Appendix J

Aquatic ecology and GDE assessment

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HVO Continuation Project- aquatic ecology and groundwater dependent ecosystem assessment

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Executive Summary

Hunter Valley Operations (HVO) is a multi-pit open cut mining complex approximately 24 kilometres (km) north-west of Singleton in the Hunter Valley of New South Wales (NSW). HVO comprises two mine sites separated by the Hunter River, HVO North and HVO South. While the two mine sites are approved under separate development consents, they are operated as one complex (the HVO Complex) with fully integrated environmental management systems.

This aquatic ecology and groundwater dependent ecosystem (GDE) assessment is an update to the assessment prepared in 2022 to support the Environmental Impact Statement (EIS) for the HVO Continuation Project (the Project), and provides an assessment of the potential impacts to GDEs and aquatic ecology as a result of the Project as amended. The report summarises the assessment methods (which remain unchanged from the 2022 assessment), and documents results and the initiatives built into the Project design to avoid and minimise impacts to GDEs and surface water ecosystems. The report also summarises the additional mitigation and management measures proposed to address residual impacts that cannot be avoided.

The assessment included a desktop assessment to identify potential GDEs in the Project area, and follow-up field surveys to determine the ecological condition of the GDEs and aquatic ecosystems. The desktop phase of the assessment used geographic information system (GIS) analysis, the GDE Atlas (BOM 2022), and previous reports to identify the following GDEs and aquatic ecosystems in the Project area:

- River baseflow systems of the Hunter River,
- Aquifer ecosystems of the Hunter River and aquifers of associated tributaries,
- River red gum populations at Carrington Billabong, and along the Hunter River and Wollombi Brook,
- River Oak Grassy Riparian Woodland of the Hunter River riparian zone, and
- Warkworth Sands Woodland community.

Field surveys occurred at 13 sites along watercourses (7 Hunter River sites, and 6 sites on other waterways), 15 bores, and 4 potentially groundwater dependent vegetation sites in the Project area. The aquatic ecology sites were sampled on 21-23 April and 14-17 September 2020, and 24-26 January 2022.

Ecological condition in the Hunter River sites was poor to moderate. Macroinvertebrate communities were dominated by pollution-tolerant taxa. While there was potential habitat for purple-spotted gudgeon, the species was considered unlikely to occur at any of the sites, nor in the Hunter River given the absence of historical records in the Hunter Valley. Sites along other watercourses were also in poor condition.

The alluvial aquifer of the Hunter River (and larger tributaries) has previously been established as stygofauna habitat. Five stygofauna taxa were collected from the bores sampled during the current surveys (2020-2022). Stygofauna were collected from the Hunter River alluvium, including the paleochannel aquifer adjacent to HVO North. The stygofauna community in the paleochannel is the same as that in the Hunter River alluvial aquifer.

The vegetation sites, which fall outside of the Project disturbance area, identified with remote sensing analysis and chosen for field assessment using the Biodiversity Assessment Methods (BAM) consisted of:

- Central Hunter Swamp Oak Riparian Forest on a lateral sand/gravel bar of the Hunter River between HVO North and South, mapped in the GDE Atlas as having a high likelihood of being groundwater dependent
- a small stand of river red gum along Wollombi Brook, mapped in the GDE Atlas as having a high likelihood of being groundwater dependent
- a relatively large stand of Central Hunter Ironbark Grassy Woodland near Warkworth shown as likely being groundwater dependent by remote sensing analysis and moderately likely in the GDE Atlas.

All vegetation stands were in low to moderate condition. The two Bull Oak Grassy Woodland of the Central Hunter Valley sites near Warkworth are considered potential GDEs, but they are situated south of the Project area and will not experience any drawdown due to the Project. The riparian forest on a gravel bar of the Hunter River, is potentially dependent on groundwater, although is likely to have a stronger dependence on surface water. The river red gum forest of Wollombi Brook potentially uses groundwater, although is likely to be more dependent on surface water.

Additional stands of river red gum forest have previously been identified in the Project area. As the condition of these stands is already known, and they are included in the *HVO River Red Gum Rehabilitation and Restoration Strategy* (HVO 2022), they were not sampled during our survey but impacts to them from groundwater drawdown are considered.

Groundwater modelling (EMM 2025a) shows only small parts of the alluvial aquifer will be impacted during the life of the Project. Alluvium along the main channel of the Hunter River is largely buffered from drawdown by low permeability groundwater barriers installed along sections of the aquifer (adjacent to the HVO Complex) and because infiltration from the regulated Hunter River recharges the aquifer, so impacts to this aquifer ecosystem and the river red gum populations are likely to be minor or negligible. The alluvial aquifer will continue to be recharged from regulated flows in the Hunter River.

Most of the stygofauna collected during the current study came from the paleochannel aquifer north of the Hunter River and west of the previously mined area. Mining in this area is already approved as part of the Carrington West Wing mining area at HVO North, which will have a significant impact on the local stygofauna community. However, the regional impact is likely to be minor as all taxa collected from the paleochannel were also collected at other locations along the Hunter River alluvial aquifer. Given the impact from the already approved mine, there will be negligible or no impact from the Project.

Changes to the groundwater systems as a result of the Project, are unlikely to have a significant impact on any of the GDEs studied. River-baseflow systems, near-river alluvial groundwater communities, and red gum riparian populations should be protected against drawdown by the combination of regulated flows down the Hunter River, and the existing and proposed groundwater barriers to prevent water loss.

Consistent with the findings of the EIS, only minor changes in water level are expected for the Hunter River alluvial aquifer. To mitigate against impacts to the aquifer community, groundwater level and quality should be continually monitored, and fed in to updated modelling so that any unexpected drawdown that is beyond that predicted by current models, can be forecast. The groundwater monitoring network will be expanded, groundwater model reviews and updates will be implemented as described in the Water Assessment report(EMM 2025b).

1. Introduction

1.1 Background

Hunter Valley Operations (HVO) is a well-established multi-pit open cut coal mining complex, comprising two mine sites separated by the Hunter River, HVO North and HVO South. HVO is approximately 24 kilometres (km) north-west of Singleton in the Hunter Valley of New South Wales (NSW) (refer to Figure 1). While the two mine sites are approved under separate development consents issued under the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act), they operate as one complex with fully integrated environmental management systems.

HVO North operates under Development Consent DA 450-10-2003 issued by the then NSW Minister for Infrastructure and Planning in 2004, which allows extraction of up to 22 million tonnes per annum (Mtpa) of run of-mine (ROM) coal until 31 December 2026. HVO North comprises the approved mining areas of West Pit, Mitchell Pit, Carrington Pit and North Pit, as well as the Hunter Valley (HV) and Howick Coal Preparation Plants (CPP) and the Howick and HVO North mine infrastructure area (MIA). The Newdell Load Point (LP) and Hunter Valley (HVLP) train loading facilities are also at HVO North.

HVO South operates under Project Approval (PA) 06_0261 issued by the then NSW Minister for Planning in 2009 and comprises the approved mining areas of Riverview Pit, Cheshunt Pit, Riverview South East Extension and South Lemington Pits 1 and 2, as well as the MIA, and the Lemington CPP (LCPP) and rail loop (approved but not constructed). PA 06_0261 allows extraction of up to 20 Mtpa of ROM coal until 24 March 2030.

The key components and approved disturbance areas associated with the HVO Complex are illustrated in Figure 2.

Significant coal resources remain across the HVO Complex beyond what is currently approved for extraction under the existing development consents. HVO is therefore seeking approval for the HVO Continuation Project (the Project) from the NSW Minister for Planning and Public Spaces, or delegate, under the provisions of Part 4 of EP&A Act. The Project broadly comprises the continuation of mining at HVO North and HVO South, beyond the current approved mining completion dates of December 2026 and March 2030 respectively. The Project will seek to maintain separate development consents for HVO North and South, as is currently the case.

Given that the two mine sites operate as one complex, one environmental impact statement (EIS, EMM 2022a) was prepared to support the two State significant development (SSD) applications for the Project, being:

- SSD-11826681 – HVO North Open Cut Coal Continuation Project
- SSD-11826621 – HVO South Open Cut Coal Continuation Project.

During the public exhibition of the EIS, submissions were received by the NSW Department of Planning, Housing and Infrastructure (DPHI) from individuals, organisations, public authorities, councils, and government agencies for the two development applications.

To respond to matters raised in submissions on the Project during the public exhibition period, a Submissions Report (EMM 2023a) was prepared, along with an Amendment Report (EMM 2023b) outlining proposed amendments to the HVO North Project.

