or quarterly intervals as per the WMP requirements. Water quality parameters were selected based on the potential mining operation contaminants as identified in the Cadia East Geochemistry Assessment (Mesh Environmental 2009).

3.3.1 SPATIAL AND TEMPORAL COVERAGE

The spatial and temporal coverage of the CVO's surface water monitoring program is largely consistent with the commitments outlined in the Cadia Water Management Plan and EPL conditions.

3.3.1.1 SPATIAL COVERAGE

The program includes a comprehensive network of monitoring sites distributed across multiple creek systems and operational zones (Figure 3-2). Over 40 surface water sampling locations (Table 3-3) are maintained across the site, covering both on-site infrastructure zones (e.g. tailings storage facilities, ore processing areas, pit storages) and off-site receiving environments such as Cadiangullong Creek, Rodds Creek, Flyers Creek, Swallow Creek, and Diggers Creek. These locations were selected based on historical seepage pathways, risk assessments, and hydrogeological connectivity, providing both point-source and catchment-scale coverage of potential impacts. Surface water monitoring sites are grouped by functional zone and catchment including:

- Upper Cadiangullong Creek zone
- Cadia Hill Pit
- Ore Processing Area
- Waste Rock Dumps
- TSF Western Zone
- TSF Southern Zone
- TSF Eastern Zone
- Receiving Environment
- Cadia Dewatering Facility

The surface water quality monitoring program undertaken at CVO comprises the water quality suites and constituents listed in Table 3-2.

Table 3-2 Surface Water Quality Monitoring Suites

Suite Name	Suite Code	Constituents
Physical Parameters (field measurement)	FP	pH, Electrical Conductivity (EC), Temperature, Oxygen Reduction Potential (ORP)
Surface Water Quality	SWQ	EC, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Alkalinity Major Ions: Calcium, Magnesium, Sodium, Potassium, Chloride, Sulphate Nutrients: Nitrite, Nitrate, Total Nitrogen, Total Phosphorus Dissolved Metals/Metalloids: Aluminium, Arsenic, Cadmium, Copper, Iron, Lead, Manganese, Molybdenum, Zinc, Antimony, Cobalt, Chromium, Mercury, Nickel, Silver
Oil and Grease	O&G	Oil and grease
Dam Algae Monitoring	ALG	Blue-green algae (cell counts)

Table 3-3 Surface Water Quality Monitoring Schedule

Catchment	Monitoring Site	Purpose / Rationale	Monthly	Quarterly(1)
Upper Cadiangullong Creek	412168	Background water quality reference location located upstream from Cadiangullong Dam		FP, SWQ
	CAWS0	Water quality for process raw water. Furthest upstream surface water monitoring location on Cadiangullong Creek	ALG (Oct–Apr)	FP, SWQ
	412144	Water quality discharging or spilling from Cadiangullong Dam and upstream of active mine operations areas	FP, SWQ	
	CAWS2	Historic mining area impacts assessment		FP, SWQ
	CAWS3			FP, SWQ
	CAWS13	Cadia Creek reference site	FP, SWQ	
Cadia Hill Pit	CAWS46	Hoares Creek Dam		FP, SWQ
	CAWS65	Cadia Hill Pit. TSF decant water quality	FP, SWQ	
Ore processing area	CAWS73	Site Runoff Pond		FP + SWQ
	CAWS78	Ore processing impact monitoring		FP, SWQ
	CAWS79			FP, SWQ
Waste Rock Dumps	412161	Potential for impact from mining, processing & Southern Waste Rock Dumps (SWRDs)		FP, SWQ
	CAWS34	Monitor development of leachate water quality from Waste Rock Dumps		FP, SWQ
	CAWS35			FP, SWQ
	CAWS37	Monitor for potential seepage impacts from SWRD and NTSF		FP, SWQ
	CAWS52	Water quality in the mixed water storage dam (Rodds Creek Dam)	ALG (Oct–Apr)	FP, SWQ
	CAWS69	Monitoring seepage effects western NTSF/STSF		FP, SWQ
TSF Eastern Zone	CAWS42	Monitor development of TSF decant water quality. Used to determine potential impacts of the TSF on surface and/or groundwater quality	FP, SWQ	
	CAWS43		FP, SWQ	

Catchment	Monitoring Site	Purpose / Rationale	Monthly	Quarterly(1)
	CAWS60	Assess potential for seepage contributions on eastern side of southern TSF	FP, SWQ	
TSF Western Zone	CAWS61	Potential impact from mining, processing and TSF		FP, SWQ
	CAWS62			FP, SWQ
	CAWS64	Assess any influence of TSF on surrounding groundwater quality	FP, SWQ	
	CAWS67	Monitor for potential for seepage impacts on the western side of the NTSF and STSF		FP, SWQ
	CAWS68			FP, SWQ
	CAWS72			FP, SWQ
	CAWS75			FP, SWQ
	CAWS76			FP, SWQ
TSF Southern Zone	412702	Assess potential impacts from entire site (most downstream monitoring location in Cadiangullong Creek)	FP, SWQ	
	CAWS54	Assess the impact of TSF on surface water quality in Rodds Creek (tributary of Cadiangullong Creek)		FP, SWQ
	CAWS55		FP, SWQ	
	CAWS56			FP, SWQ
	CAWS57			FP, SWQ
	CAWS59			FP, SWQ
	CAWS30		FP, SWQ	
	CAWS31	Assess the influence of STSF water on groundwater contributing to base flow in creek	FP, SWQ	
	CAWS41		FP, SWQ	
	CAWS63	Assess the impact of TSF on surface water quality in Rodds Creek	FP, SWQ	
Flyers Creek	CAWS44	Upstream reference site (outside mining influences)		FP, SWQ
	CAWS10	Identify any potential effects associated with Cadia activities		FP, SWQ
Diggers Creek	412166	Reference site		FP, SWQ

Catchment	Monitoring Site	Purpose / Rationale	Monthly	Quarterly(1)
Swallow Creek	412167	Reference site		FP, SWQ
Receiving Environment	CAWS70	Identify any potential effects associated with Cadia activities in the downstream of the Cadiangullong Creek		
	CAWS71	Belubula River		
	BPRS	Belubula River		
Blayney Dewatering Facility	NEC061	Upstream of decommissioned Dewatering Facility	FP, SWQ	
	NEC062	Downstream of decommissioned Dewatering Facility	FP, SWQ	
Cadia Dewatering Facility	CDW03	Upstream of Cadia Dewatering Facility		FP, SWQ
	CDW04	Downstream of Cadia Dewatering Facility		FP, SWQ
	CDW05	Downstream of CDF Filter Plant		FP, SWQ

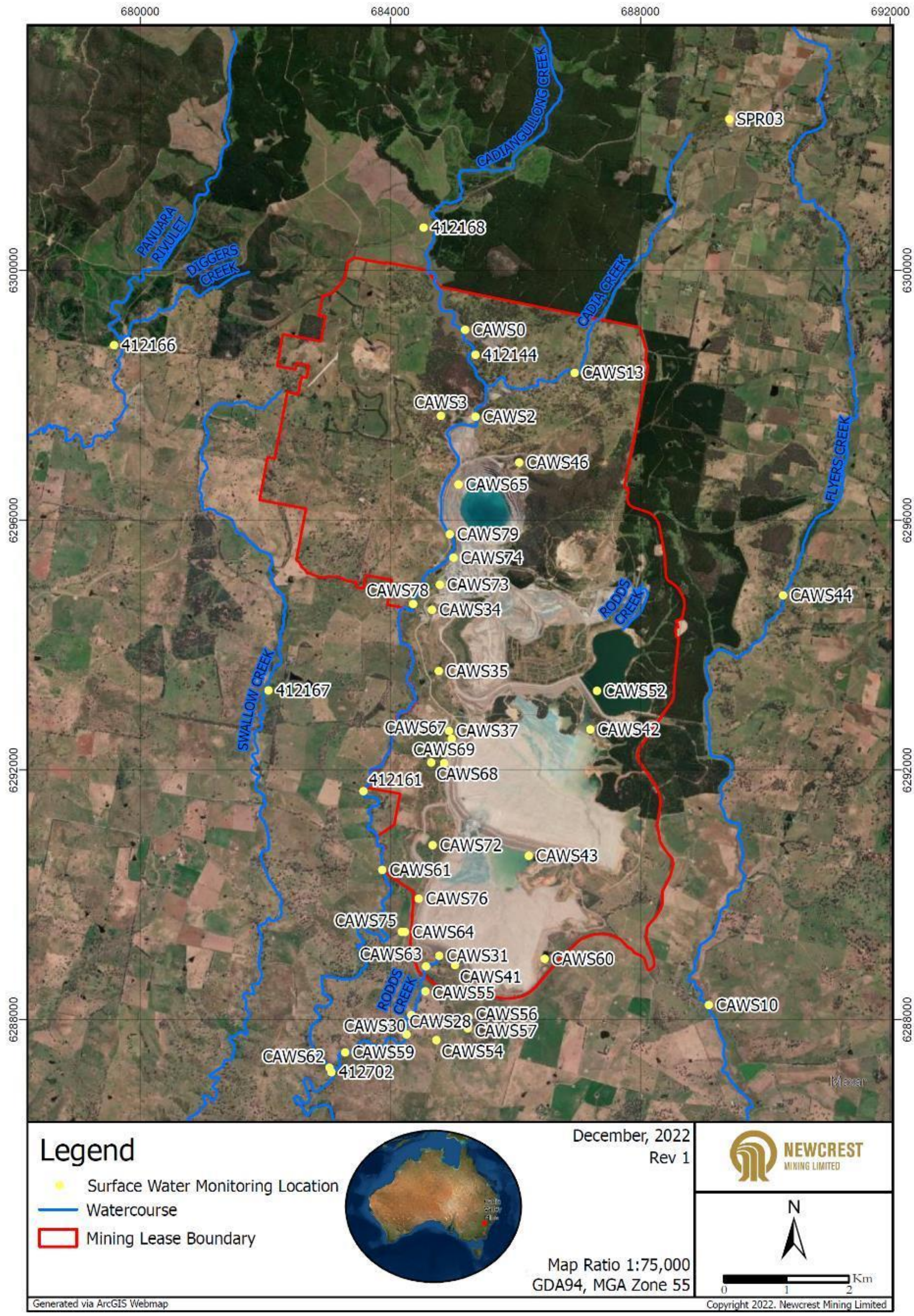

Figure 3-2 Cadia Surface Water Quality Monitoring Sites

SITE SELECTION FRAMEWORK AND RATIONALE

The surface water quality monitoring network at CVO is intended to provide spatial and functional coverage across areas potentially influenced by mining activities. It incorporates upstream reference sites, operational impact zones, and downstream compliance locations to support assessments of water quality and the attribution of observed changes to site-related activities. This approach aligns in principle with established environmental monitoring practices.

However, despite the breadth of monitoring coverage, the program lacks a clearly articulated and documented site selection framework. Although sites are generally classified as upstream, downstream, on-site, or reference locations, the rationale for their initial selection and classification particularly as control, impact, or compliance sites is not formally stated. This gap limits the conceptual robustness of the monitoring design and constrains the ability to confidently interpret results in relation to mining-related impacts.

Adjustments to the surface water quality monitoring network over time such as the addition of sites at Rodds Creek (e.g., CAWS28, CAWS54–59) and changes in the designation of certain sites have occurred without clear supporting documentation or explanation of the design implications. While network adaptation over time is a valid approach and often necessary to respond to changing operational risks, these modifications have not been accompanied by a redefinition of the monitoring design or an evaluation of the statistical implications for trend detection and impact assessment. Consequently, this has introduced uncertainty into the temporal comparability of the dataset and reduced the strength of cumulative impact assessments. However, these issues could be readily addressed through a formal review and redefinition of the monitoring design, including the establishment of clear control–impact pairings and improved documentation of site roles.

These shortcomings introduce uncertainty in the interpretation of long-term water quality trends and weaken the program's capacity to detect and attribute environmental change. A structured review of the site selection rationale, supported by a formalised monitoring design framework and paired control–impact logic, is recommended to strengthen the integrity and utility of the program. A detailed site-by-site evaluation of the monitoring network has been compiled and presented in the Table 3-4, which outlines the monitoring purpose, adequacy, and identified deficiencies for each monitoring site, along with commentary on the suitability of reference locations in the context of the monitoring network.

Table 3-4 CVO Surface Water Monitoring Site Review

Catchment	Site Code	Purpose / Rationale	Adequacy	Deficiencies / Comments
Upper Cadiangullong Creek	412168	Background water quality reference location located upstream from Cadiangullong Dam	Adequate	Reference sites are typically located outside the influence of mining or development activities and represent baseline or "natural" conditions.
	CAWS0	Water quality for process raw water. Furthest upstream surface water monitoring location on Cadiangullong Creek	Adequate	Seasonal monitoring of some analytes may limit year-round understanding
	412144	Downstream of Cadiangullong dam, upstream of active mine operations	Adequate	Not define as control or impact site
	CAWS2 CAWS3	Historic mining area impacts	Adequate	Paired control–impact logic is absent
	CAWS13	Cadia Creek reference site	Adequate	Defined as a reference site, but not a control site. Paired control–impact logic is absent
Cadia Hill Pit	CAWS46	Hoares Creek Dam	Adequate	None
	CAWS65	Cadia Hill Pit. TSF decant water quality	Adequate	None
Ore processing area	CAWS73	Site runoff pond	Adequate	None
	CAWS78 CAWS79	Ore processing impact monitoring	Adequate	Paired control–impact logic is absent

Catchment	Site Code	Purpose / Rationale	Adequacy	Deficiencies / Comments
Waste Rock Dumps	412161	Southern Waste Rock Dumps impact	Adequate	Paired control–impact logic is absent
	CAWS34	Leachate development monitoring	Adequate	None
	CAWS35			
	CAWS37	Seepage impacts from SWRD/NTSF	Adequate	None
	CAWS52	Rodds Creek Dam (mixed water storage)	Adequate	Only seasonal monitoring
	CAWS69	Seepage monitoring near western NTSF	Adequate	None
TSF Eastern Zone	CAWS42	TSF decant water development	Adequate	None
	CAWS43			
	CAWS60	Seepage contributions - east side STSF	Adequate	None
TSF Western Zone	CAWS61	Impact from TSF and mining	Adequate	Paired control–impact logic is absent
	CAWS62			
	CAWS64	Groundwater quality influence	Adequate	None
	CAWS67	Seepage monitoring - west NTSF/STSF	Adequate	None
	CAWS68			
	CAWS72			

Catchment	Site Code	Purpose / Rationale	Adequacy	Deficiencies / Comments
	CAWS75			
	CAWS76			
TSF Southern Zone	412702	Most downstream in Cadiangullong Creek	Adequate	Paired control–impact logic is absent
	CAWS54	Impact on Rodds Creek from TSF	Adequate	Paired control–impact logic is absent
	CAWS55			
	CAWS56			
	CAWS57			
	CAWS59			
	CAWS30			
	CAWS31	Baseflow influence from STSF	Adequate	None
	CAWS41			
	CAWS63	Impact on Rodds Creek from TSF	Adequate	Paired control–impact logic is absent
Flyers Creek	CAWS44	Upstream reference	Adequate	None
	CAWS10	Impact detection from Cadia	Adequate	None

Catchment	Site Code	Purpose / Rationale	Adequacy	Deficiencies / Comments
Diggers Creek	412166	Reference site	Adequate	Defined as a reference site, but not a control site. Paired control–impact logic is absent
Swallow Creek	412167	Reference site	Adequate	Defined as a reference site, but not a control site. Paired control–impact logic is absent
Receiving Environment	CAWS70	Downstream Cadiangullong Creek	Adequate	Paired control–impact logic is absent
	CAWS71	Belubula River	Adequate	Paired control–impact logic is absent
	BPRS	Belubula River	Adequate	Paired control–impact logic is absent
Blayney Dewatering Facility	NEC061	Upstream of decommissioned facility	Adequate	Paired control–impact logic is absent
	NEC062	Downstream of decommissioned facility	Adequate	Paired control–impact logic is absent
Cadia Dewatering Facility	CDW03	Upstream of Dewatering Facility	Adequate	Paired control–impact logic is absent
	CDW04	Downstream of Dewatering Facility	Adequate	Paired control–impact logic is absent
	CDW05	Downstream of Filter Plant	Adequate	Paired control–impact logic is absent

COMPARABILITY ISSUES

As summarised in Table 3-5, a key distinction in environmental monitoring design lies between reference sites and control sites. Reference sites are typically located outside the influence of mining or development activities and represent baseline or "natural" conditions. These sites are useful for understanding background variability but are not necessarily designed for direct statistical comparison with impact locations. In contrast, control sites are purposefully selected to be statistically comparable to impact sites and serve as matched comparators for detecting change attributable to site-specific disturbances.

None of the reference sites currently included in the CVO's surface water monitoring program function as true reference sites. All are subject to catchment-scale disturbances unrelated to mining, thereby confounding attribution of observed effects. While it is not clear which sites are considered to be controls, upstream sites such as 412168 (upstream of Cadiangullong Dam), appear to be treated as an upstream comparator; however, this site is situated in a modified landscape surrounded by pine plantations. Similarly, sites that appear to have been intended as controls and those labelled as reference sites are also degraded by various factors which reduces their validity as a baseline for comparison.

- Flyers Creek is impacted by land grazing and pine plantations as well as hydrological alteration;
- Swallow Creek shows elevated salinity – suggested but not confirmed as a consequence of groundwater intrusion, it has undergone riparian revegetation works which will have added variability and was possibly implemented as a result of historical clearing or streambed erosion;
- Panuara Rivulet shows evidence of nutrient enrichment and excessive algal growth and nutrification, likely linked to agriculture (especially grazing) and poor riparian condition.

A review of the CVO surface water monitoring program indicates that while several sites are designated or assumed to function as reference sites such as 412168 (upstream of Cadiangullong Dam), CAWS44 (Flyers Creek), 412166 (Swallow Creek), and 412167 (Diggers Creek), there are no clearly defined control sites that are formally paired with downstream or impacted locations. Although these reference sites may be suitable for characterising background conditions, they do not fully meet the design requirements of control sites, such as hydrological equivalence, spatial pairing, and statistical comparability.

Furthermore, the selection of reference sites appears to have been based on general assumptions about their separation from mining influences, without documented demonstration of geochemical or flow-related similarity to impact sites. As a result, the monitoring program lacks the statistical design integrity required for robust impact attribution. This weakens its capacity to support compliance assessments, detect subtle changes, or differentiate between natural and anthropogenic sources of water quality variability.

To strengthen the comparability and interpretability of monitoring data, it is recommended that the network be revised to incorporate clearly defined and documented control–impact pairings based on hydrogeological similarity, spatial alignment, and environmental relevance. This will enhance the scientific defensibility of the program and support future regulatory and environmental performance assessments.

Table 3-5 Reference Site vs Control Site

Aspect	Reference Site	Control Site
Definition	A location that represents natural or baseline conditions, ideally unaffected by the activity being assessed.	A location that is paired with an impact site and used to compare changes over time or under similar environmental conditions.

Aspect	Reference Site	Control Site
Purpose	To establish background environmental conditions against which changes can be assessed.	To enable direct comparisons with an impact site, isolating the effect of the activity (e.g., mining) from natural variability.
Proximity to Impact	Often distant from the area of potential impact and may be in a different catchment.	Typically located in the same catchment or environmental setting as the impact site but not directly influenced by the activity.
Design Role	Serves as a general benchmark for what conditions would be without development.	Serves as a matched comparator that allows for statistical testing of differences due to specific activities.
Use in Data Analysis	Used to describe natural variability or historical context.	Used in control–impact analyses, such as BACI (Before–After, Control–Impact) designs.

3.3.1.2 TEMPORAL COVERAGE

The temporal coverage of surface water monitoring at CVO extends from 1994 to date, providing over two decades of monthly and quarterly data. Sampling frequencies have generally followed the requirements set out in the Cadia Water Management Plan and Environment Protection Licence (EPL 5590). Water quality monitoring is routinely conducted at either monthly or quarterly intervals.

However, based on the review of AEMRs and associated surface water quality assessments, it is noted that CVO's temporal analysis remains largely confined to short-term annual datasets. Each reporting year, assessments primarily focus on data collected within that reporting period without undertaking cumulative temporal analysis across multiple years. Although historical data have been collected and archived since 1994, comprehensive long-term trend analysis is lacking in the available reports.

Graphical outputs included in AEMRs (e.g., time series plots) allow visual observation of intra-annual variability, and occasional comparisons to historic exceedances are presented. However, these analyses are descriptive rather than statistically rigorous and do not formally establish multi-year trends, rates of change, or cumulative impacts. No evidence was identified of systematic trend testing (e.g., Mann-Kendall trend analysis) or predictive forecasting based on historical data.

The existing temporal dataset provides an important foundation for water quality surveillance, and routine monitoring activities demonstrate general regulatory compliance. Nonetheless, the effectiveness of the monitoring program in detecting gradual changes or legacy-related impacts would be strengthened by implementing formal long-term trend analyses and consistently interpreting cumulative changes across operational phases. Establishing statistically supported temporal assessments would also enhance the program’s capacity to inform proactive and adaptive environmental management strategies.

3.3.2 PARAMETERS AND ANALYTES MONITORED

The CVO’s surface water quality monitoring program includes a comprehensive suite of physical, chemical, and biological parameters (Table 3-2) selected to assess both natural variability and potential impacts from mining activities. The analytes monitored are consistent with industry best practice, regulatory guidance, and site-specific risk assessments, and are used to evaluate water quality trends, compliance status, and potential ecological risks.

Core monitoring parameters typically include field measurements (e.g., pH, electrical conductivity, dissolved oxygen, and temperature), general laboratory analytes (e.g., total suspended solids, total dissolved solids, nutrients, and major ions), and a suite of dissolved metals and metalloids (e.g., arsenic, copper, lead, zinc, selenium) (Table 3-2).

While a wide range of physicochemical and metal/metalloid parameters are included in the current monitoring suite, dissolved organic carbon (DOC) is notably absent. Given the upcoming ratification of DOC and hardness (Ca & Mg) corrected default guideline values (DGVs) by the national regulator, it is recommended that DOC be included in future monitoring rounds to support improved risk assessment and alignment with emerging national water quality standards.

While the parameters selected provide a sound basis for assessing compliance and general water quality trends, the review identified that monitoring efforts have largely focused on standard suites without clear prioritisation of emerging contaminants or finer-scale biological indicators that could strengthen ecological risk assessments downstream. Additionally, the linkage between monitored parameters and specific risk hypotheses (e.g., runoff from TSFs, seepage migration) could be more explicitly documented to enhance the clarity of the program's design logic.

3.3.3 METHODS AND QA/QC

The surface water quality monitoring program at CVO is assumed to apply standardised field and laboratory methods consistent with general industry practices and Australian guidelines. However, based on the review of available documentation, including AEMRs and the Water Management Plan, detailed descriptions of sampling procedures, analytical protocols, and QA/QC processes are limited or not explicitly stated.

3.3.3.1 METHODS

Surface water quality monitoring is conducted routinely across multiple catchments. Monitoring appears to include in-situ field measurements (e.g. pH, EC, DO, turbidity) and the collection of grab samples, which are submitted for laboratory analysis. Sampling frequencies vary by site, typically occurring monthly or quarterly, and may be supplemented by event-based sampling.

However, the reviewed documents do not provide sufficient information on:

- Specific sampling techniques (e.g. sample preservation, equipment, handling),
- QA/QC practices in the field (e.g. field blanks, duplicates),
- Laboratory accreditation (e.g. NATA) or analytical methods used,
- Chain-of-custody protocols or sample storage conditions.

As a result, while the program likely follows standard protocols, the absence of clearly documented methodologies limits the ability to fully evaluate the reliability, consistency, and regulatory defensibility of the surface water data.

3.3.3.2 PERSONNEL COMPETENCY AND DATA HANDLING TRANSPARENCY

The manner in which surface water quality data are collected, handled, and interpreted has a direct influence on data reliability and the strength of any conclusions drawn from it. Ensuring that field and analytical work is conducted by appropriately trained and experienced personnel is fundamental to maintaining scientific and regulatory credibility.

While the reviewed reports occasionally mention that sampling was undertaken by suitably qualified personnel, they generally lack specific detail regarding the roles, qualifications, or professional backgrounds of those involved in field data collection, data management, or interpretation. Personnel information, where provided, is typically limited to document preparation and internal review acknowledgements under document control sections.

Data analysis and data assessments of the CVO monitoring program has been delivered by reputable third-party consultancies such as GHD and ALS respectively, which provides a reasonable level of confidence that appropriately skilled personnel were engaged. However, in the absence of documented qualifications or responsibilities, this confidence relies primarily on institutional reputation rather than transparent, verifiable evidence of individual competence. To improve transparency and confidence in methodological rigour, future reporting should include clear documentation of field team roles, training, and relevant qualifications.

3.3.3.3 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

Quality assurance and quality control (QA/QC) are critical to ensuring the reliability, accuracy, and defensibility of environmental monitoring data. Robust QA/QC processes are essential at every stage of data generation, from field sampling to laboratory analysis, data handling, and interpretation, particularly for long-term programs used to support compliance decisions and assess change over time.

The surface water monitoring program should include field and laboratory QA/QC measures to ensure data quality and defensibility. These include:

- Field QA/QC procedures:
  - Collection of duplicate samples at approximately 10% of sites;
  - Collection of field blanks to identify contamination during sampling and handling;
  - Calibration of field meters before and after sampling events.
- Laboratory QA/QC procedures:
  - Inclusion of method blanks, matrix spikes, laboratory duplicates, and certified reference materials;
  - Internal laboratory QA reports reviewed for quality assurance flags and corrective actions.
- Data validation and review:
  - Assessment of relative percent difference (RPD) in field and laboratory duplicates;
  - Verification of flagged non-detects, exceedances, and data anomalies;
  - Upload and review of validated data in CVO's internal environmental database as part of routine reporting cycles.

While the field and laboratory methods described in the CVO monitoring program appear consistent with general good practice and regulatory expectations, the review identified a lack of transparency and consistency in the reporting of QA/QC outcomes. Specifically, details such as the frequency and resolution of field duplicates, performance of blanks, and relative percent difference (RPD) summaries from laboratory quality checks are not consistently presented or statistically summarised in the reviewed documents. This limits the ability to independently assess data quality and interpret trends with confidence.

Furthermore, QA/QC data do not appear to be integrated into the broader data analysis process. Incorporating QA/QC results directly into analytical datasets and undertaking formal QA/QC assessments alongside data interpretation would improve the reliability and defensibility of monitoring outcomes. Greater emphasis on reporting and utilising QA/QC performance indicators is recommended to enhance the robustness of trend assessments and compliance evaluations.

3.3.4 SITE-SPECIFIC GUIDELINE VALUES (SSGVS)

3.3.4.1 REVIEW OF DERIVATION AND USE OF SITE-SPECIFIC VALUES

Cadia Valley Operations (CVO) has undertaken the development of Site-Specific Guideline Values (SSGVs) to better reflect local water quality conditions and improve the interpretability of monitoring data compared to the use of national default guideline values (DGVs). These SSGVs were initially developed by GHD (2016) and further refined in the Oaky Station SSGV Review (GHD, 2018a), particularly for site 412702, a key downstream location that integrates cumulative mining influences. These values are intended to be used as water quality benchmarks for assessing potential risks to environmental values, consistent with the ANZG (2018) framework, rather than solely as management triggers such as TARP activation thresholds.

SSGVs were developed using a tiered approach outlined in the ANZECC & ARMCANZ (2000) guidelines, adapted for ANZG (2018). This approach prioritised:

1. **Biological effects data**, where available,
2. **Local reference data**, particularly where ecological data were limited, and
3. **Default guideline values**, when local data were inadequate.

The 2018 review identified that previous SSGVs for Oaky Station were partly based on reference sites such as Flyers Creek (CAWS10/44) and site 412168 (CC5), which differ markedly in catchment land use and hydrochemistry. These differences reduced the relevance of these sites as reference locations for setting guidelines at Oaky Station. As a result, GHD (2018a) revised the SSGVs using data specific to 412702, reflecting the actual background and operational conditions at this site.

While this site-specific approach aimed to improve relevance and reduce false positive exceedances, it does introduce limitations. Notably, the revised SSGVs were derived exclusively from data at site 412702, which may already be influenced by operational activities, rather than from minimally impacted reference sites. As a result, the derivation does not fully align with the guidance under ANZG (2018), which recommends using at least 24 months of continuous monitoring data from suitable reference sites for derivation. This limitation should be clearly acknowledged, and consideration should be given to whether appropriate reference sites are available for future SSGV development that meet this requirement. The revised SSGVs were primarily calculated using the 80th percentile for metals, nutrients, and general physico-chemical stressors, and the 20th percentile where low concentrations are ecologically significant (e.g., DO). Where seasonal differences were detected, particularly for parameters like copper and manganese, the reports considered but ultimately did not recommend seasonal SSGVs due to limited explanatory power from flow data.

Where SSGVs are derived to inform ecological risk, it is essential that they are based on appropriate ecotoxicological data or effects-based methods, as recommended under ANZG (2018). SSGVs should ideally be developed using laboratory or field-based biological effects data, or from water quality data collected from suitable minimally disturbed reference sites over a sufficient monitoring period (typically ≥24 months). Applying statistical percentiles alone—particularly for toxicants such as metals—does not constitute an appropriate derivation method unless supported by a robust ecological rationale. A weight-of-evidence approach should be considered to strengthen the derivation process, incorporating multiple lines of evidence such as observed biological responses, background concentrations, and site-specific stressor mechanisms. Where SSGVs are instead derived from operationally influenced or non-comparable sites, this limits their utility as risk thresholds and may lead to normalisation of existing impacts.

It is also essential to clearly distinguish the purpose of each SSGV—whether it is intended to serve as a benchmark for environmental protection (consistent with ANZG 2018) or as an internal management or TARP value. Improved transparency around their derivation and application will help ensure consistent and scientifically robust interpretation of monitoring results.

The 2018 GHD review also recommended updating the Water Management Plan to incorporate the revised SSGVs, including explicit documentation of the methodology used and justification for site-specific derivations. Adoption of these values enhances the relevance of monitoring outcomes and reduces the likelihood of spurious exceedances due to unrealistic benchmark values.

GHD (2019) reviewed the requirement for ongoing SSGV assessment at Swallow Creek, Diggers Creek and Flyers Creek locations and found that there has been no observable influence of Cadia operations recorded at these sites. Subsequently, SSGVs are no longer proposed for these watercourses. Notwithstanding, CVO will continue to monitor the water quality of these watercourses and assess and report any changes in long-term trends in the Cadia Annual Review.

Table 3-6 presents the SSGVs for monitoring sites GS412702 and CDW05. The derived SSGVs are applied to assess water quality at receiving environment sites within the monitoring network. Where SSGVs are available, they supersede default ANZECC/ARMCANZ (2000) or ANZG (2018) trigger values in trend analyses.

Table 3-6 Surface Water Quality SSGVs

Parameter	Unit	GS412702 (Oaky Creek Gauging Station)	Cadia Dewatering Facility (CDW05)
Physicochemical			
pH	pH	6.5 - 8.5(5)	6.5 - 8.5(5)
EC	µS/cm	1,535(2)	640(5)
TSS	mg/L	50	-
Dissolved Metals			
Aluminium	mg/L	0.055(1)	0.055(1)
Arsenic	mg/L	0.013(1)	0.013(1)
Cadmium	mg/L	0.0002(1)	0.0002(1)
Copper	mg/L	0.009(4)	0.006(5)
Iron	mg/L	0.8(4)	0.2(3)
Lead	mg/L	0.0034(1)	0.0034(1)
Manganese	mg/L	1.9(1)	1.9(1)
Molybdenum	mg/L	0.034(1)	0.034(1)
Zinc	mg/L	0.08(4)	0.05(5)

Notes:

1. ANZG (2018) default guideline value for 95% protection of aquatic ecosystems (recommended for slightly to moderately disturbed ecosystems).

2. SSGV defined as the 95th percentile value of historic data supported by no detectable impact in river health macroinvertebrate taxa richness scores during periods exposed to EC in this range (GHD, 2020).

3. ANZECC & ARMCANZ (2000) guideline value for long-term irrigation.

4. SSGV defined as the 95th percentile of historic data; less than the 95th percentile of historic data recorded at reference site GS412168.

5. SSGV defined as the 80th percentile of historic data.

REVIEWER OBSERVATIONS

The use of SSGVs represents good practice in adapting monitoring criteria to local conditions and reduces the likelihood of misinterpreting naturally elevated background concentrations as anthropogenic contamination. However, the review identified the following issues:

- Derivation reports or technical summaries for all SSGVs are not consistently referenced or appended to annual reporting (e.g., AEMRs).
- The spatial extent and hydrological applicability of each SSGV (e.g., across Cadiangullong Creek versus Rodds Creek sub-catchments) are not clearly defined.
- In some instances, monitoring sites continue to be assessed against national default guidelines rather than the relevant SSGVs, resulting in inconsistency across the catchment.

RECOMMENDATIONS

- Ensure that all active SSGVs and their derivations are clearly referenced and summarised in annual reporting documents.
- Define the spatial applicability of each SSGV within the monitoring network.
- Harmonise assessment thresholds across sites to ensure consistency between SSGV and ANZG default guideline applications.
- Update EPL and Cadia Water Management Plan with any changes that were made to the SSGVs with appropriate justification.

3.3.4.2 LIMITATIONS IN THE USE OF SITE 412702 FOR DERIVING SSGVS

The derivation of Site-Specific Guideline Values (SSGVs) at Cadia Valley Operations (CVO) has relied heavily on historical data from monitoring site 412702 (Oaky Creek Gauging Station). However, this approach presents several limitations and concerns regarding scientific robustness and regulatory defensibility. As confirmed in both the *Cadia Water Management Plan* and the *Oaky Creek SSGV Review* (GHD, 2018), site 412702 is not a reference site, but rather a compliance location situated downstream of the majority of mining operations. It is specifically intended to represent cumulative mining impacts.

Earlier SSGVs were developed using upstream or background sites, including 412168 (CC5) and Flyers Creek sites CAWS10 and CAWS44. However, due to major differences in catchment land use and water chemistry, GHD (2018) concluded that these reference sites were unsuitable comparators for 412702. Consequently, SSGVs were derived directly from the percentile distributions of historical data collected at 412702 itself.

While this site-specific approach aims to reduce false positive exceedances and improve alignment with local conditions, it introduces a methodological flaw: the use of a potentially impacted site as its own baseline. This undermines the ability to detect meaningful changes in water quality or attribute exceedances to operational causes. It also risks normalising the influence of legacy impacts or persistent pollutant loads embedded in the site's historical record. Moreover, by bypassing external reference or control sites, the monitoring program reduces its capacity for robust comparative assessment.

To strengthen the scientific basis of the monitoring framework, future SSGV development should consider a hybrid approach, validating percentile-based values from impact sites with comparable upstream or minimally disturbed locations, while clearly articulating the limitations of internal baseline derivation. The absence of transparent reference–impact relationships also reinforces the broader need for a formalised and documented site selection strategy.

3.3.5 SURFACE WATER QUALITY DATA REVIEW

3.3.5.1 OVERVIEW OF DATASET (TEMPORAL AND SPATIAL EXTENT)

Analytical results from surface water sampling conducted across the CVO between 2010 and 2024 were assessed for each monitoring location. All data used in this assessment underwent a detailed quality assurance and quality control (QA/QC) review to ensure accuracy and consistency. Where analytical results were reported as below the limit of reporting (LOR), the LOR value was conservatively adopted in the statistical analysis to maintain data integrity and enable consistent trend comparisons.

Time series surface water quality graphs are presented in Appendix A and have been evaluated to determine whether mining operations, external environmental factors, or neighbouring land uses have influenced observed water quality outcomes. Notable increasing or decreasing trends in analyte concentrations were identified and discussed by sub-catchment or monitoring zone in the subsequent sections.

Water quality results showing no discernible trend, or consistently remaining below relevant guideline values from the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018) or site-specific guideline values (SSGVs), are generally not discussed in detail. Monitoring results from watercourses were compared to ANZG (2018) default guideline values (DGVs) for 95% species protection in freshwater systems to evaluate the potential for offsite environmental impacts. The applicable SSGVs used for this assessment are provided in Table 3-6.

3.3.5.2 IDENTIFICATION OF PATTERNS AND TRENDS

UPPER CADIAGULLONG CREEK

The following surface water sites are within the Upper Cadiangullong Creek area:

- CAWS0, which is a site on Cadiangullong Dam
- 412144, which is on Cadiangullong Creek downstream of the dam
- CAWS2, which is on Cadiangullong Creek upstream of the Cadia Extended Pit
- CAWS3, an historical mine adit.

Upper Cadiangullong Creek runs from the Cadiangullong Dam to the Cadia Hill Pit. This reach of the creek adjoins core processing facilities, office areas, the Cadia Extended Pit and the Cadia Hill Pit, as well as historical mining areas to the west of the creek line which all present potential sources of pollution. Cadia Creek meets Cadiangullong Creek within this reach. The focus of assessment is identifying potential impacts from mine derived pollutants on the creek as a receptor. There are no groundwater monitoring locations within Upper Cadiangullong Creek.

A review of historical surface water quality data across monitoring sites located in the Upper Cadiangullong Creek area specifically 412168, CAWS0, 412144, CAWS2, CAWS3, and CAWS13 reveals distinct temporal and spatial patterns in both general water quality parameters and dissolved metal/metalloid concentrations (Appendix A). Monitoring data for site CAWS3 is only available from 2017 onwards.

General Water Quality Parameters

Site CAWS3 consistently exhibits elevated levels of electrical conductivity (EC), bicarbonate alkalinity, total hardness, sulfate, calcium, magnesium, sodium, chloride, and total dissolved solids (TDS), with EC often exceeding 1,500 µS/cm. This suggests a localised or legacy impact likely associated with historical mining operations.

Sites 412168, 412144, and CAWS0 show relatively stable and lower values across most general water quality parameters compared to CAWS3, consistent with their locations upstream and their designation as reference or background sites.

pH in Upper Cadiangullong Creek has been relatively stable in the reporting period.

CAWS2 and CAWS13 also remain stable and low across most parameters compared to CAWS3, showing no indication of elevated salinity or hardness, supporting their role as either transitional or low-impact sites.

Nutrient parameters such as Total Nitrogen, Total Phosphorus, and Kjeldahl Nitrogen show scattered moderate elevations across all sites, but no strong upward trend is evident.

Dissolved Metals/Metalloids

Cobalt, copper, cadmium, molybdenum, nickel, and zinc concentrations are consistently higher at CAWS3 compared to other sites in Upper Cadiangullong cluster, indicate influence of seepage from the historical mine adit.

In contrast, 412168, CAWS0, and 412144 show low and stable metal/metalloid concentrations, reinforcing their roles as reference or upstream locations.

Elevated aluminium and iron concentrations have been observed at all sites except CAWS3, though no trend has been observed.

Elevated cobalt results have been observed at CAWS2 and CAWS3 likely due to the influence of historic mine seepage.

CAWS2 and CAWS13 generally maintain low metal/metalloid levels compared to CAWS3, although some variability in metals like cobalt and iron is evident.

Arsenic, mercury, selenium, and silver remain consistently low across all sites, with no discernible trend.

Key Observations and Implications

Water quality data for this zone indicated a potential impact of historical mining in the catchment in 1998. The pronounced elevation in key indicators at CAWS3, suggests that this site may be receiving historical mining-related inputs, potentially from surface or subsurface pathways.

The clear gradient between upstream sites (e.g., 412168, CAWS0, and 412144) and CAWS2 supports the conclusion that mining impacts are spatially localised and diminish with upstream distance.

CADIA HILL PIT

Operations at the Cadia Hill Pit ceased in 2012 and the pit is currently being used for tailings disposal from which water is reclaimed. In March 2018, a failure of a section of the Northern Tailings Storage Facility (NTSF) led to a modification of the Cadia East Project Approval to allow the deposition of tailings in the Cadia Hill Pit up to 713 m AHD.

The two sites associated with the Cadia Hill Pit area, CAWS46 and CAWS65, demonstrate distinctly different water quality patterns over time, with CAWS65 showing elevated concentrations for a range of parameters in recent years (Appendix A). This suggests varying levels of influence from pit-related seepage, legacy contamination, or operational discharges. Monitoring data for site CAWS65 is only available from 2018 onwards.

General Water Quality Parameters

EC, TDS, total hardness, sulfate, chloride, and major ions (Ca, Na, K) concentrations are elevated at both sites. These parameters show marked increases at CAWS65 beginning around 2018–2019.

pH remains circumneutral to slightly alkaline at both sites, but CAWS65 displays a slight upward trend, suggesting evolving geochemical conditions possibly related to oxidation or ongoing neutralisation reactions.

Turbidity and Total Suspended Solids (TSS) show isolated but significant spikes at CAWS65, including one TSS value exceeding 300,000 mg/L, likely related to an isolated sediment disturbance or discharge event.

Nutrient levels (e.g., Total Nitrogen, Kjeldahl Nitrogen) have gradually declined at both sites over the observed period, though CAWS46 initially showed higher variability and peak values in earlier years (2010–2015).

Dissolved Metals/Metalloids

Cadmium, cobalt, copper, manganese, nickel, selenium, and zinc concentrations are generally higher at CAWS46 prior to 2018, with a steady decline over time. In contrast, CAWS65 shows a more stable but rising trend for specific metals such as antimony, arsenic, Molybdenum.

Lead, Mercury, and Silver remain low across both sites, showing no meaningful increase or exceedance patterns.