Following the subsequent assessment of the Project by DPHI and request to HVO for further information, HVO completed a detailed review of the Project and is subsequently seeking to amend the SSD applications in the following ways:

- Reduce the project mine plan to avoid mining within gas Domain 1 at HVO North and reduce the total ROM coal to be extracted by the Project by approximately 220 Mt.
- Maintain the current approved maximum annual ROM coal production from HVO North of 22 Mtpa but reduce the proposed maximum annual production limit at HVO South from 18 Mtpa to 13 Mtpa.
- Reduce the maximum annual production for the HVO Complex to 26 Mtpa from the approved maximum production of 42 Mtpa.
- Reduce the proposed life of mining operations at HVO North by five years, from the end of 2050 to the end of 2045.
- Reduce the proposed life of mining operations at HVO South by three years from the end of 2045 to the end of 2042.
- Expansion of the HVO North ROM coal stockpile within the established HVO North MIA area to improve product coal management.
- Remove approval for the construction and operation of the LCPP and associated rail facilities, which is currently approved, but not constructed, under the HVO South Project Approval.
- Temporary transport of product coal by truck from the Howick CPP to the Liddell stockpile for transport to market via the Liddell coal handling and train loading facilities during upgrades of the Newdell LP.
- Establishment of a new levee (Mitchell East Levee) to provide flood protection for the final void in Mitchell Pit.

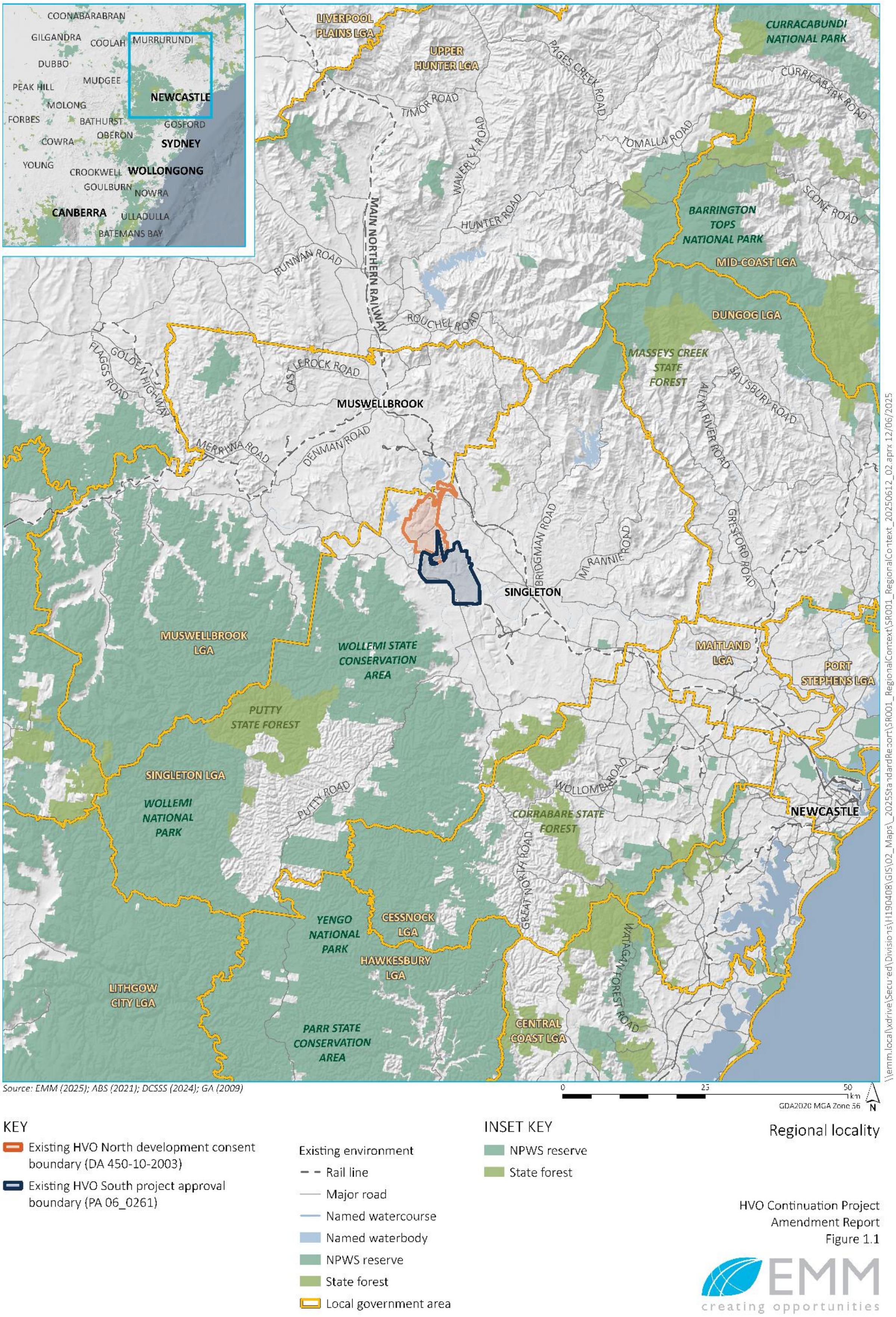


Figure 1. Regional location of HVO North and HVO South

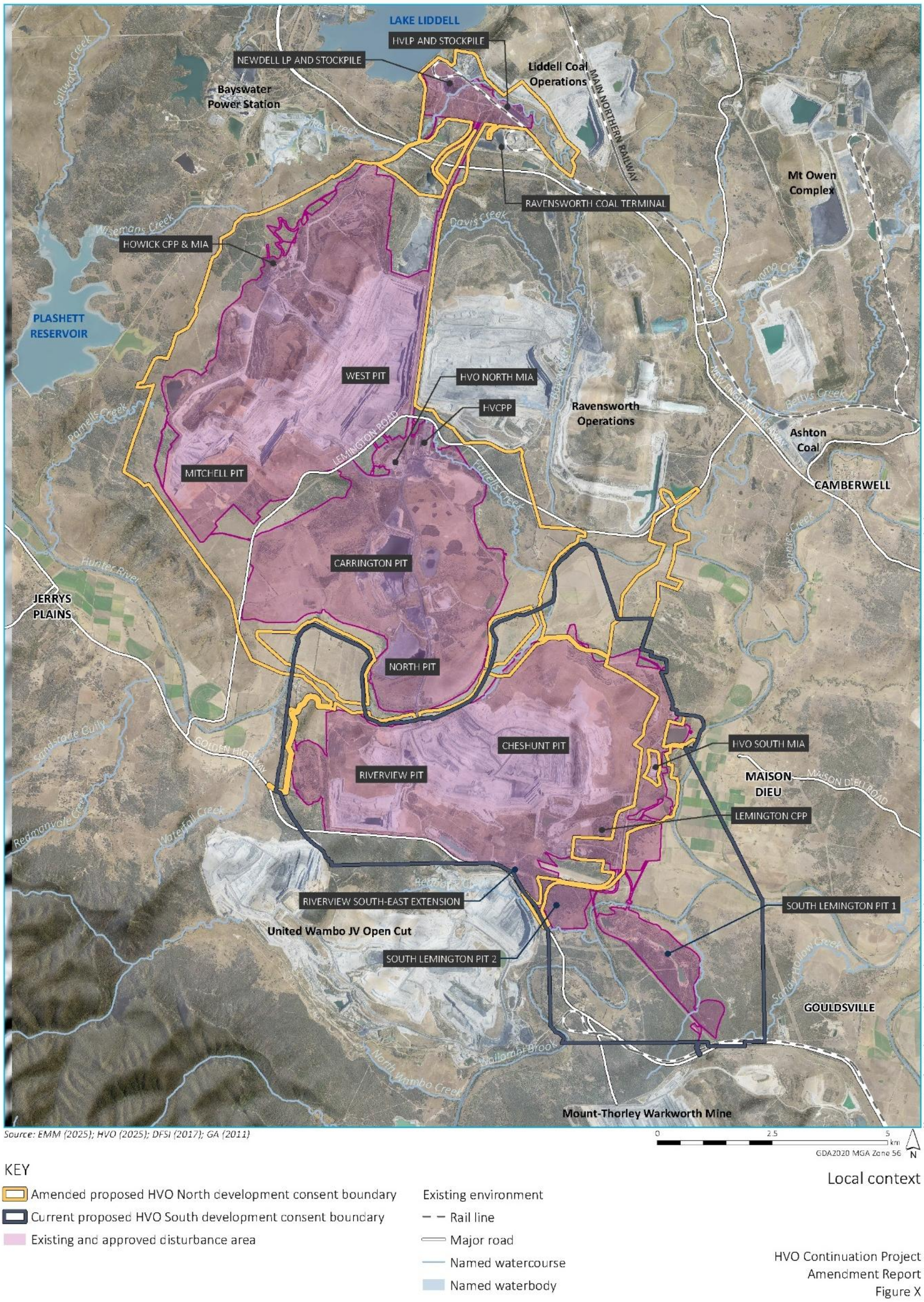


Figure 2. HVO local context

1.2 The Project

As noted in Section 1.1, the Project broadly comprises the continuation of mining at HVO North and HVO South, beyond the current approved mining completion dates of 2026 and 2030, respectively. The key components of the amended HVO North Continuation Project and HVO South Continuation Project are illustrated on Figure 3 and summarised in the sections below (for relevance for water resources).