Key Observations and Implications

The influence of tailings deposition within the Cadia Hill Pit is evident in the water quality results for CAWS65, which monitors standing water retained inside the pit. This site reflects the quality of mine-affected water retained on site, rather than conditions in downstream receiving waterways. CAWS65 shows increasing salinity and sulfate concentrations, along with emerging upward trends in antimony, arsenic, and molybdenum, indicative of ongoing geochemical changes and seepage inputs within the pit environment. CAWS46 appears to reflect a historically more impacted site, with elevated metals during the earlier part of the monitoring period (2010–2015), followed by a gradual improvement.

The divergent water quality patterns between the two sites, particularly post-2018, reinforce the value of maintaining both locations in the long-term monitoring program. CAWS65 may serve as an indicator of current pit-related impacts, while CAWS46 offers insight into legacy conditions and potential recovery trajectories.

ORE PROCESSING AREA

The ore processing area consists of the ore crushing and treatment facilities, office areas, laydown yard, workshops, process water ponds, sediment dams and ROM pads. All runoff from this area is captured within the Site Runoff Pond (SROP). The SROP (CAWS73) is a zero discharge stormwater runoff dam. The SROP is clay lined and captures site runoff and leakage from the processing plant. Though no discharges from the SROP occur and the clay lining likely prevents any significant seepage, the potential influence of the water at CAWS73 on nearby groundwater and surface water has been assessed. Site CAWS78 and CAWS79 are on Cadiangullong Creek downstream and monitor potential effects of the Ore Processing Plant.

The Ore Processing Area (OPA) monitoring sites, CAWS73, CAWS78, and CAWS79 (Appendix A), display spatial and temporal variation in both general water quality and dissolved metal/metalloid concentrations. Monitoring data for site CAWS78 and CAWS79 is only available from 2018 onwards.

General Water Quality Parameters

CAWS73 consistently exhibits elevated levels of salinity-related indicators such EC, TDS, sulfate, chloride, sodium, calcium, and magnesium compared to CAWS79 and CAWS78 throughout the dataset. EC and TDS values regularly exceed 3,000 µS/cm and 3,000 mg/L, respectively, suggesting persistent saline inputs potentially related to the ore processing system or tailings contact water. CAWS73 captures runoff from around the ore treatment complex and the water captured is recycled for reuse on site. As such, increased salinity is to be expected at CAWS73, especially during periods of low rainfall.

CAWS78 and CAWS79, in contrast, show markedly lower concentrations of these same parameters compared to CAWS73, with EC generally below 1,000 µS/cm.

Nutrient parameters such as Total Nitrogen and Nitrate are significantly higher at CAWS73, particularly prior to 2020, where Total Nitrogen exceeded 20 mg/L. Majority of the nitrogen observed at CAWS73, mostly nitrogen oxides concentrations, had been generally decreasing from 2010 to late 2018.

pH levels remain near-neutral to slightly alkaline across all sites, though CAWS73 again exhibits higher variability compared to the relatively stable trends at CAWS78 and CAWS79.

Turbidity and TSS are sporadically elevated at CAWS73, with occasional spikes above 200 NTU or mg/L. TSS concentrations at CAWS73 have been more variable, though no trend has been observed.

Dissolved Metals/Metalloids

CAWS73 demonstrates consistently higher metal concentrations across multiple analytes, notably manganese, molybdenum, copper, arsenic, nickel, and zinc. These metals show persistent presence, with manganese regularly exceeding 0.2 mg/L, molybdenum trending upwards to near 0.9 mg/L, and copper exceeding 0.1 mg/L in multiple cases.

CAWS78 and CAWS79 show higher peaks of copper, aluminium, iron, manganese and zinc compared to the derived SSGVs of Oaky Creek.

Temporal trends indicate that while molybdenum concentrations at CAWS73 have increased over time, zinc shows a slight declining trend.

Trace metals such as selenium, antimony, mercury, and silver remain low across all sites, with no indication of guideline exceedances or concerning trends.

Key Observations and Implications

Site CAWS73 exhibits distinctly different water quality characteristics compared to CAWS78 and CAWS79, likely reflecting its location within the mine water management system and the influence of process water recirculation, rather than natural surface water inputs.

Water quality trends at the Site Runoff Pond (SROP) were observed, including an increasing trend in nitrogen oxides, copper and major cation concentrations. These trends were not of concern as the SROP is a zero discharge stormwater runoff dam, where poor water quality is expected.

WASTE ROCK DUMPS

The Southern Waste Rock Dumps (SWRDs) are drained by the Northern Leachate Dam (CAWS34), Southern Leachate Dam (CAWS35), H19 Sediment Dam (CAWS37) and Rodds Creek Dam (CAWS52). The waste rock dumps have been partially rehabilitated. The nearest downstream Cadiangullong Creek site is 412161, which is the potential receptor for any impact of the SWRDs on surface water quality.

Monitoring sites associated with the Waste Rock Dumps (WRD) show consistent patterns that reflect both legacy and potentially ongoing geochemical interactions between runoff, seepage, and waste rock material (Appendix A). Sites exhibit moderate to elevated variability in salinity, nutrient, and metal/metalloid concentrations, with differences in trends observed across the network.

General Water Quality Parameters

Site CAWS35 consistently records the highest levels of salinity indicators, including EC, TDS, sulfate, and major cations (Ca, Mg, Na, K). EC values often exceed 4,000 µS/cm, and TDS values approach or surpass 5,000 mg/L, particularly from 2010 to 2018, with a gradual decline observed more recently.

CAWS34 and CAWS37 show moderate levels of salinity indicators, including EC, TDS, sulfate, and major cations (Ca, Mg, Na, K).

Site 412161 shows relatively low concentrations of nitrogen species compared to other sites in the WRDs.

Site CAWS52 shows intermittent spikes in chloride, sodium, and potassium, though generally maintains stable concentrations.

The pH of the waste rock dump leachate at CAWS34 ranges from slightly acidic and trending towards slightly alkaline, whereas the pH at CAWS35 is slightly alkaline.

The waste rock dump leachate contains very high concentrations of nitrogen oxides. These concentrations are associated with the WRDs, and have generally been higher at CAWS35 than at CAWS34. The nitrogen oxide concentrations have been decreasing gradually over time. A decreasing trend in nitrogen oxide concentrations has also been observed at Rodds Creek Dam (CAWS52), which likely reflects the influence of pumped NTSF decant water to the dam.

No trends were observed in the TSS concentrations at CAWS34 and CAWS35, which is to be expected as the leachate is not likely to carry suspended solids into the surface water in the leachate dams.

Dissolved Metals/Metalloids

Elevated concentrations of many metals have been observed at CAWS34 and CAWS35 compared to other sites in WRD area, which are attributable to the water having leached through waste rock. These metals are cadmium, cobalt, copper, manganese, nickel, selenium and zinc; concentrations of each have generally been higher at CAWS34. The concentrations of these metals have been generally decreasing over time.

Site CAWS52 displays notable increases in molybdenum over time than at the leachate dams, which, considering that molybdenum is associated with the ore mined at Cadia, indicates the influences of process water as well as tailings decant water pumped to Rodds Creek Dam from the NTSF. The CAWS52 molybdenum results have shown an increasing trend since monitoring records began.

Site 412161 shows some elevated peaks of copper and zinc compared to the derived SSGVs of Okay Creek.

Key Observations and Implications

The assessment indicated that the waste rock dump leachate is becoming more dilute over time, with decreasing trends observed for multiple parameters, including EC, nitrogen oxides and metals.

Surface water monitoring sites CAWS34 and CAWS37 reflect legacy waste rock dump (WRD) impact signatures, with historically elevated salinity and metal concentrations. However, observed declining trends across many parameters suggest improvements potentially linked to natural attenuation or management interventions. Site CAWS52 shows emerging increases in parameters such as molybdenum and pH, warranting closer observation.

TAILINGS STORAGE FACILITIES EASTERN ZONE

Surface water monitoring data from sites CAWS42, CAWS43, and CAWS60 in the TSF Eastern Zone reveal elevated and variable water quality parameters consistent with interactions between surface drainage and tailings-affected waters (Appendix A). The temporal trends indicate site-specific variations and potential management or hydrological changes over time. Monitoring data for site CAWS60 is regularly available from 2016 onwards.

General Water Quality Parameters

CAWS42 demonstrates persistently high levels of salinity-related parameters, including EC, TDS, sulfate, chloride, sodium, calcium, and magnesium compared to CAWS43 and CAWS60. EC and TDS commonly exceed 4,000 µS/cm and 3,000 mg/L, respectively, across the full monitoring period, indicating persistent saline influence.

CAWS43 generally exhibits moderate concentrations, while CAWS60 shows the lowest concentrations of these parameters, suggesting relatively less salinity impact. For alkalinity parameters (bicarbonate alkalinity and total alkalinity), CAWS60 records consistently higher concentrations than both CAWS42 and CAWS43, indicating different geochemical conditions at this site.

Nutrient parameters, including nitrate, nitrite, and total nitrogen, show episodic peaks at CAWS42 and CAWS43 in earlier years, with concentrations declining towards recent years. CAWS60 maintains consistently low nutrient levels throughout the monitoring period. Total phosphorus concentrations are low across all sites, with only a few isolated peaks at CAWS42 and CAWS43.

pH values remain near neutral across all sites, though slightly more alkaline at CAWS60, which could be indicative of alkaline seepage inputs.

For suspended solids (TSS) and turbidity, occasional peaks are observed at CAWS42 and CAWS43, while CAWS60 generally remains low for these parameters.

Dissolved Metals/Metalloids

CAWS42 shows substantial increases in metal concentrations notably antimony, arsenic, cadmium, molybdenum, iron, nickel, and aluminium from 2020 onwards, with arsenic exceeding 0.02 mg/L and molybdenum exceeding 2 mg/L. This spike suggests a recent or ongoing source of tailings-influenced drainage.

CAWS43 generally exhibits lower metal concentrations across most parameters, although minor peaks in zinc and nickel are observed. Concentrations of arsenic, cadmium, and molybdenum remain consistently lower compared to CAWS42.

CAWS60 presents sporadic elevated peaks in metals such as aluminium, cobalt, copper, iron, manganese and zinc, with occasional higher values compared to CAWS42 and CAWS43. However, for most parameters, concentrations at CAWS60 remain low or stable, suggesting fewer sustained inputs of metals relative to CAWS42.

Across all three sites, metals like chromium, lead, selenium, and silver show very low and stable concentrations, with no significant differences between the sites.

Key Observations and Implications

The analysis of the TSF eastern zone data indicated that the concentrations of nitrogen oxides in the tailings decant water have been generally decreasing across the period of monitoring. CAWS42 currently records the highest concentrations of metals within the TSFEZ monitoring network, with significant post-2020 increases in arsenic, molybdenum, and cadmium. These results reflect the site's role within the mine water management system, where process-affected water is monitored prior to internal reuse or management. This likely reflects increased seepage or redistribution of tailings-related constituents.

TAILINGS STORAGE FACILITIES WESTERN ZONE

Surface water is monitored at the following sites in TSF western zone:

- Watercourses: CAWS61, CAWS62.
- Surface water storages: CAWS64, CAWS67, CAWS68, CAWS69, CAWS72, CAWS75,
- CAWS76.

General Water Quality Parameters

Sites CAWS61, CAWS67, and CAWS68 show elevated levels of salinity-related parameters, such as EC, TDS, bicarbonate alkalinity, sulfate, calcium, and magnesium, with TDS and EC values exceeding 4,000 mg/L and 5,000 µS/cm, respectively, during peak years (notably pre-2020).

CAWS72 and CAWS75 exhibit short-term increases in several parameters like sulfate, sodium, and TDS, suggesting episodic exposure to tailings-affected water or storm-related runoff events.

CAWS62 and CAWS76 appear comparatively stable and lower in salinity and hardness, though not entirely background-like, indicating partial influence but potentially downgradient or better buffered positions.

Nutrient levels, including nitrate, total nitrogen, and Kjeldahl nitrogen, are elevated at some sites in earlier years (particularly CAWS61 and CAWS67), with concentrations gradually declining from 2015 onwards.

Turbidity and total suspended solids (TSS) remain low across most sites, with scattered high values (e.g. CAWS75) likely reflecting discrete erosion or disturbance events.

Dissolved Metals/Metalloids

Most metals show low baseline concentrations at most sites, with sporadic peaks at specific locations, indicating localised variability.

Aluminium concentrations exhibit multiple peaks, particularly at CAWS61, CAWS62, CAWS68, and CAWS76, indicating intermittent mobilisation of this metal in recent years.

Copper levels show consistent low-level detections across most sites, with elevated peaks observed at CAWS61, CAWS62, and CAWS68.

Iron concentrations display several high peaks, particularly at CAWS76, and to a lesser extent at CAWS61 and CAWS68.

Manganese shows significant spikes at CAWS68 and CAWS76, suggesting potential site-specific sources or mobilisation under reducing conditions.

Molybdenum presents irregular but repeated elevated concentrations at CAWS68, CAWS72, and CAWS76, suggesting possible localised process water or waste rock contact.

CAWS67 records notable manganese and nickel increases around 2018–2020, with manganese exceeding 8 mg/L the highest across the TSFWZ.

Trace metals such as lead, mercury, selenium, and silver remain low across all locations, showing minimal concern or upward trends.

Arsenic and antimony appear in measurable quantities across CAWS64 and CAWS75, consistent with tailings-affected discharge signatures.

Key Observations and Implications

The TSF Western Zone sites exhibit moderate to elevated variability in water quality parameters and trace metals, consistent with their proximity to tailings infrastructure and exposure to seepage pathways. The trends reflect a combination of legacy and recent discharge signatures with localised hotspots of metal enrichment and salinity.

Possible influence of TSF decant water or drainage from the TSF embankments (which were constructed with waste rock) is evident at some sediment dams and seepages along the western side of the TSFs. This was indicated by elevated molybdenum concentrations at these sites.

TAILINGS STORAGE FACILITIES SOUTHERN ZONE

Surface water is monitored at the following sites within the TSF southern zone:

- Watercourses: CAWS28, CAWS30, CAWS55, CAWS59, CAWS63, 412702.
- Surface water storages: CAWS31, CAWS41, CAWS54, CAWS56, CAWS57.

General Water Quality Parameters

Salinity-related parameters (EC, TDS, sulfate, sodium, total hardness) are consistently elevated across most sites, particularly CAWS30, CAWS55, CAWS56, and 412702. EC values generally range between 1,500 and 3,000 µS/cm, while TDS and sulfate show parallel elevation patterns with strong clustering around 1,000–2,000 mg/L.

Calcium, magnesium, bicarbonate, and chloride concentrations also track these trends, with peak concentrations observed between 2018 and 2021, suggesting increased mobilisation or seepage fluxes during that period.

Site 412702, used as a compliance and SSGV derivation point, consistently presents lower but stable concentrations than most other TSFSZ sites for general parameters yet still shows tailings influence.

CAWS41 stands out with some of the highest sodium, sulfate, and EC values compared to other TSFSZ sites, indicating stronger or more direct seepage pathways.

Nutrient concentrations such as total nitrogen, nitrate, and Kjeldahl nitrogen remain low across the zone, with only occasional spikes, reflecting limited nutrient input or uptake in stagnant/seepage waters.

Turbidity and TSS remain generally low but show occasional isolated peaks at CAWS59 and CAWS54, suggesting episodic sediment mobilisation.

Dissolved Metals/Metalloids

Aluminium, arsenic, iron, copper, molybdenum, manganese, nickel, and zinc are frequently detected, with CAWS41 and CAWS55 showing the most pronounced peaks.

Molybdenum at CAWS41 increases steadily across time, with concentrations approaching 0.03 mg/L, reinforcing its role as a seepage tracer.

Site 412702, generally exhibits moderate metal concentrations, suggesting it integrates broader TSF impacts. Site 412702 consistently records higher peaks for aluminium, copper, iron, and zinc compared to the derived SSGVs of Okay Creek.

Antimony, mercury, silver, and lead remain consistently low or near detection levels across all sites, indicating limited mobilisation or effective attenuation.

Key Observations and Implications

The TSF Southern Zone shows consistently elevated and temporally variable surface water quality trends, reflecting the influence of tailings seepage, operational runoff, and potentially evolving hydrogeochemical processes. Notably, several sites show persistent salinity and metal load signatures.

The TSF Southern Zone exhibits persistent chemical signatures of tailings-related seepage, with CAWS41, CAWS55, and CAWS30 demonstrating the most affected profiles.

The temporal stability in elevated salinity and metals suggests persistent, rather than transient, loading, pointing to the need for long-term seepage mitigation or interception strategies.

BLAYNEY DEWATERING FACILITY

The Blayney Dewatering Facility was in care and maintenance for the first half of 2019-2020. Demolition of the facility occurred between March and April 2020.Surface water quality at the Blayney Dewatering Facility (BDF), represented by monitoring sites NEC061 and NEC062, is characterised by generally consistent water chemistry across the monitoring period (2010–2024), with a few isolated spikes in metals and salinity parameters. Temporal trends suggest stable baseline conditions with limited evidence of ongoing or emerging impacts.

General Water Quality Parameters

Salinity indicators such as EC, TDS, total hardness, sodium, sulfate, and major cations (Ca, Mg) are consistently moderate and stable at both sites. EC values generally range between 400 and 700 µS/cm, while TDS levels fluctuate between 200 and 450 mg/L, with no significant long-term increasing or decreasing trends.

pH is generally neutral to slightly alkaline, varying between 6.5 and 8.2, and is relatively consistent over time.

Nutrient parameters, including total nitrogen, nitrate, and total Kjeldahl nitrogen, are low and stable across both sites, with very few isolated exceedances.

Turbidity and suspended solids (TSS and SS) remain low, suggesting limited sediment input or disturbance.

No significant shifts were observed in bicarbonate, carbonate, or total alkalinity, which remained within a moderate range throughout the monitoring period.

Dissolved Metals/Metalloids

Most metal concentrations are low and stable across both sites, with no evidence of sustained upward trends.

Manganese exhibits some elevated concentrations and fluctuations (up to ~1.5 mg/L), particularly between 2016 and 2020, at both NEC061 and NEC062, but has shown a declining pattern since.

Arsenic, copper, and zinc show sporadic peaks especially at NEC061 with arsenic occasionally exceeding 0.01 mg/L, though these spikes are not sustained.

Aluminium and iron display isolated higher values at NEC061 in the earlier years (pre-2016), but have since stabilised.

Cadmium, chromium, lead, nickel, selenium, and silver remain low or near detection levels, with minimal variation or concern.

Key Observations and Implications

Variability in water quality parameters is generally observed at both sites, though some spatial trends are apparent, such as copper concentrations generally being higher at the downstream of the two monitoring sites, and manganese and iron concentrations higher at upstream site. Following the conclusion of operations at the Blayney Dewatering Facility copper concentrations have generally reduced, though historical drought conditions have resulted in elevated copper concentrations at the downstream site, which were likely associated with historical contamination at the site.

CADIA DEWATERING FACILITY

The surface water quality monitoring data for Cadia Dewatering Facility sites—CDW03 (blue), CDW04 (orange), and CDW05 (green)—exhibit moderately elevated but stable water quality conditions across most parameters, with some localised and temporal variations suggesting operational influences and minor episodic impacts.

General Water Quality Parameters

Electrical conductivity (EC), TDS, total hardness, and major ions (sodium, calcium, magnesium, sulfate, and bicarbonate alkalinity) are consistently elevated across all three sites, particularly at CDW03 and CDW05, where EC values approach or exceed 1,000 µS/cm and TDS is generally 200–400 mg/L.

CDW05 shows slightly lower values for some parameters but demonstrates similar trends, suggesting hydrological or operational connectivity between the sites.

Chloride and sulfate concentrations appear stable with moderate temporal variation, but no persistent increasing trends.

Nutrients, including total nitrogen, nitrate, and total Kjeldahl nitrogen, remain generally low across all sites, though occasional peaks are evident, particularly at CDW05.

Turbidity and TSS show isolated spikes, especially at CDW05, possibly indicating short-term runoff or sediment mobilisation during rainfall or maintenance activities.

pH remains neutral to slightly alkaline across the monitoring period, with values ranging between ~6.5 and 8.5, consistent with site-specific guideline ranges.

Dissolved Metals/Metalloids

CDW03 displays higher variability and occasional spikes in metal concentrations compared to CDW04 and CDW05. Notable exceedances include:

- Iron (up to ~30 mg/L),
- Manganese (peaking at ~6 mg/L),
- Aluminium, copper, and arsenic also show intermittent spikes.

CDW04 and CDW05 maintain lower and more consistent metal concentrations, with only occasional exceedances in elements such as molybdenum, manganese, and copper.

Cadmium, mercury, silver, selenium, and lead remain consistently low and stable across all three sites, showing no increasing trends or exceedances.

Zinc concentrations have declined over time across all sites, suggesting attenuation or improved containment, particularly post-2020.

Key Observations and Implications

The potential influence of the Cadia dewatering facility has been observed based on elevated concentrations of copper and molybdenum at the monitoring sites within close proximity of the facility.

CDW03 appears to be the most reactive site in terms of water chemistry variability and episodic metal spikes, possibly due to its location, proximity to discharge infrastructure, or influence from operational fluctuations.

Overall water quality across the Cadia Dewatering Facility sites remains stable, with no sustained upward trends in key contaminants. However, episodic peaks at CDW03 indicate the need for ongoing close monitoring.

3.3.5.3 HIGHLIGHT DATA GAPS AND INCONSISTENCIES

Several issues were identified in the structure, quality, and analytical robustness of the current surface water quality data management and data analysis. Key observations and recommendations are summarised below:

Temporal Limitations in Trend Analysis

While surface water quality monitoring at Cadia Valley Operations (CVO) formally commenced in 1994, the available dataset for review predominantly spans from 2010 onwards. This 13–15 year monitoring window, although valuable for assessing recent patterns and contemporary water quality conditions, limits the ability to evaluate long-term environmental trends or legacy impacts associated with the early phases of mining development and expansion. The absence of baseline or early-stage monitoring data (pre-2010) creates a significant gap in the historical record, making it difficult to retrospectively determine the extent and timing of initial contaminant release, hydrological changes, or cumulative catchment responses attributable to mining activities. As a result, the current dataset cannot be used to confidently assess the full environmental trajectory from the inception of operations, nor can it fully capture the baseline condition against which long-term changes could be benchmarked. This limitation should be acknowledged when interpreting trend outcomes or attributing causality to observed exceedances and variations in water quality.

Data Integrity and Entry Issues

- Some data points are entered as zero, which is inappropriate where a limit of reporting (LOR) exists. These should be recorded as below LOR or flagged as not sampled, rather than defaulted to zero.
- There is inconsistency in how limits of detection (LOD) and LORs are applied across datasets.
- The current data entry format includes numerous unnecessary columns, making the dataset difficult to interpret and manage. A streamlined, standardised format is recommended for future data submissions.

Lack of Formal Trend Analysis

- Despite over two decades of monitoring, no formal long-term trend analysis was identified in the reviewed documentation.
- This limits the ability to detect gradual or cumulative changes in water quality associated with ongoing operations or post-rehabilitation recovery.

Limited Use of Statistical Testing

- The reviewed reports do not demonstrate the use of hypothesis testing (e.g., ANOVA, Kruskal–Wallis) to assess statistically significant differences between upstream, downstream, or reference locations.
- Multivariate methods (e.g., Principal Component Analysis [PCA], cluster analysis) are also absent. These tools could assist in identifying spatial or temporal patterns across analytes or catchments.

Weak Integration of Hydrological Context

- While some recent assessments (e.g., AEMRs 2021–2023) provide qualitative commentary on the relationship between rainfall and water quality, there is limited use of quantitative correlation techniques (e.g., Pearson or Spearman correlations) to formally explore these relationships.
- Improved statistical analysis of rainfall, flow, and water quality responses would strengthen the interpretation of potential cause–effect relationships.

3.4 KNOWLEDGE GAPS AND INCONSISTENCIES

While the surface water monitoring program at CVO is extensive and generally aligned with environmental risk and regulatory expectations, the review identified several knowledge gaps and inconsistencies that limit the program's ability to fully characterise potential impacts or adapt to evolving site conditions. These are outlined below:

Limited Integration Between Water Quality and Ecological Health Assessments

Although macroinvertebrate monitoring is undertaken biannually at select sites, there is minimal integration of biological health assessments with surface water chemical monitoring outcomes. Specifically:

- Exceedances in key water quality indicators (e.g., EC, nitrate, dissolved metals) are not directly discussed in relation to observed ecological changes;

- There has been limited use of biomonitoring as a tool for confirming or disproving chemical impacts on aquatic ecosystems.

The lack of formal linkage between chemical exceedances and ecological health limits the robustness of ecological risk interpretations and diminishes the ability of the monitoring program to detect early signs of biological degradation.

Uncertainty Surrounding Site-Specific Guideline Value (SSGV) Application

Site-specific guideline values (SSGVs) have been developed for several metals and parameters to improve relevance compared to national default values. However, the review identified several concerns:

- The derivation of SSGVs for some parameters is not consistently referenced, documented, or summarised in the annual reporting.
- The spatial applicability of certain SSGVs across different sub-catchments or hydrological zones is not clearly defined.
- In some cases, downstream sites continue to apply ANZECC (2000) default guideline values while adjacent sites apply SSGVs, creating inconsistencies in exceedance interpretation.

Inconsistent Sampling Frequency and Site Representation

While monthly and quarterly sampling is generally maintained, the review observed that:

- Some legacy or low-flow sites are excluded from monitoring during dry periods;
- Upstream/downstream comparisons are sometimes weakened due to incomplete data coverage.

Irregular temporal coverage reduces the ability to conduct reliable trend analysis and compromises comparisons critical to assessing potential impacts from site operations.

Limited Incorporation of Event-Based Monitoring Results

Event-based sampling such as during high rainfall, overflow risks, or other hydrologically significant events is a critical component of surface water quality monitoring, particularly for capturing episodic contaminant mobilisation. However, CVO's current surface water monitoring program provides little to no evidence that event-based sampling is formally implemented, discussed, or reported. Neither the Water Management Plan nor the reviewed Annual Environmental Management Reports (AEMRs) clearly outline protocols, triggers, or incorporation of such data.

This omission limits the monitoring program's ability to:

- Capture worst-case runoff scenarios that may occur during storm events or infrastructure exceedances;
- Evaluate short-term contaminant pulses that may pose ecological risks but are missed by routine (e.g., monthly or quarterly) sampling.

Formalising an event-based sampling strategy and ensuring that results are incorporated into routine reporting and risk assessments would significantly improve the monitoring program's ability to assess short-term, high-risk discharge events and inform more adaptive water management responses.

4. RIVIEW OF GROUNDWATER MONITORING PROGRAM

This section presents a comprehensive review of the groundwater monitoring program implemented at Cadia Valley Operations (CVO). The program is designed to evaluate the extent and nature of potential impacts from mining and associated activities on groundwater quality, levels, and flow regimes. The review assesses the suitability of the monitoring network, data quality, and alignment with environmental protection objectives and regulatory obligations under EPL 5590, the Mining Leases (ML1405, ML1481), and Project Approval PA06_0295.

The assessment is informed by a range of documents, including

- Cadia Water Management Plan (2023)
- Review of Surface Water and Groundwater Data - 2010/2011 AEMR
- Cadia Valley Operations- Groundwater Data Review Report – GHD 2016
- Cadia Annual Groundwater Monitoring Review 2020/2021
- Cadia Annual Groundwater Monitoring Review – 2021/2022

- Cadia Annual Groundwater Monitoring Review 2022/2023
- Cadia Annual Groundwater Monitoring Review 2023/2024
- CVO AEMR - Surface and Groundwater Assessment Report (GHD, 2019)
- CVO AEMR - Surface and Groundwater Assessment Report (GHD, 2020)
- Annual Environmental Management Reports (AEMRs) from 2011–2024

4.1 MONITORING NETWORK DESIGN AND OBJECTIVES

The groundwater monitoring network at CVO comprises over 150 bores, including:

- Operational bores within the vicinity of the Cadia East and Ridgeway underground mines, Cadia Hill Pit, and tailings storage facilities;
- Perimeter and downstream bores to evaluate regional groundwater movement;
- Dedicated monitoring bores within the Tertiary Basalt aquifer, weathered zone, fractured rock (Ordovician volcanics), and Silurian sediments.

The primary objectives of the network are to:

- Detect groundwater level and quality changes associated with tailings seepage, dewatering drawdown, and mine inflows;
- Track regional and local flow direction and gradients;
- Identify potential risks to groundwater-dependent ecosystems (GDEs) and downstream users;
- Support compliance with groundwater performance criteria outlined in project approval conditions and the Cadia Groundwater Management Strategy.

The monitoring network is stratified by hydrogeological unit and spatially distributed to capture vertical and horizontal gradients across the mine footprint, TSFs, and key receptors.

4.2 SPATIAL AND TEMPORAL COVERAGE

Cadia's WMP describes monitoring requirements for 121 monitoring bores, 74 of which require groundwater level and quality monitoring, while 47 require groundwater level monitoring only (Figure 4-1). The frequency of monitoring ranges from a monthly cadence to an annual cadence (Table 4-1). Additionally, Cadia WMP defines Site Specific Guideline Values (SSGVs) for 55 monitoring bores, which are used to assess potential impacts to groundwater. Note that the WMP defined monitoring network is not the entire groundwater monitoring network that is active at Cadia.

Groundwater level gauging and groundwater quality sampling is conducted by Cadia personnel as per Cadia's groundwater sampling procedure (Newcrest, 2022). It is understood that most monitoring bores are sampled via the low-flow sampling technique using dedicated in-situ bladder pumps. Purging using bailers is adopted as a backup methodology for monitoring bores where the bladder pump is not available or suitable. A high level review of both the sampling procedure and the sampling fieldsheets for the most recent groundwater sampling round was undertaken by AGE. Sampling is largely undertaken in accordance with Cadia's groundwater sampling procedure (including associated industry guidelines).

The spatial and temporal coverage of the groundwater monitoring program at CVO is designed to capture changes in groundwater levels and quality across key hydrogeological units, operational zones, and potential environmental receptors. The program's design reflects both the complex geology of the site and its diverse range of mining activities, including underground mining, tailings deposition, and dewatering.

4.2.1 SPATIAL COVERAGE

The monitoring network comprises over 150 groundwater bores distributed across the following key zones:

- **Mine Infrastructure and High-Risk Zones**
  Monitoring bores are located around the Cadia East and Ridgeway underground mines, the Cadia Hill Pit, and surrounding the Northern and Southern Tailings Storage Facilities (NTSF and STSF). These bores are used to monitor drawdown, tailings seepage, and potential hydraulic gradients toward receiving environments.
- **Perimeter and Downstream Areas**
  Groundwater bores have been installed along the southern lease boundary, within the Rodds Creek and Cadiangullong Creek sub-catchments, and adjacent to Flyers Creek and Swallow Creek. These locations help assess the broader regional influence of mine operations on offsite groundwater systems and support early detection of potential migration toward sensitive receptors.
- **Hydrogeological Unit Representation**
  The network includes bores screened across multiple geological units:
  - Tertiary Basalt Aquifer – shallow, fresh water-bearing unit
  - Silurian Sediments – low-permeability aquitards
  - Ordovician Volcanics – deeper fractured rock aquifers
  - Weathered Zone and Alluvium – interface areas supporting shallow flows and spring discharge

This spatial distribution allows for the assessment of both vertical and horizontal gradients and ensures adequate representation of hydraulic connections between site infrastructure and surrounding environments.

Table 4-1 Groundwater Monitoring Locations

Mine Area	Bore ID	Purpose / Rationale	Monthly	Quarterly	Biannual	Annual
Cadia East	MB43	Assess potential effects of Cadia East on groundwater levels and quality	Level			
	MB44A		Level			
	MB44B		Level			
	MB46		Level			
	MB47A		Level			FP + GWQ
	MB47B		Level			
	MB48		Level			FP + GWQ
	MB49		Level			FP + GWQ
	MB50		Level			
	MB51		Level			FP + GWQ
	MB52		Level			
	MB62		Level			FP + GWQ
	MB73		Level			
	MB76		Level			
	MB82		Level	FP + GWQ		
	MB88		Level			FP + GWQ
	RB07			Level		
North-east of Cadia East	MB53	Assess extent of depressurisation associated with Cadia East		Level		FP + GWQ
	MB54			Level		FP + GWQ
	MB55			Level		
	MB56			Level		FP + GWQ

Mine Area	Bore ID	Purpose / Rationale	Monthly	Quarterly	Biannual	Annual
	MB63			Level		FP + GWQ
	MB64			Level		FP + GWQ
	MB65			Level		FP + GWQ
	RB01			Level		
	RB02			Level		
Regional	MB71	Cadia East regional groundwater monitoring (reference sites)		Level		FP + GWQ
	MB72			Level		FP + GWQ
	MB74			Level		FP + GWQ
	MB75			Level		FP + GWQ
	RB02			Level		
PTSF	MB30	Assess potential influence of PTSF on groundwater levels and quality	Level	FP + GWQ		
	MB91		Level			
	MB92		Level	FP + GWQ		
	MB93		Level	FP + GWQ		
	MB94		Level + FP + GWQ			
	MB96		Level + FP + GWQ			
	MB97		Level + FP + GWQ			
	MB99A		Level + DL + FP + GWQ			
	MB99B		Level + DL + FP + GWQ			
	MB100		Level + DL + FP + GWQ			
	MB101		Level + DL + FP + GWQ			

Mine Area	Bore ID	Purpose / Rationale	Monthly	Quarterly	Biannual	Annual
	PZ4		Level			
	PZ5		Level			
	PZ10		Level			
	PZ10A		Level			
	PZ89		Level			
	PZ89A		Level			
	PZ90		Level			
Processing Facilities	MB1A	Assess potential influence of the processing plant on groundwater levels and quality		Level + FP + GWQ + HYD		
	MB1B			Level		
	MB2A			Level + FP + GWQ + HYD		
	MB2B			Level		
	MB3A			Level + FP + GWQ + HYD		
	MB3B			Level		
Processing Facilities	CB14A	Monitoring drawdown associated with production bore RH64	Level			
	CB14B		Level			
Production Bores	CB6A	Supplementary water supply for processing plant	Level	FP + GWQ		
	CB8A	Site potable water supply	Level			
	CB8B		Level			
Western Mining Lease Boundary	MB81	Assess extent of mining effects on groundwater levels and quality	Level	FP + GWQ		
	RB03			Level		
	RB04			Level		

Mine Area	Bore ID	Purpose / Rationale	Monthly	Quarterly	Biannual	Annual
	RB05			Level		
Cadia Extended Pit	CX1(2)	Monitor water level and quality of the Cadia Extended Pit	Level + FP + GWQ			
	CQ098	Monitor water level of Cadia Extended Pit	Level			
Ridgeway Area	RGMB01	Ridgeway pit area — groundwater level and quality assessment		FP + GWQ		
Ridgeway Area	RGMB02	〃		FP + GWQ		
Ridgeway Area	RGMB03	〃		FP + GWQ		
Ridgeway Area	RGMB04	〃		FP + GWQ		
Ridgeway Area	RGMB05	〃		FP + GWQ		
Ridgeway Area	RGMB06	〃		FP + GWQ		
Northern TSF	TSF13	Northern TSF seepage and groundwater condition monitoring		FP + GWQ		
Northern TSF	TSF15	〃		FP + GWQ		
Northern TSF	TSF17	〃		FP + GWQ		
Northern TSF	TSF18	〃		FP + GWQ		
Southern TSF	STSF1	Southern TSF seepage and groundwater condition monitoring		FP + GWQ		
Southern TSF	STSF2	〃		FP + GWQ		

Mine Area	Bore ID	Purpose / Rationale	Monthly	Quarterly	Biannual	Annual
Southern TSF	STSF3	〃		FP + GWQ		
Southern TSF	STSF4	〃		FP + GWQ		
Southern TSF	STSF5	〃		FP + GWQ		
Processing Facilities	OFMB01	Processing facilities — seepage monitoring		FP + GWQ		
Processing Facilities	OFMB02	〃		FP + GWQ		
Processing Facilities	OFMB03	〃		FP + GWQ		
Processing Facilities	OFMB04	〃		FP + GWQ		
Processing Facilities	OFMB05	〃		FP + GWQ		

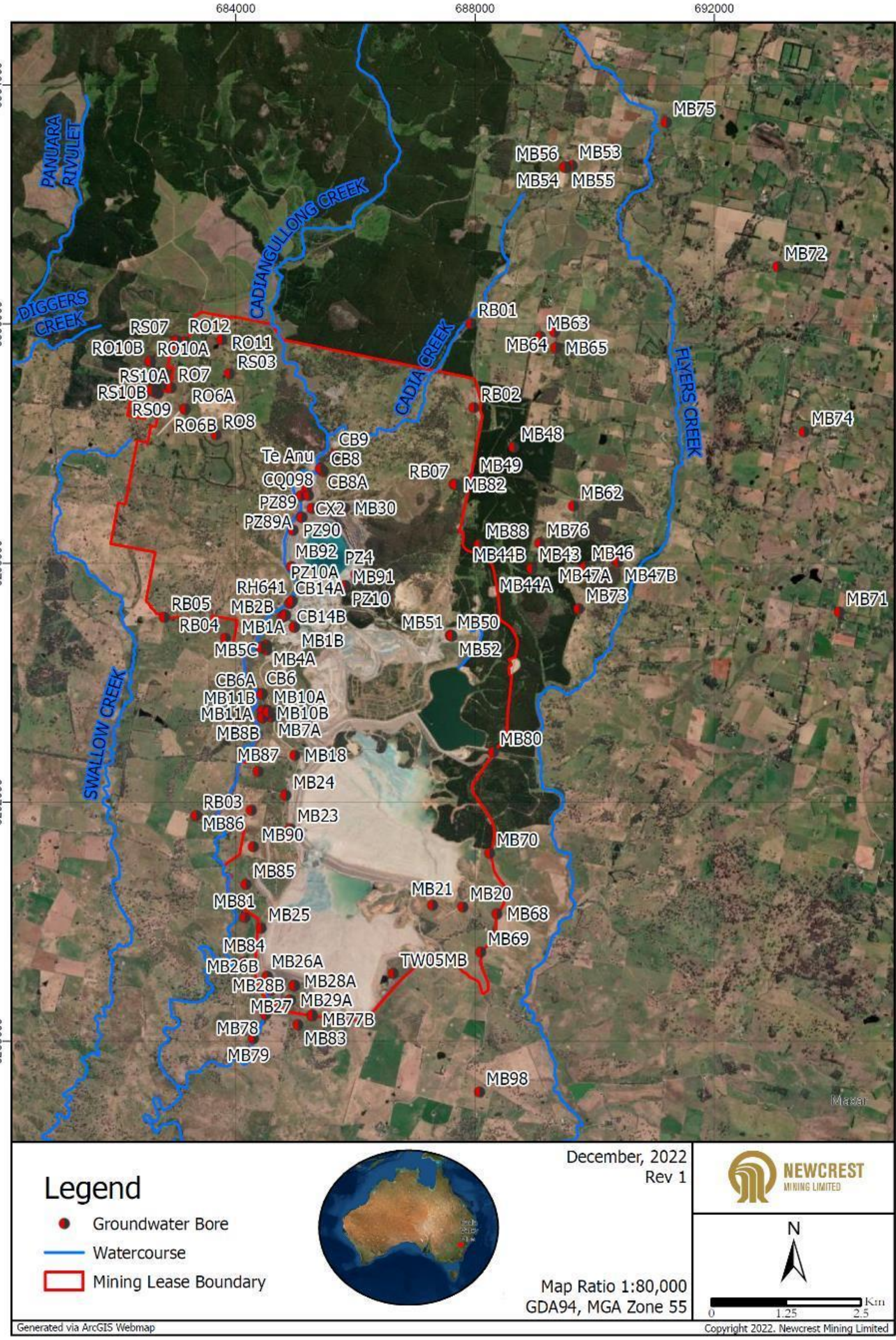

Figure 4-1 CVO groundwater monitoring network

4.2.2 TEMPORAL COVERAGE

Groundwater monitoring at CVO has been in place since the early stages of the operation and has evolved with the expansion of mining activities. Key features of temporal coverage include:

- Monthly and Quarterly Monitoring
  Selected bores, especially those around TSFs, dewatering areas, and compliance boundaries, are monitored monthly or quarterly to detect short-term changes and support operational decision-making.
- Annual Sampling
  Background and perimeter bores that have shown historically stable conditions are sampled annually to confirm long-term trends and track any gradual changes over time.
- Long-Term Trend Analysis
  Decades of monitoring data (from pre-1998 to the present) have been compiled, allowing for robust trend analyses in water levels, salinity, and trace metals. This long-term dataset supports model calibration, risk assessment, and compliance reporting.
- Automated Water Level Logging
  Several key bores are equipped with automated data loggers, enabling high-resolution temporal tracking of water level responses to rainfall, mining dewatering, and TSF inputs. This has enhanced understanding of aquifer dynamics in real time.

4.2.3 BORE SELECTION FRAMEWORK AND RATIONALE

The groundwater monitoring network at CVO is intended to provide spatial and hydrogeological coverage across areas potentially influenced by mining activities. It includes bores located near key infrastructure components (e.g., tailings storage facilities, waste rock dumps, dewatering systems) as well as off-site locations to support assessments of groundwater quality, hydraulic response, and potential migration pathways. In principle, this approach aligns with accepted groundwater monitoring practices, which involve strategic placement of bores to characterise background conditions, identify potential sources of impact, and monitor downgradient compliance.