1.2.1 HVO North

The key Project elements at HVO North for which approval is sought include those activities required to carry out open cut coal mining and processing and include:

- changes to the HVO North development consent boundary, as illustrated Figure 3
- continuation of mining operations at HVO North from 1 January 2027 until 31 December 2045
- production of up to 22 Mtpa with no separation of extraction limits between West Pit and Carrington Pit
- infrastructure upgrades, as listed below:
    - realignment of Lemington Road and construction of a new bridge over the Hunter River
    - relocation of the HVO North site access road off the existing Lemington Road
    - increase in the capacity of Parnells Dam from approximately 1 gigalitre (GL) to approximately 4 GL
    - expansion of the HVO North ROM coal stockpile within the established HVO North MIA
    - maintenance and ancillary infrastructure required to support construction activities and mining operations within the Project disturbance area, including communication towers, installation and maintenance of water supply works and works on waterfront land, construction and use of buildings for construction or mining operations, installation of environmental monitoring equipment including piezometers, and explosives storage and transport.
- management of tailings in accordance with a Tailings Management Strategy
- implementation of a revised water management system including construction of levees, clean water diversions and the Carrington West Wing low permeability barrier wall (as approved)

Other than as modified above, all activities that are currently approved under the existing HVO North development consent are intended to continue.

1.2.2 HVO South

The key Project elements at HVO South for which approval is sought include those activities required to carry out open cut coal mining and processing and include:

- changes to the HVO South development consent boundary, as illustrated in Figure 3
- continuation of mining operations at HVO South from 24 March 2030 until 31 December 2042
- a reduction in the approved maximum extraction rate from 20 Mtpa to 13 Mtpa
- removal of coal extraction from the mine plan for the Riverview South East Extension (RSEE), and South Lemington Pit 1 and 2 (SLP 1 and 2)
- infrastructure upgrades including:
    - removal of the approval for the construction and operation of the LCPP and rail facilities

- transport product coal by truck or overland conveyor from all CPPs to loading points (HVLP, Newdell LP and Lemington LP)
- continuation of integrated water management with HVO North and water transfers with other mining operations (where permitted under the development consents that apply to those other mining operations)
- construction of the Cheshunt and Riverview flood protection levees
- enlargement of Lake James from approximately 0.7 GL to 1.9 GL

Other than as modified above, all activities that are currently approved under the existing HVO South development consent are intended to continue.

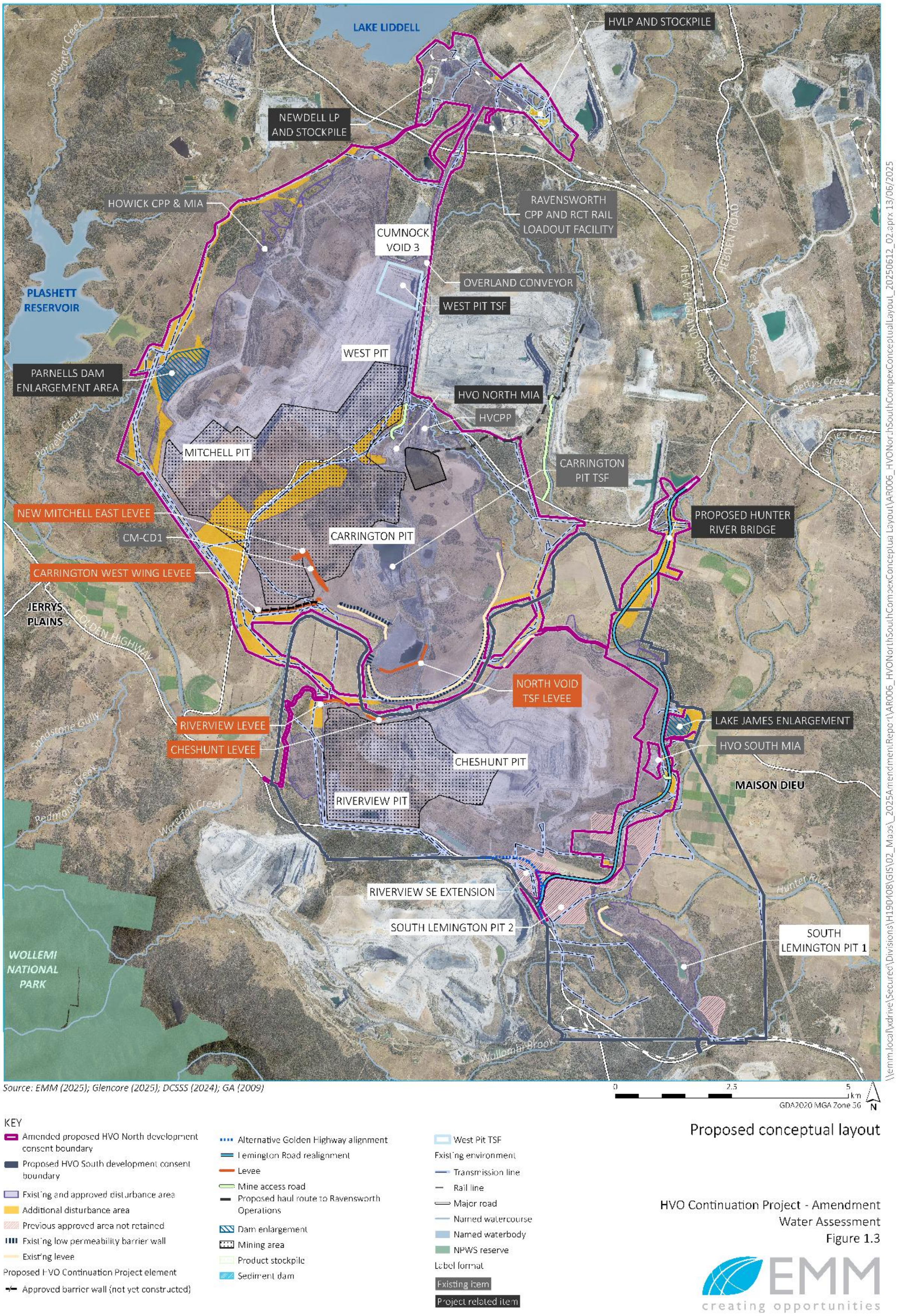


Figure 3. Proposed conceptual layout

2. Study area

2.1 Location

HVO is a multi-pit open cut mining complex comprising two mines north and south of the Hunter River. The HVO North and HVO South mines are approximately 24 km north-west of Singleton in the Hunter Valley, NSW.

2.2 Local geology and groundwater

Quaternary alluvium of the Hunter River consists of 10-20 m of unconsolidated gravels, sands, silts and clays (AGE 2022). The alluvium is generally saturated in the central, thicker section but becomes less permanently saturated towards the aquifer margins. Recharge occurs mostly via seepage through the bed and bank of the Hunter River, infiltration from rainfall, and upward leakage from coal measures in some places. The alluvial sediments generally run along the current course of the Hunter River with a width of approximately 1 to 2 km (Figure 4). These consist of a fine-grained sediment of clay, silt, and sand, overlaying coarser basal sediment of sand and gravel. Flow in the aquifer is largely controlled by surface topography.

A paleochannel, formed by an ancient meander, extends north of the Hunter River at HVO North. The sediment here consists of clay, silt, sand, and gravel, and the paleochannel thickness is 12 to 20 m.

The two main alluvial tributary aquifers include the one along Bowmans Creek, north-east of HVO North, and the alluvium of Wollombi Brook, south-east of HVO South. Bowmans Creek alluvium consists of similar sediments to the Hunter River alluvium and is 2 to 10 m thick, although the saturated thickness is patchy. Wollombi Brook alluvium consists of sand, gravels, and minor silt and clay.

The Permian sediments consist of coal seam layers interspersed with layers of sandstone, siltstone, tuffs and conglomerate. Strata generally dip to the south, south-east. The coal seams are typically 2.5 to 10 m thick and have a low to moderate permeability though are poor water-bearing strata. Interburden layers consist of very low yielding sandstone, siltstone, and conglomerate and are considered aquitards. Therefore, mining induced depressurisation in the Permian strata will not result in significant vertical leakage from the alluvium to the bedrock and drawdown in the adjacent alluvium at HVO North and South (AGE 2022).