However, despite the breadth of bore coverage across the site, the program lacks a clearly documented bore selection framework. While bores are informally understood to function as background, compliance, or impact locations, the rationale for their original siting and classification is not clearly articulated in the reviewed documents. This limits the transparency of the monitoring design and hinders the confidence with which observed groundwater trends can be interpreted or attributed to specific mining activities.

Over time, the groundwater network has been modified through the addition, decommissioning, or reclassification of monitoring bores. These changes, however, are not consistently supported by clear documentation or rationale explaining the design implications, such as how new bores integrate into existing conceptual models or whether they maintain statistical continuity with historic datasets. This lack of transparency introduces uncertainty in trend assessments and undermines the robustness of cumulative impact evaluations.

To strengthen the integrity and utility of the groundwater monitoring program, it is recommended that a formal review of the monitoring design be undertaken, including the development of a documented site selection framework, hydrogeological justification for bore placement, and clear designation of each bore’s role.

4.3 PARAMETERS AND ANALYTES MONITORED

The groundwater monitoring program at CVO includes a suite of field and laboratory parameters designed to detect changes in groundwater quality, assess the movement of potential contaminants, and evaluate the hydrochemical evolution of aquifer systems in response to mining activities. Parameters have been selected based on site-specific risks, historical trends, and regulatory requirements under EPL 5590 and Project Approval PA06_0295.

Monitoring is conducted across bores representing various geological units, including the Tertiary Basalt, Silurian Sediments, and Ordovician Volcanics, as well as shallow weathered profiles. Sampling is undertaken at monthly, quarterly, or annual intervals, depending on bore location and risk profile.

Table 4-2 Groundwater Quality Monitoring Suites

Suite Name	Suite Code	Constituents
Physical Parameters (field measurement)	FP	pH, Electrical Conductivity (EC), Temperature, Oxygen Reduction Potential (ORP)
Surface Water Quality	GWQ	EC, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Alkalinity Major Ions: Calcium, Magnesium, Sodium, Potassium, Chloride, Sulphate Nutrients: Nitrite, Nitrate, Total Nitrogen, Total Phosphorus Dissolved Metals/Metalloids: Aluminium, Arsenic, Cadmium, Copper, Iron, Lead, Manganese, Molybdenum, Zinc, Antimony, Cobalt, Chromium, Mercury, Nickel, Silver
Oil and Grease	O&G	Oil and grease
Dam Algae Monitoring	ALG	Blue-green algae (cell counts)

4.4 METHODS AND QA/QC

The groundwater monitoring program at CVO employs established field and laboratory methods that align with Australian standards and regulatory guidelines to ensure data quality, traceability, and consistency. The procedures are guided by the Cadia Groundwater Management Strategy, internal standard operating procedures, and best practice methods outlined in the National Environment Protection (Assessment of Site Contamination) Measure (NEPM, 1999; amended 2013).

Groundwater monitoring at CVO is undertaken routinely across a network of bores spanning key operational and environmental receptors. Monitoring activities appear to involve the collection of groundwater samples for laboratory analysis, accompanied by in-situ field measurements such as pH, electrical conductivity (EC), dissolved oxygen (DO), and water level. Sampling frequencies vary between bores but are typically monthly, quarterly, or biannually, depending on bore classification and risk profile.

However, the reviewed documentation does not provide sufficient detail on critical aspects of the groundwater sampling program, including:

- Specific sampling techniques (e.g. purging procedures, sample preservation, low-flow vs bailer sampling),
- Field QA/QC practices (e.g. use of field blanks, duplicates, or equipment rinsates),
- Laboratory accreditation (e.g. NATA certification) and the analytical methods employed,
- Chain-of-custody protocols or sample storage and transport conditions.

While it is likely that standard industry protocols are followed, the absence of clearly documented methods and QA/QC procedures limits the ability to comprehensively assess the reliability, consistency, and regulatory defensibility of the groundwater quality data. To enhance transparency and support confidence in trend analysis and compliance assessment, future reporting should include detailed methodological descriptions and QA/QC summaries.

4.4.1 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

Quality assurance and quality control (QA/QC) are critical for ensuring the reliability, accuracy, and defensibility of groundwater monitoring data. Given the role of groundwater monitoring in compliance reporting, trend evaluation, and impact assessment, robust QA/QC processes must be embedded throughout all stages of data collection, laboratory analysis, and interpretation.

The groundwater monitoring program at CVO should incorporate comprehensive QA/QC protocols to support data integrity. These would typically include:

- Field QA/QC procedures:
  - Collection of duplicate groundwater samples at a minimum of 10% of sites;
  - Use of field blanks to assess potential contamination during sampling, purging, or handling;
  - Calibration of field instrumentation (e.g. pH, EC meters) before and after each sampling round;
  - Documentation of purge volumes, stabilisation criteria, and field logs.
- Laboratory QA/QC procedures:
  - Inclusion of method blanks, matrix spikes, laboratory duplicates, and certified reference standards;
  - Provision of internal laboratory QA reports highlighting quality flags, detection limits, and corrective actions where applicable.
- Data validation and review:
  - Evaluation of relative percent difference (RPD) for field and lab duplicates;
  - Confirmation of anomalous results, including non-detects, exceedances, and outliers;
  - Integration of validated data into CVO's environmental database for use in long-term trend analysis and reporting.

While field and laboratory methods for groundwater appear to follow general industry standards, the reviewed documentation lacks transparency and consistency in reporting QA/QC outcomes. Information such as the frequency of field duplicates, performance of blanks, and RPD summaries are either inconsistently presented or entirely absent from routine groundwater monitoring reports. This limits the ability to independently evaluate data quality or to assess the robustness of groundwater trends.

Moreover, QA/QC results do not appear to be routinely integrated into the analytical or interpretive processes, meaning potential data quality issues may not be adequately considered during trend or compliance assessments. Incorporating QA/QC data directly into analytical datasets and performing parallel QA/QC assessments as part of interpretation workflows would enhance the reliability of groundwater quality evaluations. To improve data defensibility and program transparency, it is recommended that QA/QC procedures and performance metrics be more consistently documented and reported in future groundwater monitoring outputs.

4.5 GROUNDWATER QUALITY DATA REVIEW

4.5.1 OVERVIEW OF DATASET (TEMPORAL AND SPATIAL EXTENT)

Groundwater quality monitoring at CVO has been conducted across a wide network of monitoring bores since the early 1990s, with increased intensity following the commencement of large-scale mining operations in 1998. The dataset spans over two decades, providing a substantial foundation for assessing groundwater conditions across the site. Temporal coverage varies by bore, with many core monitoring sites having data extending for 10 to 20 years, while others particularly new or replacement bores have shorter data records.

Spatially, the monitoring network includes over 150 groundwater bores across multiple hydrogeological zones and operational areas, including:

- Cadia East underground mine (depressurisation monitoring and seepage assessment),
- PTSF (Cadia Hill Pit Tailings Storage Facility) and Open Pit zone,
- Southern and Northern TSFs (including embankment and seepage monitoring),
- Processing facilities (including leachate risk zones),
- Waste rock emplacement areas,
- Ridgeway Mine (now in care and maintenance),
- Regional reference sites (background conditions),
- Private landholder bores (sensitive receptor monitoring).

Each monitoring location is assigned a specific monitoring objective such as operational monitoring, regional background reference, or compliance and is sampled at varying frequencies (monthly, quarterly, biannually, or annually) depending on risk, accessibility, and historical performance.

The monitoring program covers a range of aquifers and perched groundwater zones, including fractured rock aquifers and shallow regolith systems. This spatial stratification allows for the comparison of operationally influenced groundwater against natural background conditions.

Temporal consistency, while generally strong, shows some variability due to dry bore conditions, inaccessibility, or bores being decommissioned or replaced.

The long-term dataset supports the identification of broad spatial patterns in groundwater chemistry and the tracking of potential contaminant transport over time. However, the review identified limited application of formal statistical tools (e.g. trend analysis, multivariate methods) to fully utilise the richness of the dataset across space and time.

Analytical results from groundwater sampling conducted across CVO between 2010 and 2024 were assessed for each monitoring bore. All data included in this assessment underwent a detailed quality assurance and quality control (QA/QC) review to ensure accuracy, consistency, and suitability for trend analysis. Where analytical results were reported as below the limit of reporting (LOR), the LOR value was conservatively used in statistical assessments to preserve dataset integrity and enable consistent comparison over time.

Time series groundwater quality graphs are presented in Appendix B and have been evaluated to identify whether observed patterns may be influenced by mining activities, regional hydrogeological conditions, or external factors. Notable increasing or decreasing trends in analyte concentrations are highlighted and interpreted by hydrogeological zone or bore cluster in the subsequent sections.

4.5.2 IDENTIFICATION OF GROUNDWATER QUALITY PATTERNS AND TRENDS

All the groundwater quality graphs relevant to this section was included in the Appendix B.

4.5.2.1 CADIA HILL PIT

Groundwater quality is monitored at MB30, MB91, MB92, and MB93, on a monthly basis. Monitoring bore MB95 and MB94 are no longer active and have been inundated by tailings (May 2020 and February 2022) and were decommissioned due to rising tailings levels exceeding their headworks.

General Water Quality Indicators

Electrical Conductivity (EC) levels at MB93 commonly exceed 5,000 µS/cm, with maximums reaching 7,200 µS/cm, compared to <1,500 µS/cm in background bores (e.g., MB90). This indicates a persistent saline influence in the Cadia Hill Pit groundwater system, likely related to tailings seepage and mineralised geological inputs.

Total Dissolved Solids (TDS) at MB93 typically range from 3,200 to 4,800 mg/L, whereas background TDS levels are generally below 1,000 mg/L. These values further support the presence of concentrated dissolved ions in the pit-affected zone.

Major cations (Ca, Mg, Na, K) and anions (Cl, SO_4^{2-}) exhibit patterns consistent with salinity trends. MB93 show high concentrations of calcium and sulfate. Major ions including calcium and sulfate show elevated concentrations at MB93 with calcium peaking at ~400 mg/L and sulfate at ~2,500 mg/L, well above typical background levels of <100 mg/L and <500 mg/L, respectively.

pH levels generally remain within neutral to slightly alkaline ranges (6.5–8.5), though some scatter exists especially in MB93 indicating minor variability in buffering conditions.

Bicarbonate and Total Alkalinity are also elevated in MB92, with bicarbonate concentrations reaching 800 mg/L, suggesting strong buffering conditions and possible interaction with carbonate-rich strata or process water. Nitrate and Total Nitrogen levels are low in most bores, with a few episodic peaks (e.g., MB91 and MB93 around 2018–2019).

Monitoring Bore MB94, where groundwater levels were affected by tailings prior to be the monitoring bore being decommissioned, had increasing concentrations of TDS, sulfate, sodium, arsenic, copper, and molybdenum.

MB94, which is positioned downgradient and hydraulically connected to the Cadia Hill Pit area, consistently reports as the most impacted bore, reflecting water quality changes associated with pit seepage or pit wall interactions. This bore's proximity and hydraulic linkage to the pit suggest that its water chemistry is influenced by pit-related processes, distinguishing it from background or less-affected monitoring locations.

Dissolved Metals/Metalloids

Manganese, iron, arsenic, cobalt, and zinc show distinct increasing trends, particularly in MB93 and MB92.

Arsenic is notably elevated and shows a strong upward trend in MB92 and MB93 since 2019, potentially indicating geochemical mobilisation influenced by changes in redox conditions or mining-related drawdown.

Manganese and iron are consistently elevated in multiple bores and show increasing trends, suggesting ongoing mobilisation from aquifer materials under reducing conditions. Manganese reaches up to 4 mg/L in MB93 (background <0.1 mg/L).

Cobalt and cadmium display variable but upward trends in some bores, particularly MB92.

Other metals such as selenium and nickel remain relatively low or stable, while copper shows occasional spikes in bores like MB30 and PZ4.

Key Trends and Implications

MB93 appear to be the most impacted bores, with higher concentrations of multiple parameters.

MB30 and PZ5, in contrast, exhibit more stable and lower concentrations.

The groundwater level at a monitoring bore located in the immediate vicinity of the pit, MB95, showed an increasing trend similar to the pit water level, indicating ongoing connection between pit water and groundwater at the site. Arsenic, molybdenum and nickel concentrations were elevated in the pit decant water and were either elevated or increasing at the nearby bore. The assessment found that it is likely that seepage from the pit is influencing localised groundwater.

The current pit water level is above that of lower catchment sites, and there could be a net flow from the pit to more downstream sites. It matters less that sites in groundwater above the pit water level are flowing towards the pit if there is a pathway from the pit to lower elevation sites.

4.5.2.2 TSF EASTERN ZONE

Groundwater is monitored in the zone to the east of the STSF and NTSF at MB20, MB21, MB68, MB69 and MB70 and MB80.

General Water Quality Indicators

Elevated EC and TDS values are consistently observed at MB20 across the monitoring period, exceeding 7000 µS/cm and 6000 mg/L respectively, indicating sustained saline conditions. MB21 and MB80 show moderate EC and TDS values, while MB70, MB69, and MB68 are comparatively lower. Total alkalinity and bicarbonate concentrations follow similar spatial trends, with MB20 exhibiting the highest concentrations.

MB20 displays significantly elevated sulfate (>3000 mg/L) and sodium (>400 mg/L) levels, with relatively stable but high concentrations over time, indicating potential influence from tailings seepage. Other bores show moderate (MB69, MB80) to lower (MB70, MB68) levels.

pH values across bores generally range from ~6.5 to 7.5, with slightly acidic trends in MB20 and MB21 in earlier years.
Nitrate, nitrite, and total nitrogen concentrations are elevated at MB69 (up to ~35 mg/L of NO_3^-+NO_2^-), showing a declining trend after ~2018. MB20 and MB21 also show moderate levels but appear more stable.

Dissolved Metals/Metalloids

MB20 has persistently high concentrations of cobalt (>0.4 mg/L), manganese (>500 mg/L), and nickel (>0.1 mg/L), indicating a strong signature of TSF-related groundwater contamination. Declining trends are evident in cobalt and manganese after 2017–2018, which may indicate dilution or improved containment.

MB20 shows episodically high copper concentrations (up to 600 µg/L) and extremely elevated zinc (up to ~350 µg/L). These peaks are not mirrored in the other bores, reinforcing MB20 as a key impact site.

Arsenic concentrations are relatively low across bores, with occasional minor elevations at MB80. Cadmium is slightly elevated in MB20 and MB80 but remains generally below 0.005 mg/L.

Mercury is low overall but shows a slow increasing trend at MB80 since 2018. Selenium is sporadically detected at MB20 and MB21, with values just above 0.01 mg/L in early years, tapering off later.

Key Trends and Implications

MB20 is the most impacted bore, exhibiting strong indicators of seepage influence including salinity, sulfate, major ions, and trace metals. It also shows some declining trends in key parameters (e.g., cobalt, manganese).

MB69 and MB80 show moderate impact signatures, with elevated nitrates and metals like arsenic or mercury in recent years.

MB70, MB68, and MB21 serve as relatively lower-impact or reference locations, with generally stable and lower concentrations.

Surface–groundwater interaction is not directly inferred from this data but the persistently high EC, sulfate, and metal loads in MB20 suggest vertical or lateral migration from TSF seepage zones.

4.5.2.3 TSF WESTERN ZONE

Groundwater is monitored to the west of the TSFs by MB84, MB85, MB86, MB87 and MB90 (MB19A/B was destroyed in 2018 and has been replaced by MB90). MB23, MB25 have been replaced by the MB130 to MB135 series as part of the change in the monitoring network. Similarly, bores MB18, and MB24 have been decommissioned in preparation for TSF expansion and replaced with MB130–MB135.

General Water Quality Parameters

Several indicators of salinity and geochemical loading exhibit persistently elevated concentrations across the majority of TSFWZ bores:

Electrical Conductivity (EC) and Total Dissolved Solids (TDS) are consistently high across most bores (notably MB86, MB84), with values often exceeding 5,000 µS/cm and 6,000 mg/L respectively. These trends suggest a long term influence of tailings seepage. Major cations (Calcium, Magnesium, Sodium) and sulfate also follow this elevated trend, reinforcing the saline and sulfate-rich character of the groundwater near the TSF embankments. Chloride concentrations are highest at MB86, with gradual increases over time.

pH is generally circumneutral across all bores but shows a declining trend post-2018 at some sites (e.g. MB87), potentially indicating shifting redox conditions or buffering capacity changes.

Total Alkalinity and Bicarbonate Alkalinity are consistently elevated at several monitoring locations (e.g., MB84, MB86, MB90), with total alkalinity values ranging from 400 to 650 mg/L. These concentrations have remained relatively stable over the monitoring period, indicating ongoing carbonate buffering likely derived from interaction with carbonate-bearing lithologies or residual lime additions from tailings processes.

Total Hardness is notably high at MB84 (600–800 mg/L), MB86 (~750 mg/L), and MB90 (~700 mg/L). These levels reflect dominance of calcium and magnesium ions in solution, consistent with weathering of tailings material and mineralised waste rock. Such patterns support a geochemical source linked to TSF seepage rather than diffuse regional inputs. Total Nitrogen (TN) and Nitrate (NO_3^-) concentrations are elevated MB86, with TN ranging from 2 to 4 mg/L and nitrate up to 3.5 mg/L, significantly above typical background levels of <1 mg/L. MB84 also shows episodic nitrate peaks (~2.5 mg/L), potentially linked to historical blasting residues or seepage containing nitrate-bearing process water.

Dissolved Metals and Metalloids

Iron and Manganese show pronounced increasing trends at MB90, MB87, and MB86 from 2018 onwards. Iron concentrations at MB90 exceed 2.0 mg/L, with manganese over 2.4 mg/L indicative of reducing conditions or dissolution from tailings materials.

Arsenic, Cadmium, and Cobalt exhibit increasing trends at MB24 particularly post-2020.

Molybdenum exhibits moderate elevation and a subtle increasing trend at MB84 and MB87, with concentrations ranging from 0.03 to 0.08 mg/L, compared to background levels typically <0.01 mg/L. This trend is noteworthy because molybdenum is a known indicator of TSF decant water seepage, and its mobility in oxidised, alkaline environments underscores its relevance as a seepage tracer. Nickel and Zinc concentrations are episodically elevated but spatially inconsistent. These scattered patterns suggest localised mobilisation events rather than a sustained source, and may be linked to short-term hydrological fluctuations or minor infrastructure influences. Antimony, Mercury, and Silver remain low or at detection limits across all sites.

Key Trends and Implications

MB90, although showing historically lower concentrations, has exhibited marked increases in iron and manganese since 2018, suggesting evolving geochemical conditions or plume migration.

MB84 and MB86 show elevated salinity and moderately elevated metals, consistent with long-term TSF interaction.

The elevated EC, TDS, sulfate, and molybdenum across several TSFWZ bores suggest ongoing seepage from tailings materials, particularly affecting MB86.

4.5.2.4 TSF SOUTHERN ZONE

Electrical Conductivity (EC) and Total Dissolved Solids (TDS) are consistently elevated across all bores, with values ranging from ~1500 to over 3000 µS/cm (EC) and ~1000–2000 mg/L (TDS).

Chloride, sulfate, and bicarbonate alkalinity show stable to slightly increasing trends, particularly at MB27, MB83, and MB28B, suggesting persistent seepage influence.

Calcium and magnesium levels follow similar patterns, indicating mineral dissolution or TSF-related inputs.

pH remains generally circumneutral (6.5–8), but shows a slight downward trend over time at some locations (e.g., MB26B, MB83), potentially reflecting subtle acidification processes or buffering capacity changes.

Nitrate and Total Nitrogen concentrations are relatively low across all bores, though MB27 and MB83 exhibit moderate elevations during early periods of monitoring.

Total Kjeldahl Nitrogen and phosphorus levels remain low and stable, suggesting limited organic nutrient inputs or degradation.

Total Suspended Solids (TSS) values are generally low (<100 mg/L), with a few sporadic spikes at MB79 and MB26B, likely attributable to sampling disturbances or transient groundwater-surface water interactions.

Dissolved Metals and Metalloids

Arsenic and molybdenum display consistent upward trends at several bores, especially MB26A, MB27, MB28B, and MB83, with arsenic reaching ~0.006 mg/L and molybdenum exceeding 0.03 mg/L in some samples. These analytes are known seepage indicators from tailings materials.

Iron concentrations have increased steadily across the monitoring period, particularly at MB27 and MB83, where levels surpass 6 mg/L, likely due to reducing conditions mobilising Fe from aquifer solids or tailings.

Manganese, nickel, cobalt, and cadmium show sporadic elevations, again consistent with TSF influence. MB26B and MB83 are notable for high manganese (up to ~80 mg/L in isolated events).

Lead, selenium, chromium, silver, and mercury remain consistently low or near detection limits across most bores and timeframes.

Antimony, copper, and zinc are occasionally detected but without consistent upward trends.

Key Trends and Implications

Across the southern TSF bores, high EC, TDS, and sulfate suggest long-term influence of tailings seepage.

These metals serve as strong geochemical tracers of TSF influence. The consistent increase in their concentrations at multiple bores highlights ongoing or intensifying seepage effects.

Iron and manganese enrichment at certain bores points to redox-driven mobilisation likely exacerbated by seepage conditions.

Nitrate, phosphorus, and Kjeldahl nitrogen concentrations remain mostly low, indicating minimal nutrient contamination risks from TSF seepage.

Several bores (e.g., MB83, MB26A, MB27) show increasing trends post-2018, suggesting a possible shift in seepage dynamics or local hydrogeological responses to storage or structural changes at the TSF.

The groundwater chemistry in the TSF Southern Zone monitoring network reflects consistent seepage influence from the TSF, characterised by elevated salinity, rising arsenic and molybdenum concentrations, and iron/manganese enrichment. While some parameters show improving trends, others (particularly metals linked to tailings seepage) continue to increase, warranting ongoing monitoring and potential mitigation strategies at impacted bores.

4.6 REVIEW OF GROUNDWATER SITE-SPECIFIC GUIDELINE VALUES (SSGVS)

The CVO Water Management Plan outlines a framework for the derivation and application of groundwater Site-Specific Guideline Values (SSGVs) at selected monitoring locations. SSGVs have been derived for bores in targeted areas of environmental sensitivity or elevated risk, including:

- Monitoring bores situated between the southern waste rock emplacement and Cadiangullong Creek to assess potential leachate migration;
- Bores adjacent to the Primary, Northern, and Southern Tailings Storage Facilities (PTSF, NTSF, STSF) to detect possible tailings water seepage into surrounding groundwater and surface water systems.

The methodology used to derive groundwater SSGVs is broadly consistent with standard practice, combining:

- The 95th percentile of historical baseline data in locations considered to be unaffected by mining,
- ANZECC & ARMCANZ (2000) guideline values for livestock watering and long-term irrigation suitability, and
- Regulatory agency recommendations, where applicable.

This multi-source derivation approach is generally appropriate, particularly where site-specific baseline data are robust and unaffected by legacy or operational impacts. However, the documentation does not clearly outline the data volumes, temporal coverage, or statistical robustness of the datasets used to calculate the 95th percentile values. In addition, the criteria for confirming the absence of historical influence (i.e., confirmation of negligible mining impact) are not explicitly stated, reducing transparency and confidence in the selected SSGV values.

Importantly, groundwater SSGVs have not been developed for bores within the predicted drawdown zone of the Cadia East underground operation, with justification that observed changes in water quality in these areas would primarily reflect altered groundwater flow rather than contamination. While this is a reasonable assumption from a hydrogeological perspective, continued water quality monitoring in these bores remains critical. The plan to review quarterly monitoring data with input from an independent hydrogeologist is a positive control measure, though it would benefit from clearer documentation regarding interpretation criteria and response thresholds in the absence of fixed SSGVs.

The application of SSGVs in the CVO groundwater program is linked to Trigger Action Response Plans (TARPs). These include:

- Tiered investigation levels, beginning with internal review (Level 1) and escalating to external expert assessment (Level 2) if mining influence is suspected.
- Defined management and mitigation pathways, depending on the nature and persistence of exceedances.

It is noted, however, that while the WMP presents most water quality triggers under the SSGV umbrella, only those derived from the 95th percentile of historical data can technically be considered SSGVs. Other trigger values appear to be direct guideline-based thresholds, and this distinction should be made clearer in documentation to avoid misinterpretation.

Overall, while the groundwater SSGV framework aligns with regulatory expectations and incorporates a precautionary multi-source approach, greater transparency is needed in the rationale for bore selection, statistical treatment of baseline data, and the classification of trigger types. This would improve the confidence and defensibility of the groundwater impact assessment process and strengthen the program’s capacity to support timely mitigation and regulatory compliance.

4.7 DATA GAPS AND INCONSISTENCIES – GROUNDWATER MONITORING

A review of the groundwater monitoring program at Cadia Valley Operations (CVO) has identified several data quality, analytical, and structural limitations that constrain the robustness of environmental interpretation and compliance assessment. Key issues are summarised below:

Temporal Limitations in Trend Analysis

While groundwater monitoring at CVO has been ongoing for an extended period, the available dataset used in this review primarily spans from 2010 onwards. This restricts the ability to assess long-term trends or evaluate legacy impacts that may have occurred during the early stages of mining. The lack of pre-2010 baseline data creates a significant gap, limiting retrospective assessments of initial contamination events, hydrological changes, and cumulative impacts. Consequently, the current groundwater dataset cannot fully represent the environmental trajectory from the commencement of mining operations, nor can it provide a reliable benchmark for long-term impact attribution.

Bore Selection and Monitoring Network Design

Changes to the groundwater monitoring bore network such as bore replacement, new installations, or reclassification of bore roles are not consistently documented in reviewed reports. The absence of a clearly articulated rationale for bore selection, and limited explanation of how bores relate to contaminant sources or receptors (e.g., hydraulic gradients), weakens the interpretive strength of the program. Formal documentation of network design and hydrogeological context for each monitoring bore is recommended to support transparent assessment and defensible site coverage.

Data Integrity and Entry Issues

The reviewed datasets exhibit several issues that affect data usability and statistical integrity:

- Some results are recorded as zero, even where a Limit of Reporting (LOR) applies—these should instead be flagged as "<LOR" or "not sampled."
- There is inconsistency in the application and recording of Limits of Detection (LOD) and LORs.
- The database format includes excessive and inconsistent column structures, complicating interpretation and increasing the risk of misanalysis. A streamlined, standardised format for groundwater data entry is recommended.

Lack of Formal Trend and Statistical Analysis

Despite over a decade of groundwater data, the reviewed reports generally lack formal statistical assessments. Specifically:

- There is no consistent application of trend analysis to identify gradual or cumulative groundwater quality changes over time.
- There is limited use of hypothesis testing (e.g., ANOVA, Mann–Whitney U) to compare conditions across bores or over time.
- Multivariate statistical tools such as Principal Component Analysis (PCA) or cluster analysis, which could help identify spatial patterns or contaminant sources, have not been applied.

Inadequate Integration of QA/QC in Analysis

While groundwater QA/QC procedures are expected to be in place, there is a lack of transparency in how QA/QC outcomes (e.g., field duplicates, blanks, Relative Percent Difference [RPD]) are reported or used in interpretation. QA/QC data are generally not integrated into groundwater data analysis spreadsheets, limiting the ability to independently assess data reliability. A more structured approach to QA/QC reporting and integration is needed to support trend evaluation and exceedance determination.

Trigger Values and SSGV Implementation

Current water quality triggers in groundwater are presented as Site-Specific Guideline Values (SSGVs), though in practice many are derived from default guideline values rather than site-specific data. The distinction between true SSGVs (95th percentile of baseline data) and guideline-based triggers is not clearly stated. Furthermore:

- SSGVs have primarily been established for bores with known elevated concentrations—this reactive approach misses opportunities for early detection.
- Non-toxicant analytes such as TDS and sulfate, which are useful seepage indicators, should have SSGVs even at low concentrations to detect early changes.

An alternative two-tiered compliance framework is recommended:

- Observation Bores – Located adjacent to potential sources (e.g., TSFs, WRDs), these bores should have SSGVs for non-toxicants, aiding early detection.
- Compliance Bores – Located down-gradient of observation bores and between sources and receptors, these should be assessed using SSGVs for both toxicants and non-toxicants where sufficient baseline data exist.

The adoption of dissolved molybdenum as an indicator analyte is also recommended due to its high concentrations in TSF decant water relative to background groundwater and its utility in tracing seepage migration.

4.8 GROUNDWATER MODELLING

The following documents were reviewed to investigate the groundwater modelling:

- Cadia Mine Update to Groundwater Model – AGE (2016).
- Cadia Groundwater Model Update 2021 – AGE (2021).
- Cadia modification 15 - Groundwater impact assessment – Advisian (2023).

Several groundwater models have been developed for the CVO. First, the Cadia East model was developed in 2009 by Australasian Groundwater and Environmental Consultants Pty Ltd (AGE). Since then, the model was updated in 2013, 2016, 2019 and 2021 to reflect new mining developments and key hydrogeological processes in the mining area.

Major technical improvements included:

- Transitioning from a steady-state model to a transient model in 2013, improving the models' prediction ability.
- Upgrading the modelling platform from MODFLOW-SURFACT to MODFLOW-USG in 2016 to better handle complex geological conditions and improve representation of the mining area through an enhanced computation mesh.
- Upgrading and expanding the model in 2021 along with coupling with SWAT+ to simulate interactions between surface water and groundwater.

These updates have progressively improved the model's performance by integrating new data, updated knowledge and advanced modelling techniques. Regular updates and refinements of groundwater models are considered good practice, ensuring the model remains relevant and fit for purpose as site conditions evolve.

4.8.1 CRITICAL ISSUES

4.8.1.1 DISCREPANCY IN REPORTING OUTCOMES

A significant discrepancy existed between the groundwater level changes identified in Advisian (2023) and the summarised findings in Cadia 2024 annual review. Advisian (2023) identified two key trends:

- A period of over 15 m decline in water level in late 2020 near the Cadia East mine, specifically in monitoring bores MB50, MB5 and MB52. These changes were interpreted as potential mining impacts, followed by recent response to climate change.
- Rising groundwater levels to the west of the NTSF, in boreholes MB18, MB23, and MB24. This was attributed to compression of the groundwater system under the TSFs, caused by the loading of the tailings bulk mass.

However, the Cadia 2024 annual review summarised the report findings as 'there were no mining-related drawdowns indicated by the data collected at monitoring bores.' The contradictory statements suggest a potential misrepresentation or inaccurate summarisation of the Advisian (2023) report's findings in the Cadia 2024 annual review. This discrepancy raises serious concerns about the accuracy and reliability of the reporting.

4.8.1.2 LACK OF INCORPORATION OF FAULTS INTO THE NUMERICAL MODEL

AGE (2021) identified a notable decline in groundwater levels at MB45 monitoring borehole, potentially influenced by mining activity at Cadia East and hydraulic connectivity through carbonate faults. This observation highlighted the critical role of fault structures in influencing groundwater behaviour and the importance of their representation in the groundwater model.

To account for observed groundwater changes at MB45 borehole, the 2021 model update incorporated a Connection Linear Network (CLN) package to simulate enhanced connectivity between carbonate fault located to the north of Cadia East. Moreover, AGE (2021) recommended permeability testing to better characterise the hydraulic conductance of carbonate faults.

However, beyond this specific fault, multiple major and minor faults are known to be present within the broader mining area. Although these were incorporated into the conceptual model, they were not explicitly incorporated into the numerical model.

This discrepancy is concerning. The conceptual model provides a qualitative understanding of the hydrogeological system. It describes the relationships between geological units and the overall flow patterns of groundwater. In contrast, the numerical model, is a quantitative tool that uses mathematical equations to simulate groundwater flow. It is used to predict how the system will respond to stresses such as mine dewatering or TSF modifications.

Faults can play contrasting roles—acting either as conduits that enhance groundwater flow or as barriers that restrict it. If a fault behaves as a conduit, omitting it could lead the model to underestimate contaminant migration rates or the extent of drawdown. Conversely, if it acts as a barrier, the model may overestimate drawdown effects. Failing to incorporate faults into the numerical model therefore introduces a significant source of uncertainty in predictions of groundwater flow, drawdown extent, and potential impacts on water resources or groundwater-dependent ecosystems.

It is a critical limitation that this exclusion was not addressed in the report. While data limitations may constrain the ability to model faults in detail, the report should have included a transparent discussion of this issue, along with the potential implications and associated uncertainties. Acknowledging such limitations is essential for providing a balanced, credible, and scientifically robust assessment of potential groundwater impacts.

However, it is important to note that the numerical model, as constructed, incorporates local refinements and performs within calibration targets for groundwater level trends across the broader monitoring network. The model successfully reproduces observed regional and local drawdowns, suggesting that, while not all faults are explicitly represented, the model remains functionally reliable for its intended predictive applications.

5.REVIEW OF AQUATIC ECOSYSTEM MONITORING PROGRAM

5.1 SCOPE AND PURPOSE OF SECTION

This section evaluates the aquatic ecology monitoring program at Cadia Valley Mine, implemented by Cadia Vally Operations, focusing on data quality, analytical rigour, and interpretative integrity. The assessment considers whether data have been collected and managed to an appropriate standard, whether statistical methods are capable of detecting impacts, and whether the conclusions presented in the reports are supported by evidence and transparently communicated. This review considers the available Aquatic Ecosystem Monitoring Project (AEMP) published reports from 2011onwards, including one long-term review covering the period from 2006 to 2017, to the latest report available at the time of writing, (currently 2024).

5.2 SUMMARY OF AQUATIC ECOSYSTEM MONITORING PROJECT

The AEMP has been implemented biannually since 2006 with sampling conducted in spring and autumn and results reported in annual reports. A long-term review covering 2006–2017 was also completed. The program focusses on the assessment of water quality, macroinvertebrates, fish, platypus and aquatic habitat condition potentially impacted by mine operations, within and surrounding the Cadia Mine lease area (MLA). This subsection briefly summarises the monitoring studies conducted.

The AEMP sampling focuses on four key areas that include both the aquatic habitat and associated fauna, studies on platypus and sediment quality added more recently. These include:

- Water quality – in situ measurements of physicochemical parameters (e.g. pH, EC, DO, temperature) as well as laboratory analyses of nutrients and metals in surface water and sediments, this is in addition to the separate, dedicated surface water assessments discussed in Section 3.
- Sediment quality – monitoring was introduced in 2018 and involves the collection of surface sediment samples for analysis of total metal concentrations.
- Habitat Assessments – assessments were typically based on visual scoring methods, (e.g. VisAssess, mRCE), which provide qualitative evaluations only.
- Macroinvertebrates – conducted using AUSRIVAs protocols targeting riffle and edge habitat where available.
- Fish - sampling primarily used electrofishing but was substituted for bait traps and visual surveys when electrofishing was not feasible due to safety, access or water depth issues.
- Platypus – based on eDNA sampling with supplemental visual records.

As of 2024, the monitoring program included 12 sites. Cadiangullong Creek was the primary receiving watercourse with associated sites spanning upstream of the mine, through operational zones, and downstream receiving environments. Sites on Flyers Creek, Panuara Rivulet and Swallow Creek were listed as reference sites, Rodds Creek was listed as on-site, and Diggers Creek as upstream. Cadiangullong, Flyers and Swallows creek have been consistently sampled since 2006, while Panuara Rivulet, Rodds Creek and Diggers Creek were subsequently added.

Despite extensive data collection over 18 years, structural and methodological limitations compromise the program’s capacity to detect, explain, or rule out mining-related ecological impacts.

5.3 TEMPORAL TRENDS INCLUDED IN ECOSYSTEM MONITORING REPORTS

Although the AEMP has generated biannual data since 2006, formal analysis of long-term ecological trends remains limited. The most comprehensive examination of temporal patterns was undertaken in the GHD 10-Year Review (2006–2017), with more recent reports relying on descriptive statistics, seasonal comparisons, and data visualisations without formal trend modelling. The following subsections include a summary of the temporal trend information available in the aquatic ecosystem monitoring reports.

5.3.1 WATER QUALITY

Water quality has been monitored biannually since 2006 through in situ measurements and laboratory analysis. As per the overall AEMP reporting, temporal analysis was limited to the GHD 10 year review with no statistical trend testing from 2018 onwards. This section outlines the temporal insights available from the monitoring reports.

- Electrical Conductivity (EC):
  The 10-Year Review reported increasing trends in EC at CC5, RC1, and FC1/FC2, and decreasing

trends at SC1 (GHD, 2018). More recent AEMP reports continue to show a longitudinal increase in EC downstream along Cadiangullong Creek, attributed in the reports to groundwater inputs to the waterway (GHD, 2024). Seasonal variation in EC appears to be inconsistent but no clear comparisons have been made between reporting years.

- Nitrate and Nutrients:
  The 10-Year Review detected increasing nitrate trends at DG1 and an increasing trend was indicated at in the provided table (Table 11) CC4 (GHD, 2018). Subsequent reports did not show progressive changes but continued to monitor nitrate alongside total nitrogen and phosphorus. The 2018 Annual Environmental Management Report (as opposed to the Aquatic Ecosystem Monitoring Program Reports), noted “Decreasing trends in NOx, nitrate and total nitrogen at all monitoring locations” (Newcrest Mining, 2018).
- pH:
  From 2007 – 2017 temporal analysis results showed a decrease at CC5, increases over time at CC4, SC1, FC2 and significant increases at RC1 and FC1. Recent reports noted “with the exception of sites CC5 and CC1 there was slightly higher pH at all sites during autumn compared to spring” (GHD, 2024). A temporal comparison to previous reports has not been mentioned.
- Alkalinity:
  Significantly decreasing alkalinity at CC2 and CC3 and increasing trends at FC1 (and possibly FC2) were reported from 2006 – 2017 (GHD, 2018). Alkalinity continued to show seasonal variation, with higher values in spring. There is no ANZG DGV for alkalinity, and no formal trend analyses have been applied post-2017.
- Dissolved Oxygen (DO):
  Exceedances below the lower DGV (90%) have been frequent across monitoring years, particularly during spring. CC2, CC3, and CC4 typically recorded higher DO than more saline creeks such as SC1 or RC1, which consistently fell below guideline values (GHD, 2023). These trends were not attributed to mine activities, and variability was linked to seasonal temperature and flow differences.
- Turbidity:
  No temporal trends were detected for turbidity from 2006 – 2018 (GHD, 2018). Generally, remains well below the ANZG guideline of 25 NTU. The most recent report did not report any exceedances of the ANZG guidelines for turbidity (GHD, 2024)
- Metals and metalloids:

  The 10-Year Review (GHD, 2018) found no statistically significant temporal trends in surface water concentrations of copper, arsenic, or aluminium at any monitoring sites. However, significant decreasing trends were reported for iron and manganese at CC4, identified using flow-adjusted analysis. A possible decreasing trend in copper at CC4 was noted, but the direction was considered uncertain due to data variability. Isolated exceedances of copper and aluminium were recorded in surface water at Diggers Creek and other sites during earlier monitoring years (e.g. 2013–2014) and were attributed to catchment runoff. In AEMP reports from 2019–2024, metals continued to be monitored, but no targeted temporal analysis was conducted for these parameters in surface water. Copper was the most frequently discussed metal, particularly due to consistent exceedances in sediment (especially at CC2 and CC3), but surface water concentrations were generally below guideline values. Iron and manganese were not emphasised in recent surface water quality discussions, although historical reports noted elevated levels at CC1.

The 10-Year Review as well as more recent reports stated “There was no evidence to suggest mining activities have impacted on water quality of Cadiangullong Creek or Rodd’s Creek.” (GHD, 2022) or words to similar effect.

5.3.2 SEDIMENT

Sediment quality monitoring is mentioned periodically in AEMP reports, primarily in relation to exceedances of guideline values or site-specific observations. The 10-Year Review (GHD, 2018) recommended that sediment sampling be continued as part of the AEMP but did not include temporal trend analysis for sediment parameters. Subsequent reports (e.g. FY23) note the continuation of sediment sampling to assess seasonal variation and potential relationships with macroinvertebrate communities, particularly following some observed correlations in 2018. However, across the reporting period, no formal statistical analysis of long-term trends in sediment quality has been presented. Sediment results are typically interpreted spatially, with reference to exceedances of ANZG (2018) default guideline values, particularly for copper at CC2 and CC3, but these are not analysed as part of a consistent temporal dataset. As such, temporal trends in sediment quality have not been assessed within the AEMP framework to date.

5.3.3 HABITAT ASSESSMENTS

Aquatic and riparian habitat condition has been assessed biannually throughout the AEMP using the NSW AUSRIVAS Visual Assessment of Disturbance Related to Human Activities (VisAssess), with the modified Riparian, Channel and Environmental (mRCE) inventory incorporated in 2015, but was not consistently applied in all subsequent monitoring periods. Across the monitoring period, sites such as CC2 have consistently recorded high to extreme disturbance ratings, attributed to sedimentation and proximity to disturbed surfaces (GHD, 2013). While habitat results are routinely presented in tables and discussed descriptively, no formal long-term statistical trend analysis of VisAssess or mRCE scores is provided in the reports. Instead, changes in habitat condition are reported qualitatively. For example, reports from 2012–13 and 2013–14 describe riparian vegetation as stable over time, with variations attributed to high flow events and drought conditions (GHD, 2013, 2014). Sedimentation is repeatedly identified as a key influence on aquatic habitat condition, particularly at on-site or downstream locations. Although, the 10-Year Review (2006–2017) examined habitat as part of multivariate analyses linking environmental variables to macroinvertebrate communities, it did not analyse habitat assessment scores for temporal trends (GHD, 2018). Recent reports (2019–2024) continued to describe habitat status for each monitoring event but did not include any statistical modelling or trend analysis. Overall, the AEMP reports concluded that habitat condition has remained relatively consistent at most sites, with changes typically linked to episodic natural events rather than progressive temporal patterns.

5.3.4 MACROINVERTEBRATES

The 10-Year Review (GHD, 2018) for the period 2006 - 2017 concluded that there was no clear increase or decrease in the biological indices over time at the majority of sites assessed, including those on Cadiangullong Creek immediately downstream of Cadia Valley Operations. Overall, macroinvertebrate community indices generally indicated sites remained in reasonable condition.

AUSRIVAS banding for edge habitats at most sites were typically classified in Bands A (reference condition) or B (significantly impaired) over time. The 10-Year Review noted that upstream sites (CC1 and CC5) on Cadiangullong Creek fluctuated more widely in their AUSRIVAS O/E 50 results for edge habitats compared to downstream sites. In contrast, sites downstream of the main mining operations (CC3 and CC4) remained relatively steady throughout the 2006-2017 period. Site CC4, the most downstream Cadiangullong Creek site, was notably one of the most consistent and the only Cadiangullong Creek site to score Band X (better than reference condition) at some point (2012-13). More recent reports continued to show most edge habitat sites allocated to Band A, though some sites like CC2 were allocated to Band B (GHD, 2024), and upstream sites like CC1 and CC5 were also noted in Band B in earlier years (GHD, 2023). Overall, the reports concluded that recent AUSRIVAS results for edge habitats did not suggest consistent patterns indicating site on the mine site or downstream sites were more impacted compared to upstream and reference sites.

Riffle habitats were more variable and frequently assessed as impaired (Bands B or C), particularly at CVOCC2, where long-term results indicated persistently lower than expected family richness and impaired AUSRIVAS scores (GHD, 2013). Earlier analyses identified increasing SIGNAL-2 scores at downstream edge habitat sites such as CVOCC4 and Swallow Creek (CVOSC1) (GHD, 2013), but these trends were not explicitly identified in the 10-Year Review or recent AEMP summaries. Recent reports presented current SIGNAL-2 scores in tables and bi-plots and discussed comparisons (e.g., against quadrant boundaries) (GHD, 2024), but did not do formal statistical trend testing over multiple years.

Since 2018, macroinvertebrate results have been presented in graphical and tabular form without additional statistical trend testing. While some appendices included long-term plots of AUSRIVAS scores, SIGNAL-2, and taxa richness, these were not accompanied by formal assessments of trend direction or significance.

5.3.5 FISH

Fish populations have been assessed biannually under the AEMP since spring 2006. Throughout the monitoring period, the native Mountain Galaxias (*Galaxias olidus*) has remained the dominant and only native species recorded across the study area, including Cadiangullong Creek, Flyers Creek, and Swallow Creek. More recent AEMP reports also confirmed its presence in Diggers Creek and Panuara Rivulet, though absence at Panuara Rivulet during low-flow periods (e.g., autumn 2023) suggested flow dependency (GHD, 2018).

The Mountain Galaxias population is consistently described as healthy and self-sustaining, with evidence of spring recruitment and increased mean length in autumn, indicating seasonal growth and successful reproduction (GHD, 2022, 2023). With reference to Mountain Galaxias, the 2022–2023 report explicitly stated that "all site treatments are maintaining self-sustaining populations with breeding and subsequent recruitment occurring" (GHD, 2023).

The 10-Year Review (GHD, 2018) examined fish data using length-frequency analyses grouped by year, which suggested a broader size structure and greater recruitment success in later years (2010–2012) compared to earlier years. However, the review did not apply formal temporal trend analysis to fish abundance or community composition.

Since 2018, fish community data have continued to be reported qualitatively, summarising species presence, abundance, and size by site and season. No statistical modelling of long-term trends has been applied. Introduced species such as Redfin Perch (*Perca fluviatilis*), Eastern Gambusia (*Gambusia holbrooki*), Rainbow Trout (*Oncorhynchus mykiss*), and Brown Trout (*Salmo trutta*) have been recorded intermittently at low abundance and typically isolated to specific sites. No consistent multi-year trends have been reported for these exotic species, although one notable decline was observed at CVOCC1, where Redfin Perch declined from 12 individuals in spring 2011 to 3 in autumn 2012, likely due to specimen removal during monitoring in accordance with permit requirements (GHD, 2012). During the site visit for this review in February 2025, carp (*Cyprinus carpio*, introduced) observed in the Belubula River at multiple sites and in the lower reaches of Cadiangullong Creek. Murray River rainbowfish (*Melanotaenia fluviatilis*, native) were observed in lower Rodds Creek and Swallows Creek.

5.3.6 PLATYPUS

Platypus (*Ornithorhynchus anatinus*) presence has been monitored using environmental DNA (eDNA) sampling since March 2019, with surveys conducted biannually. Results indicated a stable distribution in the upper and mid-reaches of Cadiangullong Creek. Regular detections have been recorded in Pools 1 and 2 (upstream of CC2) and in Pool 7 (approximately 1 km downstream of CC2) (GHD, 2024).

Following a trial environmental flow release in July 2019, platypus were detected in Pool 10, and have been regularly recorded there since April 2020, the report suggested that recolonisation was occurring following flow improvement (GHD, 2024). In contrast, detection at Pools 17/18 near CC4 has been sporadic, with confirmed results only in March 2019 and November 2022, and equivocal detections in June 2020 and December 2021 (GHD, 2024). No formal statistical trend analysis has been applied to platypus eDNA results, and the data do not provide information on abundance or population dynamics. Sampling methods have evolved over time, with increased water volumes and pump-assisted filtration likely improving detection sensitivity. Overall, eDNA results suggested consistent upstream and midstream presence, but limited downstream occupancy, with no quantified trend in distribution or extent.

5.4 CRITICAL REVIEW AQUATIC ECOLOGY MONITORING PROGRAM

5.4.1 DATA COLLATION AND PERSONNEL EXPERTISE

How data are collected and handled has a strong influence on the quality of the data and strength of conclusions that can be drawn from it. It is important that those collecting the data are suitably trained, qualified and experienced. Some reports provide limited personnel information with regards to document preparation and internal review as part of the document control section of the reports. Names and roles of laboratory analysts are also often included.

While reports typically stated that samples were collected by suitably qualified personnel but the specific personnel responsible for data collection, management and interpretation were not consistently named. Based on the limited personnel information available, at least one sampler has been identified as having an engineering background, rather than formal training in environmental science. While this does not imply a lack of competence, it highlights the absence of clear role-to-qualification alignment and reinforces the importance of transparent reporting of field team expertise.

The monitoring program is delivered by reputable consultancies such as GHD and ALS, and it is reasonable to assume that qualified staff were engaged. However, in the absence of documented personnel roles or credentials, this assumption cannot be independently verified. As such, confidence in the methodological rigour of the program ultimately rests on institutional reputation, rather than transparent evidence of individual competence.

5.4.2 SITE SELECTION AND CONTROL SITE COMPARABILITY

The following subsections detail critical flaws in the monitoring program's capacity to detect mine-related impacts, primarily due to inadequate site classification, comparability issues, and an absence of formal study design.

5.4.2.1 SITE SELECTION FRAMEWORK AND RATIONALE

The monitoring program lacks a clearly articulated design framework, particularly in its classification and justification of site roles. Sites were generally classified as *upstream, downstream, on-site* or *reference*, rather than clearly designating sites as control or impact, although intended reference sites were defined. This lack of detail weakens the conceptual framework of the study, particularly given the absence of a stated formal design. This obscures the basis for comparison and makes it difficult to determine which comparisons were intended to demonstrate mining impacts, or lack thereof.

Changes to the monitoring network over time further weakened the program. New sites (e.g. Rodds Creek, Diggers Creek) were added, and others appear to have changed designation without documented justification. While program adaptation is not inherently problematic and is a valid principle, these changes were not clearly justified, and there was no accompanying redefinition of the monitoring design or statistical implications. This introduced uncertainty into temporal comparisons and reduced the power of the dataset to detect cumulative or long-term trends.

5.4.2.2 COMPARABILITY ISSUES

None of the sites currently included in the Aquatic Ecosystem Monitoring Program (AEMP) function as true reference sites. All are subject to catchment-scale disturbances unrelated to mining, thereby confounding attribution of observed effects. While it is not clear which sites are considered to be controls, upstream sites such as CC5 Cadiangullong Creek appear to be treated as an upstream comparator; however, this site is situated in a modified landscape surrounded by pine plantations. Impacts to other sites along Cadiangullong Creek include disruption to flow regimes in which a permanent flow has been created in a system that may have been historically intermittent, grazing in the mid to lower catchment causing riparian degradation, erosion and nutrient input and potential geogenic sources of copper. Similarly, sites that appear to have been intended as controls and those labelled as reference sites are also degraded by various factors which reduces their validity as an ecological baseline for comparison.

- Flyers Creek is impacted by land grazing and pine plantations as well as hydrological alteration;
- Swallow Creek shows elevated salinity – suggested but not confirmed as a consequence of groundwater intrusion, it has undergone riparian revegetation works which will have added variability and was possibly implemented as a result of historical clearing or streambed erosion.
- Panuara Rivulet shows evidence of nutrient enrichment and excessive algal growth and nutrification, likely linked to agriculture (especially grazing) and poor riparian condition.

The use of already-impacted sites as baselines introduces significant confounding variables that can mask or dilute potential mining impacts, particularly where changes are subtle or spatially localised. AUSRIVAS band classifications support this, with some reference sites falling outside Bands A and B, suggesting impairment, inconsistent with reference condition expectations.

Observations made in the field also suggested that many sites were misaligned with map-based expectations (mismatches in creek connectivity and possible groundwater inputs). Notably, Cadiangullong Creek exhibits higher-than-expected downstream flows below Rodds Creek, suggesting potential groundwater contributions. Given that Rodds Creek drains the Tailings Storage Facility (TSF), this raises legitimate concerns about mine-related subsurface seepage. These mismatches violate a core assumption of comparative ecosystem monitoring, that control or reference sites are representative of the monitored system in the absence of the stressor of interest.

These findings reveal a critical flaw: the monitoring design presumes that reference and test sites differ primarily by the presence or absence of mining stressors. In practice, the upstream (presumably intended as a control) and reference sites are subject to distinct, non-mining stressors, such as forestry, grazing, or salinity, while downstream sites are influenced by altered flows, sedimentation, and potentially mine-related seepage. These differences violate the core principle of a reference site, which should be minimally disturbed, as well as a control site, which should differ only in exposure to the stressor of interest, i.e. mining. Because these sites differ along multiple, uncontrolled axes, direct ecological comparisons are invalidated and the ability to isolate and attribute mining-related effects is fundamentally compromised.

5.4.2.3 IMPLICATIONS FOR IMPACT DETECTION

The combination of unclear site roles, evolving site selection, and poor ecological comparability undermines the monitoring program's ability to reliably detect mining impacts. In the absence of true controls or ecologically equivalent baselines, the signal of mining-specific stressors is masked by pervasive catchment-level degradation.

The lack of a formal experimental design and inconsistent site designation reduces the analytical power of the program. As acknowledged in GHD (2024), mining impacts would need to exceed all other land-use disturbances to be detectable under the current structure. This is an unreasonably high threshold, particularly where changes are subtle, localised, or cumulative.

Consequently, the program is likely to either:

- Underestimate mining impacts due to elevated baseline degradation ("false negatives"); or
- Misattribute general catchment degradation to mining activity ("false positives").

This limitation should be explicitly acknowledged when interpreting trends, drawing compliance conclusions, or informing management actions. Without a redesign that incorporates stratified site roles, hydrological connectivity assessments, and formal statistical power analysis, the program cannot fulfil its intended role as a robust impact detection tool.

5.4.3 APPROPRIATENESS OF FIELD METHODS

The suitability of the applied methods is critical for determining whether mine-related impacts on aquatic ecosystems were reliably detected. This section assesses the appropriateness of both biological and physico-chemical sampling techniques in the context of the site-specific hydrological and geomorphological conditions.

5.4.3.1 WATER AND SEDIMENT SAMPLING

In situ water quality measurements were collected with multiparameter probes, reportedly calibrated prior to use, with calibration certificates included for some years (e.g. GHD, 2016). Sediment and water samples were sent to NATA accredited laboratories with standard QAQC methods applied.

Hydrological regimes vary across the different waterways sampled. Some waterways are intermittent (e.g. Swallow Creek and Panuara Rivulet), while Cadiangullong Creek has an artificially maintained permanent flow due to dam releases. Different flow regimes can result in different sediment deposition rates and behaviour, sediment stability and contamination. In regulated systems, sediment dynamics and deposition may be altered by reduced scouring and upstream trapping of fines. These differences in sediment dynamics between the sites reduces between-system comparability and reliability in reported spatial patterns of contaminant concentration. Additionally, in intermittent or highly variable systems, sediment may collect in temporary pools that are not representative of long-term sediment contamination conditions. In these cases, seasonal snapshot sampling may fail to capture representative conditions or peak contaminant loads.

Sediment analysis does not currently include an assessment of bioavailability, such as porewater metal concentrations or dilute acid-extractable fractions. While total metal concentrations allow for comparison with Interim Sediment Quality Guidelines (ISQG), they may overestimate or underestimate ecological risk depending on sediment characteristics. Contaminants in dissolved forms are considered more bioavailable than those bound to sediments, and the measurement of porewater metals is recognised as useful for assessing exposure to benthic organisms. Similarly, acid-extractable metal concentrations often provide a more appropriate estimate of bioavailable metals than total concentrations, particularly when metals are mineralised or strongly bound to sediment particles (Simpson et al., 2013). Without the inclusion of these metrics, sediment assessments remain incomplete, and the potential risk to biota may be over- or underestimated. Similarly, water quality assessments are based on total metal concentrations, without accounting for dissolved forms, which more accurately reflect ecological exposure and potential biological effects. While this provides temporal coverage across different flow conditions, no event-based sampling is implemented. Consequently, episodic contaminant inputs, such as those associated with rainfall or operational discharges, may be missed. This limits the program's capacity to detect short-term exceedances or worst-case scenarios.

The program commendably employs recognised multivariate techniques, including RELATE, BEST, and DISTLM, to examine relationships between sediment chemistry and macroinvertebrate community structure. This represents good practice in ecological monitoring and reflects an understanding of the potential influence of contaminants such as copper. Statistically significant associations have been identified, for example between copper and riffle communities at CC2. However, these signals have not been further investigated through targeted toxicological testing or bioavailability-based analyses. As a result, the extent to which sediment-bound metals contribute to observed biological variation remains uncertain, and the ecological implications are conservatively interpreted.

5.4.3.2 HABITAT ASSESSMENTS

Habitat condition assessments were conducted using established protocols, with the primary method based on the New South Wales AusRivAS Sampling and Processing Manual (Turak *et al.*, 2004). These assessments incorporated both physical measurements and visual evaluations of instream and riparian conditions and were generally applied biannually at all monitoring sites during spring and autumn. While the intended sampling frequency was consistent, full seasonal coverage at all sites was not always achieved due to environmental constraints such as dry conditions.

The Visual Assessment of Disturbance Related to Human Activities (referred to as VisAssess) protocol was consistently applied and scores four habitat domains: water quality, instream features, riparian zone, and catchment disturbance, on a scale from 0 to 4. Total scores range from 0 (no disturbance) to 16 (severe disturbance). This method was used throughout the program and aligns with the AusRivAS manual, although it is inherently subjective, as acknowledged in the guideline itself. Despite frequent references to "experienced aquatic biologists," no evidence of observer calibration, inter-observer error testing, or detailed training protocols was provided in the reviewed documents. This introduces a potential source of variability between field teams and across years, particularly given the visual nature of the assessments.

From spring 2012 onwards, habitat data were recorded using a digital MS Access database developed by GHD, based on field sheets adapted from the First National Assessment of River Health (FNARH). The database structure reflected variables drawn from the AusRivAS manual and included streambed composition, aquatic and riparian vegetation cover, in-stream organic material, canopy cover, habitat types, bank height, and channel width. While the database improved consistency in data storage, no metadata standards or quality assurance protocols specific to habitat data were described in reporting outputs.

The modified Riparian, Channel and Environmental (mRCE) inventory by Chessman et al., 1997, was introduced during the autumn 2015 sampling round as a supplementary habitat assessment (GHD, 2015). This method uses 13 habitat criteria scored from 0 to 4, with higher scores indicating better condition. Its application, however, was inconsistent. It was completed in spring 2016 but omitted in autumn 2017 due to a lack of communication about its inclusion (GHD, 2017), and was not mentioned in later reports. This irregular use limits its value as a complementary line of evidence.

Several reports referenced the Reference Condition Selection Criteria from the Queensland AusRivAS framework by the Department of Natural Resources, (2001), which rates anthropogenic impacts across five criteria. However, these criteria were not consistently applied in site designation, and there is little evidence that they influenced analytical interpretation or site classification.

Habitat data were collected alongside macroinvertebrate and fish community data throughout the program. While exploratory multivariate analyses such as BEST were used to examine relationships between macroinvertebrate composition and sediment contamination, no equivalent formal analyses appear to have assessed the influence of physical habitat on biological communities. However, there is limited evidence that an equivalent formal statistical integration, such as using habitat scores as covariates in models or partitioning variance attributable to habitat versus other drivers was consistently applied across the full monitoring period. This is notable given that several reports acknowledged habitat as a likely driver of biological condition, and in some cases, suggested it may have exerted a stronger influence than chemical stressors (GHD, 2023).

In summary, while the monitoring program maintained long-term collection of habitat data using recognised protocols, a lack of documented quality control, particularly given the likelihood of changing field personnel over the long timeframe, constrains the interpretive strength of the dataset. The lack of incorporation of habitat assessment variables into statistical models seems to be a missed opportunity and currently, the ability of habitat assessments to contribute to supporting robust causal inferences is limited.

5.4.3.3 MACROINVERTEBRATE SAMPLING

Macroinvertebrate sampling followed protocols from the NSW AusRivAS Sampling and Processing Manual (Turak et al., 2004), targeting edge and riffle habitats where available. Littoral or edge habitats were sampled using sweep nets in low-flow areas such as backwaters and macrophyte beds. Riffle habitats were sampled using kick techniques. The specific mesh size (250 µm) and transect length (10 m), while standard practice, were not consistently reported in program documentation. Equipment cleaning between sites, though common, was also not explicitly noted.

Macroinvertebrates were live-picked in the field by trained biologists for a minimum of 40 minutes, up to a maximum of 60 minutes. Preservation initially used 70% ethanol and reportedly transitioned to 100% ethanol for long term archiving. Long term archiving is a strength of the monitoring program, ensuring that any significant taxonomic changes in future can be accommodated for. Taxonomic updates were applied during analysis to ensure consistency, and newly added sites post-2015 followed the same methods, though this was implied rather than explicitly confirmed.

Ecological condition was assessed using AUSRIVAS and SIGNAL-2 indices. AUSRIVAS calculates Observed/Expected (O/E) scores compared to reference models, banded to reflect condition (e.g. Band A = reference; Band C = impaired). SIGNAL-2 averages taxa sensitivity on a 1–10 scale based on species presence/absence but does not consider abundance. Taxonomic richness and EPT (Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)) were also calculated. These metrics are common practice and provide indication of ecological health and water quality based on the pollution tolerance of recorded taxa. Taxonomic revisions over the monitoring period were addressed during analysis, with some taxa reclassified or removed to maintain consistency across years. However, both AUSRIVAS and SIGNAL-2 scores are sensitive to taxonomic resolution, and changes in identification practices, particularly in the presence or absence of certain pollution-sensitive groups, can influence condition assessments over time.

While field protocols were standardised and consistently applied, several factors constrained the ability of macroinvertebrate monitoring to detect mine-related impacts. Reference sites such as Flyers Creek, Swallow Creek, and Panuara Rivulet exhibited signs of ecological degradation, including elevated salinity, grazing pressure, and riparian damage. AUSRIVAS band classifications supported this, with some reference sites falling outside Bands A and B, suggesting impairment inconsistent with reference condition expectations. Furthermore, field observations suggested that reference sites were ecologically and or hydrologically dissimilar to Cadiangullong Creek (expanded further in section 5.4.2.2). These conditions challenge AUSRIVAS assumptions of minimal disturbance and ecological similarity between reference and test sites, increasing uncertainty in O/E scores comparisons.

In addition to reference site limitations, AUSRIVAS is relatively insensitive to sublethal or chemically mediated stressors (Chessman, 2021). Elevated copper concentrations at sites such as CC2 did not consistently align with changes in macroinvertebrate indices and reporting suggested that habitat conditions were likely more influential (GHD, 2023). As Chessman (2021) notes "…many studies have found AUSRIVAS O/E to be a weak or inconsistent indicator of exposure to anthropogenic or human-influenced stressors," with detection generally limited to severe impacts. SIGNAL-2, which is generally more responsive to pollution stress, was calculated throughout the program but was rarely emphasised in impact interpretation.

Challenges were also associated with riffle habitat sampling. These habitats are dependent on flow and were not consistently present across all sites and seasons. Riffle sites, including reference locations, were frequently assessed as Significantly or Severely Impaired. Sites such as CVOCC2 consistently returned lower scores and were identified as potentially impacted by sedimentation or immature channel form. Despite repeated consultant recommendations to implement quantitative or replicated riffle sampling, these enhancements were not consistently adopted.

Taxonomic quality assurance procedures were not well documented. The 10-Year Data Review (GHD, 2018) identified inconsistencies linked to staff turnover and changes in taxonomic practice. Although some taxa were removed to address classification discrepancies, the absence of measures such as blind re-identification or inter-analyst validation limits confidence in the long-term consistency of identifications.

In summary, macroinvertebrate monitoring was conducted using recognised national protocols and maintained procedural consistency. However, its effectiveness in detecting mine-related impacts is constrained by degraded and ecologically dissimilar reference sites, AUSRIVAS's limited sensitivity to chemical stressors, underutilisation of SIGNAL-2, and inconsistent riffle data. These limitations highlight the need for cautious interpretation and targeted methodological refinements in multi-stressor systems.

5.4.3.4 FISH SAMPLING

Fish sampling at Cadia Valley Operations was primarily conducted using backpack electrofishing, in accordance with the Australian Code of Electrofishing Practice. Surveys typically spanned a reach equivalent to ten times the bank-full width and targeted a variety of in-stream habitats. Several reports state that electrofishing was conducted using a multipass approach (up to three passes per hydraulic unit), with a maximum sampling duration of two hours per reach, although these details are not consistently reported across all monitoring years. While quantitative data were recorded, including species, counts, and total length, the reports note that abundance was not standardised for effort, and that variation in site characteristics constrained the ability to apply a consistent sampling design. Where electrofishing was not feasible due to depth, turbidity, conductivity, or access constraints, alternative bait trapping supplemented by visual observation were employed. Bait traps were deployed overnight (approximately 12 hours), baited with dry cat biscuits, and used opportunistically at sites such as CC5, SC1, PR1, and PR2 depending on flow conditions and available habitat.

Captured fish were identified to species level using standard references. In the early years of the program, the first 50 fish captured at each site were measured for total length (TL). This practice was revised between autumn 2013 and the 2013–14 reporting period, when the number measured was reduced to 20 individuals per site. The rationale provided was that 20 fish was considered sufficient to estimate length and age structure; however, no statistical justification, variance analysis, or supporting documentation was presented. Later analyses were standardised by using only the first 20 *Galaxias olidus* per site per event to improve comparability across years. While this adjustment addresses variability in sampling effort, it may still introduce size-class bias, particularly where no randomisation or stratification process was described for the selection of individuals. Reports from 2022 to 2024 do not explicitly confirm the continuation of this method, but in the absence of any statement indicating further changes, it is likely that the 20-fish threshold remains current. This shift, and its undocumented assumptions, limit the interpretability of temporal trends and size distribution metrics in the fish dataset.

GHD's 10-year review (GHD, 2018) recommended that fish sampling be conducted only in autumn rather than in both spring and autumn. The rationale was to avoid disturbance during peak spawning times for native species and to reallocate resources toward additional monitoring efforts, such as sediment assessments or new sites. However, this recommendation did not appear to have been adopted in subsequent years. Later reports continued to include fish sampling data from both seasons, but do not explicitly discuss the recommendation or provide justification for continuing biannual sampling. This lack of clarity creates uncertainty around seasonal comparability and may limit the interpretability of inter-annual trends if seasonal effects are not adequately accounted for.

Electrofishing and bait trapping produce non-comparable results and should not be treated as interchangeable methods. Electrofishing is more effective for detecting benthic and cryptic species, as well as small-bodied or structure-associated species such as *G. olidus*, while bait traps may miss less mobile or bottom-dwelling taxa, limiting comparability across sites. No calibration, correction, or standardisation of effort was implemented to reconcile differences in detectability across methods, limiting comparability of richness, abundance, and length-frequency data between sites or over time.

The program consistently emphasised *G. olidus* (Mountain Galaxias), the most frequently recorded native species, as a proxy for ecological condition. Reports describe it as dominant across most sites and use its abundance and size-class distribution to infer population health. While this provides valuable insight into a key native species, the singular focus limits broader community interpretation. Non-native species, including redfin perch (*Perca fluviatilis*), eastern gambusia (*Gambusia holbrooki*), rainbow trout (*Oncorhynchus mykiss*), and brown trout (*Salmo trutta*) have been routinely recorded, and some reports acknowledged their potential impacts, such as predation on *G. olidus* or competitive pressure. Redfin perch, a declared noxious species, was noted as ecologically concerning in several reports. However, these references were generally brief and qualitative; the program has not included detailed or consistent evaluation of how non-native species influence native fish populations or ecosystem dynamics. This narrow analytical focus limits the ability to detect broader ecological changes or interactions within the fish community.

Several reports acknowledged environmental constraints likely to influence fish communities, such as dense macrophyte cover, modified hydrology, and variable stream depth, but these factors were not formally incorporated into the analysis of fish distribution, abundance, or size structure. Established multivariate methods (e.g. DISTLM, PERMANOVA) or even basic regression models could have been used to assess the influence of habitat variables on fish metrics. Their omission has limited the program's ability to distinguish between natural variation, sampling effects, and potential mining-related impacts.

In summary, fish sampling was conducted using recognised techniques and in compliance with ethical guidelines. However, the program's capacity to detect mine-related ecological impacts has been constrained by uncalibrated mixed methods, limited attention to introduced species dynamics, and a narrow analytical scope. Future improvements could include the adoption of standardised effort metrics, integration of non-invasive detection tools such as eDNA, and more comprehensive analysis of fish community responses over space and time.

5.4.3.5 PLATYPUS MONITORING

Platypus (*Ornithorhynchus anatinus*) monitoring has been implemented using environmental DNA (eDNA) sampling, supplemented with visual surveys, which represents a scientifically appropriate and minimally invasive method for detecting the presence of this cryptic species. The use of species-specific mitochondrial DNA assays developed by EnviroDNA ensured high taxonomic specificity, and laboratory procedures incorporated quality controls such as triplicate qPCR and negative controls. Sampling protocols improved over time, transitioning from handheld syringe collection (~200 mL) to battery-powered pumps filtering up to 5 L per site. This significantly increased detection sensitivity but introduced a discontinuity in sampling methodology between 2019 and 2021, which may affect temporal comparability across this discontinuity. While eDNA is highly suitable for detecting presence or absence, it does not provide information on abundance or population viability.

Downstream transport of eDNA is a recognised limitation in flowing systems, with potential for false positives from upstream sources (Deiner and Altermatt, 2014; Shogren et al., 2017). Although platypus-specific degradation distances are unquantified, studies have mitigated this risk by spacing sites ≥1 km apart or sampling in disconnected tributaries (Lugg et al., 2018; Brunt et al., 2025). Seasonal conditions can influence eDNA detection, with factors such as lower temperatures, higher flows, and reduced animal activity in winter and spring likely to reduce detection probabilities. Conversely, sampling during periods of peak species activity, such as summer and autumn, may improve detection outcomes (Sales et al., 2020). Mammal eDNA is generally less persistent and more locally constrained than aquatic taxa due to lower shedding rates and faster degradation (Sales et al., 2020). While some downstream movement is possible, detections are typically interpreted as reflecting local presence when supported by suitable survey design.

5.4.4 STATISTICAL METHODS AND ANALYTICAL LIMITATIONS

5.4.4.1 STATISTICAL TECHNIQUES APPLIED

The AEMP employs a broad suite of statistical techniques across different ecological components, though their application is not uniform. The most comprehensive analyses have been applied to macroinvertebrate data, with other components, particularly fish, having received more limited statistical treatment.

For macroinvertebrates, consistent univariate metrics have included taxa richness, EPT (Ephemeroptera, Plecoptera, Trichoptera) richness, SIGNAL-2 scores, and AUSRIVAS Observed/Expected (O/E) ratios. These indicators have been widely used to assess ecological condition and sensitivity to pollution and have been applied across all years and sites.

Multivariate methods have also been well developed in the macroinvertebrate component. Non-metric multidimensional scaling (nMDS) has been used to visualise community structure, ANOSIM to test for spatial and temporal differences between site types, and SIMPER to identify taxa contributing most to observed dissimilarities. Hierarchical clustering has been applied to group sites by similarity in assemblage composition. Relationships between macroinvertebrate communities and environmental variables, particularly sediment quality, have been explored using RELATE to assess correlation, followed by BEST (Biota–Environment Matching) to identify explanatory variables. Where significant correlations were found, DISTLM (Distance-Based Linear Modelling) was used to quantify the proportion of community variation explained by individual sediment analytes. These analyses were implemented in PRIMER software and used intermittently, depending on the outcome of the RELATE procedure.

Water and sediment quality data have been evaluated using descriptive statistics and, in selected years, multivariate techniques. Principal Components Analysis (PCA) has been applied to summarise sediment chemistry and identify major spatial patterns in contaminant distribution. In the 10-year review, additional statistical methods such as Kendall tau correlation, Sen slope estimation, Kruskal-Wallis tests, Dunn's test, and locally weighted scatterplot smoothing (LOWESS) were used to assess spatial and temporal trends in water quality (GHD, 2018). However, these specific techniques were not applied to biological data. While macroinvertebrate communities were analysed using univariate and multivariate approaches, formal time series or trend-based analyses were not employed to examine long-term ecological change.

Aquatic habitat variables, derived from the AUSRIVAS protocol and VisAssess method, have occasionally been included in exploratory multivariate analyses, such as BIOENV and BVStep, to investigate correlations between physical habitat and macroinvertebrate community composition. While habitat data are an integral component of the AUSRIVAS predictive models used to assess site condition, they have not been routinely incorporated as covariates in other statistical models comparing ecological responses across site types. Outside the AUSRIVAS framework, habitat variables have not been used in hypothesis-driven analyses or model-based assessments to explicitly test for habitat effects or control for confounding variation when interpreting biological patterns.

In contrast to the macroinvertebrate component, fish data have received relatively limited statistical treatment. Earlier reports applied single-factor ANOVA to assess differences in *G. olidus* length across seasons and sites, and this analysis was used intermittently up to at least 2018. In more recent reports, however, the emphasis shifted toward descriptive summaries and visual interpretation of length-frequency distributions. Histograms and kernel density curves were presented to illustrate size structure and infer recruitment patterns, but statistical comparisons were rarely reported. No formal models have been used to account for differences in sampling method. Sites where bait traps were used instead of electrofishing were either excluded from further analysis or treated qualitatively, with no attempt at calibration or adjustment for sampling efficiency. Survey effort has not been standardised, and no catch-per-unit-effort calculations have been applied. While electrofishing was the dominant method, detectability may vary across environmental conditions and has not been accounted for in any analyses. The decision to reduce the number of measured individuals from 50 to 20 was not supported by statistical rationale or evaluation of its consequences. Although length-frequency outputs have been presented, they were used descriptively rather than analytically, and no formal tests have been applied to assess size-class structure, recruitment dynamics, or spatial and temporal variation. This reduction in measurement effort further constrained the program's capacity to detect shifts in population structure and suggests that the length data have been under-utilised. Finally, multivariate methods such as non-metric multidimensional scaling, analysis of similarities, and BEST, which have been routinely applied to macroinvertebrate data, have not been used for fish data. As a result, broader community-level patterns and environmental drivers of fish distribution remained unexplored.

5.4.4.2 EVALUATION OF ANALYTICAL RIGOUR

A fundamental limitation of the AEMP to date is the absence of formal temporal modelling, despite having compiled 18 years of biannual ecological data. This omission is not just a technical shortfall it represents a major lost opportunity to detect subtle, cumulative, or delayed ecological responses to mine-related disturbance. Time-series models, generalised or generalised linear mixed-effects frameworks, or other longitudinal analyses have not been applied to macroinvertebrate or fish datasets. The only instance of trend analysis using Kendall tau and LOWESS smoothing was limited to water quality variables in the 10-year review, which was not been sustained in subsequent reporting. Given the temporal resolution of the dataset and its potential to characterise ecosystem trajectories, the failure to implement long-term statistical analysis substantially undermined the program's ability to distinguish between natural variability and anthropogenic impact. Without such analysis, the program cannot determine whether ecological condition is improving, declining, or stable over time, nor can it identify early-warning signals of degradation.

As discussed in the section above, fish data analysis remained limited. Length-frequency data for *G. olidus* were only summarised descriptively, with minimal statistical inference. Differences in sampling method and sample size constraints were not analytically addressed, and community-level drivers were not explored using multivariate tools. The decision to reduce fish sampling to autumn only was recommended in the 10-year review (GHD, 2018), with the rationale being to minimise disturbance during spring spawning and redirect resources toward potentially more beneficial efforts, such as additional sites or sediment analysis. While this trade-off is understandable, the change reduced seasonal representativeness and may have limited detection of temporal variability in recruitment or species activity. These implications have not been explicitly evaluated in subsequent reports.

Differences in sampling methods have also not been addressed analytically. Although electrofishing was the primary fish sampling method, bait traps were used at sites where electrofishing was infeasible. In several instances, bait trap data were excluded from further analysis due to the inability to correct for sampling bias. However, where both methods were reported, no calibration, adjustment for sampling efficiency, or effort standardisation has been applied. Catch-per-unit-effort has not been calculated, and no modelling has been used to account for detectability or environmental variation. These inconsistencies reduced the reliability of spatial or temporal comparisons.

No statistical power analysis has been undertaken. Given the natural variability among sites, low sample sizes, and the degraded condition of reference streams, the program's ability to detect ecologically meaningful change is likely to be low. In the absence of power estimates, conclusions that differences were absent or non-significant cannot be interpreted as evidence of no impact. Without a clearer understanding of the program's statistical sensitivity, the confidence in negative findings remains uncertain.

While chemical, biological, and habitat data were all collected through the AEMP, their integration in analysis has been limited and inconsistently applied. Some reports have used exploratory multivariate procedures, such as BIOENV and BVStep, to investigate the relationship between habitat variables and macroinvertebrate communities. These methods, based on habitat metrics derived from AUSRIVAS protocols, offered insight into potential drivers of community structure. However, their use was intermittent and restricted to correlation-based exploration rather than formal hypothesis testing or predictive modelling. Habitat variables were not routinely incorporated as covariates in statistical comparisons such as ANOSIM, nor were they included in any form of temporal modelling. Techniques such as variance partitioning, which could quantify the relative influence of habitat, sediment chemistry, and spatial structure, have not been applied. Habitat data have also not been integrated with fish community analysis, which remained descriptive and methodologically isolated.

In summary, while the program has applied a suite of established biomonitoring and statistical tools, its analytical framework was primarily exploratory and lacked inferential strength. The absence of formal hypothesis testing, the lack of long-term temporal analysis, and limited integration of datasets constrained the program's ability to identify key ecological drivers or confidently attribute observed changes to mining-related activities. Without greater analytical cohesion and statistical rigour, the interpretive power of the monitoring data remained limited.

5.4.5 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

Quality assurance and quality control (QA/QC) are critical to ensuring the reliability, accuracy, and defensibility of environmental monitoring data. Robust QA/QC processes are essential at every stage of data generation, from field sampling to laboratory analysis, data handling, and interpretation, particularly for long-term programs used to support compliance decisions and assess change over time.

5.4.5.1 QAQC IN FIELD SAMPLING

Instrument calibration

Physicochemical parameters were typically collected with multiparameter water quality probes, such as YSI meters, with most reports stating that they were calibrated prior to use in accordance with specifications. Some calibration records have been included, for example in the 2014 - 2015 (GHD, 2015) and 2015 – 2016 (GHD, 2016) AEMPs but were missing from other reports, which undermines the reliability of *in situ* water quality results.

QAQC samples

Collection of QAQC samples such as duplicates and replicates are necessary for validating the accuracy of results, this applies to chemical analyses as well as aspects like macroinvertebrate sampling. Some reports did mention duplicates or replicates but the number of duplicate samples was not specified, no comparative results for duplicates were presented or discussed and there was no assessment of variability or uncertainty based on field replicates.

Some QAQC is included was standard in laboratory analysis such as matrix spikes, laboratory duplicates and blanks along with the outcomes of QAQC sample analysis as part of the laboratory reports. Upon inspection of the reports, it appeared that any laboratory analysis issues were resolved internally via redigestion and reanalysis, however a statement in the main body of the report acknowledging any QA issues, even minor ones, would increase confidence in the robustness of the results and assist in identifying any patterns of failure that may indicate a method limitation or contamination issue.

Field sheet metadata

Standardised field sheets for water quality, macroinvertebrates and habitat assessments were mentioned in multiple reports. Habitat condition field sheets were routinely included in the appendices, while raw macroinvertebrate and fish data were included only in some instances, e.g. 2010 – 2011 (ALS, 2011) and 2016 - 2017 (GHD, 2017) reports. Water quality observations were generally recorded within broader site or habitat field sheets. The consistent and standardised inclusion of all relevant field sheets would improve transparency and support independent verification of results.

Use of SOPs

The monitoring reports referenced several standardised protocols for habitat assessment. Most consistently, they cited the NSW AUSRIVAS Sampling and Processing Manual for macroinvertebrate and habitat procedures, and rapid bioassessment (RBA) methods for visual habitat scoring. While these references indicated alignment with best-practice methodologies, the reports did not consistently cite specific versions or adaptations of these protocols, and no SOPs were appended or directly quoted. The actual application of these methods in the field, such as scoring procedures, how observer consistency is maintained, was not described. As a result, the reviewers cannot assess whether procedural consistency has been maintained across years. Some reports refer to internal tools (e.g. GHD's Aquatic Ecology and Water Quality Monitoring Database), suggesting embedded QA systems, but no documentation was provided regarding data validation, quality checks, or error correction procedures.

The absence of detailed procedural documentation limits the transparency and verifiability of the monitoring program and constrains independent assessment of long-term consistency and data quality.

5.4.5.2 QA/QC IN LABORATORY ANALYSIS

Certificates of Analysis (CoAs) from the laboratory (ALS) were routinely included in the report appendices and provided information on laboratory QAQC, including method blanks, matrix spikes, laboratory duplicates, recovery rate and precision checks. The CoAs also reported on any QAQC issues, such as poor precision (e.g. for chromium or manganese) and detailed how these issues were managed, usually via re-digestion and reanalysis, which suggests that QA issues were being effectively managed in the laboratory. As mentioned above, no comment was included in the main report regarding the QAQC of the laboratory analysis. Similarly, there was no comment on how any data were flagged, excluded or qualified based on laboratory QAQC findings.

While CoAs provided some detail regarding sample ID, collection date etc. Chain of Custody (CoC) documents that formally detailed the handling of samples from field collection to laboratory analysis were not included. The lack of this documentation made it difficult to discern whether samples have been handled appropriately in a way that would not compromise QAQC.

While internal QAQC systems appeared to be functioning, the lack of integration between laboratory outputs and reporting and lack of CoC documentation hindered the ability of independent reviewers to validate analytical results. Inclusion of these aspects would improve confidence in the data.

5.4.5.3 QA/QC FOR BIOLOGICAL DATA

Macroinvertebrates

No QAQC information or data were provided for macroinvertebrate sampling in accordance with AUSRIVAS protocols. Specifically, there was no mention of quality assurance measures to ensure accurate taxonomic classification, such as double-blind re-identification, cross checking by a third-party taxonomist or accuracy scoring. While these measures were not specifically mentioned in AUSRIVAS protocols, the manual does specify that '… it is important when undertaking sampling for AUSRIVAS that appropriate quality control and quality assurance procedures are followed, particularly when conducting large-scale monitoring programs' [such as Cadia Valley], (Turak et al., 2004). The lack of verification reduces confidence in the accurate identification of macroinvertebrates.

Replicate samples have not been routinely collected. The 2006 – 2017 data review document included a statement that "Results for AUSRIVAS O/E 50 were collated with average O/E 50 scores calculated where replicate sample data existed…", (GHD, 2018). This provided evidence that replicate samples were collected in some instances between 2006 and 2017 and used to calculate average AUSRIVAS O/E 50 scores for analytical purposes, but the details of when and where replicate samples were collected remained unclear. The recommendation to include replicate macroinvertebrate sampling, particularly of riffle habitats, was consistently suggested from 2012 – 2017 (GHD, 2012, 2013, 2014, 2015, 2016, 2017). Despite this repeated recommendation made in the GHD reports and statements that it would improve understanding of the extent of impacts, GHD does not appear to have implemented its own recommendations for reasons unknown. The lack of replicate samples limits confidence in the data as within site variability cannot be quantified nor accuracy verified.