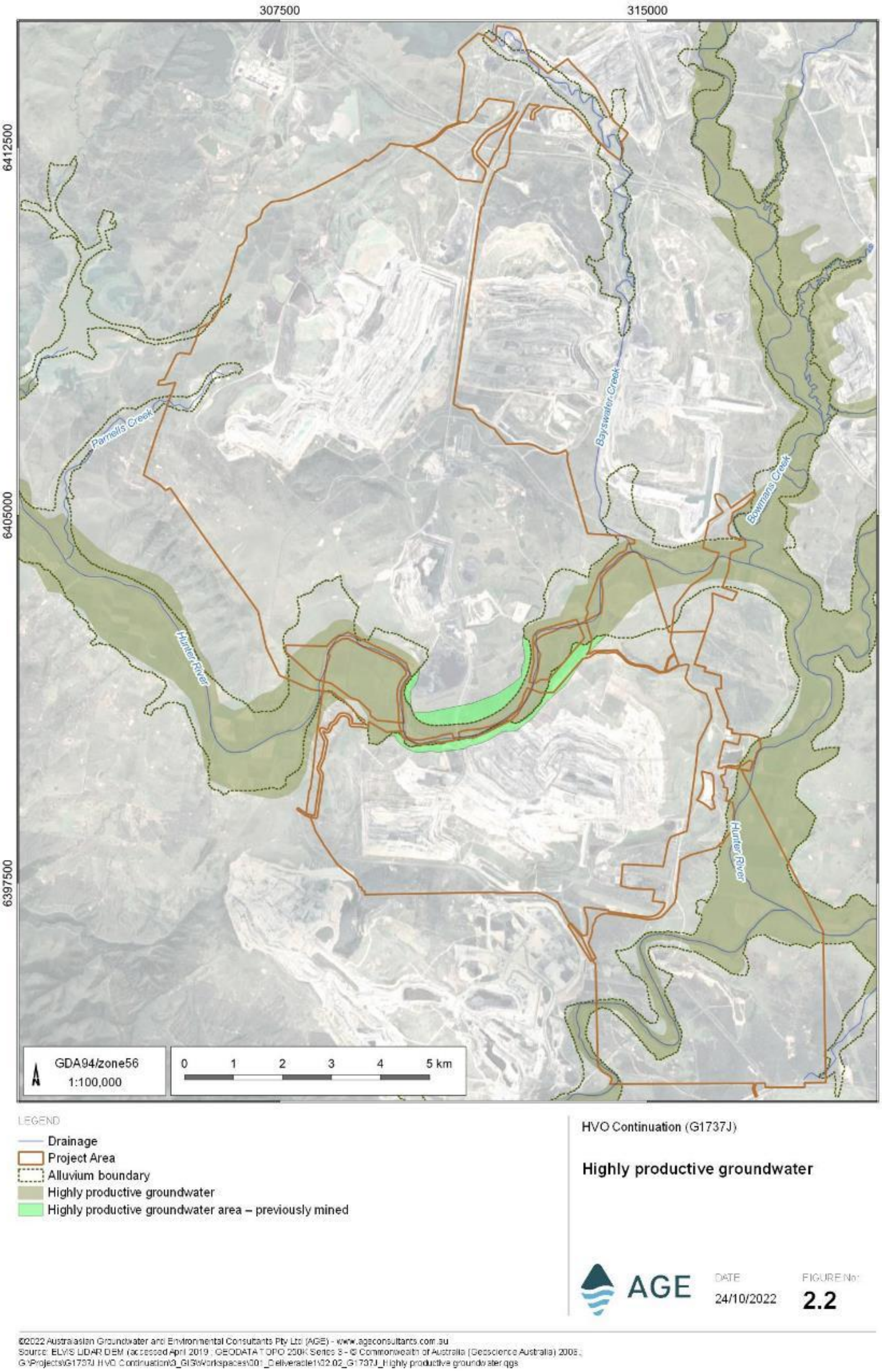


Figure 4. Extent of Hunter River alluvium and highly productive groundwater (AGE 2022)

3. Policy and legislative context

The importance of aquifer and aquatic ecosystems is being increasingly recognised by NSW and Commonwealth Governments. The following policies are relevant to their protection and management of for this current assessment.

3.1 *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)

The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) considers water resources affected by large coal mining developments to be a matter of national environmental significance. It is likely that approval under Part 3, Division 1 of the EPBC Act will be required for the Project. Referrals were submitted to the Department of Climate Change, Energy, Environment and Water (DCCEEW) for the Project (HVO North and HVO South) regarding potential impacts to listed threatened species and ecological communities and water resources to determine if it is a controlled action under the EPBC Act. At the time of finalisation of this report, DCCEEW's determination is still pending.

3.2 Water Management Act 2000

The *Water Management Act 2000* (WM Act) is the key piece of legislation for the management of water in NSW. The WM Act aims to provide for the sustainable and integrated management of the water sources of NSW for the benefit of both present and future generations. The following objects of the WM Act are relevant to the management of GDEs and aquatic ecosystems to:

- Apply principles of ecologically sustainable development.
- Protect, enhance and restore water sources, their associated ecosystem, ecological processes and biological diversity and their water quality.
- Recognise and foster the significant social and economic benefits to the State that result from the sustainable and efficient use of water, including benefits to the environment.
- Integrate the management of water sources with the management of other aspects of the environment, including the land, its soils, its native vegetation and its native fauna.

The WM Act also provides water management principles and the following general principles are relevant to the management of GDEs:

- Water sources, floodplains and dependent ecosystems (including groundwater and wetlands) should be protected and restored and, where possible, land should not be degraded.
- Habitats, animals and plants that benefit from water or are potentially affected by managed activities should be protected and (in the case of habitats) restored.
- The quality of all water sources should be protected and, wherever possible, enhanced.
- The cumulative impacts of water management licences and approvals and other activities on water sources and their dependent ecosystems, should be considered and minimised.
- The principles of adaptive management should be applied, which should be responsive to monitoring and improvements in understanding of ecological water requirement.

3.3 Information guidelines for assessing groundwater dependent ecosystems

These guidelines (Doody et al. 2019) were released by the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (the IESC), which is a statutory body under the EPBC Act. They are intended to assist proponents in preparing environmental impact assessments for coal seam gas (CSG) and large coal mining (LCM) development proposals. They provide a logical sequence of steps to identify GDEs in the impact area, then determine the level of dependence, their baseline condition, and potential to be impacted. The guidelines prioritise avoidance and mitigation measures to minimise impacts.

3.4 Risk Assessment guidelines for groundwater dependent ecosystems

The *Risk assessment guidelines for groundwater dependent ecosystems* (Serov et al. 2012) was developed jointly by the then NSW DPI Office of Water to:

- Assist agency staff to support the requirements of the WM Act.
- Provide methods to identify and value GDEs and assist reporting against the state-wide targets that aim to improve the ability of groundwater systems to support GDEs and designated beneficial uses (as part of the NSW Natural Resources Monitoring, Evaluation and Reporting Strategy 2010–2015).
- Provide a risk assessment framework for GDEs for the National Water Commission Project Coastal Groundwater Quality and GDEs.
- Provide detailed methods for defining, identifying and assessing ecological value and risk through a risk analysis conceptual framework for GDEs, with supporting background information. The conceptual framework allows potential and actual impacts of proposed activities on GDEs to be assessed in accordance with the WM Act and other relevant legislation.

3.5 NSW Groundwater Quality Protection Policy, 1998

The Groundwater Quality Protection Policy aims to protect water below the ground surface by providing a framework for management of groundwater quality, so resources can sustain environmental, social and economic uses in NSW. The policy has nine management principles to protect groundwater quality, quantity and GDEs. These are as follows:

- All groundwater systems should be managed such that their most sensitive identified beneficial use (or environmental value) is maintained.
- Town water supplies should be afforded special protection against contamination.
- Groundwater pollution should be prevented so that future remediation is not required.
- For new developments, the scale and scope of work required to demonstrate adequate groundwater protection shall be commensurate with the risk the development poses to a groundwater system and the value of the groundwater resource.
- A groundwater pumper shall bear the responsibility for environmental damage or degradation caused by using groundwaters that are incompatible with soil, vegetation or receiving waters.
- GDEs will be afforded protection.
- Groundwater quality protection should be integrated with the management of groundwater quantity.

- The cumulative impacts of developments on groundwater quality should be recognised by all those who manage, use, or impact on the resource.
- Where possible and practical, environmentally degraded areas should be rehabilitated, and their ecosystem support functions restored.

3.6 NSW Aquifer Interference Policy, 2012

The Aquifer Interference Policy (AIP) aims to clarify requirements for obtaining water licences for aquifer interference activities under NSW legislation. It establishes and defines considerations in assessing and providing advice on whether more than minimal impacts might occur to key water dependent assets. Of relevance to GDEs, under the AIP proponents will be assessed on their:

- ability to demonstrate that adequate arrangements will be in place to ensure that the minimal impact considerations specified in the AIP can be met; and
- proposed remedial actions for impacts greater than those that were predicted as part of the relevant approval. The requirement for remedial actions may occur where modelled predictions were inaccurate or where planned mitigation, prevention or avoidance strategies have failed. The assessment will include:
  - i consideration of the potential types and risks of unforeseen impacts that may occur during the operational phase or post-closure of the aquifer interference activity;
  - ii whether the proposed mitigation, prevention or avoidance strategies will minimise these risks;
  - iii whether the proposed remedial actions are adequate, should the proposed risk minimisation strategies in (ii) fail;
  - iv advice on what further mitigation, prevention, avoidance or remedial actions may be required; and
  - v appropriate conditions that maintain any mitigation, prevention, avoidance or remediation actions until they are no longer required to keep the impacts at or below the predicted levels.

3.7 NSW *Environmental Planning and Assessment Act 1979* (EP&A Act)

All developments in NSW are assessed in accordance with the provisions of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act). The EP&A Act provides a system for environmental planning and assessment, including approvals and environmental impact assessment requirements for proposed developments. Implementation of the EP&A Act is the responsibility of the Minister for Planning, statutory authorities and local councils.