Fish

Fish identification in the AEMP relies on published taxonomic keys, including Allen et al. (2002), Lintermans (2007, 2023), and Kuiter (2013). However, there was no indication of formal QA/QC procedures such as re-identification, cross-checking, or observer calibration to ensure taxonomic consistency over time. Although only one member of the *G. olidus* species complex is likely to occur in the Cadia region (Raadik, 2014), the program continues to report this species under its historical name without expert verification or genetic confirmation. While this may not significantly affect species-level interpretation in this context, the absence of taxonomic validation procedures across all fish taxa has introduced uncertainty into long-term monitoring datasets. This gap reduced confidence in the reliability of species records over time and limited the program's ability to detect misidentification, observer drift, or emerging ecological patterns. It also weakened the scientific defensibility of the dataset and may have obscured impacts on species of conservation concern. In a long-term monitoring context, the failure to adapt to known taxonomic advances limits the interpretive value of the fish data and reduces confidence in any conclusions drawn about population trends or ecological health.

The frequency of fish sampling has also not been clearly documented. The 10-year review (GHD, 2018) recommended a shift from biannual to autumn-only sampling to reduce disturbance during spring spawning and reallocate resources. However, it is unclear whether this change was implemented, as subsequent reports continued to present results from both spring and autumn without consistently stating the rationale or confirming alignment with the revised strategy. This lack of clarity reduced transparency and may have complicated interpretation of long-term population trends if seasonal variability was not accounted for.

The change from measuring 50 individuals to measuring 20 individuals only may have introduced size-class bias in length-frequency analysis, as discussed above, particularly at high-abundance sites.

Mixed sampling methods have also been used across the program. Electrofishing and bait trapping are considered complementary, not interchangeable; they target different parts of the fish community and differ in efficiency, introducing methodological bias when used interchangeably without correction.

Environmental DNA (eDNA) has been suggested in several reports (e.g. GHD, 2019, 2020) as a less invasive and more standardisable alternative, particularly to address ethical concerns with bait traps and improve consistency at hard-to-access sites. However, despite this recommendation, eDNA has not been adopted to date, and no rationale for this decision has been provided.

Platypus

The eDNA-based platypus monitoring program follows established laboratory protocols and incorporates several key quality assurance measures. Laboratory analysis was conducted by EnviroDNA using a species-specific qPCR assay targeting a mitochondrial DNA region specific to platypus. Each sample was analysed in triplicate, and negative controls were included during both DNA extraction and amplification steps to detect any contamination. A site was only classified as positive for platypus presence if at least two of six total PCR replicates returned positive results, providing a conservative and quality-controlled framework for detection.

Field sampling protocols specified that duplicate water samples were to be collected at each site by filtering up to 5 L of water through a 0.22 µm Sterivex filter using a Smith-root eDNA pump. Between March 2019 and December 2021, hand-held syringes were used instead, with a standard filtered volume of approximately 200 mL due to sediment clogging. While the shift to pump-assisted filtration would have improved DNA yield and detection sensitivity, quality control procedures for field collection remain poorly documented. No mention was made of decontamination procedures, or the use of single-use gloves and consumables. It was also unclear whether field staff conducting eDNA collection received specific training in contamination prevention, filtration techniques, or sample handling protocols, factors known to significantly influence data quality in eDNA programs (Sales *et al.*, 2020; Brunt *et al.*, 2025). These gaps limited confidence in the consistency of field practices and the interpretability of site-level detection data. While the laboratory QA/QC framework was robust, the absence of documented field QA/QC procedures represented a notable shortcoming.

Habitat

Habitat assessment methods in the AEMP were described in section 5.4.3. These were based on recognised protocols, primarily the Visual Assessment of Disturbance Related to Human Activities (VisAssess) as outlined in the NSW AUSRIVAS Manual (Turak et al., 2004), and, from 2015, the modified Riparian, Channel and Environmental (mRCE) inventory (Chessman, Growns and Kotlash, 1997). These methods applied structured scoring systems across water quality, instream habitat, riparian condition, and catchment disturbance.

While these tools offer a consistent framework for field assessment, their subjective nature and the absence of documented quality assurance procedures limited confidence in long-term comparability. No evidence of observer training, inter-observer calibration, or consistency testing was presented in the reviewed reports. This lack of procedural control introduced a risk of scoring variation, particularly given the likely turnover in personnel across the multi-decade program.

As noted in section 5.4.3, application of the mRCE protocol was inconsistent across years, and no corrective processes were documented following omissions or reporting gaps. These lapses undermined the comparability of scores over time and weakened the method's value as a complementary line of evidence.

Since 2012, habitat data have been collected using GHD's internal Aquatic Ecology and Water Quality Monitoring database, which was based on AUSRIVAS and FNARH field sheets. While the database likely improved data structure and efficiency, no validation rules, error-checking procedures, or field sheet audit protocols were described in reporting outputs. This lack of documentation limited confidence in data quality. Photographic records were referenced sporadically but were not standardised or linked to a documented quality control process.

In summary, while habitat assessment methods were grounded in established protocols, the absence of documented quality assurance procedures for field implementation, data handling, and observer consistency reduced the reliability and long-term comparability of the dataset. These limitations constrained the ability of habitat metrics to robustly support interpretations of ecological change or attribution of mining-related impacts.

5.4.5.4 QA/QC GAPS, LIMITATIONS AND IMPLICATIONS

While individual reports described various elements of quality assurance and control, the overall QA/QC framework lacked consistency, transparency, and traceability. This absence of a formalised structure was not confined to isolated instances but reflected a systemic limitation that cumulatively eroded confidence in the long-term integrity of the monitoring program.

Based on the reports that were available over the monitoring period, QAQC procedures appeared to be inconsistently applied and poorly documented. Calibration logs, replicate sampling, chain of custody, and internal reviews were present in some years and absent in others. It is unclear how collection and handling of data was managed to ensure quality, for example, how environmental samples are collected to ensure quality, or how data were handled, for example management of outliers. In effect, this review has relied on assumed institutional competence, rather than demonstrable procedural rigour.

Of particular concern was the absence of documented internal standardisation for subjective assessments, such as those used in evaluating habitat condition. Without formal calibration or training protocols, these assessments would have been vulnerable to observer bias, introducing unquantifiable uncertainty.

The gaps in QA/QC reduced the reliability of the data and confidence in the conclusions that could be drawn. For a long-term dataset intended to support compliance assessment and detect mining-related impacts, the lack of a formalised and transparent QA/QC system undermined the defensibility of the conclusions and the scientific credibility of the program.

5.4.6 DATA VALIDITY AND INTERPRETATION OF RESULTS

Despite the extensive temporal scope of the AEMP, its analytical framework does not capitalise on the full potential of the dataset. Inconsistencies in data collection, poor integration across ecological components, and the absence of robust statistical modelling constrained the program's capacity to detect, explain, or attribute ecological change with confidence. These structural limitations reduced the strength of interpretive conclusions and the program's value as a regulatory and early-warning tool.

5.4.6.1 COMPLETENESS AND CONSISTENCY

The AEMP has generated a substantial long-term dataset spanning more than 18 years, which is a significant strength. However, several issues of incomplete parameter coverage, inconsistent documentation, and weak integration reduced its overall interpretive value.

Key contaminants such as sediment copper were not incorporated into the program until 2018 limiting the ability to assess long-term trends in one of the primary contaminants of concern. Similarly, several water quality analytes including antimony, selenium, silver, chromium, and aluminium were reported inconsistently across earlier years, with notable data gaps at some sites and during some sampling events.

Discontinuities in biological and habitat data collection have also been identified. For example, seasonal mRCE scores were omitted in autumn 2017 due to internal miscommunication. Subsequent reports did not consistently clarify whether both spring and autumn scores were collected, reducing the temporal comparability of habitat data. The reduction in fish length measurements from 50 to 20 individuals per site was implemented without statistical justification or clear documentation (see Section 5.4.4).

As noted in section 5.4.4, while exploratory analyses such as RELATE and BEST have been used to examine associations between macroinvertebrate communities and sediment quality, they were not consistently applied. As noted in section 5.4.3, the 10-year review (GHD, 2018) recommended a shift from biannual to autumn-only fish sampling to minimise disturbance during spring spawning and reallocate resources. However, subsequent reports did not consistently specify whether this recommendation was adopted. This lack of clarity limited confidence in the consistency of fish data collection and may have obscured seasonal trends in recruitment, abundance, or behaviour. Fish data remained analytically isolated. The results were typically summarised using descriptive statistics and length-frequency plots, with no integration into multivariate models or formal testing of relationships with other environmental variables. Although habitat condition and sediment quality were recorded, they have not been incorporated consistently into the analysis of fish community structure or population patterns.

Platypus eDNA sampling has been conducted since 2019, but variability in collection method (e.g. syringe versus pump) and unclear documentation of QA/QC procedures introduced some uncertainty in year-to-year comparability. Nonetheless, these data provided important supplementary evidence of ecological integrity in Cadiangullong Creek.

A major missed opportunity was the absence of formal temporal analysis. Despite 18 years of biannual data, no time-series modelling or mixed-effects frameworks have been applied to assess long-term trends, cumulative impacts, or delayed responses. While the 10-year data review included trend analysis for selected water quality parameters, these methods have not been consistently extended to biological datasets or embedded in routine reporting. The consistent biannual sampling design provided a robust foundation for such analysis, and the failure to exploit this limited the ability to distinguish background variability from mine-related impact.

5.4.6.2 POTENTIAL BIASES IN INTERPRETATION

Interpretation of AEMP results was constrained by several biases and limitations. As noted in section 5.3.2, elevated copper concentrations in sediment were repeatedly documented, particularly at downstream sites such as CC2 and CC3, where levels frequently exceeded ANZG (2018) guideline values. However, source attribution remained weak. Some reports referenced possible geogenic inputs due to natural mineralisation within the Cadia Hill area or suggest agricultural activities as contributors. Others inferred a mining origin based on spatial patterns. Yet none presented supporting data or applied geochemical tracing techniques to distinguish between natural, agricultural, and mining sources. While descriptive comparisons between upstream and downstream sites were made, these were not embedded in a systematic modelling framework, and multivariate analyses such as PCA have only been used to characterise site groupings rather than apportion source contributions. Recommendations in some reports to undertake sediment tracing or 2D modelling have not been actioned, leaving potential mine-related impacts insufficiently investigated. This absence of rigorous source analysis limited confidence in the conclusions drawn about sediment copper and its ecological significance.

Similarly, high electrical conductivity (EC) readings were frequently attributed to groundwater expression without hydrological evidence to support this claim. In a highly modified system where mine-related groundwater discharge is plausible, the assumption of natural sources without verification introduced uncertainty and weakened confidence in interpretation.

In several reports, exceedances of water or sediment quality guidelines were acknowledged but downplayed through language such as “slightly above” or “not ecologically significant,” often without accompanying evidence or threshold justification. This rhetorical framing risked masking early indicators of degradation, potentially undermining the precautionary principle and enabling regulatory complacency.

As discussed in section 5.4.2, interpretative confidence was further compromised by the program’s reliance on hydrologically and ecologically dissimilar reference sites. Furthermore, Flyers Creek, Swallow Creek, and Panuara Rivulet all exhibited signs of ecological disturbance, including salinity, nutrient enrichment, and poor riparian condition. As GHD (GHD, 2024) itself acknowledged, “*…the ability to detect impacts within the mine (i.e., on-site treatment) will require those impacts to be greater than what currently occurs at upstream and reference sites outside the mine. That is, the effect of any mining activities on water quality, sediment quality, and biological communities will need to be more detrimental compared to other land use activities*…” This raised the threshold for detecting mine-related impacts and increased the likelihood of Type II error, where real effects remained undetected due to baseline impairment.

5.4.6.3 ARE CONCLUSIONS SUPPORTED BY THE DATA?

Routine AEMP reporting often concluded that there was no evidence of mining impact on aquatic ecosystems (GHD, 2021, 2022, 2023, 2024). However, these conclusions were not strongly supported by inferential analysis. In particular, fish data were analysed using basic descriptive statistics, without statistical testing or integration with environmental datasets. Macroinvertebrate data received more detailed treatment, but key limitations persisted.

No statistical power analysis has been undertaken to assess the program’s sensitivity to ecological change. Given the high natural variability among catchments, small sample sizes, and limitations in reference site condition, the risk of failing to detect subtle or cumulative impacts was high. Without power estimates, the repeated conclusion of “no impact” cannot be interpreted as definitive evidence of no effect.

Furthermore, several internal recommendations, such as the implementation of replicate sampling for riffle macroinvertebrate habitats and eDNA sampling for fish have not been actioned. These omissions compromised the program’s capacity to track ecological change at the species or community level and reduced the utility of the data for detecting subtle shifts.

In summary, while the AEMP represented a long-term investment in aquatic monitoring, interpretation of the data was constrained by gaps in completeness, inconsistent integration across components, limited application of inferential statistics, and failure to act on previously identified improvements. These shortcomings limited the defensibility of "no impact" conclusions and highlighted the need for a more rigorous analytical framework moving forward.

5.5 SUMMARY OF KEY ISSUES

This section outlines the most salient limitations and weaknesses identified in the Aquatic Ecosystem Monitoring Program (AEMP), grouped by severity to clarify their relative influence on the defensibility of the program's conclusions.

5.5.1 CRITICAL ISSUES

The most serious limitation in the AEMP is the absence of true reference sites. All so-called 'reference' locations: Flyers Creek, Swallow Creek, and Panuara Rivulet were ecologically degraded and hydrologically and likely ecologically distinct from mine-affected sites. These creeks exhibited salinity, nutrient enrichment, grazing impacts, and flow alterations, violating core assumptions of the AUSRIVAS assessment framework for reference sites. Comparisons between these sites and those within or downstream of the mine lease cannot isolate mining-related effects because they differed along multiple, uncontrolled environmental axes. This flaw was not incidental; it was structurally embedded in the monitoring design. The program relied on the premise that reference and test sites were ecologically equivalent except for mining activity. In practice, they were not. The program's own reporting acknowledged that under this structure, impacts from mining would need to be more severe than all other background disturbances to be detectable. This set an unreasonably high threshold for detection and rendered the program incapable of identifying subtle, cumulative, or temporally delayed effects.

Compounding this issue was the absence of formal trend analysis, despite 18 years of biannual data. No temporal analysis has been applied to investigate ecological change over time. This omission squanders one of the program's greatest strengths, its duration, and reduces its value as a tool for understanding long-term or cumulative impacts.

The program also lacked any form of statistical power analysis. Without estimating its ability to detect real change, the confidence in any 'no impact' finding was severely undermined. Small sample sizes, natural variability, and compromised reference conditions meant that the risk of Type II errors (false negatives) was high.

Finally, site classifications such as 'upstream,' 'downstream,' or 'on-site' do not reflect a clear analytical design framework and as such - it was difficult to tell which sites were comparable.

5.5.2 MODERATE ISSUES

Several methodological and reporting limitations constrained the interpretability of the results. Sediment metals particularly copper, a key contaminant of concern, were only added to the program in 2018. This delay limited the capacity to assess long-term sediment contamination trends.

Sampling consistency was also lacking. Macroinvertebrate data were generally collected reliably, but fish and habitat data, including mRCE scores, were missing from some seasons or locations, and this was not always explained. Seasonal variation was known to influence fish population metrics, so these omissions hindered interpretation of inter-annual trends.

Taxonomic QA/QC procedures were undocumentedand introduced unquantifiable uncertainty into the identification of taxa, which directly affected derived metrics.

Fish data, in particular were under-analysed. While standard sampling protocols were followed, the results were presented descriptively using length-frequency histograms, with no statistical analysis or integration with environmental drivers such as sediment quality or habitat condition. The potential influence of exotic species was acknowledged but not systematically assessed. Platypus presence was recorded using robust eDNA methods, but the results were not formally analysed or integrated into broader ecological interpretations.

In some cases, speculative explanations were presented without supporting data. For instance, elevated electrical conductivity is sometimes attributed to groundwater inflows without hydrological evidence. These interpretations can deflect attention from potential mine-related causes and obscure the true source of observed impacts.

5.5.3 MINOR ISSUES

Some procedural and documentation issues, while not individually critical, reduce transparency and limit the ability of reviewers to fully assess data reliability. Examples included:

- Field sheets and metadata were not consistently appended across all reports, limiting traceability.
- Chain-of-custody documentation for laboratory samples was not included, reducing confidence in sample handling.
- GHD's internal database system for habitat and water quality data was described but lacked documented QA/QC protocols for validation or error checking.
- Photographic records of habitat assessments were mentioned sporadically but were not standardised or used systematically.
- The seasonal frequency of fish sampling was inconsistently reported, and it was unclear whether internal recommendations to shift to autumn-only surveys have been adopted.

While these limitations were less severe than structural design flaws, they contributed to cumulative uncertainty and should be addressed to improve consistency and confidence in the dataset.

5.5.4 MISSED OPPORTUNITIES

The AEMP includes several components that, if better integrated or more fully implemented, could substantially improve its interpretive power. Repeated internal recommendations to collect replicate macroinvertebrate samples—particularly from riffle habitats—have not been adopted, limiting the ability to estimate within-site variability.

Following the taxonomic revision of *G. olidus* by Raadik (Raadik, 2014), multiple reports recommended expert identification or genetic analysis to confirm species presence. Despite this, no evidence was available to suggest these steps were taken, introducing potential misclassification into long-term fish population analyses.

While data on macroinvertebrates, fish, water quality, sediment chemistry, habitat, and platypus distribution were all collected, they are rarely analysed in an integrated fashion. Multivariate tools such as RELATE, BEST, or variance partitioning were used inconsistently, and almost never applied to fish or platypus datasets. The absence of integrated modelling across these components reduced the program's ability to detect causal relationships or interactions between stressors.

Finally, platypus eDNA monitoring was scientifically robust and has been implemented across multiple seasons and locations. However, the results remained under-analysed and disconnected from broader assessments of ecological condition or hydrological risk.

5.5.5 CONCLUSION

The Aquatic Ecosystem Monitoring Program (AEMP) has compiled a long-term dataset spanning nearly two decades. However, the program lacked the analytical depth, design rigour, and data integration required to reliably detect and attribute ecological change. While field methods generally aligned with national protocols, the interpretive tools necessary for confident ecological assessment remained underdeveloped.

Major structural limitations included the absence of valid reference sites, the lack of statistical power analysis and trend modelling, and the limited integration of biological and environmental datasets. Fish and platypus data were collected but remained analytically isolated, and quality assurance and quality control procedures for taxonomy and habitat assessment were either poorly documented or not described at all.

Because of these limitations, confidence in the current assessments is low. Repeated conclusions of "no mining impact" were not supported by inferential evidence and cannot be considered reliable without methodological improvements. The program, in its current form, is unlikely to detect subtle, cumulative, or delayed ecological responses associated with mining activity.

Comprehensive reform is essential. Priority actions include redesigning the site network to incorporate ecologically appropriate control locations, applying formal statistical methods to assess patterns over time and across space, standardising quality control procedures, and integrating datasets across all monitoring components. Without these changes, the program will remain observational rather than diagnostic and will not provide a credible basis for assessing environmental risk or regulatory compliance.

5.6 REGULATORY FRAMEWORK AND APPROVALS

Aquatic ecological monitoring at Cadia Valley Operations (CVO) is conducted under multiple regulatory instruments:

- Fisheries permits issued under Section 37 of the *Fisheries Management Act 1994 (NSW)*, which authorise aquatic sampling, including electrofishing, across watercourses in and adjacent to the Mining Lease Area (MLA). These permits specify approved methods, expiry dates, and site coverage (e.g. Cadiangullong Creek, Swallow Creek, Flyers Creek, Panuara Rivulet).
- Cadia East Project Approval (PA06_0295) and Environment Protection Licence (EPL 5590), which require aquatic ecosystem monitoring and reporting under the Annual Environmental Management Review (AEMR) framework.
- Annual Reviews and AEMRs, which serve as the key instruments for demonstrating compliance with aquatic-related conditions of approval and environmental performance criteria.

These instruments collectively defined the scope, frequency, and intent of aquatic monitoring, with an emphasis on detecting potential impacts from mining on ecosystem condition and informing adaptive management responses.

5.6.1 GUIDELINE APPLICATION AND BENCHMARKING

The aquatic ecology program has used several national water quality and sediment guidelines as benchmarks for compliance and ecological interpretation:

- ANZECC/ARMCANZ (2000) and ANZG (2018) guidelines for surface water quality, applied against data from upstream and downstream sites across seasons.
- Interim Sediment Quality Guidelines (ISQG), used for interpreting total metal concentrations in sediment samples.

However, the AEMP does not currently apply site-specific guideline values (SSGVs) for either water or sediment. Instead, comparisons have been routinely made against default guideline values (DGVs) from ANZECC (2000) or ANZG (2018), despite repeated recommendations to develop and apply SSGVs for chemical and biological indicators. This approach contrasted with other components of the CVO monitoring program, such as surface and groundwater assessments, where SSGVs have been developed and routinely applied. This absence weakened the program's ability to assess compliance in a locally relevant context, particularly given the mineralised geology of the Cadia region.

Within the AEMP, the water quality assessments rely on total metal concentrations, without considering dissolved fractions that are more directly linked to bioavailability and ecological risk. Sediment assessments similarly rely on total metal concentrations compared against ISQG thresholds, without incorporating porewater chemistry or other indicators of bioavailable metal fractions. These omissions limit the ecological relevance of reported exceedances and may result in over- or underestimation of actual exposure risk. The absence of bioavailability-based metrics reduces the interpretive strength of the program and constrains its value for defensible compliance reporting.

5.6.2 DEMONSTRATION OF COMPLIANCE

While formal compliance is reported in AEMRs and supported by monitoring data, multiple structural limitations constrain the program's ability to meaningfully demonstrate that aquatic ecosystems are protected in accordance with regulatory intent:

- Reference site condition: All designated upstream or reference sites (e.g. Flyers Creek, Panuara Rivulet, Swallow Creek) are ecologically impaired to varying degrees, exhibiting salinity, nutrient enrichment, grazing pressure, or altered flow regimes. These sites do not meet AUSRIVAS assumptions of minimal disturbance and thus do not provide a valid baseline for detecting mining-related impacts.
- Lack of statistical power analysis: The program has not evaluated its capacity to detect ecologically meaningful change over time. Without power analysis, conclusions of "no significant difference" cannot be interpreted as evidence of no impact.
- Temporal gaps in parameter coverage: Key contaminants of concern (e.g. sediment copper) were not monitored prior to 2018. This omission prevents the program from assessing long-term trends or cumulative effects and undermines continuity in compliance assessments.
- No formal time-series analysis: Despite 18 years of biannual ecological data, no trend-based or mixed-effects modelling has been applied to assess directional change or delayed impacts.
- Incomplete QA/QC documentation: The program lacks documented procedures for key quality assurance elements—such as macroinvertebrate re-identification, fish taxonomic validation, and inter-observer consistency in habitat assessments. These gaps reduce confidence in dataset reliability and weaken the defensibility of reported conclusions.
- Inconsistencies in reporting and interpretation: Differences between AEMRs and the 10-year review are evident in the treatment of sediment copper, conductivity, and pH exceedances. Reports frequently use vague qualifiers such as "slightly above" or "not ecologically significant" without reference to toxicological thresholds, statistical comparisons, or clear decision rules. This reduces transparency and impedes objective interpretation.
- Unsubstantiated attribution of exceedances: Elevated sediment copper concentrations at CC2 and CC3 are consistently reported but have not been investigated using isotopic tracing or geochemical fingerprinting. Similarly, high electrical conductivity is often attributed to "groundwater influence," yet no hydrological validation is presented. In both cases, conclusions are based on inference rather than evidence, weakening the credibility of compliance statements—particularly where guideline exceedances are dismissed without systematic justification.

There are inconsistencies in how ecological risks and exceedances are interpreted across reporting outputs. Notably, differences between AEMRs and the 10-year review are apparent in the treatment of sediment copper, conductivity, and pH exceedances. Furthermore, the frequent use of vague qualifiers such as "slightly above" or "not ecologically significant" without supporting evidence (e.g. toxicological thresholds, statistical testing) diminishes transparency.

Compliance interpretations often rely on institutional experience rather than formalised reasoning. For example, elevated sediment copper concentrations at sites CC2 and CC3 are acknowledged but not traced to a source, and no isotopic or geochemical fingerprinting has been employed to confirm mining versus natural origins. Similarly, high electrical conductivity is attributed to "groundwater influence" without hydrological validation. These gaps reduce the defensibility of compliance statements, particularly where guideline exceedances are dismissed without systematic justification.

5.6.3 ADAPTIVE MANAGEMENT AND UPTAKE OF RECOMMENDATIONS

Multiple internal reviews, including the 10-year data analysis and successive AEMR appendices, have identified improvements necessary to enhance analytical rigour and compliance defensibility. However, many of these recommendations have not been implemented. These included:

- Derivation and application of SSGVs for key contaminants
- Adoption of bioavailability assessments (e.g. dissolved metals, sediment porewater analysis)
- Implementation of replicate sampling for macroinvertebrate habitats, particularly riffles
- Statistical integration of biological, habitat, and chemical datasets to support causal interpretation
- Taxonomic clarification for *G. olidus* following Raadik (2014), including expert ID or genetic confirmation
- Transition to autumn-only fish sampling, as recommended to reduce spawning disturbance and reallocate effort
- Expanded use of eDNA for fish monitoring, as proposed in multiple reporting years
- Source attribution methods such as isotopic tracing or geochemical fingerprinting for sediment metals

The absence of follow-through on these actions weakens the program's alignment with adaptive management principles and reduces its capacity to respond to known limitations. It also signals a missed opportunity to increase ecological and regulatory confidence in the program's conclusions.

5.6.4 SUMMARY OF KEY COMPLIANCE GAPS

Issue	Implication for Compliance
Use of default guidelines without SSGVs	Reduces site relevance of exceedance interpretation
Total metals used without bioavailability metrics	Limits ecological accuracy of risk assessments
Reference sites are ecologically degraded	Undermines baseline integrity and weakens confidence in impact comparisons
Ecologically in**appropriate control sites**	Prevents attribution of observed effects specifically to mining
No statistical power or trend analysis	Cannot determine if monitoring is sensitive enough to detect impacts
QA/QC not systematically documented	Reduces confidence in biological data accuracy and defensibility of reported outcomes
Vague or unsupported compliance statements	Increases regulatory uncertainty and weakens report defensibility

Issue	Implication for Compliance
Missed uptake of internal improvement actions	Signals poor alignment with adaptive management expectations and reduces responsiveness to known risks

5.6.5 CONCLUSION

While the aquatic ecology component of the CVO monitoring program meets the structural obligations of regulatory approvals, it does not currently provide a defensible line of evidence for demonstrating functional compliance. The absence of validated reference sites, site-specific benchmarks, and formal analytical sensitivity prevents the program from reliably detecting or attributing mine-related ecological impacts. To ensure regulatory credibility, the monitoring design and analytical framework must be revised to reflect best practice standards in compliance monitoring, anchored in site relevance, statistical defensibility, and transparent interpretation.

6. ASSESSMENT OF RISKS AND IMPACTS

6.1 INFRASTRUCTURE CONTAINMENT PERFORMANCE AND POTENTIAL GROUNDWATER RISKS FROM KEY INFRASTRUCTURE (TSFS, PIT, ETC.)

Effective containment of mine-affected water and waste is fundamental to the environmental management strategy at CVO. Key infrastructure elements including the Northern and Southern Tailings Storage Facilities (NTSF and STSF), the Cadia Hill open cut pit, and associated water holding and sediment control structures play a central role in isolating potentially contaminated materials from surrounding groundwater and surface water systems.

This section reviews the design, performance, and monitoring outcomes associated with these containment systems, drawing on available seepage assessments, groundwater monitoring data, geotechnical reviews, and historical incident records. Particular attention is given to the potential for seepage, liner integrity, hydraulic connectivity, and the mobilisation of contaminants to underlying aquifers or adjacent catchments. The analysis also considers known containment risks, such as historical embankment failures, seepage mitigation measures, and changes in infrastructure use over time (e.g., pit backfilling and TSF decant management).

This review provides an evaluation of both the current containment performance and the potential groundwater risks posed by key infrastructure, to support a more integrated understanding of environmental risk and inform future management actions.

6.1.1 NORTHERN TAILINGS STORAGE FACILITY (NTSF)

NTSF is located over the former Rodds Creek. Stage 1 of the embankment, at the southern side of the TSF, was completed in May 1998. It included a clay core and a foundation cut-off of unknown depth. The storage was not lined and relied on the foundation of hard clay and/or extremely weathered rock to limit seepage to acceptable levels. The Stage 1 embankment was 50m high and 1.68km long.

The embankment was subsequently raised in several stages, initially by three downstream raises, then one centreline raise, and six upstream raises, up to Stage 9, which was completed in December 2016. At that time the embankment was 91m high and about 4km long, and the storage surface area covered about 450ha.

As the embankment was raised, it extended along the western side of the storage, where it is understood to overlie part of the Werribee-Cadiangullong Fault Zone.

Construction of Stage 10, comprising a 3 m upstream raise and a buttress against the downstream face and toe, was in progress when a slump occurred in March 2018. About 300m at the western end of the southern embankment failed, displacing embankment materials and tailings into the rear of STSF. The consequent investigation concluded that the section of embankment had failed through a unit of weak extremely weathered volcanic material in the foundation.

In 2000, seepage was reported from the downstream toe of the right (eastern) abutment of the southern embankment and downstream of the toe of the left abutment. The decant pond and tailings in STSF encroached on the toe of NTSF, such that separate seepage could no longer be observed.

6.1.2 SOUTHERN TAILINGS STORAGE FACILITY (STSF)

STSF is adjacent to the southern (downslope) side of NTSF and its tailings surface is presently about 50m lower than NTSF.

Stage 1 was commissioned in 2002, with an upstream clay liner in the embankment but apparently no significant foundation cut-off. A downstream raise and four upstream raises followed. During 2025 Stage 7 was under construction, comprising a downstream raise of predominantly rockfill, again with clay liner at the upstream face. When completed, the embankment will have a maximum height of 57m where it crosses the original creek alignment and more typically 40m along the southern side. The embankment crest will be 3.9km long and the tailings surface area will cover more than 370ha.

The executive summary of the Stage 7 Design Report stated that seepage analyses were undertaken for the design but the relevant appendix was not provided for this review. Stability analyses appeared to have been based on adopted phreatic surfaces rather than modelled pore water pressures. The report noted that foundation excavation works had previously encountered preferential seepage paths and the same was expected for Stage 7, but the focus of that consideration was on the potential for seepage to initiate piping failure, and not on environmental implications downstream

STSF has an existing seepage collection system that includes the Southern Leachate Dam (SLD) and collection ponds. The design proposed further seepage collection sumps at topographic low points around the Stage 7 toe and acknowledged that seepage is “a form of environmental release”. Given the water pressure head associated with NTSF and STSF – the former is nearly 130m higher than the downstream toe of the combined facilities – the occurrence of seepage is not surprising. Monitoring to date has shown localised impacts on shallow groundwater and nearby surface waters (e.g., Rodds Creek tributaries), particularly for nitrogen oxides and molybdenum. However, the Stage 7 Design

Report stated that "there is evidence of a groundwater divide between the TSFs and Cadiangullong Creek to the west" and water quality in the main Cadiangullong Creek remains within acceptable ranges.

6.1.3 CADIA HILL PIT (PTSF)

The floor of Cadia Hill Pit reached 220m AHD, 501m below the surface overflow level of 721m AHD. The sides of the pit intersect various geological units, including fractured volcanics in the southwestern quadrant. The pre-mining groundwater level was about 705m AHD at the south-western side of the pit (downgradient) and the downstream invert of Cadiangullong Creek in the same area is 707m AHD. The pit has a footprint of about 140ha.

Application for approval to deposit tailings in pit was first made in April 2018 (Mod 11). That application was for a final tailings elevation of 420 m AHD with an unchanged pit lake level of 670m AHD. The maximum interim tailings level, prior to consolidation, was not specified. The Mod 12 application, made in August 2018, raised the final, consolidated, tailings level to 560m AHD, again without changing the final pit lake level or imposing a specific limit on maximum operational tailings level. Both of these applications were made in the context of PTSF remaining a long-term groundwater sink and lower than the adjacent creek invert, so that seepage to groundwater or surface waters would not occur.

In September 2019, the Mod 13 application was made, including for a maximum "pre-consolidation" tailings level of 713 m AHD on the basis that the tailings would consolidate down to a lower elevation, with the long-term pit lake level fluctuating from 687m to 699m AHD. The supporting geotechnical studies suggested that the tailings could settle to below 700 m within about seven years of the end of tailings deposition, while the final void water balance modelling was based on the decant water being rapidly pumped down to about 680 m AHD then rising back to the long-term level after closure. That is, there would be a period of years during and after operation where there could be seepage from PTSF into regional groundwater and into Cadiangullong Creek. To mitigate this the operator proposed to locate cracks and faults in the south-western quadrant of Cadia Hill Pit between 694m and 713 m AHD and seal them, for example, by injection. As of April 2025, the decant/tailings elevation was 664 m AHD. Advice was not received that the cracks and faults have yet been located and sealed.

Even if sealing of fractures and faults within the nominated range is successfully completed, there may be potential for the pressure head differential – from 713 m AHD in- pit to 705 m AHD regional groundwater – to drive seepage under the sealed zone. The potential for seepage through the weathered regolith that presumably is present between the pit and Cadiangullong Creek does not appear to have been addressed. With regard to the transition from operational seepage source to long-term sink, the time prediction is not considered robust because it appears to have been based on parameters derived from a single settlement test; the rationale for those parameter values could not be assessed because the report figures referenced had incorrect graphs. Finally, the definition of "pre-consolidation tailings level" was ambiguous and might be interpreted in a way that materially changes the time period over which the pit would act as a source. For example, PTSF might be filled to say 705m AHD and then left for a few years while tailings were instead deposited in STSF; it is arguable whether the tailings would still be considered pre-consolidated, allowing more tailings to be discharged into PTSF.

6.1.4 SEEPAGE AND GROUNDWATER-SURFACE WATER INTERACTION

This section evaluates the occurrence, pathways, and potential impacts of seepage from major infrastructure (NTSF, STSF, PTSF) at CVO, with a focus on groundwater–surface water connectivity and the manifestation of expressed groundwater conditions. It integrates hydrogeological context, infrastructure layout, historical containment concerns, and long-term water quality data from groundwater bores across key zones (TSF Eastern, Southern, Western, and Cadia Hill Pit) to determine the degree of interaction and associated environmental risks.

6.1.4.1 OBSERVATIONS AND INTERPRETATION

SEEPAGE PATHWAYS AND GROUNDWATER EXPRESSION

Historical seepage observations from the downstream toes of the NTSF (early 2000s) and subsequent reports of preferential flow paths in STSF foundations (including during Stage 7 works) indicate that groundwater expression resulting from seepage is an ongoing feature around these facilities. This is supported by elevated water levels and observable discharge zones downstream (e.g., Southern Leachate Dam and Rodds Creek tributaries), particularly following rainfall or elevated tailings levels.

The hydraulic gradient from NTSF to STSF is substantial (over 130 m), and although seepage collection infrastructure (e.g., toe sumps, collection ponds) has been installed, the water quality data from surrounding bores suggests partial containment. Elevated concentrations of molybdenum, and conductivity in shallow bores in TSF Western and Southern zones (e.g., MB23, MB25, MB87, MB78) support this.

Notably, the Stage 7 design documentation itself acknowledged that seepage is “a form of environmental release”, and its modelling focused primarily on geotechnical stability rather than downstream water quality risks.

GROUNDWATER–SURFACE WATER CONNECTIVITY

While modelling has proposed the existence of a localised groundwater divide between the TSFs and Cadiangullong Creek, field data suggests that some interaction is occurring. This is evident through:

Western Zone bores (e.g., MB25, MB87): Elevated nitrogen and molybdenum concentrations over time, consistent with TSF-related water chemistry.

Southern Zone bores (e.g., MB78, MB83): Persistent elevated iron, manganese, and conductivity, alongside increases in metals like arsenic and cobalt, particularly post-2018.

Eastern Zone bores (e.g., MB20, MB80): High historical concentrations of metals (e.g., copper, cobalt, nickel, cadmium) between 2013–2016, declining in later years. This temporal pattern is consistent with historic seepage episodes and subsequent mitigation.

Despite the assumptions in pit backfilling approvals (Mod 11–13) that the Cadia Hill Pit would remain a long-term groundwater sink, hydrochemical trends suggest at least transient periods of hydraulic reversal and contaminant mobilisation. Groundwater bores in proximity to the pit (e.g., MB91, MB93, and MB95) show elevated arsenic, iron, manganese, and sulfate levels since 2020, which may reflect local expression of tailings pore water or decant seepage migrating through fractures or weathered regolith.

In particular, MB93 show increasing trends in arsenic (peaking ~0.06 mg/L) and iron (~5–6 mg/L) since 2020, consistent with pit lake elevation rise and lateral migration.

Sulfate and EC levels in these bores also indicate a shift in groundwater composition post-pit deposition commencement.

These findings challenge assumptions in earlier Mod assessments that discounted short-term groundwater mounding or lateral migration risks during operational filling.

SUMMARY OF KEY RISKS

TSF-related seepage is measurably impacting shallow groundwater, particularly in the western and southern zones, with some constituents indicative of tailings pore water.

Hydraulic gradients and infrastructure elevation differentials are sufficient to drive seepage, especially in unlined or partially lined zones.

Monitoring bores adjacent to Cadia Hill Pit show evidence of expressed groundwater, with rising contaminant concentrations since commencement of tailings deposition and partial pit filling, suggesting incomplete containment.

Groundwater–surface water interaction is plausible, particularly in Rodds Creek tributaries and the broader Cadiangullong Creek catchment, despite groundwater divides predicted in conceptual models.

RECOMMENDATIONS

Reassess hydrogeological models for the TSF and pit interaction zones, incorporating updated data on water levels, tailings elevation, and seepage observations.

Undertake targeted groundwater tracing studies (e.g., isotopic or tracer-based) to confirm flow pathways from TSF to creek systems.

Upgrade seepage mitigation systems where trends persist, especially around STSF Stage 7 toe zones and the southwest quadrant of Cadia Hill Pit.

Define trigger thresholds for key parameters (e.g., arsenic, molybdenum, NOx, EC) at relevant bores to facilitate early detection and response to seepage events.

6.2 SURFACE WATER RISKS (INCLUDING THOSE FROM EXPRESSED GROUNDWATER)

This section evaluates the risks to surface water quality at Cadia Valley Operations (CVO) arising from both direct mining activities and indirect groundwater–surface water interactions, with particular emphasis on seepage migration and expressed groundwater from key infrastructure such as the Northern and Southern Tailings Storage Facilities (NTSF and STSF) and the Cadia Hill Pit (PTSF).

Groundwater expression in the form of baseflow contributions, seepage emergence, and the discharge of contaminated or altered groundwater presents a complex risk pathway. These interactions may influence creek systems such as Cadiangullong Creek and Rodds Creek tributaries, particularly in zones where historical or ongoing seepage has occurred.

6.2.1 KEY RISKS IDENTIFIED

6.2.1.1 GROUNDWATER DISCHARGE AND HYDRAULIC CONNECTIVITY

Groundwater discharge to surface water environments at CVO is influenced by topography, infrastructure elevation differentials, and local hydrogeological conditions. Observations around STSF and the western embankment of NTSF suggest that seepage is occurring along preferential flow paths, particularly in areas of weak or weathered geology. Bore data (e.g., MB25, MB87) show elevated concentrations of molybdenum and nitrate species, consistent with tailings pore water chemistry. In some locations, this expressed groundwater may reach tributaries of Rodds Creek.

At Cadia Hill Pit, monitoring bores adjacent to the pit (e.g., MB93, MB94) indicate rising concentrations of arsenic, iron, and manganese since tailings deposition commenced, suggesting lateral migration of impacted water. While the pit is intended to operate as a long-term groundwater sink, these trends raise concerns about short- to medium-term hydraulic reversal, particularly along the southwestern quadrant where fractured volcanics intersect the pit wall.

6.2.1.2 MINE WATER AND UNCONTROLLED DISCHARGES

A 2021 incident involving the uncontrolled discharge of approximately 3.9 ML of mine water adjacent to Cadiangullong Creek (between CAWS78 and CAWS79) highlighted the vulnerability of stormwater containment infrastructure. While follow-up sampling showed no adverse effects on downstream users or aquatic systems, the event underscored the potential for short-term surficial flows to connect with sensitive creek zones, particularly during high-rainfall periods or storage exceedance events.

6.2.1.3 UNCERTAINTY IN LONG-TERM SURFACE WATER QUALITY PREDICTIONS

There is limited confidence in long-term water quality modelling, particularly regarding the cumulative impacts of expressed groundwater and potential lag effects from infrastructure seepage. For example, modelling associated with PTSF (Mod 13) assumed post-closure settlement and containment but did not fully address interim seepage risks during decant drawdown and consolidation. Additionally, predictive limitations exist regarding how groundwater expression might evolve under variable climatic or operational conditions.

6.2.2 IMPLICATIONS AND RECOMMENDATIONS

6.2.2.1 MONITORING GAPS AND INFRASTRUCTURE LIMITATIONS

Several surface water monitoring sites do not correspond with known or suspected zones of groundwater discharge. For instance, low flows observed near the Cadiangullong Creek diversion outlet contrast with sustained baseflow at site 412161 further downstream, implying groundwater inputs in the intervening section. Installation of additional gauging stations and continuous water level and flow monitoring infrastructure in these areas is recommended to better capture baseflow contributions and flow anomalies.

6.2.2.2 ADAPTIVE MONITORING FRAMEWORK

Given the dynamic and variable nature of seepage and expressed groundwater, CVO should implement a formalised adaptive monitoring strategy. This should include responsive monitoring triggers tied to infrastructure elevations, rainfall thresholds, and observed chemical trends in both groundwater and surface water datasets particularly during wet years and during post-rehabilitation transitions.

6.2.2.3 LOAD-BASED WATER QUALITY ASSESSMENT

Current monitoring approaches are heavily reliant on concentration data, which limit understanding of pollutant load contributions to surface waters. Incorporating flow monitoring and load calculations (e.g., kg/year for nitrate, sulfate, metals) will enable a more meaningful assessment of cumulative impacts and temporal variability across climatic scenarios.

6.2.2.4 INTEGRATED HYDROGEOCHEMICAL RISK ASSESSMENT

Observed groundwater quality trends particularly those from bores adjacent to TSFs and the pit should be integrated with surface water quality exceedance records to identify likely discharge pathways. This linkage is critical to evaluating whether elevated parameters in surface waters are driven by expressed groundwater, tailings seepage, or surficial runoff. Parameters such as nitrate, molybdenum, arsenic, and conductivity should be prioritised in this assessment due to their strong spatial and temporal correlation with infrastructure zones.

6.3 SURFACE WATER QUALITY IN CADIANGULLONG CREEK AND POTENTIAL MINING IMPACTS

Figure 6-1 presents temporal trends of four key water quality parameters (Copper, Molybdenum, Zinc, and Electrical Conductivity) across multiple monitoring sites along Cadiangullong Creek, spanning from upstream (e.g., CAWS0, CAWS2) to downstream locations (e.g., 412161, 412168). Site-Specific Guideline Values (SSGVs) and Default Guideline Values (DGVs) are included for reference.

Copper

Copper concentrations exhibit notable exceedances of both the SSGV and DGV at several downstream locations (particularly 412161 and CAWS78) from around 2018 to 2023. The highest concentrations are clustered after 2020, aligning temporally with reported infrastructure incidents and increasing decant return operations at TSFs. This suggests a probable influence of mine-related seepage or expressed groundwater into surface flows in the mid-to-lower reaches of Cadiangullong Creek. While upstream sites show occasional exceedances, the pattern intensifies downstream, indicating a cumulative effect of mining activity.

Molybdenum

Molybdenum levels remain below the DGV for most locations and time periods, although an upward trend is observed at several downstream sites, particularly CAWS78 and 412161, beginning around 2019–2020. These sites also align with reported seepage zones associated with TSF and pit discharge areas. The pattern is suggestive of minor but increasing mobilization of molybdenum, likely influenced by groundwater–surface water interaction, although current levels remain within guideline thresholds.

Zinc

Zinc concentrations exhibit spatial and temporal variability, with scattered exceedances of the DGV and SSGV. A mild increasing trend is evident in downstream sites (notably 412161 and CAWS78) around 2020–2022, corresponding to the timing of increased groundwater expression and tailings-related activities. While the exceedances are intermittent, their downstream concentration supports the possibility of mine-affected water contributing to elevated zinc levels.

Electrical Conductivity (EC)

EC trends show a significant rise in values at downstream sites (especially CAWS61 and 412161) during and after 2020, with many instances exceeding the SSGV of 875 µS/cm. The marked increase suggests a rise in dissolved salts, consistent with potential inputs from tailings seepage or groundwater return flows with elevated ionic content. Upstream sites remained relatively stable, reinforcing the interpretation that mining operations and infrastructure-related seepage are influencing downstream water quality.

6.3.1 CONCLUSION

The data indicate clear spatial and temporal patterns of surface water quality change in Cadiangullong Creek, with increased concentrations of copper, zinc, and electrical conductivity in downstream segments since ~2020. These changes align with known periods of tailings deposition, seepage incidents, and pit water management challenges. While molybdenum remains largely within thresholds, the upward trend at certain locations merits continued observation.

The patterns support the inference that groundwater expression and mine-related seepage are influencing surface water chemistry in mid- to lower reaches of the creek. Further integration of flow data and isotopic/hydrogeochemical tracing would assist in quantifying the contribution of expressed groundwater and evaluating the ecological risk more robustly.

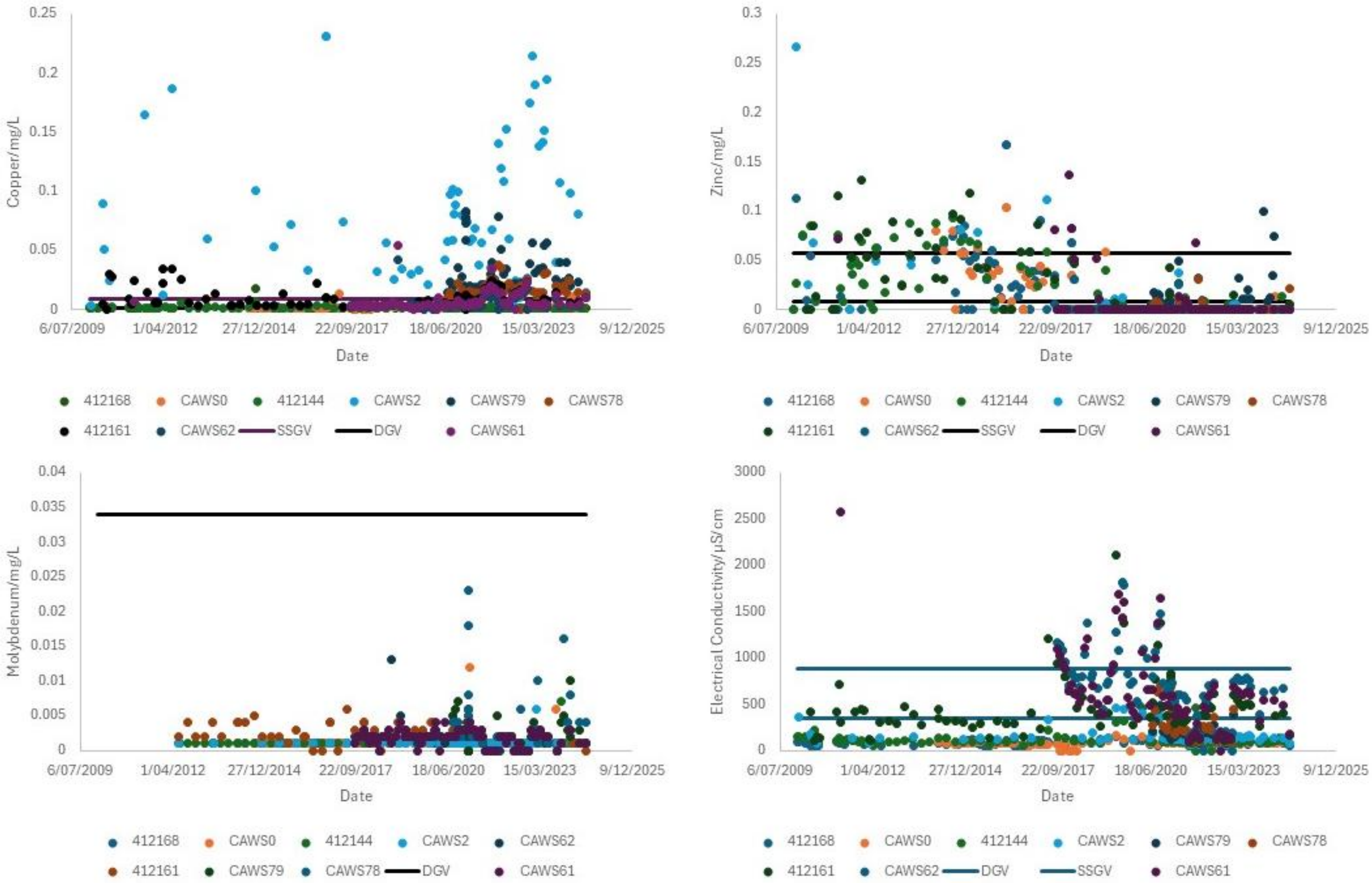

Figure 6-1Surface water quality changes in Cadiangullong Creek from upstream to downstream

6.4 POTENTIAL AND OBSERVED IMPACTS OF CVO ON ENVIRONMENTAL VALUES

Cadia Valley Operations (CVO) is situated within a complex and environmentally sensitive landscape that includes interconnected creek systems (e.g., Cadiangullong and Rodds Creeks), regionally significant groundwater aquifers, and downstream ecosystems such as the Belubula River. The environmental values potentially at risk from mining activities encompass:

- Aquatic ecosystem health
- Beneficial uses such as stock watering and irrigation
- Downstream water users and broader catchment integrity

6.4.1 BIOLOGICAL AND SEDIMENT MONITORING

Biological monitoring of macroinvertebrate assemblages across multiple surface water sites has consistently shown lower-than-expected diversity and richness. These trends are considered to be the result of multiple stressors, including:

- Historical and current agricultural land uses
- Elevated salinity and electrical conductivity
- Sediment quality disturbances linked to natural and anthropogenic sources

Localized contamination in aquatic sediments—particularly with copper—has been recorded downstream of the mining footprint, including at site CC2. These observations are consistent with episodic transport and deposition of mine-derived or legacy materials. However, copper concentrations were found to decline further downstream, suggesting attenuation processes and limited spatial extent of contamination.

6.4.2 SURFACE AND GROUNDWATER QUALITY OBSERVATIONS

Groundwater quality monitoring, particularly in areas downgradient of major infrastructure such as the Southern Tailings Storage Facility (STSF), Northern TSF (NTSF), and Cadia Hill Pit (PTSF), has recorded elevated concentrations of key analytes including nitrate, molybdenum, manganese, and in some locations, arsenic and iron. While there is evidence that some of this groundwater discharges to nearby tributaries, there has been no documented impact on downstream surface water quality that would constitute a breach of environmental or regulatory thresholds for aquatic ecosystems, irrigation, or stock watering.

Temporal trends in surface water quality across multiple monitoring sites in Cadiangullong Creek reveal both spatial and temporal patterns of mine-related influence. Copper concentrations demonstrate notable exceedances of both the SSGV and DGV at multiple sites, particularly 412161 and CAWS78, from approximately 2018 onwards. While occasional exceedances are noted at upstream sites, downstream monitoring locations display sustained and higher frequency exceedances, suggesting cumulative downstream impacts attributable to mining activity.

Molybdenum generally remains below DGV thresholds across all monitoring sites; however, a subtle upward trend is evident at downstream sites, notably CAWS78 and 412161, from around 2019–2020. This corresponds spatially with known seepage-affected zones and temporally with changes in tailings and pit water management. Although concentrations currently remain within guideline limits, the trend indicates minor but increasing mobilisation of molybdenum, warranting continued monitoring.

Zinc concentrations vary across time and location, with intermittent exceedances of the DGV. These exceedances predominantly occur at downstream sites, especially 412161 and CAWS78, between 2020 and 2022. Patterns correlate with operational periods of increased tailings deposition and groundwater expression, suggesting mine-affected water contributions to zinc levels, despite the intermittent nature of exceedances.Electrical Conductivity (EC) trends indicate a clear and significant increase at downstream sites, particularly CAWS78 and 412161, from 2020 onwards. EC values frequently exceed the relevant SSGV and DGV, indicating elevated dissolved salt loads likely driven by tailings seepage and groundwater return flows. In contrast, upstream monitoring locations display relatively stable and lower EC values, reinforcing the interpretation of downstream impacts from mining operations.Downstream sites consistently record higher salinity indicators (EC, TDS, sulfate, chloride, sodium, calcium, magnesium) and elevated metal concentrations compared to upstream or less-affected sites.

In summary, the combined dataset demonstrates progressive downstream deterioration of surface water quality in Cadiangullong Creek, with distinct increases in salinity, copper, zinc, and, to a lesser extent, molybdenum concentrations.

6.4.3 RISK ATTRIBUTION AND CONFIDENCE

Despite the presence of some water quality and sediment exceedances, there is currently no conclusive evidence linking CVO's operational activities to significant degradation of downstream environmental values. Nevertheless, the persistence of localised trends particularly elevated metals in groundwater and sediments highlights the need for ongoing assessment of cumulative and lagged effects.

6.4.4 RECOMMENDATIONS FOR ENHANCED ENVIRONMENTAL VALUE PROTECTION

To strengthen the early detection of emerging risks and improve attribution of observed changes, the following actions are recommended:

- Integrated monitoring: Combine water, sediment, and biological datasets to identify patterns, correlations, and potential cause-effect pathways.
- Trend-based analysis: Develop statistical trend assessments for key sites and analytes to detect gradual changes and assess the influence of infrastructure use and rehabilitation status.
- Targeted ecological investigations: Where exceedances are persistent (e.g., nitrate, molybdenum, copper in sediment), supplement monitoring with bioassays or targeted fauna surveys to confirm or rule out sub-lethal effects on aquatic biota.
- Adaptive risk management: Prioritise areas with known seepage influence or historical non-conformance (e.g., TSF toes, pit margins) for closer monitoring and adaptive management, especially during post-closure transition phases.

7. REVIEW OF TRIGGER ACTION RESPONSE PLAN (TARP)

7.1 OVERVIEW OF TARP

The Trigger Action Response Plan (TARP) is a critical risk management tool designed to outline predefined indicators (triggers), corresponding actions, and responsible personnel in response to identified environmental risks. In the context of CVO, the TARP forms part of the site's broader Water Management Plan and is intended to proactively manage surface water and groundwater risks associated with mining activities.

The primary aim of each TARPs is to:

- define appropriate trigger levels for surface water and groundwater resources;
- implement specific actions in response to a potential impact to surface water and groundwater resources; and
- implement appropriate and effective management and mitigation measures.

7.1.1 SUITABILITY FOR MANAGING POLLUTION RISKS

The TARPs implemented at CVO are a key component of the site's adaptive environmental management framework. TARPs have been established for surface water and groundwater aspects . Each TARP outlines a staged response mechanism based on monitoring exceedances of site-specific guideline values (SSGVs), aligning with regulatory expectations and the site's Environment Protection Licence (EPL 5590).

The TARPs are structured in two levels of response:

Level 1 triggers an internal review, focusing on data validation, comparison to reference site values, assessment of climatic influences, and identification of whether the exceedance occurred during the baseline monitoring period.

Level 2 escalates the response to involve independent specialists, who assess potential impacts on high-value receptors (e.g., private water supply bores) and provide recommendations for mitigation measures. Reporting to regulators and implementation of corrective actions are integral to this level.

This framework represents a sound conceptual approach for pollution risk management, particularly in identifying early warning signs of potential mining-related impacts. However, the suitability and effectiveness of the TARP system for managing pollution risks at CVO could be strengthened through the following observations and recommendations:

- Clear escalation process with defined responsibilities at each level.
- Integration with monitoring data and reference sites, enabling catchment-wide vs. mine-specific impact differentiation.
- Alignment with regulatory compliance frameworks, including the Aquifer Interference Policy (AIP) for groundwater and relevant ANZG/SSGV criteria for surface water.

7.1.2 RECOMMENDATIONS FOR IMPROVEMENT

1. **Timeliness and Transparency of Level 2 Responses**
   While TARPs provide a mechanism for escalation, documentation and transparency around the timing of Level 2 responses and reporting are limited. Regular reporting on the *outcomes of Level 2 investigations* and the *effectiveness of implemented mitigation* should be standardised to demonstrate accountability.

2. **Linkage to Incident Management and Emergency Protocols**
   Although pollution incidents are addressed separately under the Pollution Incident Response Management Plan (PIRMP), the interface between TARPs and PIRMP actions during pollution events could be more clearly documented. This would ensure a seamless response during acute pollution episodes.

   Recommendation: Develop a formal procedure that clearly outlines how TARPs escalate into PIRMP actions during acute pollution events. This should include cross-referencing key personnel responsibilities, communication pathways, and timelines to ensure seamless integration of TARP triggers within broader emergency response frameworks.

3. **Limited Event-Based Data Integration**
   Despite references to event-triggered sampling and investigations in the Water Management Plan, actual event-based TARP activations and data incorporation into assessments appear

sparse. This limits the TARP's effectiveness in addressing episodic or extreme weather-related pollution risks.

Recommendation: Establish a protocol to ensure that all significant rainfall, flooding, and operational upset events automatically trigger TARP responses and event-based sampling. Incorporate the resulting data systematically into regular reviews of water quality risk assessments, trend analysis, and TARP trigger evaluations.

4. **Uncertainty in Trigger Definitions at Some Sites**
   While trigger values are defined for many monitoring points, in some cases the *rationale for SSGVs* or the *spatial validity of reference sites* is unclear. This ambiguity can reduce confidence in the appropriateness of Level 1 and Level 2 responses, particularly for emerging issues or expanding infrastructure footprints.

   Recommendation: Conduct a formal review of all current SSGVs and reference site selections, ensuring alignment with ANZG (2018) guidelines. Clearly document the derivation method, data sources, and justification for reference site selection. Where uncertainty exists, prioritise developing new SSGVs using appropriate minimally impacted sites and sufficient datasets.

5. **Operational Feedback Loops**
   Opportunities exist to better link TARP outcomes to operational decision-making (e.g., modifications to sediment basins, stormwater controls, or tailings discharge management). Documenting how TARPs inform such operational changes would demonstrate continuous improvement in pollution risk mitigation.

   Recommendation: Implement a formal operational feedback mechanism that requires any TARP trigger activation to be reviewed for potential infrastructure or operational adjustments (e.g., sediment basin capacity, stormwater diversion improvements, or tailings water management). Document all reviews and decisions within regular water management reports to demonstrate adaptive management and continuous improvement.

8. RECOMMENDATIONS

8.1 SURFACE WATER

Based on the comprehensive review of the design, implementation, and data interpretation components of CVO's surface water monitoring program, the following recommendations are provided to enhance the program's scientific robustness, regulatory defensibility, and effectiveness in identifying and managing site-related impacts:

1. Strengthen Monitoring Network Design and Documentation
    - Formalise the site selection framework, clearly defining the rationale and functional roles (reference, control, impact, compliance) for each site based on hydrogeological, hydrological, and land use considerations.
    - Establish paired control–impact site design, using hydrologically and geochemically comparable sites to enable statistically defensible assessments of change attributable to mining activities.
    - Review and update site classifications in line with current catchment conditions and operational changes, ensuring control sites are not affected by legacy or external influences.
2. Improve Temporal and Spatial Data Analysis
    - Conduct formal long-term trend analyses using statistical tools such as Mann–Kendall or Sen's slope estimators to assess cumulative changes over the full monitoring period (1994–2024).
    - Incorporate multi-year comparisons and predictive modelling into Annual Reviews to support adaptive management and forecasting of water quality conditions.

- Maintain year-round coverage at legacy or low-flow sites to improve dataset continuity and robustness of upstream/downstream comparisons.

4. Integrate Streamflow and Load-Based Assessments
    - Combine streamflow and concentration data to calculate contaminant loads (e.g. kg/day or tonnes/year), facilitating better understanding of source contributions and impact magnitude.
    - Develop mass balance models to evaluate cumulative contaminant fluxes across catchments and within hydrologically connected zones.
    - Install gauging stations at hydrologically significant but currently unmonitored locations (e.g. rejoining creek channels) to assess baseflow and flow continuity.
5. Expand Event-Based and Reactive Monitoring Capacity
    - Develop and implement an event-based sampling protocol, including triggers (e.g. rainfall thresholds, infrastructure overflows), site priorities, and sample timing.
    - Incorporate event-derived data into compliance assessments and risk evaluations to better capture episodic impacts and worst-case scenarios.
6. Enhance QA/QC Transparency and Data Integrity
    - Standardise data entry protocols, ensuring consistent use of LOR/LOD flags (e.g. "<LOR" rather than zero values), and streamline database formats for usability.
    - Require routine QA/QC reporting, including summaries of field duplicates, blanks, relative percent difference (RPD), and laboratory recovery rates.
    - Integrate QA/QC performance outcomes directly into data interpretation and exceedance assessments.
7. Improve Use and Transparency of SSGVs
    - Ensure that all SSGV derivations and technical justifications are clearly referenced and appended in annual reporting (e.g., AEMRs).
    - Define the spatial and hydrological applicability of each SSGV, including across sub-catchments, and standardise use across monitoring zones to avoid inconsistencies.
    - Avoid relying solely on operationally influenced sites (e.g., 412702) for deriving Site-Specific Guideline Values (SSGVs), as this may not reflect conditions protective of environmental values. Instead, where feasible, adopt a scientifically defensible approach consistent with ANZG (2018) by identifying and utilising minimally impacted, ecologically comparable reference sites with at least 24 months of continuous monitoring data. Where suitable reference sites are unavailable, SSGVs should only be used as site management benchmarks, not as ecological risk thresholds, and clearly differentiated from triggers derived from laboratory or field-based biological effects data.
8. Strengthen Integration of Water Quality Data with Ecological Outcomes
    - Establish formal linkages between water quality exceedances and macroinvertebrate/ecological health indicators to enhance ecological risk interpretation.
    - Develop ecological risk frameworks that align exceedance thresholds with potential ecological consequences, particularly for toxicants of concern (e.g., metals, nitrogen species).
9. Update and Modernise Monitoring Parameters
    - Expand the current suite of analytes to include Dissolved Organic Carbon (DOC) and apply hardness correction for metals, in line with emerging ANZG guidance.
    - Specifically, apply DOC and hardness corrections to test site data when comparing to DGVs (this is no longer applies for copper), as these are based on biological effects data and require adjustment for local water chemistry.

- Do not apply DOC or hardness corrections when comparing monitoring data to Site-Specific Guideline Values (SSGVs), as SSGVs reflect naturally elevated concentrations from minimally impacted reference sites and are not derived from biological effects data.

10. Regularly review the parameter list to address emerging contaminants and refine monitoring based on updated site-specific risk profiles. Build Transparency into Methods and Personnel Competency
    - Include clear documentation of sampling methodologies, equipment calibration, chain-of-custody procedures, and sample handling processes in the Water Management Plan and AEMRs.
    - Specify field team qualifications and roles to ensure accountability and build confidence in data quality and interpretation.

8.2 GROUNDWATER

To enhance the robustness, transparency, and regulatory defensibility of the groundwater monitoring program at CVO, the following recommendations are proposed:

1. Establish and Document a Comprehensive Monitoring Network Framework
    - Develop a formal site selection rationale for each bore, clearly describing its role (e.g., background, observation, compliance) and hydrogeological context (e.g., aquifer characteristics, hydraulic gradient, proximity to potential sources).
    - Maintain an up-to-date network design map and register detailing bore status (active/inactive), history of installation, replacement, and any role reclassification.
    - Ensure bore-specific information is consistently documented in annual reports and relevant appendices.
2. Address Temporal Gaps in the Dataset
    - Where possible, retrieve and compile any pre-2010 groundwater data from legacy reports or archives to extend the baseline period.
    - Acknowledge current limitations in historical coverage and clearly distinguish between baseline and operational phases in trend assessments.
3. Improve Data Management and Standardisation
    - Implement a consistent and centralised database structure with clearly defined fields for analyte names, units, detection limits, qualifiers (e.g., "<LOR"), and QA/QC metadata.
    - Eliminate zero entries where LORs apply, replacing with appropriate flags (e.g., <LOR or NA).
    - Standardise units, analyte names, and data formatting across datasets to support repeatable analysis.
4. Integrate Statistical and Trend Analyses
    - Apply formal time series analyses to detect trends in groundwater quality parameters.
    - Consider applying multivariate methods (e.g., PCA, cluster analysis) to detect contaminant source patterns or site grouping behaviours.
5. Strengthen QA/QC Protocols and Reporting
    - Routinely include QA/QC summaries in reporting, including:

      Field duplicate precision (%RPD),

      Field blank contamination results,

      Laboratory QA flags (e.g., spikes, blanks, CRMs).
    - Integrate QA/QC flags into primary groundwater datasets to enable filtered analyses and identify anomalies or uncertainty bounds.
6. Clarify and Expand SSGV Use

- Differentiate clearly between guideline-based triggers and true Site-Specific Guideline Values (SSGVs) based on the 95th percentile of baseline data.
- Develop SSGVs not only for known elevated sites but also for lower-concentration observation bores to facilitate early warning detection.
- Adopt a two-tiered framework for water quality compliance:

  Observation bores near sources: SSGVs for non-toxicants (e.g., TDS, sulfate).

  Compliance bores down-gradient of sources: SSGVs for both toxicants and non-toxicants, supported by baseline data where available.

- The adoption of dissolved molybdenum as an indicator analyte is also recommended due to its high concentrations in TSF decant water relative to background groundwater and its utility in tracing seepage migration.

7. Align groundwater and surface water assessments where relevant to evaluate interactions and cumulative effects.

8. Address discrepancies in the interpretation of monitoring data across reporting documents to ensure consistent and evidence-based conclusions.

8.3 AQUATIC ECOLOGY

To address the limitations identified in the aquatic ecology component of this review, the following recommendations are proposed:

1. Redesign the Monitoring Framework

- Review and clarify the roles of all sites in the monitoring network, explicitly identifying reference, control, impact, and downstream locations.
- Consider relocating or adding new reference sites that are ecologically and hydrologically comparable to test sites and less affected by regional land use.
- Formalise the program’s conceptual model, incorporating hydrological connectivity and known pressures.

2. Incorporate Temporal and Statistical Power Analyses

- Apply time-series modelling or mixed-effects frameworks to ecological datasets to identify long-term trends.
- Conduct power analyses to assess the sensitivity of the program to detect real ecological changes.

3. Improve QA/QC Protocols and Documentation

- Develop and document standard operating procedures for all field and laboratory tasks.
- Implement inter-observer calibration and routine verification of taxonomic identifications.
- Standardise the collection, archiving, and reporting of field sheets, chain-of-custody forms, and photographic records.

4. Enhance Data Integration and Interpretation

- Integrate chemical, biological, habitat, and eDNA datasets using multivariate and causal modelling techniques.

- Extend statistical analyses beyond descriptive summaries, particularly for fish and platypus data.
- Explore environmental drivers of observed ecological patterns, ensuring interpretations are supported by data.

5. Adopt Missed Methodological Recommendations

- Implement replicate macroinvertebrate sampling as previously recommended.
- Investigate genetic identity of *Galaxias olidus* populations in light of taxonomic revision.
- Clarify and standardise fish sampling frequency and seasonality.

These actions would strengthen the scientific rigour of the AEMP and increase its ability to detect and attribute mine-related impacts with confidence. They should be implemented alongside ongoing engagement with regulatory stakeholders to ensure alignment with best practice and compliance expectations.

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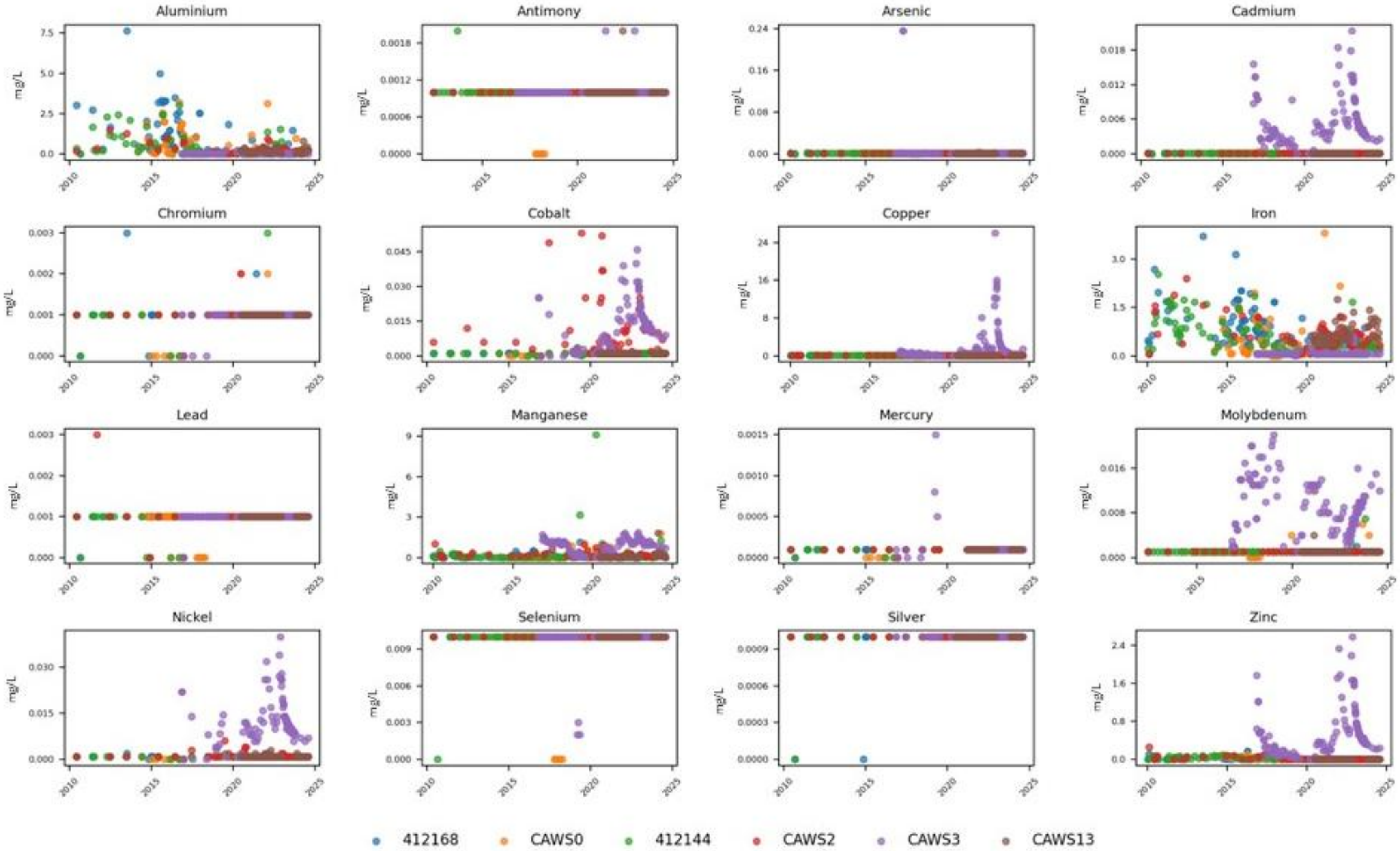
APPENDIX A. SURFACE WATER QUALITY GRAPHS

UPPER CADIANGULLONG

Metals/Metalloids



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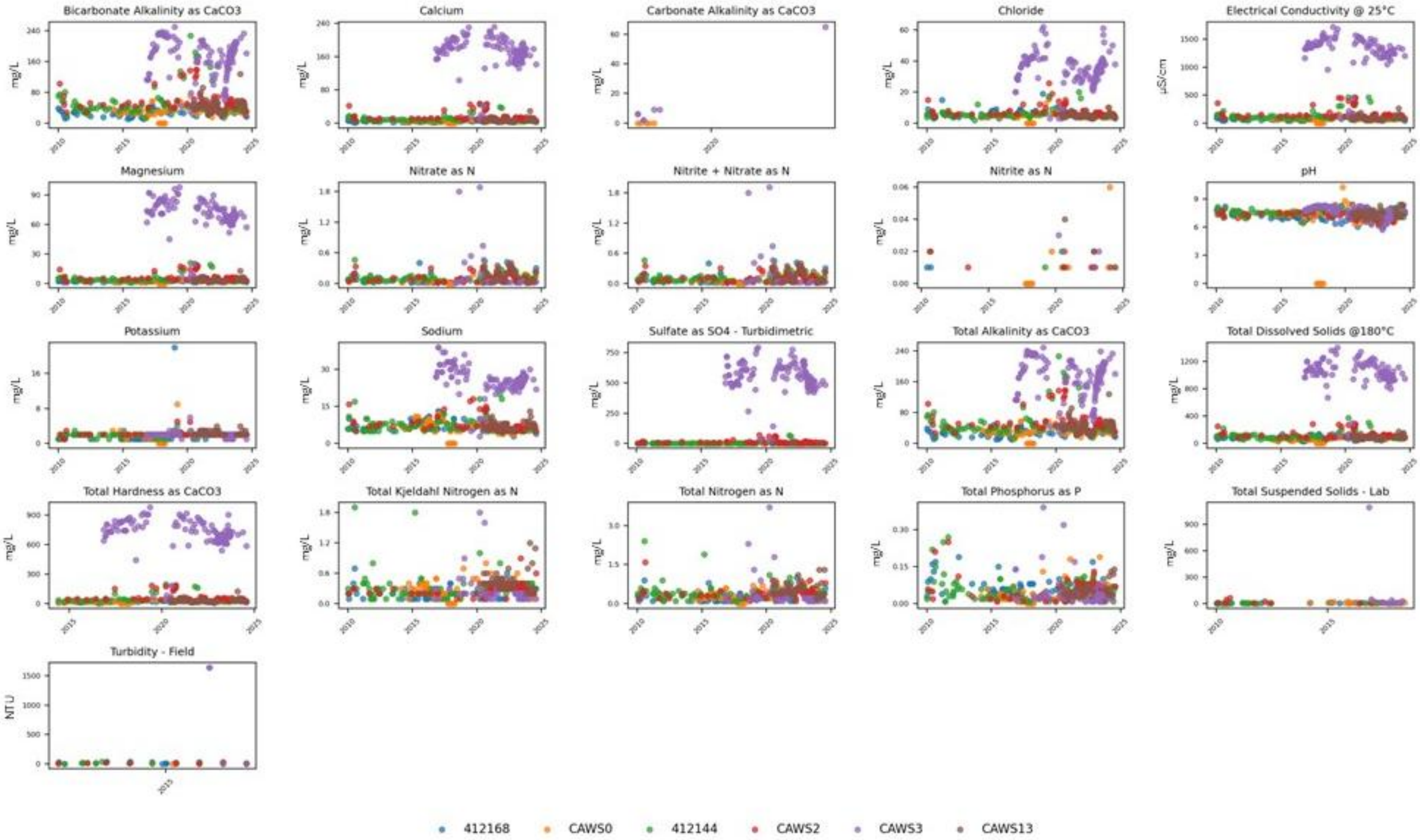
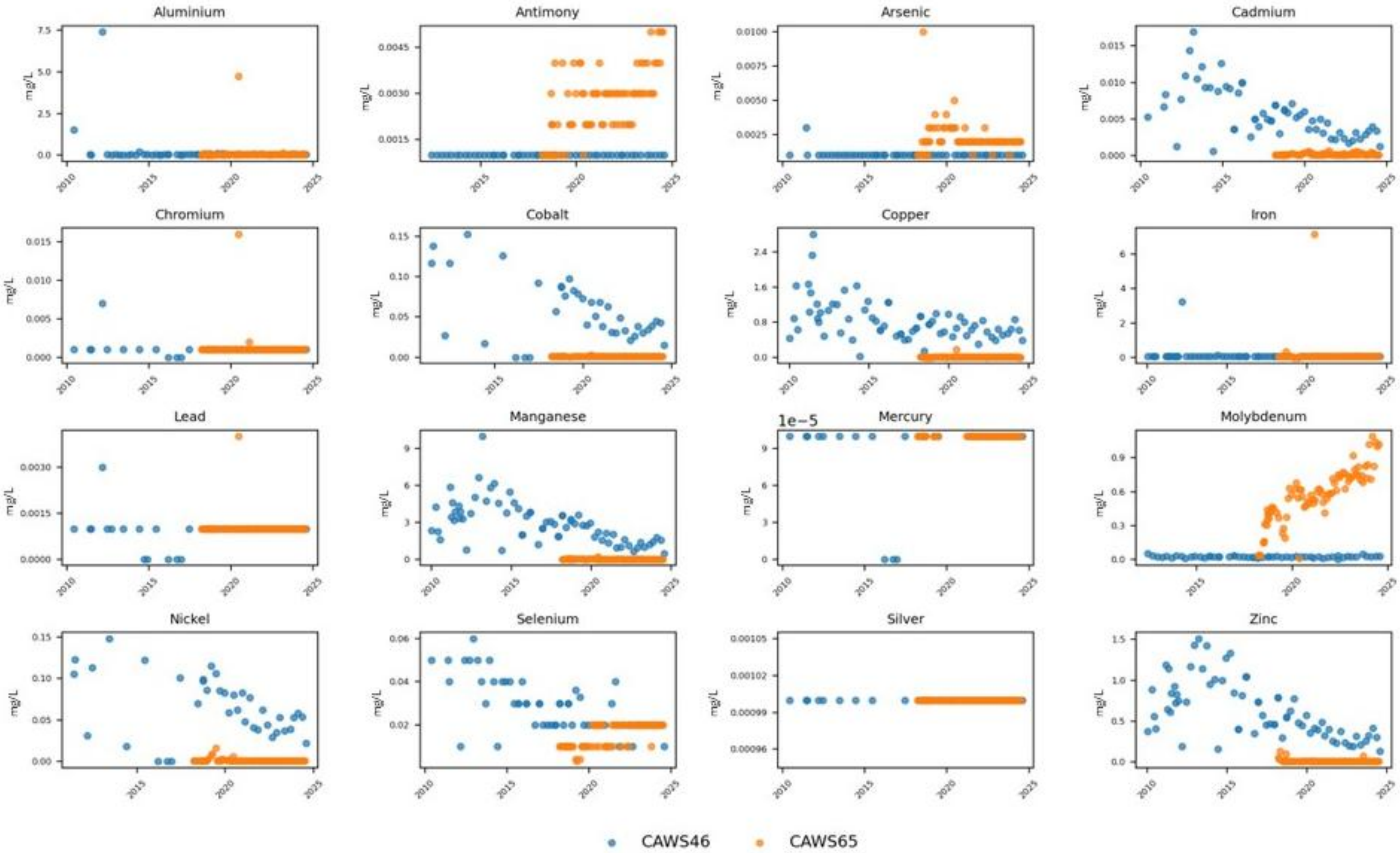


CADIA HILL PIT

Metals/Metalloids



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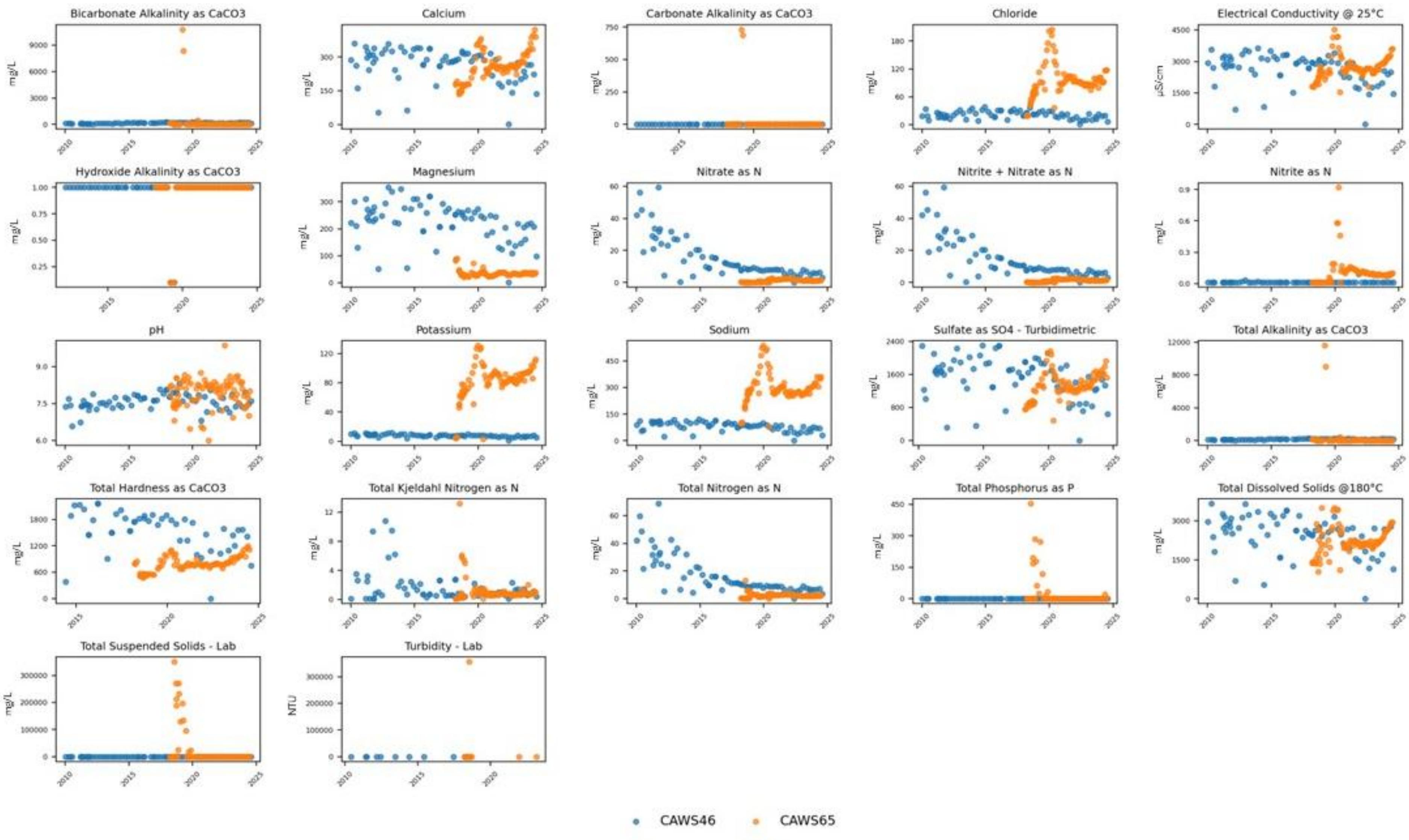
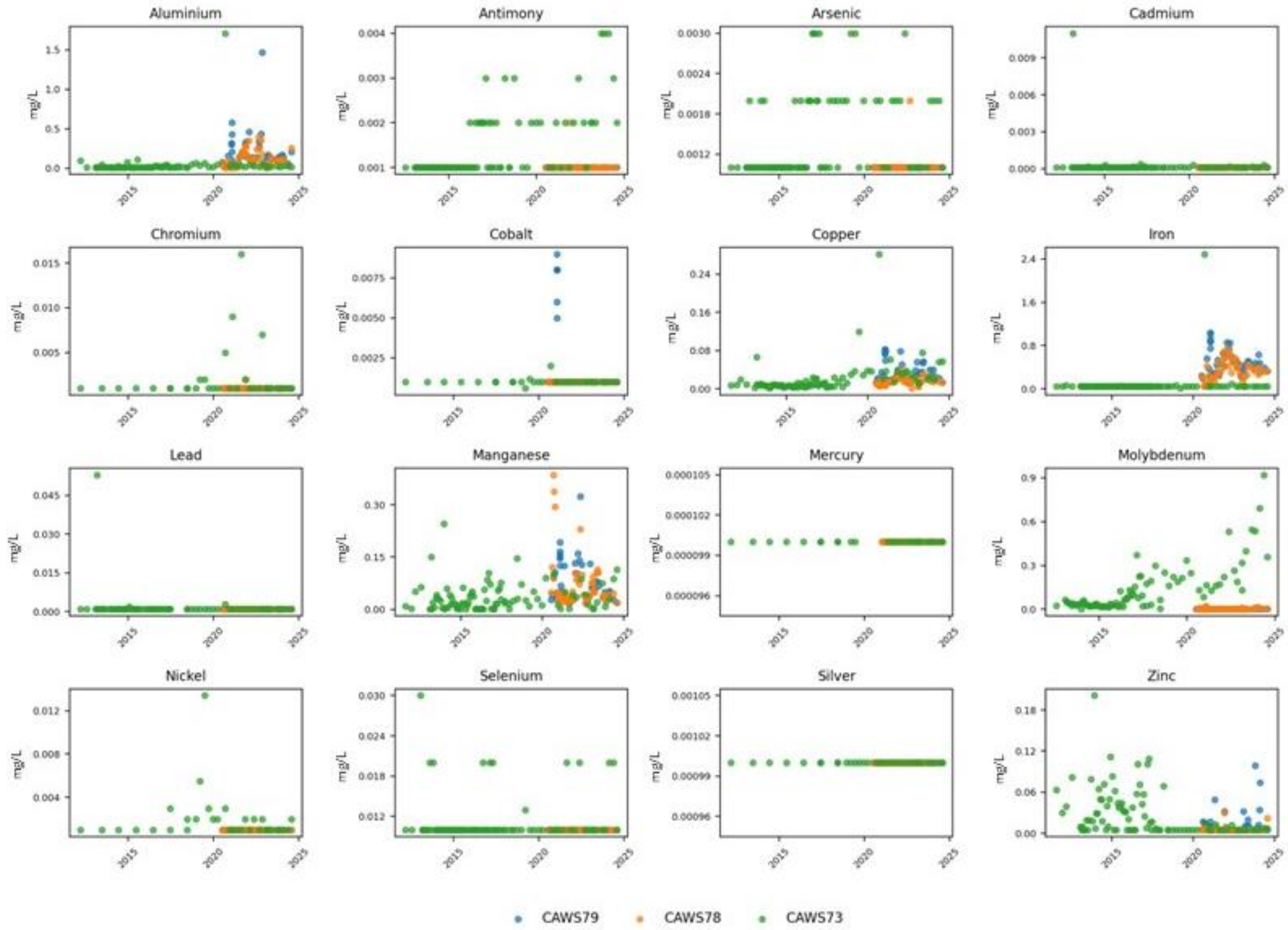