To enable the Project to proceed, two new SSD consents are required; one for HVO North and one for HVO South, under Part 4, Division 4.1 of the EP&A Act. The Project will seek to maintain separate development consents for HVO North and South, as is currently the case. Given that the two mine sites operate as one complex, one EIS has been prepared to support the two development applications required for the Project.

3.8 NSW *Biodiversity Conservation Act 2016* (BC Act)

Under the BC Act, any activities assessed under Part 5 of the EP&A Act must apply the test of significance to determine whether the proposed activity is likely to significantly impact threatened species or ecological communities. If a significant impact is likely, the proponent may choose to opt into the Biodiversity Offsets Scheme (BOS) or undertake a Species Impact Statement (SIS). These are included elsewhere in the Biodiversity Development Assessment Report (Umwelt 2025).

3.9 NSW *Fisheries Management Act 1994* (FM Act)

The FM Act is the principal piece of legislation protecting aquatic habitat in NSW. The FM Act aims to conserve fish stocks, key fish habitat, aquatic vegetation, and threatened species, populations and communities. Threatened aquatic species, populations and communities are listed under Schedules 4, 4A and 5 of the FM Act, while key threatening processes are listed under Schedule 6. Any impact to groundwater level or quality needs to be considered under the FM Act for groundwater dependent rivers if it has the potential to block fish passage.

Purple-spotted Gudgeon are mapped as occurring in some tributaries of the Hunter River, including Wollombi Brook. An assessment of significance for this species is included in Appendix A. The Project is not considered a threat to this species. There are no other threatened species, populations or communities listed under the FM Act that are likely to use the site or depend on it for habitat.

3.10 NSW State Groundwater Dependent Ecosystems (GDE) Policy

This policy aims to protect the ecological processes and biodiversity of ecosystems that depend on groundwater. The GDE policy was developed in 2002, and outlines the following principles for managing GDEs:

- The scientific, ecological, aesthetic and economic values of GDEs, and how threats to them may be avoided, should be identified and action taken to ensure the most vulnerable and valuable ecosystems are protected.
- Groundwater extractions should be managed sustainably so that ecological processes and biodiversity are maintained and/or restored.
- Priority should be given to ensuring enough groundwater of a suitable quality is available when needed for:
    - Protecting ecosystems which are known to be, or most likely to be, groundwater dependent; and
    - GDEs which are under immediate or high degree of threat from groundwater-related activities.
- Where scientific knowledge is lacking, the precautionary principle should be applied to protect GDEs.
- Planning, approval and management should aim to minimise adverse impacts on GDEs by:
    - Maintaining natural patterns of groundwater flow and not disrupting groundwater levels that are critical for ecosystems;
    - Not polluting or causing adverse changes in groundwater quality; and
    - Rehabilitating degraded groundwater systems where practical.

4. Methods

The methods below are the same as used in the Environmental Impact Statement, but are reproduced here for completeness.

4.1 Desktop assessment

Searches were made of the Bureau of Meteorology (BOM) GDE Atlas as a preliminary step in identifying whether potential GDEs are present. The Project area was searched for groundwater dependent terrestrial vegetation, as well as aquatic and subterranean GDEs. Searches for additional areas of potential groundwater dependence were made using supplementary information, such as groundwater and ecological reports and data from previous HVO assessments, and reports from surrounding projects. It is noted that the vegetation communities mapped in the GDE Atlas are not as accurate as detailed site-based mapping, and often need to be verified by vegetation surveys. Vegetation mapping by Umwelt (2022) was used to give site-specific vegetation communities.

Searches were made of the NSW Fisheries Spatial Portal and BioNET to determine whether there are any threatened fish or significant aquatic habitat in the Hunter River and nearby waterways (including Bayswater Creek, Parnells Creek, Farrells Creek, Hobden Gully, Wollombi Brook, Pikes Creek, Bowmans Creek). This information was used in an initial desktop assessment of aquatic habitat quality.

4.2 Aquatic ecology assessment

The aquatic ecology assessment determined baseline condition along the Hunter River, and at sites on Bayswater Creek, Wollombi Brook, Bowmans Creek and Farrells Creek. Water quality samples and habitat assessments were made at thirteen sites in April and September 2020, while macroinvertebrate samples were collected at a subset of seven sites (Table 1). An additional five sites were added in January 2022 to collect background data upstream and downstream of locations used for three of the Hunter River Salinity Trading Scheme (HRSTS). There are four licensed discharge sites in the Project area:

- Parnells Dam, discharging from HVO North and entering the Hunter River via Parnells Creek near Jerrys Plains;
- Dam 11N, discharging from HVO North and entering the Hunter River via Farrells Creek;
- Lake James, discharging from HVO South and entering the Hunter River opposite Maison Dieu Road; and
- Alluvial Lands, discharging from HVO North and entering the Hunter River at the Alluvial Lands rehabilitation area (not targeted for sampling).

Table 1. Site description for aquatic ecology sites (coordinates given as GDA94, Zone 56).

Sites	Waterway	Description	Easting (mE)	Northing (mS)	Method
HVO1	Hunter River	Golden Hwy (Bowmans Crossing)	297884	6407283	Invertebrates, water quality, habitat
USP	Hunter River	Upstream Parnells HRSTS (added Jan 2022)	301288	6405404	Invertebrates, water quality, habitat

Sites	Waterway	Description	Easting (mE)	Northing (mS)	Method
DSP	Hunter River	Downstream Parnells HRSTS (added Jan 2022)	302222	6405240	Invertebrates, water quality, habitat
HVO2	Hunter River	Lemington Road (Moses Crossing, existing site W109)	306211	6400426	Water quality, habitat
HVO3	Hunter River	Lemington Road realignment	316651	6404128	Invertebrates, water quality, habitat
USFC	Hunter River	Upstream Farrells Creek HRSTS confluence (added Jan 2022)	314026	6403101	Invertebrates, water quality, habitat
DSFC	Hunter River	Downstream Farrells Creek HRSTS confluence (added Jan 2022)	314029	6403763	Invertebrates, water quality, habitat
HVO4a	Hunter River	Downstream Wollombi Brook	319374	6396675	Invertebrates, water quality, habitat
HVO5	Wollombi Brook	Warkworth Bridge	314466	6395038	Invertebrates, water quality, habitat
HVO6	Wollombi Brook	Existing site W2	314935	6396333	Water quality, habitat
HVO7	Bowmans Creek	off Brunkers Lane	3168324	6405001	Invertebrates, water quality, habitat
HVO8	Hunter River	Existing site W1	309348	6402281	Invertebrates, water quality, habitat
HVO9	Bayswater Creek	Existing site Bayswater Creek downstream	313947	6413188	Water quality, habitat
HVO10	Hunter River	Carrington Billabong	310379	6402014	Water quality, habitat
HVO11	Hunter River	Existing site H1 (upstream Lake James HRSTS site)	317290	6400170	Water quality, habitat
DSLJ	Hunter River	Downstream Lake James HRSTS site (added Jan 2022)	317064	6399573	Invertebrates, water quality, habitat
HVO12	Hunter River	Existing site H3	318186	6396698	Invertebrates, water quality, habitat
HVO13	Farrells Creek	Existing site W11	310888	6407143	Water quality, habitat

Macroinvertebrate samples were collected using AUSRIVAS protocols with a standard 250 µm sweep net (Turak *et al*. 2004). Samples were collected from edge habitats, as riffles were not present at all sites. At each site, the net was moved through a total length of 10 m. Net contents were emptied into a white sorting tray and scanned for 40 minutes so that representatives from each invertebrate taxon could be removed and preserved in a jar of 70% ethanol. If additional taxa were still being collected after 40 minutes, the sample was scanned for an additional 20 minutes.

Invertebrates were identified to family in the laboratory using a Leica M80 dissecting microscope. Each family was assigned a Stream Invertebrate Grade Number-Average Level (SIGNAL) score based on Chessman (2003). The SIGNAL score indicates how sensitive an invertebrate family is to disturbance and is used as an indication of habitat health. Families that are sensitive to pollution have scores between six and ten and are likely to only occur in healthy habitats, while those with scores below six can tolerate pollution and will occur in impacted stream habitats (Gooderham and Tsyrlin 2002).

Another index of ecological condition used in this assessment was the taxonomic richness of macroinvertebrates collected from each site. This is the total number of families present in the samples. Sites with higher taxonomic richness are considered in better condition than those with low taxonomic richness.

Macroinvertebrate community data was analysed using the Primer v7 software package (PRIMER-E Ltd 2006). Prior to analysis, data was grouped in factors based on date (April 2020, September 2020, January 2022), and location relative to HVO (upstream/downstream). Data was transformed for presence/absence and a Bray-Curtis similarity matrix developed. Non-metric multidimensional scaling (nMDS) plots were generated to visually display data. Sites with similar communities overlap or appear close together in nMDS plots while those with communities that have different community compositions are further apart (Clarke and Gorley 2006).

Analysis of Similarities (ANOSIM) was used to test for similarities between the pre-selected factors of habitat, year and location relative to the mine. ANOSIM tests are multivariate approximations of the standard univariate analysis of variance (ANOVA) tests and use the same similarity matrix generated for nMDS (Clarke and Gorley 2015).

To complement biological data, physico-chemical parameters were measured at two points for each site. Temperature, dissolved oxygen (DO), electrical conductivity (EC) and pH were measured with a calibrated YSI-556 meter. Turbidity was measured with a Hach 2100Q Turbidimeter and alkalinity was measured with a Hanna HI755 Freshwater Alkalinity Checker. The meters were calibrated in the laboratory prior to the field survey and the DO was calibrated at the start of each field survey day.

The *Australian and New Zealand Guidelines for Fresh and Marine Waters 2018* (ANZG) replaced the *Australian Water Quality Guidelines for Fresh and Marine Waters 2000* (ANZECC) in August 2018. The physico-chemistry data was compared to the ANZG (2018) guidelines protection of aquatic ecosystems in slightly disturbed upland rivers in southeast Australia.

Aquatic habitat assessments were based on the *Policy and Guidelines for Fish Habitat Conservation and Management* (Fisheries NSW 2013), which outlines the features important for fish habitat in freshwater, estuarine, and marine areas. The guidelines recognise the importance of links between upstream and downstream reaches, and the potential impact of riparian management and in-stream barriers to the ongoing health of fish and aquatic communities.

Aquatic habitat variables (environmental data) were recorded using the Australian River Assessment System (AUSRIVAS) datasheets at each site. This included brief descriptions of characteristics such as:

- General signs of disturbance
- Habitat type
- Channel topography
- Current water level
- Bank and bed slope
- Degree of river shading
- Amount of detritus
- Macrophyte type and extent
- Riparian zone width
- Snags and large woody debris coverage
- Stream width and depth
- Surrounding land use
- Description of the natural substrate
- Extent of bank overhang
- Amount of trailing bank vegetation.

4.3 GDE assessment

GDE sites identified on the GDE Atlas or desktop assessment were visited so that their ecological value and condition can be assessed using the protocol outlined in the *Risk Assessments Guidelines for Groundwater Dependent Ecosystems* (Serov et al 2012). The assessment considered all relevant GDE types, including river baseflow systems, aquifer ecosystems, terrestrial vegetation, and wetlands. AGE (2022) indicates that the river red gum community along the Hunter River and Wollombi Brook may be groundwater dependent, and that some of the larger rivers in the study area (Hunter River and Wollombi Brook) receive minor groundwater contributions to baseflow. Previous work by ELA (summarised in Section 5.6) also indicates that the alluvial aquifer of Hunter River contains stygofauna and is a GDE.

From our preliminary assessment of the area, our site visits targeted the following GDE types:

- Groundwater dependent terrestrial vegetation (September 2020)
- River baseflow systems (April 2020, September 2020, January 2022)
- Aquifer ecosystems (April 2020, September 2020, January 2022)

As part of our assessment, we determined the ecological condition of four terrestrial vegetation GDE sites. The ecological condition of terrestrial vegetation communities was assessed using changes visible through satellite imagery and confirmed with ground-truthing. Data were collected during the site visit using the 20 m x 50 m vegetation plots in spring.

Groundwater invertebrate (stygofauna) communities were used to indicate ecological condition of aquifer ecosystems. Twenty-five bores were visited in April 2020, of which twelve could not be sampled because they were dry or bore diameter was too narrow (Figure 5). An additional 6 bores were visited in October 2020 in an attempt to collect stygofauna from the Alluvial Lands rehabilitation area. Two of these were suitable to sample. Five bores were sampled in January 2022.

Samples were collected using a specifically designed net that was lowered to the bottom and slowly retrieved six times. Net contents were emptied at the top of each haul until a total of six hauls were completed. At each bore, physico-chemical parameters (temperature, DO, EC, pH) were measured using a YSI-556 meter. The meter was calibrated in the laboratory prior to the field survey, and DO probe was calibrated at the start of each survey day.

Stygofauna samples were sorted and identified in the laboratory using a Leica M80 dissecting microscope. Any previously unidentified taxa were assigned a morphospecies name and kept as a reference specimen for future comparison.

4.4 Remote sensing analysis

To detect potential groundwater dependent vegetation communities, ELA conducted a remote sensing analysis. Remote sensing analysis for GDEs was done by comparing rainfall data with Normalised Difference Vegetation Index (NDVI) for Landsat imagery sourced from between 2013 and 2020.

The average driest and wettest months for the area were selected from 1920 to 2020 (for long term estimates) and 1961 to 1990 (for shorter term estimates) rainfall data from Doyles Creek weather station (number 061130). The wettest months were January and February, which averaged 74.4 and 77.6 mm for the long-term, and 90.6 and 80.5 mm for the shorter term. July, August, and September were the driest months, with 40.7, 35.8, and 41.8 mm respectively for the long-term data, and 35.2, 37.6, and 36.5 mm for the shorter term.

Landsat imagery over HVO was sourced via the Glovis website (https://glovis.usgs.gov/app). Images were chosen from recent years covering times of wet and dry periods based on monthly mean rainfall obtained from BOM website (Table 2). Wet period images were chosen from dates approximately 2 to 4 weeks after a heavy rainfall period to allow for the vegetation to respond to the event. Imagery that was affected by cloud cover were not selected for the analysis. Where possible Sentinel 2 imagery was obtained in order to provide the highest quality imagery available, however due to cloud cover and timing of captured images Landsat 8 imagery was sourced for the wet period in 2020 and 2013. All Sentinel images have both near infra-red (NIR) and red bands with a pixel resolution of approximately 10 m, whilst Landsat resolution is 30 m. Five images were selected ranging from time periods between 2013 and 2020, to capture both wet and dry periods. Images dates and scene information for both wet and dry periods are listed in Table 3.

Table 2: Monthly rainfall totals at Doyles Creek weather station (number 061130) from 2013 to 2020 (Source: Bureau of Meteorology)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2013	143.2	102.2	64.6	6.6	13	NR	23.2	6.2	33.6	15.6	91.0	15.4
2014	7	95	187.8	NR	8	25	40.8	54.4	30.2	24.6	20.4	132.2

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2015	107	10	29.6	194.8	37.8	26.4	32.2	44.8	8	22	144	47.2
2016	184.4	5	27.4	2.4	28	107.4	52.4	19.6	120	37.4	36	78.6
2017	44.6	12.6	NR	32	19.4	17.6	2.2	14.4	6.6	66.8	22.8	44
2018	8.2	60.4	73.2	18.8	6.2	16	1.8	24.4	38.2	69	57.8	38.6
2019	83	17.2	116.4	0	15.4	4	5.6	13.8	23.8	11.4	24.8	0
2020	81.4	132.6	85.4	23.8	10.2	32	80.2	NR	NR	90.2	24.2	150.6

(NR= no record)

Table 3: Source and imagery dates

Date	Scene ID	Data Set	Condition indicator
17/02/2020	LC08_L1TP_090082_20200217_20200225_01_T1	Landsat 8 OLI/TIRS C1 Level 1	Wet period
29/07/2019	L1C_T56HLK_A012497_20190729T000248	Sentinel 2 Level-1C	Dry period
04/02/2019	L1C_T56HLK_A018903_20190204T000237	Sentinel 2 Level-1C	Wet period
23/08/2017	L1C_T56HLK_A011324_20170823T000219	Sentinel 2 Level-1C	Dry period
27/03/2013	LC08_L1TP_090083_20130327_20170505_01_T1	Landsat 8 OLI/TIRS C1 Level 1	Wet period

4.5 Vegetation condition assessment

The ecological condition of four vegetation patches (Figure 5), selected following desktop and remote sensing analysis as potentially groundwater dependent, was assessed during a field visit by using the Biodiversity Assessment Methodology (BAM) (DPIE 2020). In accordance with the BAM, ELA adopted the standard nested 50 m x 20 m and 20 m x 20 m quadrat (Biometric plot) for all monitoring sites. Biometric transects run downslope from the start point, with the nested 20 m x 20 m floristic quadrat located at the upslope end of the transect. Each vegetation community is described in more detail in Umwelt 2022.

The GDE sites assessed were:

- GDE 1: a small stand of Central Hunter Swamp Oak Riparian Forest (PCT4015) on a lateral sand/gravel bar of the Hunter River between HVO North and South, mapped in the GDE Atlas as having a high likelihood of being groundwater dependent.
- GDE2: a small stand of Namoi-Upper Hunter River Red Gum Forest (PCT4089) along Wollombi Brook, mapped in the GDE Atlas as having a high likelihood of being groundwater dependent.
- GDE3: a relatively large stand of Central Hunter Ironbark Grassy Woodland (PCT3431) near South Lemington Pit 1 shown as being likely GDE by remote sensing analysis and moderately likely in the GDE Atlas.
- GDE4: a relatively large stand of Central Hunter Ironbark Grassy Woodland (PCT3431) near Warkworth shown as being likely GDE by remote sensing analysis and moderately likely in the GDE Atlas.