ORE PROCESSING AREA

Metals/Metalloids



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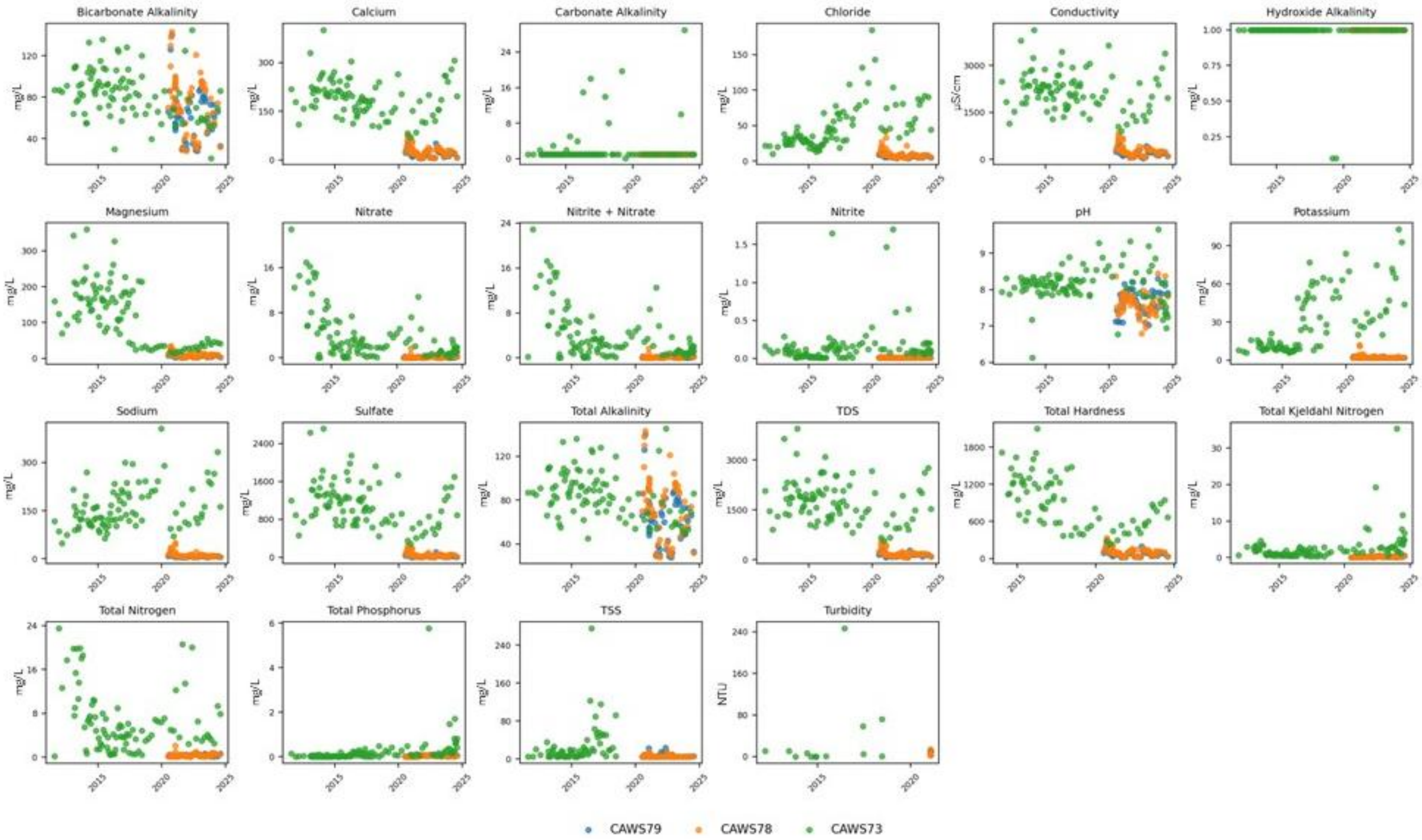
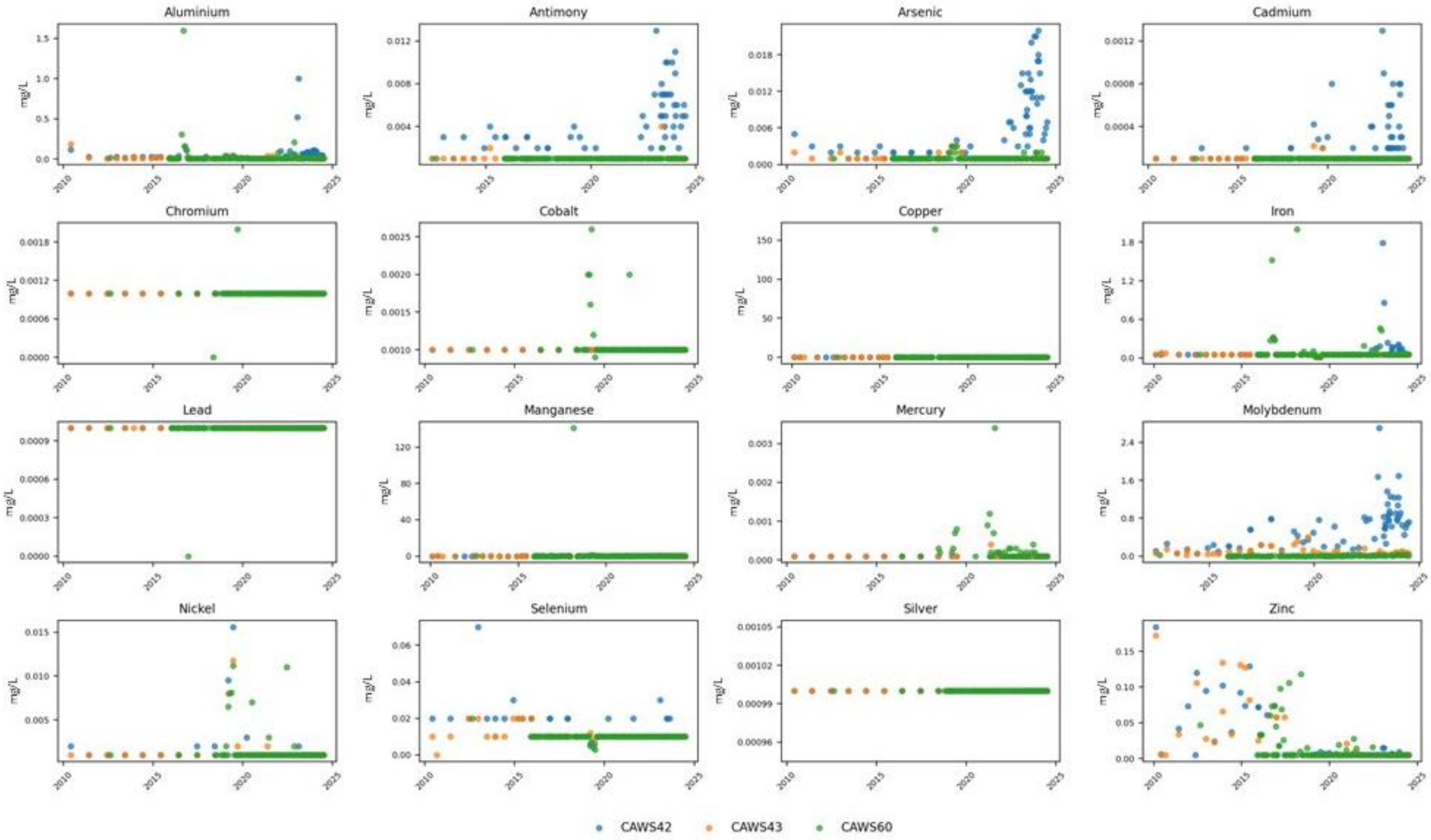


TSF EASTERN ZONE

Metals/Metalloids



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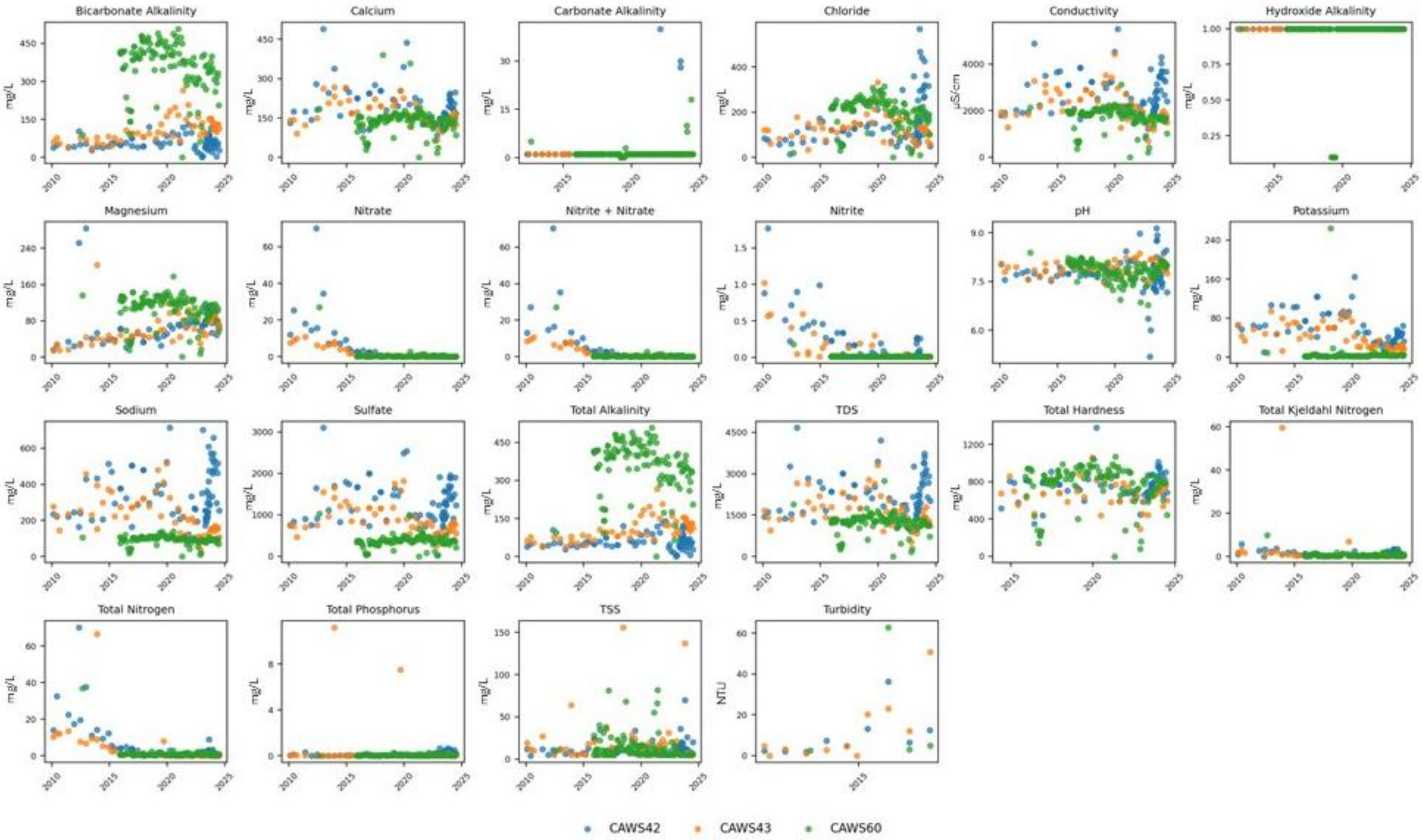
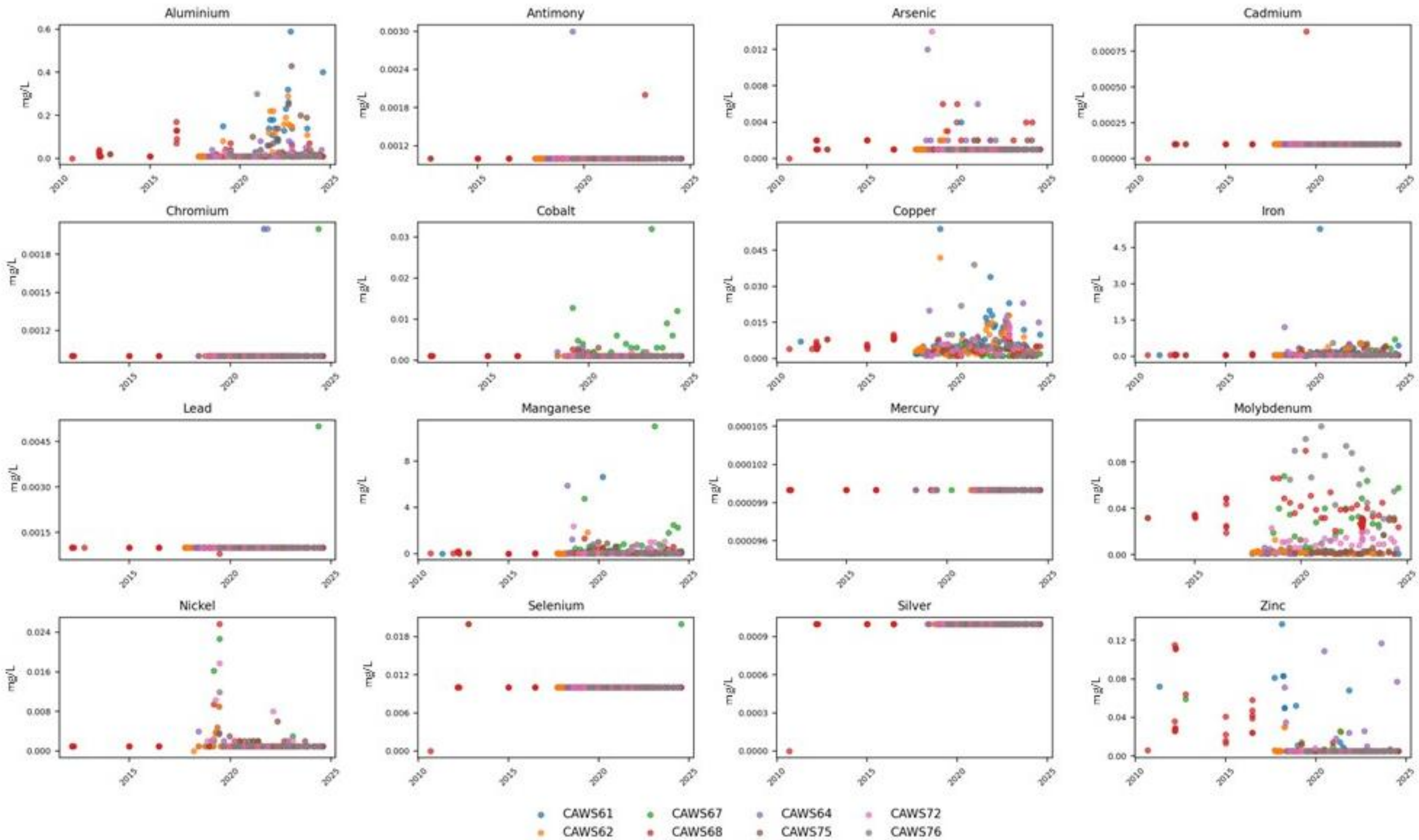


TSF WESTERN ZONE

Metals/Metalloids



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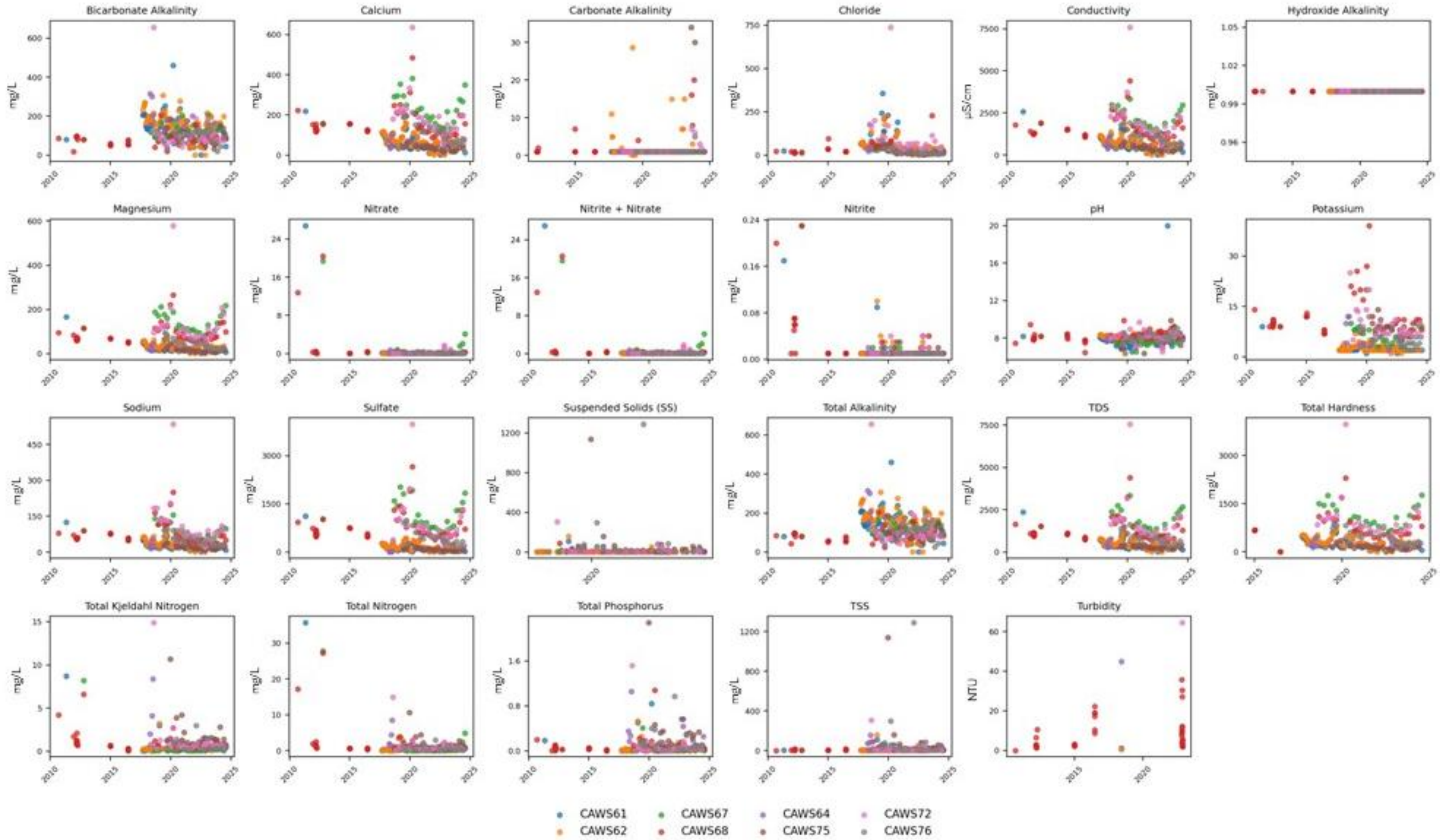
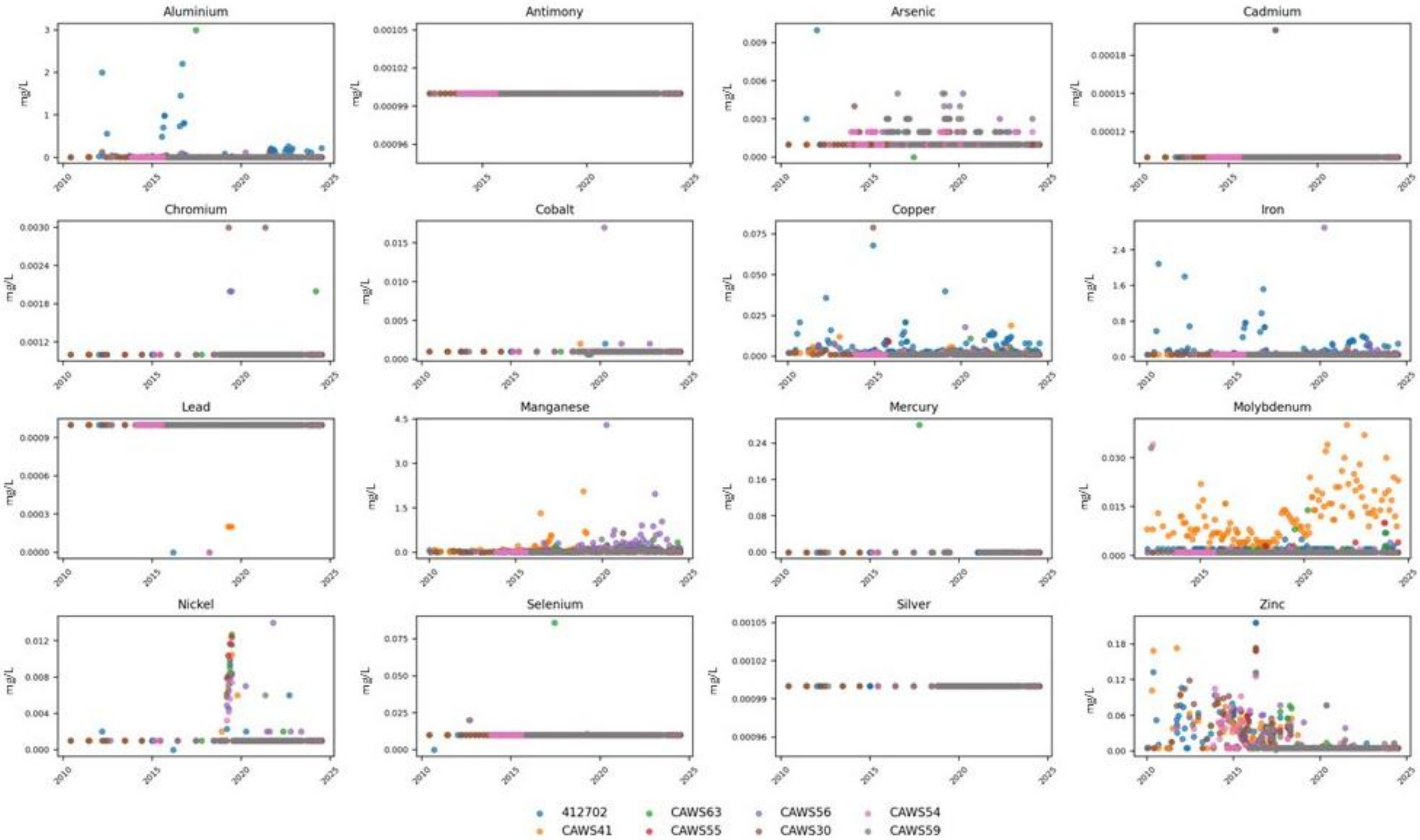


TSF SOUTHERN ZONE

Metals/Metalloids



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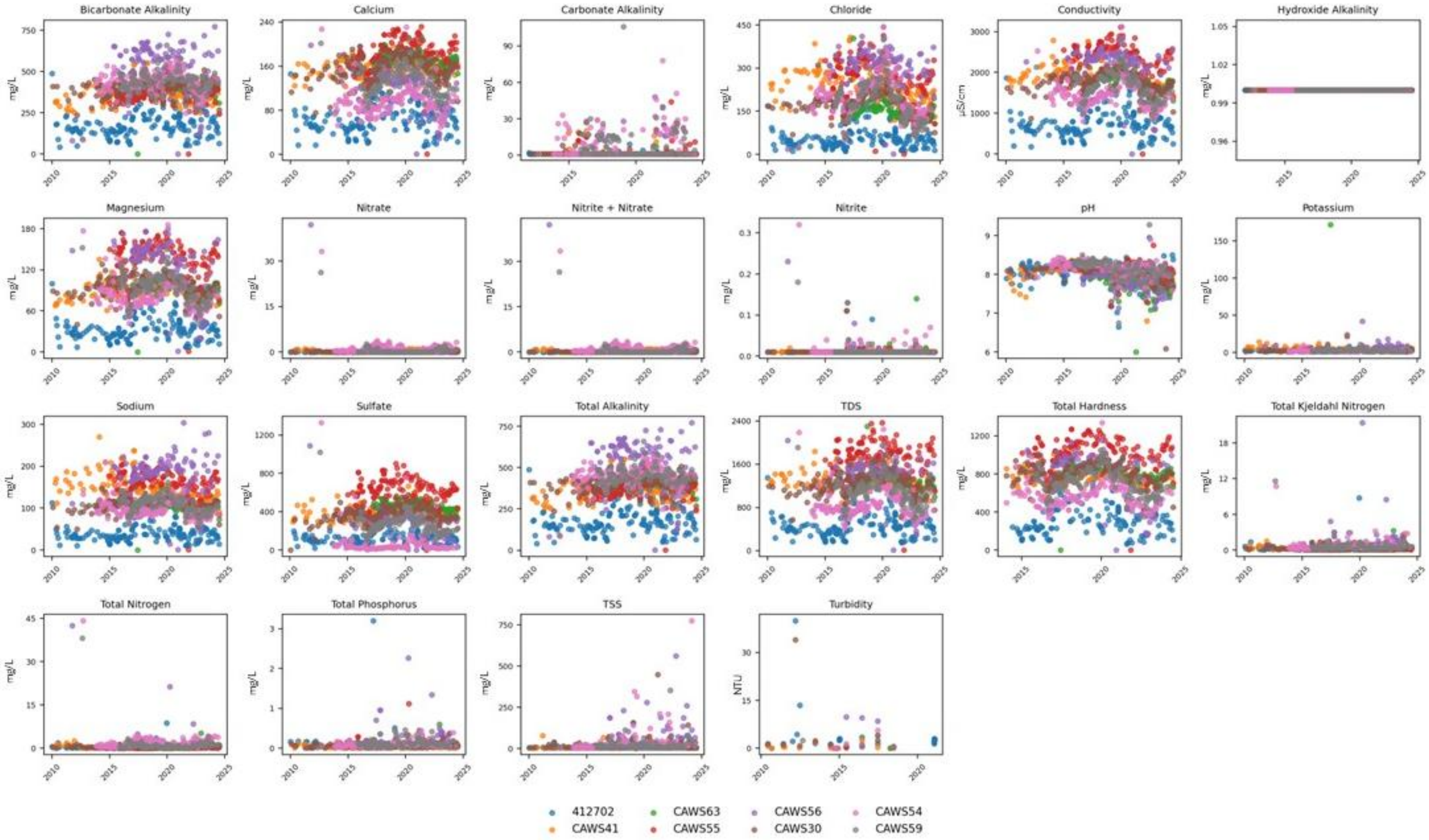
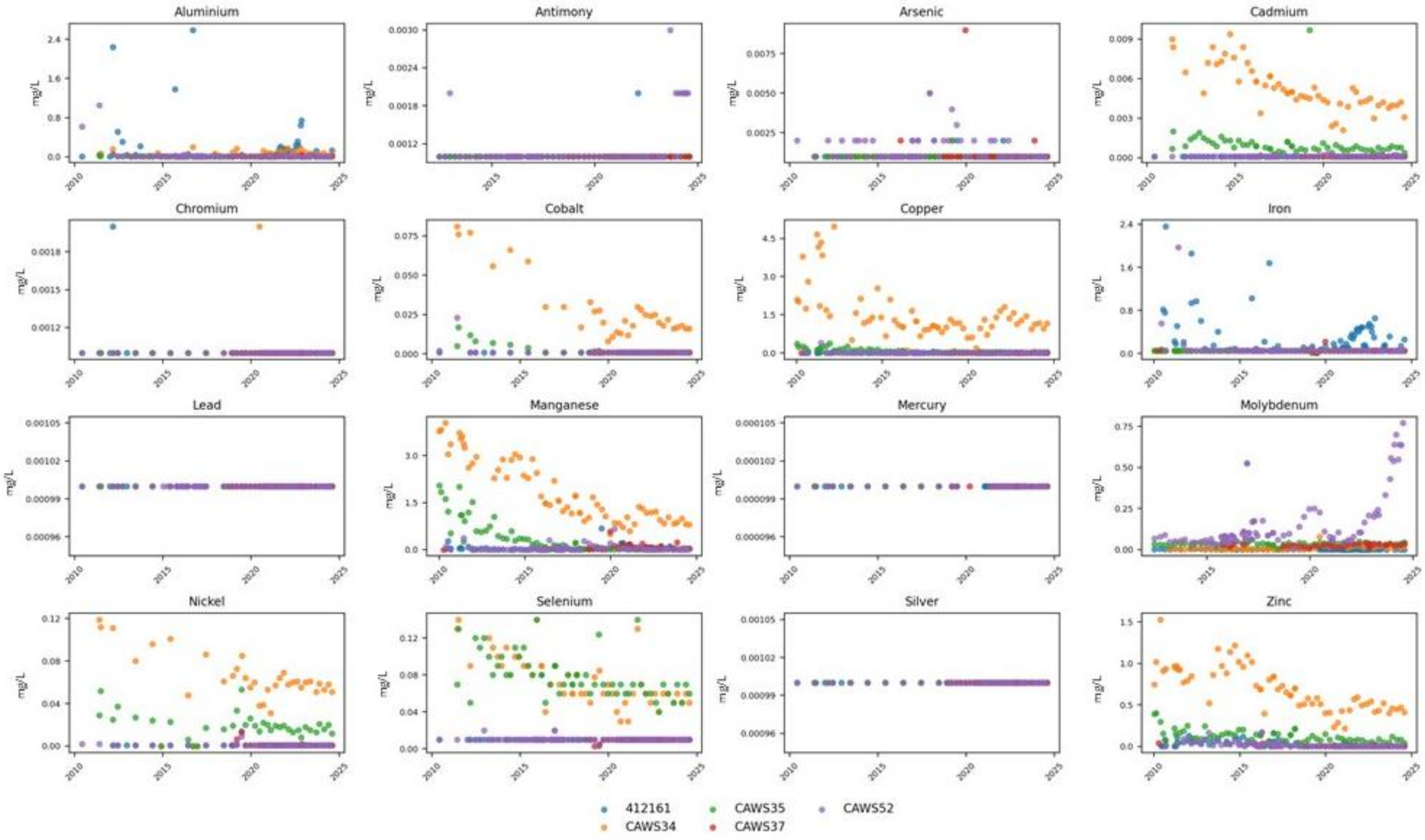


WASTE ROCK DUMPS

Metals/Metalloids



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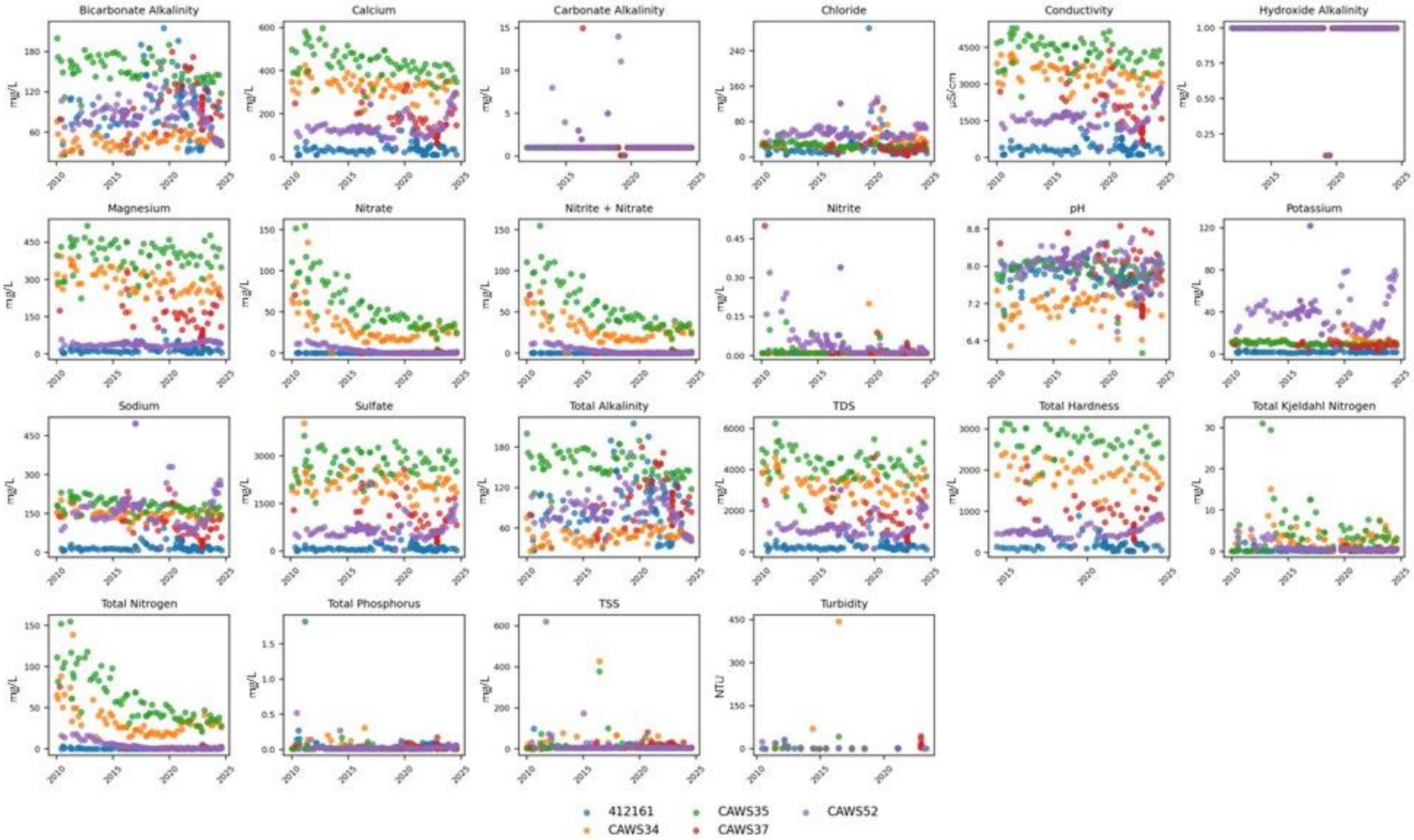
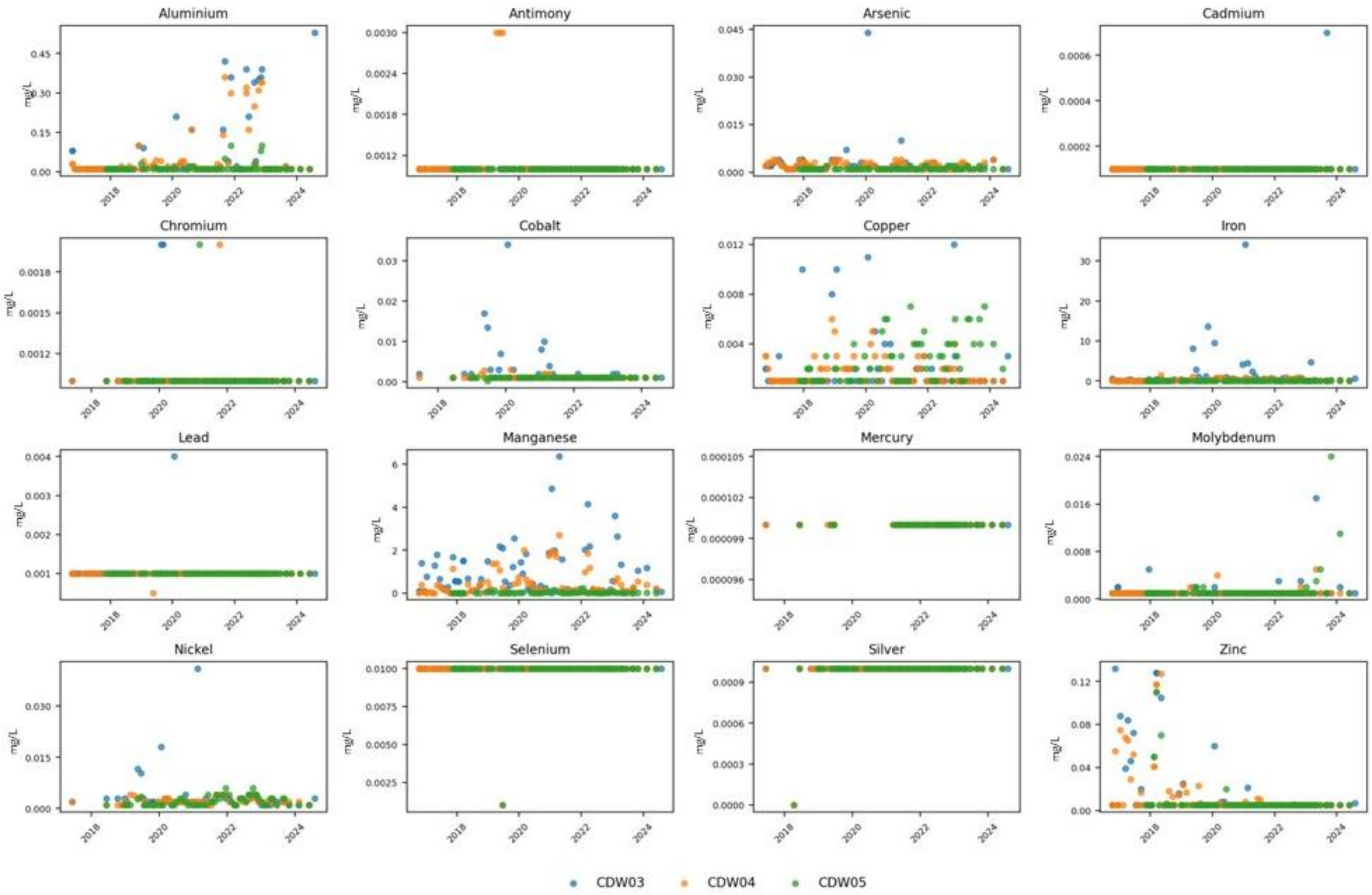


CADIA DEWATERING FACILITY

Metals/Metalloids



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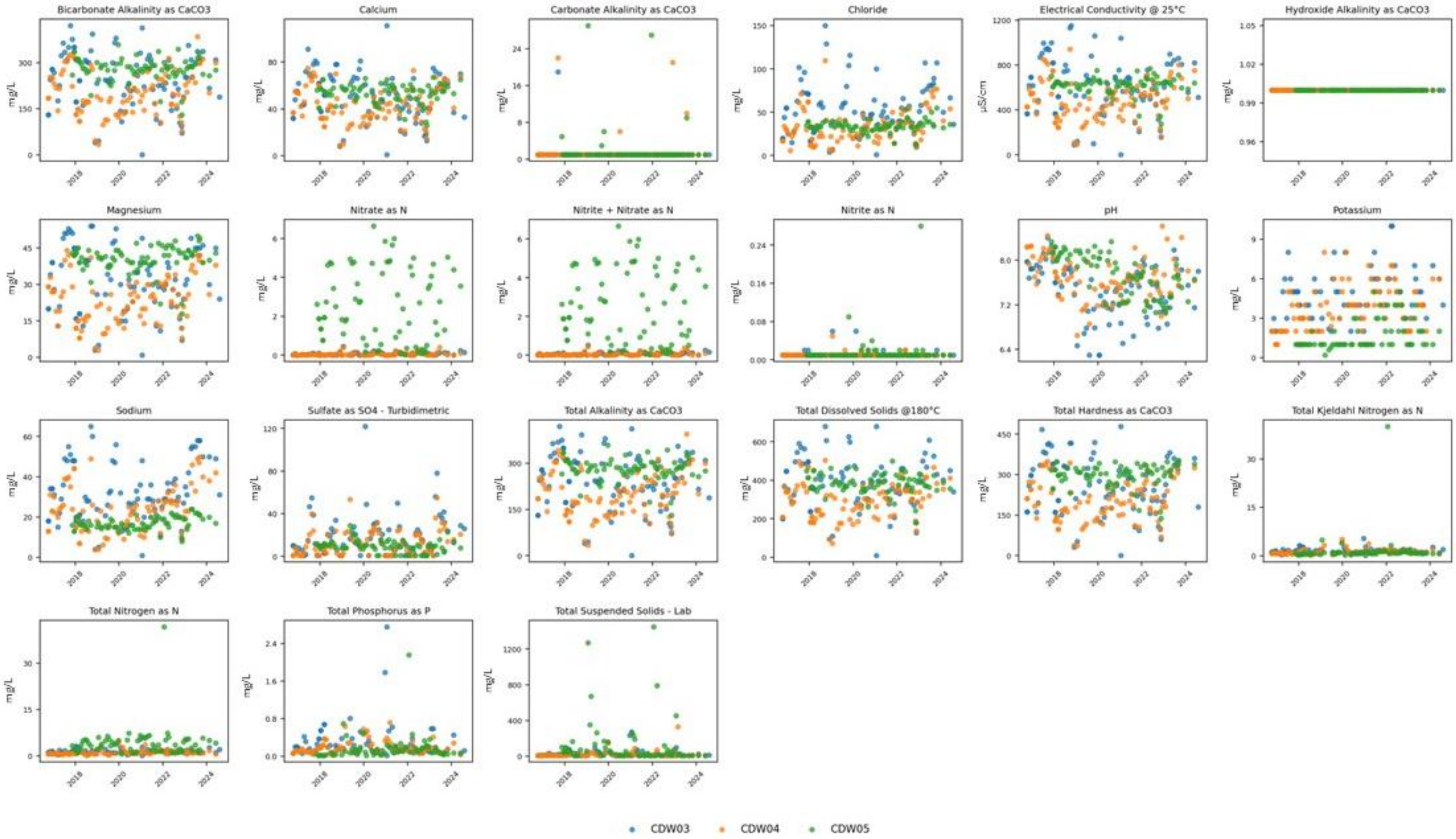
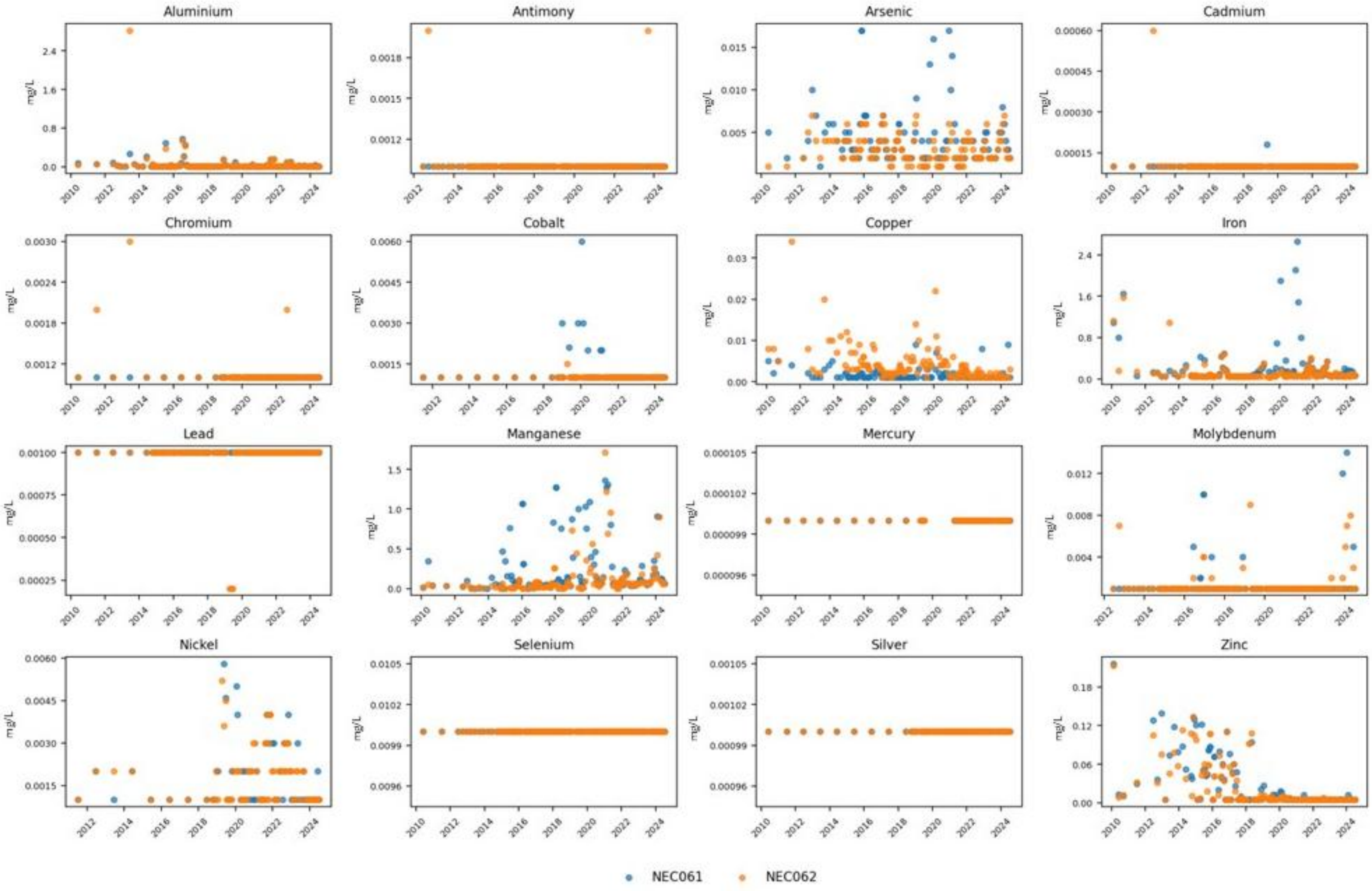


BLAYNEY DEWATERING FACILITY

Metals/Metalloids



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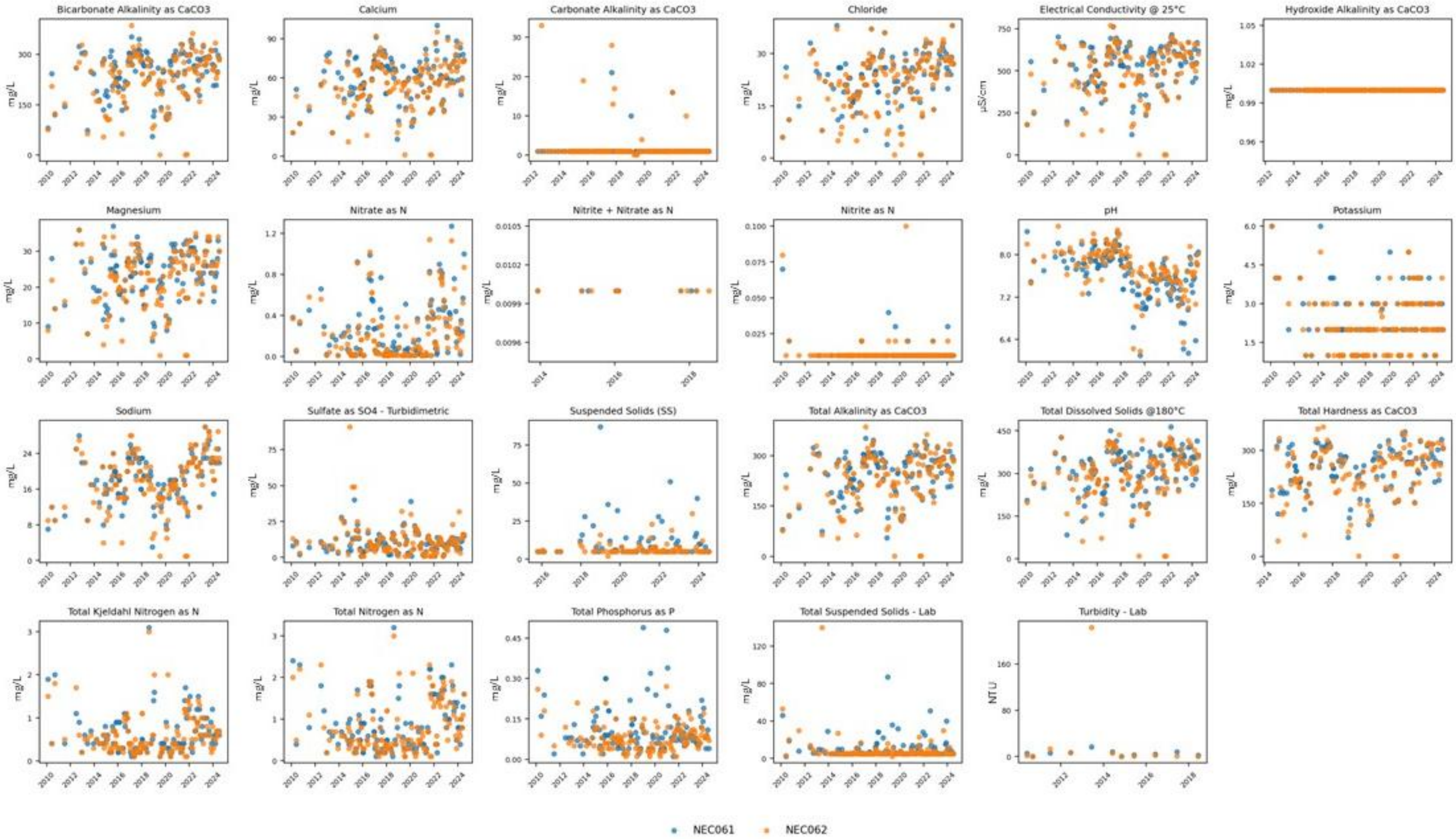
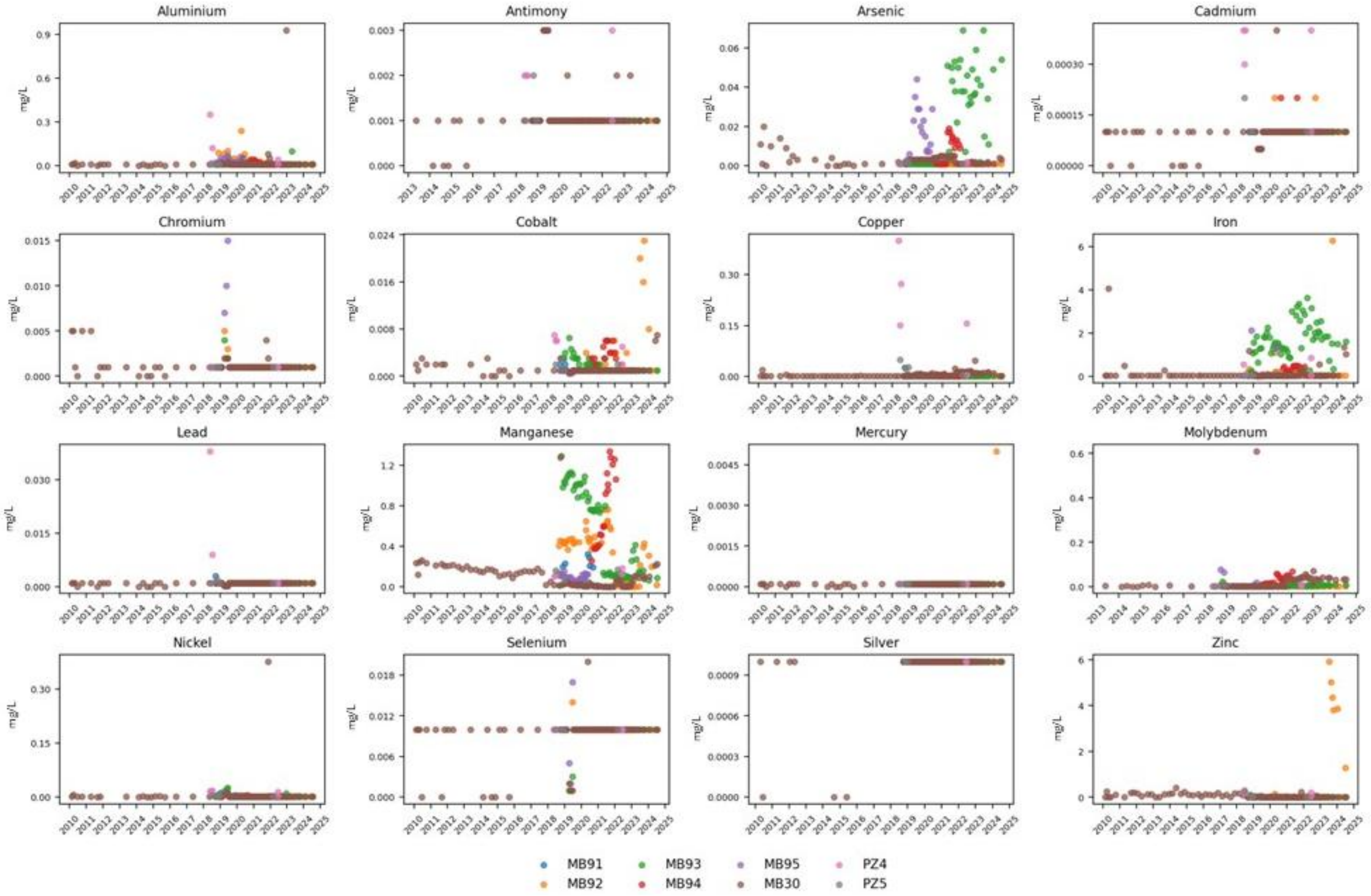


APPENDIX B. GROUNDWATER QUALITY GRAPHS

CADIA HILL PIT

Metals/Metalloids



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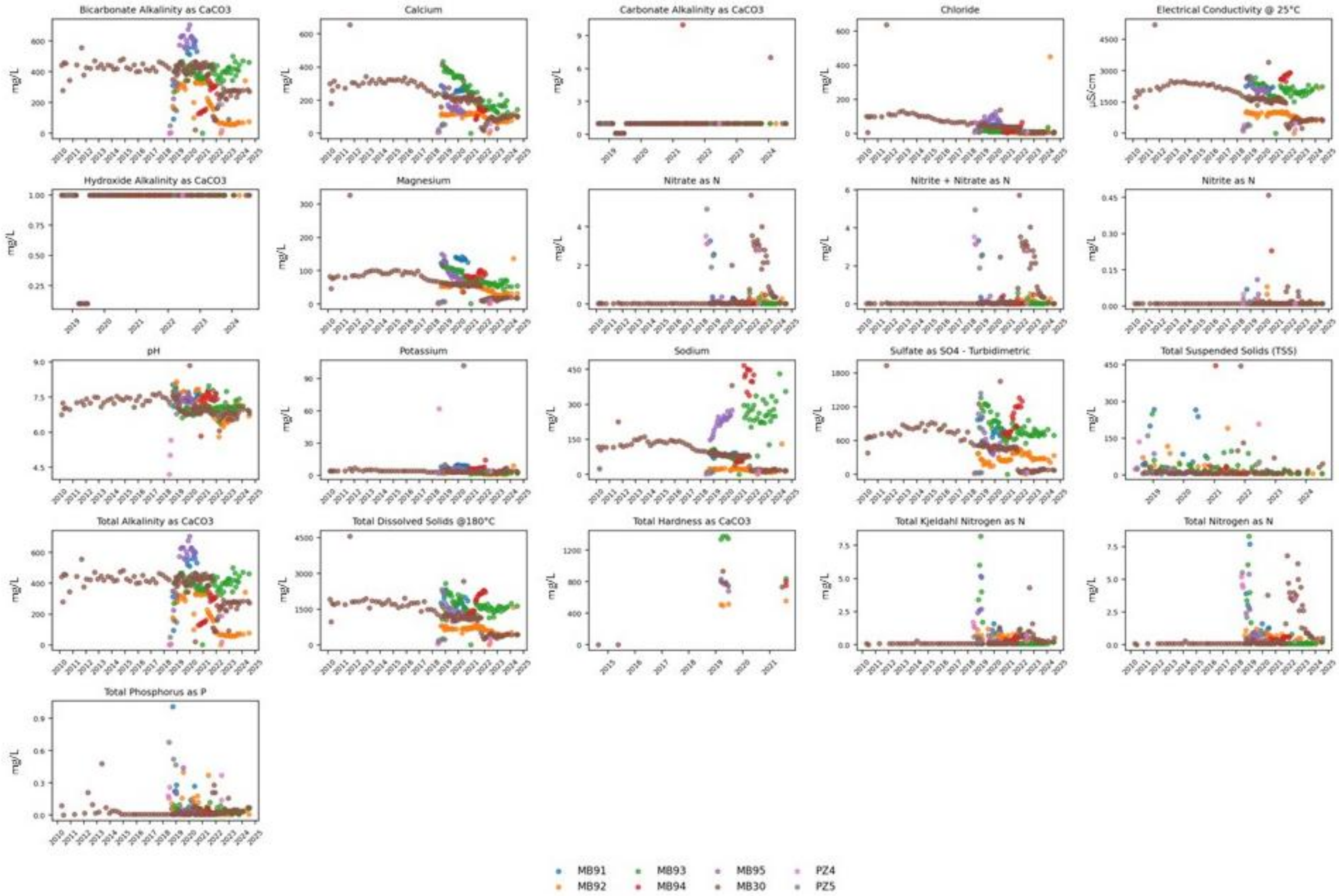
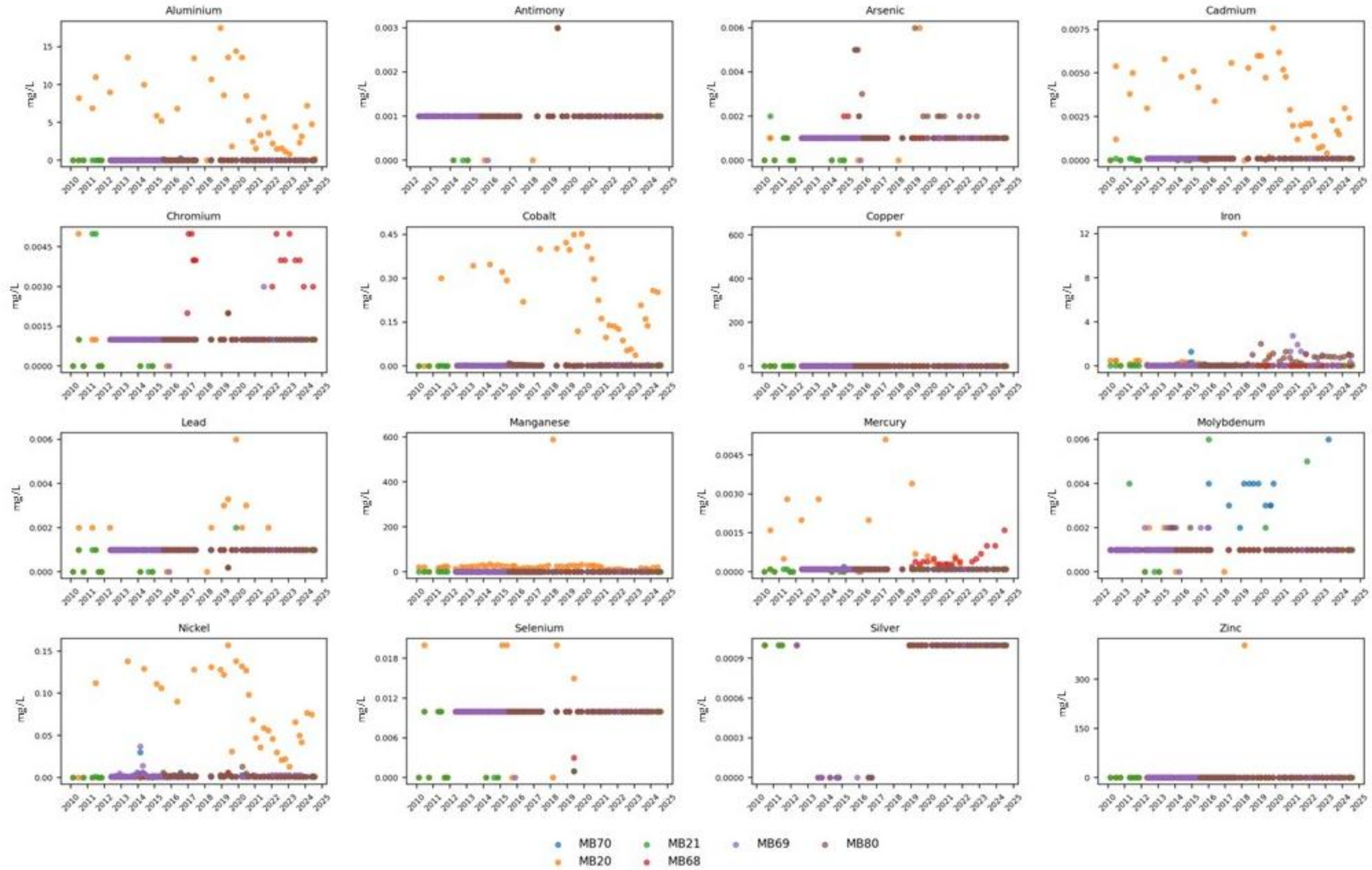


TSF EASTERN ZONE

Metals/Metalloids



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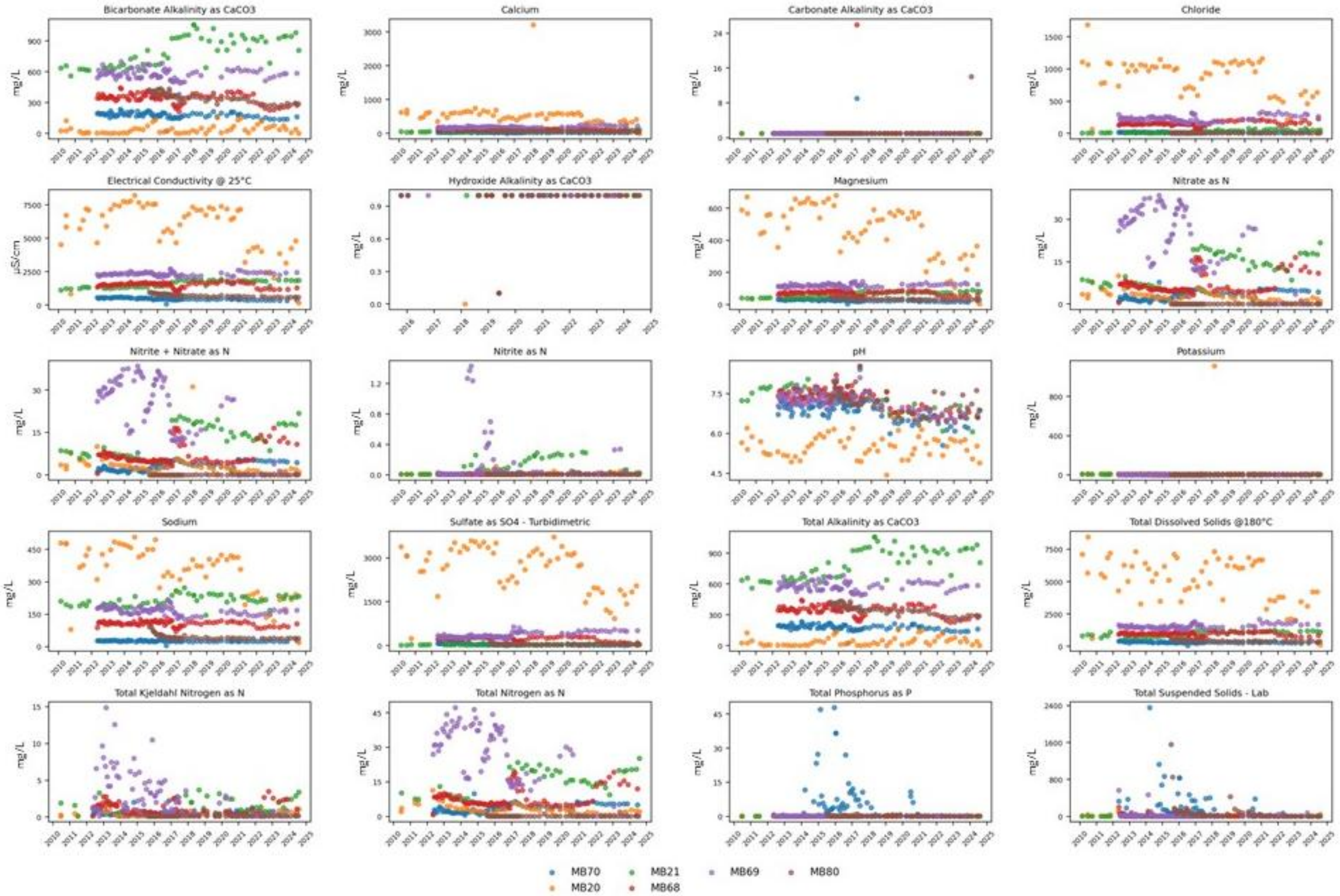
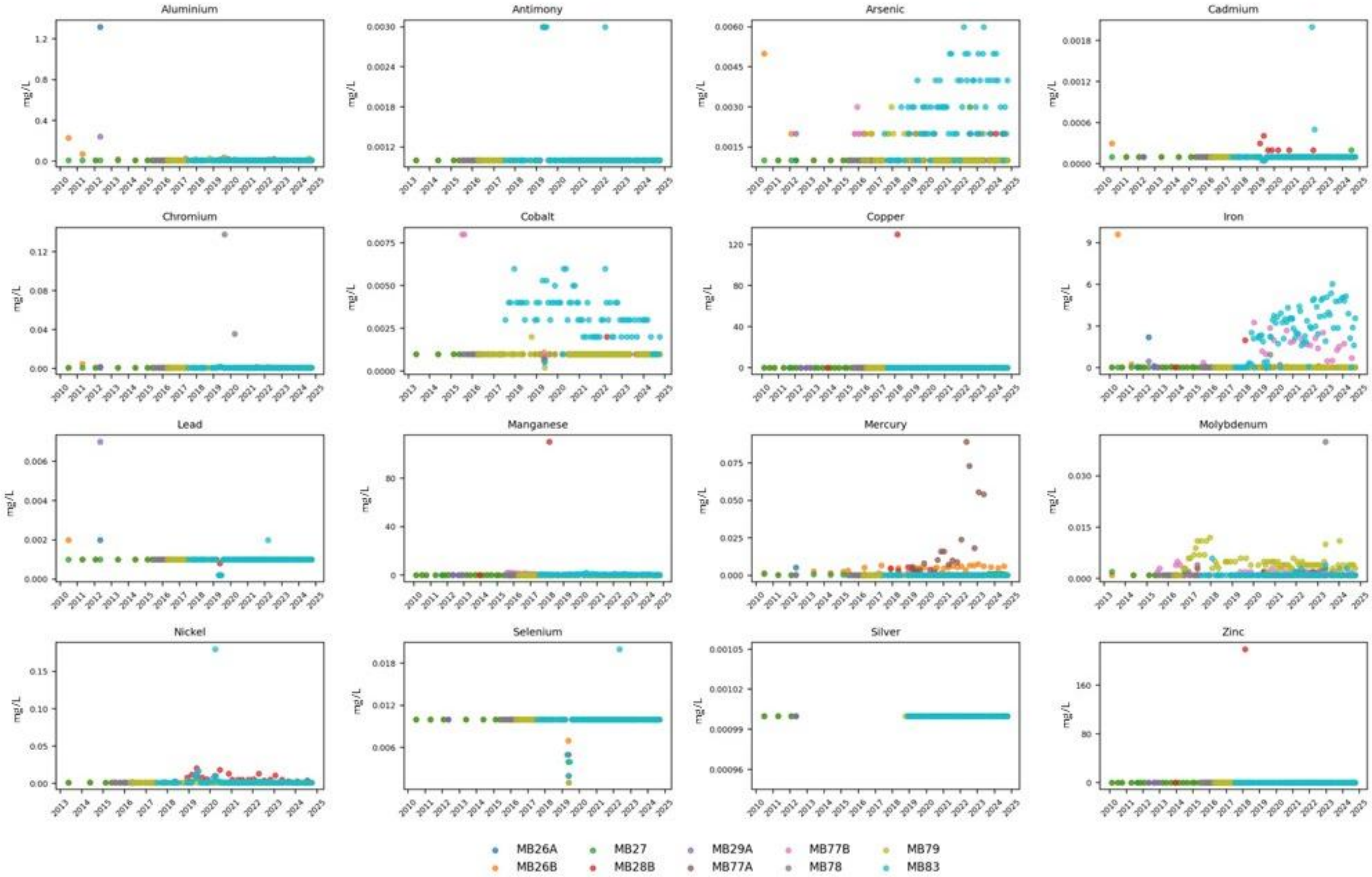


TSF SOUTHERN ZONE

Metals/Metalloids



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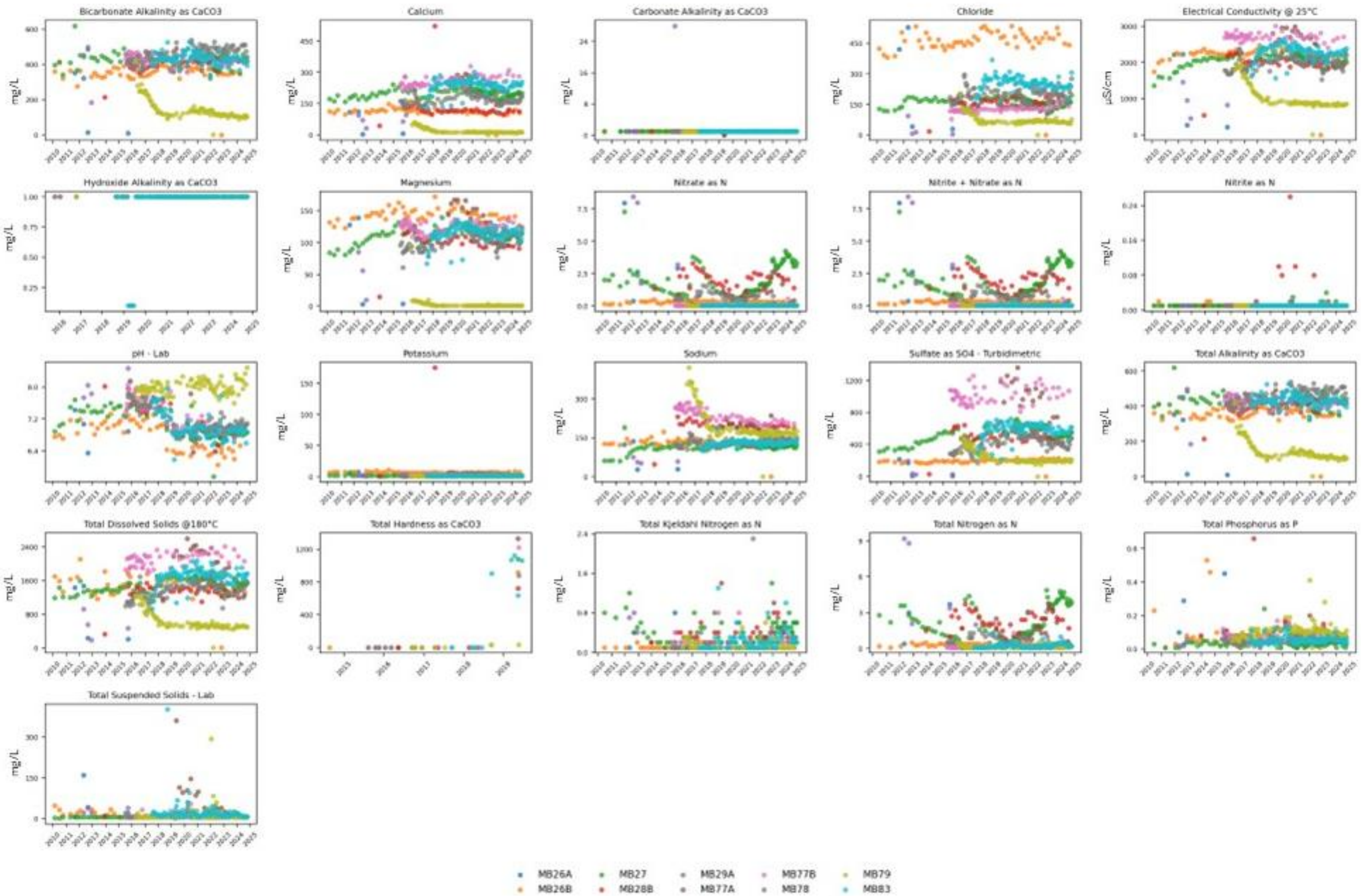
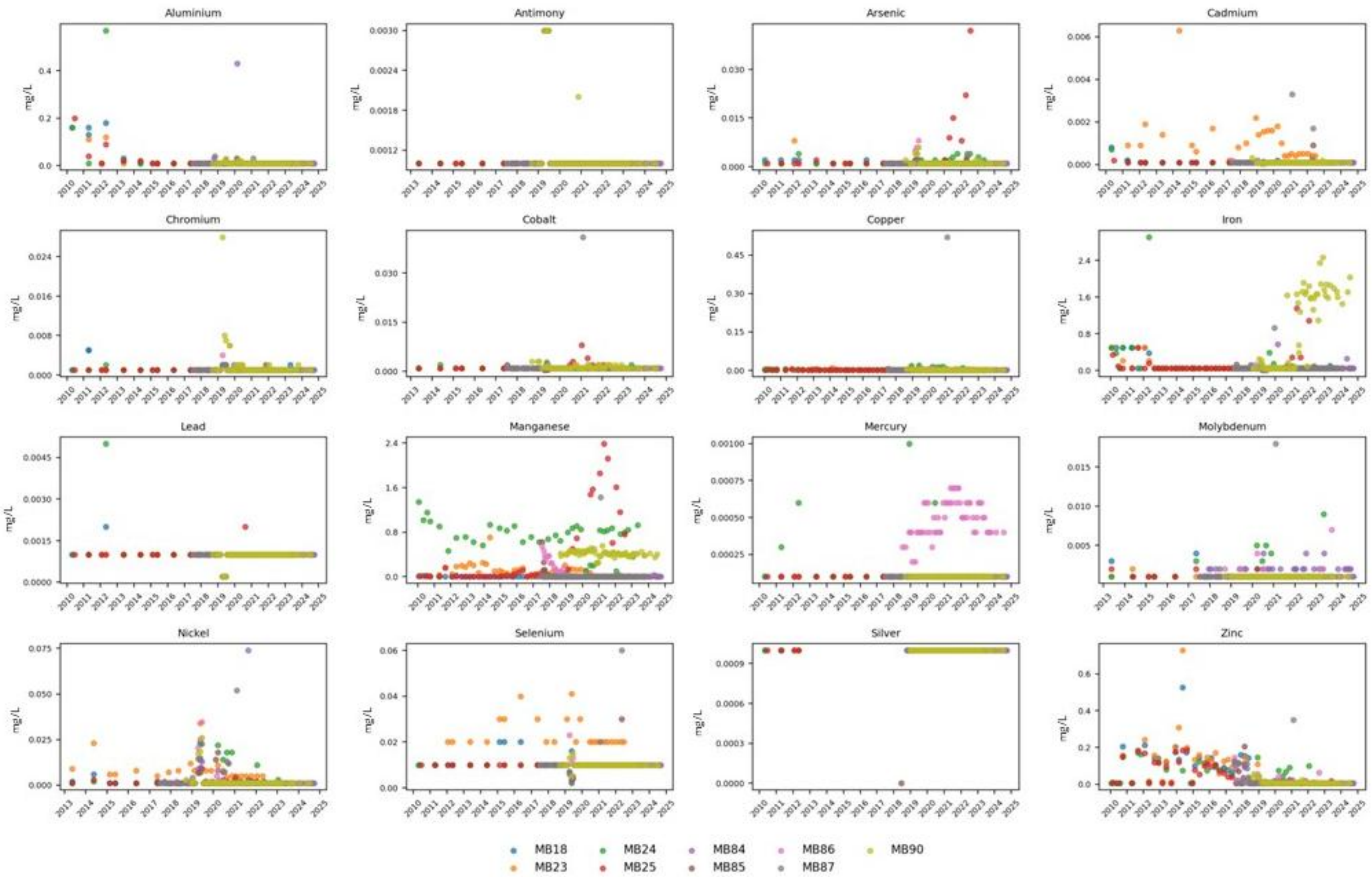


TSF WESTERN ZONE

Metals/Metalloids



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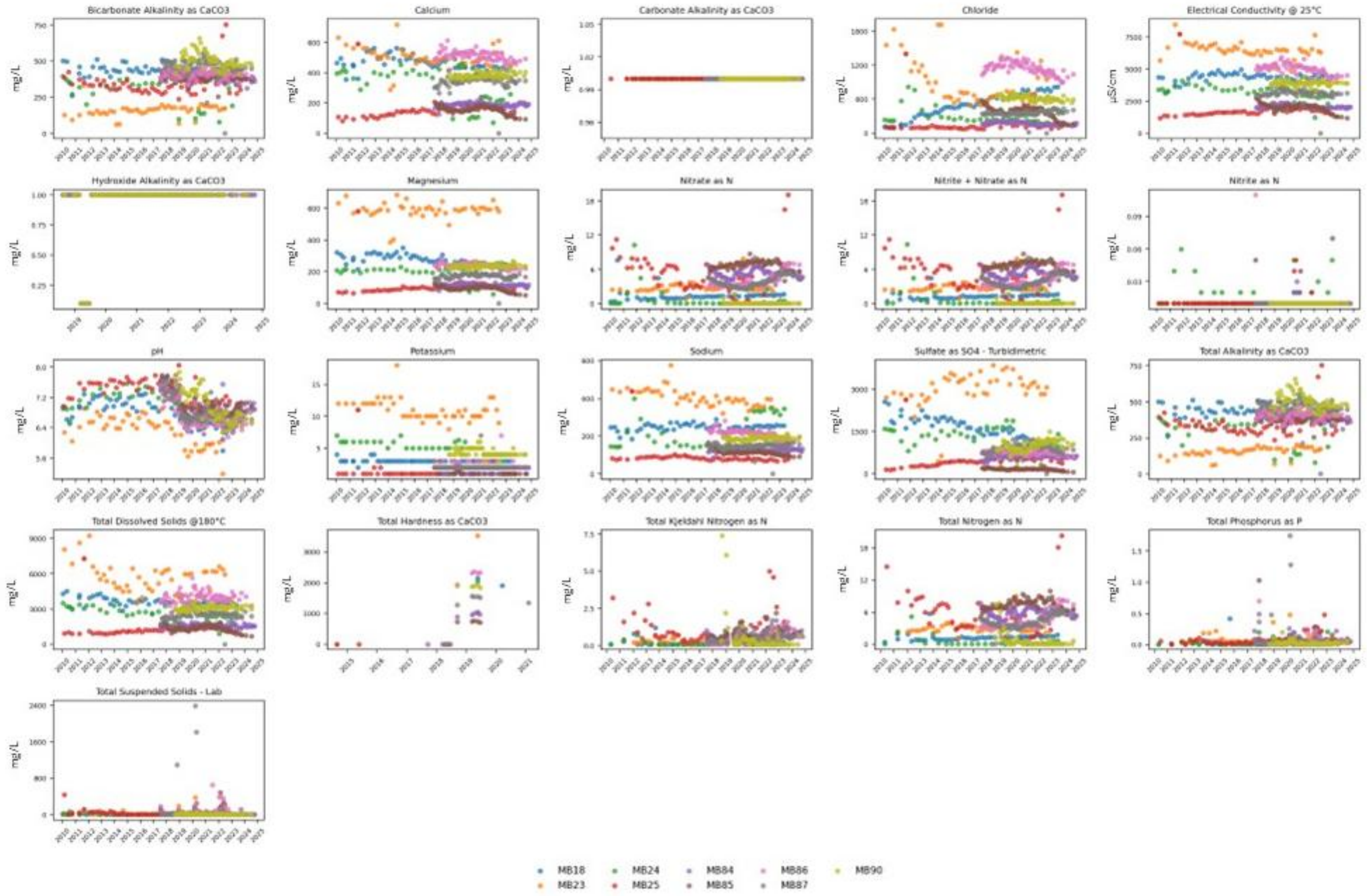

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