Within a 50 m x 20 m quadrat, the following data was collected:

- Number of large trees
- Tree regeneration
- Tree stem size class
- Total length of fallen logs
- Number of hollow bearing trees
- Litter cover within five 1 m x 1 m sub-plots

Within a 20 m x 20 m quadrat, the following data was collected:

- Species name: Scientific name and common name
- Stratum (& layer): in which each species occurs
- Cover: an estimate of the appropriate cover measure for each recorded species: from 1-5% and then to the nearest 5%
- Abundance: A relative measure of the number of individuals or shoots of a species within the plot using the following intervals: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 50, 100, 500, 1000, or specify a number greater than 1000 if required
- Form: (T) Tree; (S) Shrub; (G) Grass and grass like (F) Forb; (E) Fern; (O) other

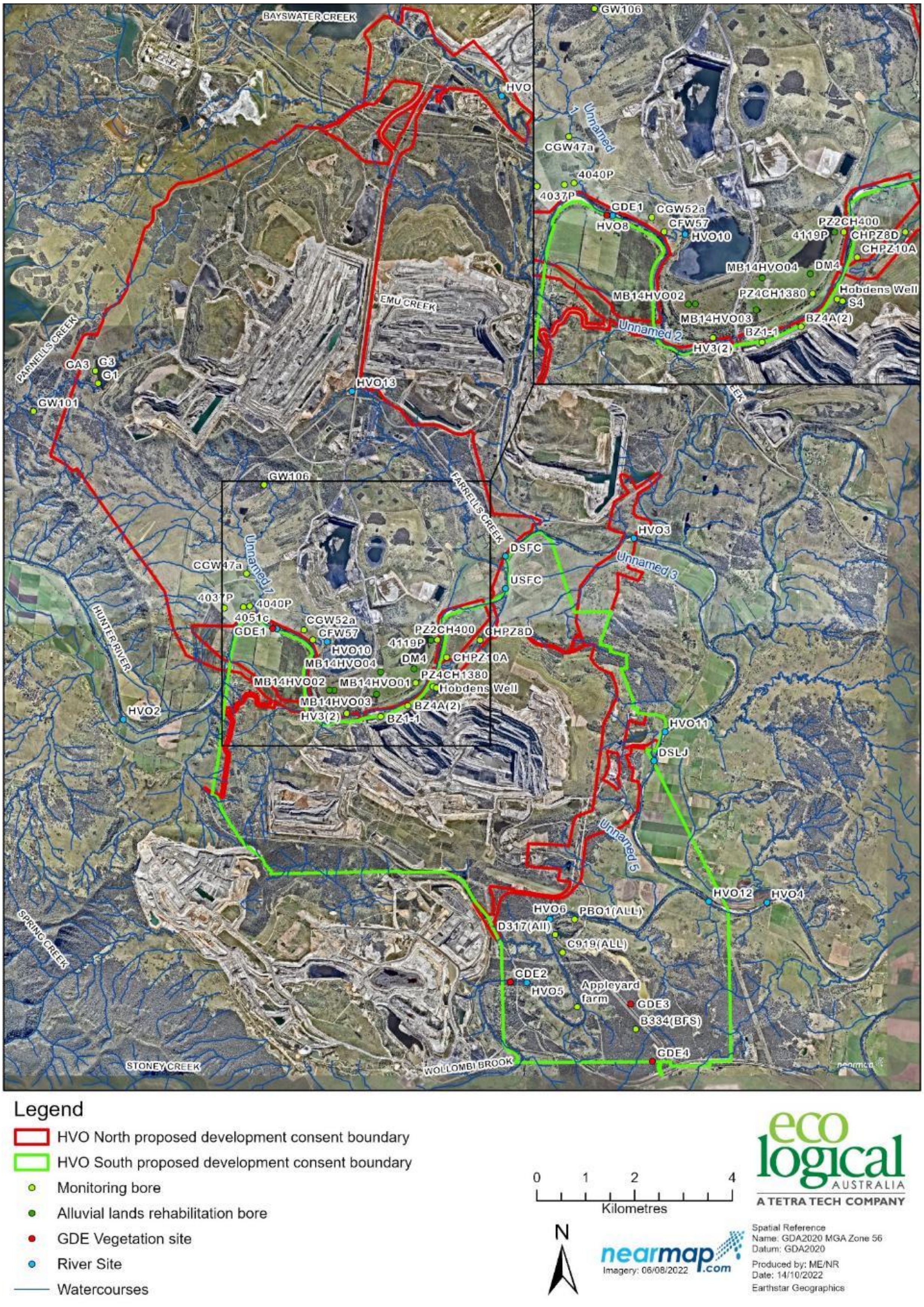


Figure 5. Locations of bores, river sites, and groundwater dependent vegetation sites sampled at HVO.

4.6 Risk assessment process

Risk Assessment Guidelines for Groundwater Dependent Ecosystems (Serov et al 2012) outlines the processes for risk assessment of GDEs. The steps involved in the assessment process (specific to aquifer ecosystems) are:

- Identify and classify the ecosystems;
- Assess the level of dependence on groundwater;
- Identify high ecological value components of the aquifer;
- Determine the ecological value of the aquifer;
- Determine the impact of the activity on the aquifer community;
- Determine risk magnitude to the aquifer community;
- Apply the GDE Risk Matrix; and
- Apply management actions, including mitigation measures.

The GDE Risk Matrix (Table 4) is a method of outlining appropriate management responses for an environmental value under a particular activity.

The matrix consists of a vertical axis that plots ecological value, and a horizontal axis that plots the level of risk of an activity. The ranking of both ecological values and risk is divided into a three-category system of "High, Medium, and Low" values.

The Risk Matrix management action table (Table 5) identifies both the level of management action required and the time frame in which this action needs to be implemented (Action Priority). The management action is aligned with ecological value and does not vary with changes in risk (i.e. the rules for the management of high ecological value ecosystems or aquifers are the same whether the risk is high or low). However, the timing of the management action is aligned and determined by the level of risk.

Table 4: GDE Risk Matrix (Serov et al. 2012)

	Category 1: Low Risk	Category 2: Moderate Risk	Category 3: High Risk
Category 1: High Ecological Value (HEV) Sensitive Environmental Area (SEA)	A	B	C
Category 2: Moderate Ecological Value (MEV) Sensitive Environmental Area (SEA)	D	E	F
Category 3: Low Ecological Value (LEV)	G	H	I

Table 5: Risk Matrix Management Actions (Serov et al. 2012)

Risk Matrix Box	Descriptor	Management action		
		Short term	Mid-term	Long term
A	High value/Low risk	Protection measures for aquifer and GDEs. Baseline risk monitoring.	Continue protection measures for aquifers and GDEs. Periodic monitoring and assessment.	Adaptive management. Continue monitoring.
B	High value/Moderate Risk	Protection measures for aquifer and GDEs. Baseline risk monitoring. Mitigation action.	Protection measures for aquifer and GDEs. Monitoring and periodic assessment of mitigation.	Adaptive management. Continue monitoring.
C	High Value/High Risk	Protection measures for aquifer and GDEs. Baseline risk monitoring. Mitigation.	Protection measures for aquifer and GDEs. Monitoring and annual assessment of mitigation	Adaptive management. Continue monitoring.
D	Moderate Value/Low Risk	Protection of hotspots. Baseline risk monitoring.	Protection of hotspots. Baseline Risk monitoring.	Adaptive management. Continue monitoring.
E	Moderate Value/Moderate Risk	Protection of hotspots. Baseline risk monitoring. Mitigation action.	Protection of hotspots. Monitoring and periodic assessment of mitigation.	Adaptive management. Continue monitoring.
F	Moderate Value/High Risk	Protection of hotspots. Baseline risk monitoring. Mitigation action.	Protection of hotspots. Monitoring and annual assessment of mitigation.	Adaptive management. Continue monitoring.
G		Protect hotspots (if any).	Protect hotspots (if any).	

Risk Matrix Box	Descriptor	Management action		
		Short term	Mid-term	Long term
	Low value/Low risk	Baseline risk monitoring.	Baseline risk monitoring.	Adaptive management. Continue monitoring.
H	Low Value/Moderate Risk	Protect hotspots (if any). Baseline risk monitoring. Mitigation action.	Protect hotspots (if any). Monitoring and periodic assessment of mitigation.	Adaptive management. Continue monitoring.
I	Low Value/High Risk	Protect hotspots (if any).	Protect hotspots (if any).	Adaptive management. Continue monitoring.

5. Desktop review of groundwater dependent ecosystems in the Project area

5.1 GDE Atlas results and DPIE GDE mapping

A review of the BOM GDE Atlas indicates that there are large areas of low potential groundwater dependent vegetation and smaller areas of moderate to high potential dependence (Figure 6). It should be noted that some of the areas shown as being groundwater dependent are inaccurate, and occur in locations that have been disturbed.

Two vegetation types in the vicinity of the Project area have a high potential for groundwater dependence, and two have a low potential for groundwater dependence. The high potential GDEs are:

- Namoi-Upper Hunter River Red Gum Forest, which occurs next to the Hunter River, and
- Central Hunter Swamp Oak Riparian Forest, which occurs along Redbank Creek, an ephemeral tributary of Wollombi Brook near Warkworth. These areas correspond with Central Hunter Ironbark Grassy Woodland, as mapped by Umwelt (2025). As the Umwelt surveys are more recent, and have been confirmed by site visits, their classification is considered most accurate and will be used throughout this report.

The low potential GDEs are more widespread and occur away from the main Hunter River. These are:

- Central Hunter Ironbark Grassy Woodland
- Hunter Valley Footslopes Slaty Gum Forest

In addition to the terrestrial vegetation GDEs, the GDE Atlas shows some known and potential aquatic GDEs:

- Wollombi Brook has been confirmed by regional studies to be an aquatic GDE, dependent on connection to the alluvial aquifer.
- Hunter River is considered a high potential aquatic GDE, dependent on its connection to the Hunter River alluvial aquifer.

Two sites were selected from the vegetation types with high potential for groundwater dependence. One was in the area mapped as Central Hunter Ironbark Grassy Woodland near the river site HVO8. A second site was selected in the Namoi-Upper Hunter River Red Gum Forest, close to river site HVO5. The condition of both vegetation patches was determined using the methods outlined in Section 4.5.

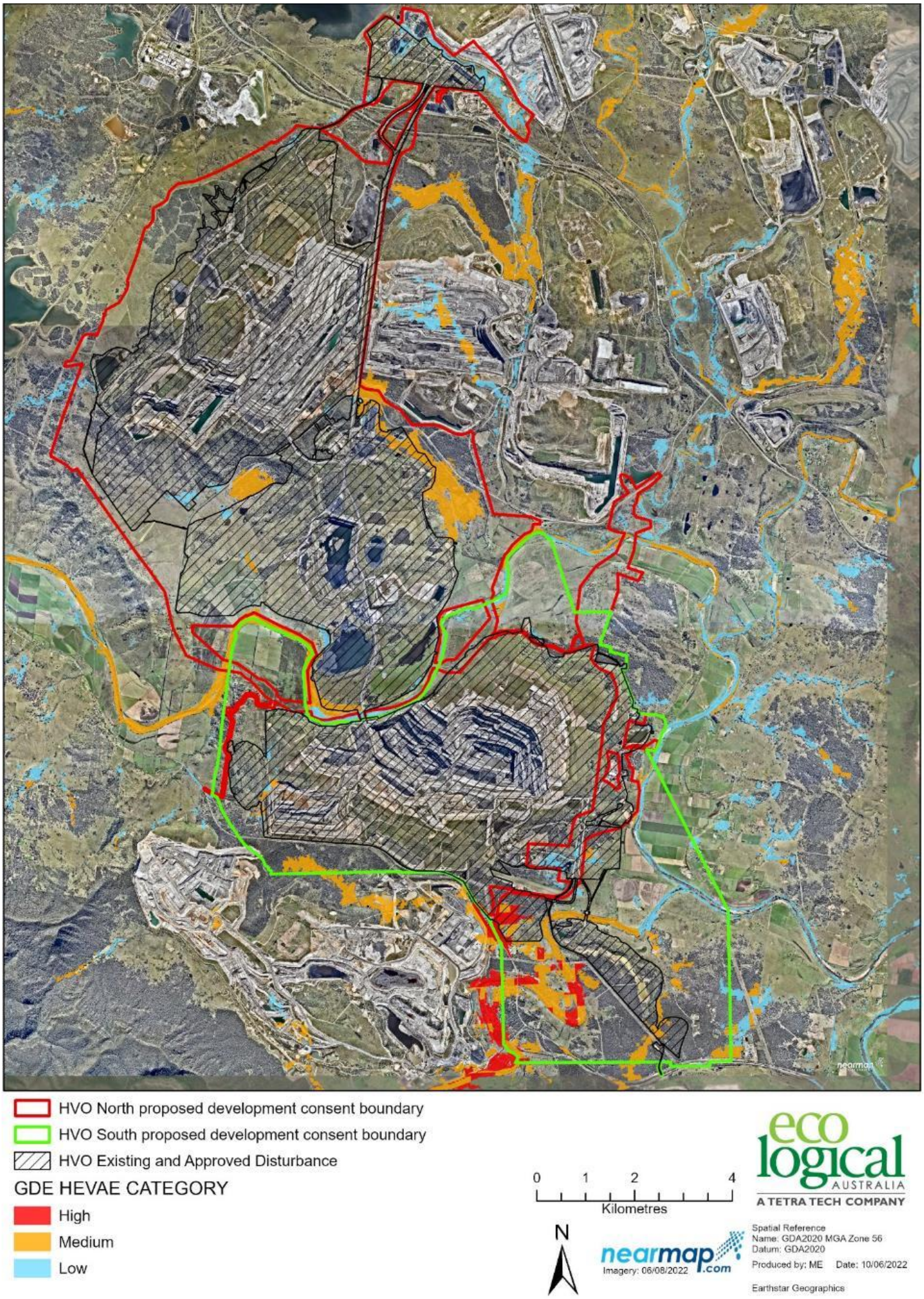


Figure 6. Groundwater dependent vegetation mapped for the HVO area. Data source is DPE (2021) High Ecological Aquatic Ecosystem (HEVAE) Vegetation GDE Value-Hunter/Central Rivers

5.2 Warkworth Sands Woodland Community

The Warkworth Sands Woodland Community may potentially use perched groundwater following high rainfall events but remain dry otherwise, as evidenced by monitoring at groundwater bores installed in 2020. Warkworth Sands Woodland communities are thought to access rainfall infiltration and perched groundwater when it occurs. Smaller patches occur at the northern, north-western, and western extents of HVO North.

5.3 River Red Gum Rehabilitation and Restoration Strategy

River red gums (*Eucalyptus camaldulensis*) in the Hunter Valley have been listed as an Endangered Population under the BC Act. River red gums occur in both HVO North and South areas. This includes the red gum population of Carrington Billabong and the riparian and floodplain zones of the Hunter River and Wollombi Brook (HVO 2022). River red gums are thought to be potentially dependent on groundwater (from alluvial aquifers fed by the Hunter River) but primarily rely on flooding for germination.

Extensive surveys and monitoring of river red gum stands at HVO North and South gathered baseline data on river red gum populations at Carrington Billabong and along the Hunter River and Wollombi Brook (Umwelt 2010, Ecoplanning 2021). These studies concluded that:

- there is low recruitment of river red gums,
- many old trees are dying or have already died,
- a high proportion of adult trees are suffering dieback,
- in most places there are few native groundcover species,
- there is an abundance of herbaceous weed species,
- there is a very low diversity and abundance of small tree and shrub species.

River red gum stands in the Project area are generally small, isolated, and have a high proportion of weeds and dieback (HVO 2022, Ecoplanning 2021). They are generally in poor condition. Impacts to river red gum populations have occurred from historical management activities that have included:

- alteration of the water regime through irrigation,
- alteration of the water regime after the commissioning of Glenbawn Dam in 1958 and recently modified surface runoff,
- unrestricted grazing across most of the billabong,
- pest plants and animals, and
- previous vegetation clearance.

The *River Red Gum Rehabilitation and Restoration Strategy* includes a three-tier approach based on level of impact and the probability of success. It includes Carrington Billabong as requiring High Level Intervention, 6 sites with native recruitment as Intermediate Level Intervention and poorer condition stands as Low Level Intervention (HVO 2022).

5.4 Fisheries database searches

Search of the Fisheries NSW Spatial Data Portal (17 December 2020) show that the freshwater fish community in the Hunter River is in good condition, but that the community of Wollombi Brook is in fair condition. 'Good' condition indicates that the fish community in the river contains a relatively high proportion of native species, that the species expected to occur in the river are present, and that the native species are recruiting successfully (Riches et al. 2016).

Purple spotted gudgeon (*Mogurnda adspersa*) is a threatened fish species mapped to occur in Wollombi Brook. Although mapped for the area based on habitat availability, no records of the species are recorded in Wollombi Brook (Atlas of Living Australia search, September 2022). The nearest confirmed specimens were collected from Mudgee.

A five-part test was conducted to assess potential impacts to purple spotted gudgeon (Appendix A). This concluded that the Project does not pose a significant threat to purple spotted gudgeon.

5.5 Remote sensing analysis for GDEs

Vegetation showing little or no change in Normalised Difference Vegetation Index (NDVI) through time, regardless of changes to rainfall, is potentially using groundwater. Remote sensing analysis for GDEs was done by comparing rainfall data with NDVI for 5 Landsat images sourced from between 2013 and 2020. Analysis identified five areas where NDVI did not change significantly between comparisons (Figure 7), the largest two patches were near South Lemington Pit 1 at HVO South. Two sites were selected from these locations, for field assessment of vegetation condition. These were GDE3 and GDE4 shown in Figure 5.

Patches at 27, 29, and 31 in Figure 7 are unlikely to be groundwater dependent because they are in areas that have previously been disturbed. These are not considered further.

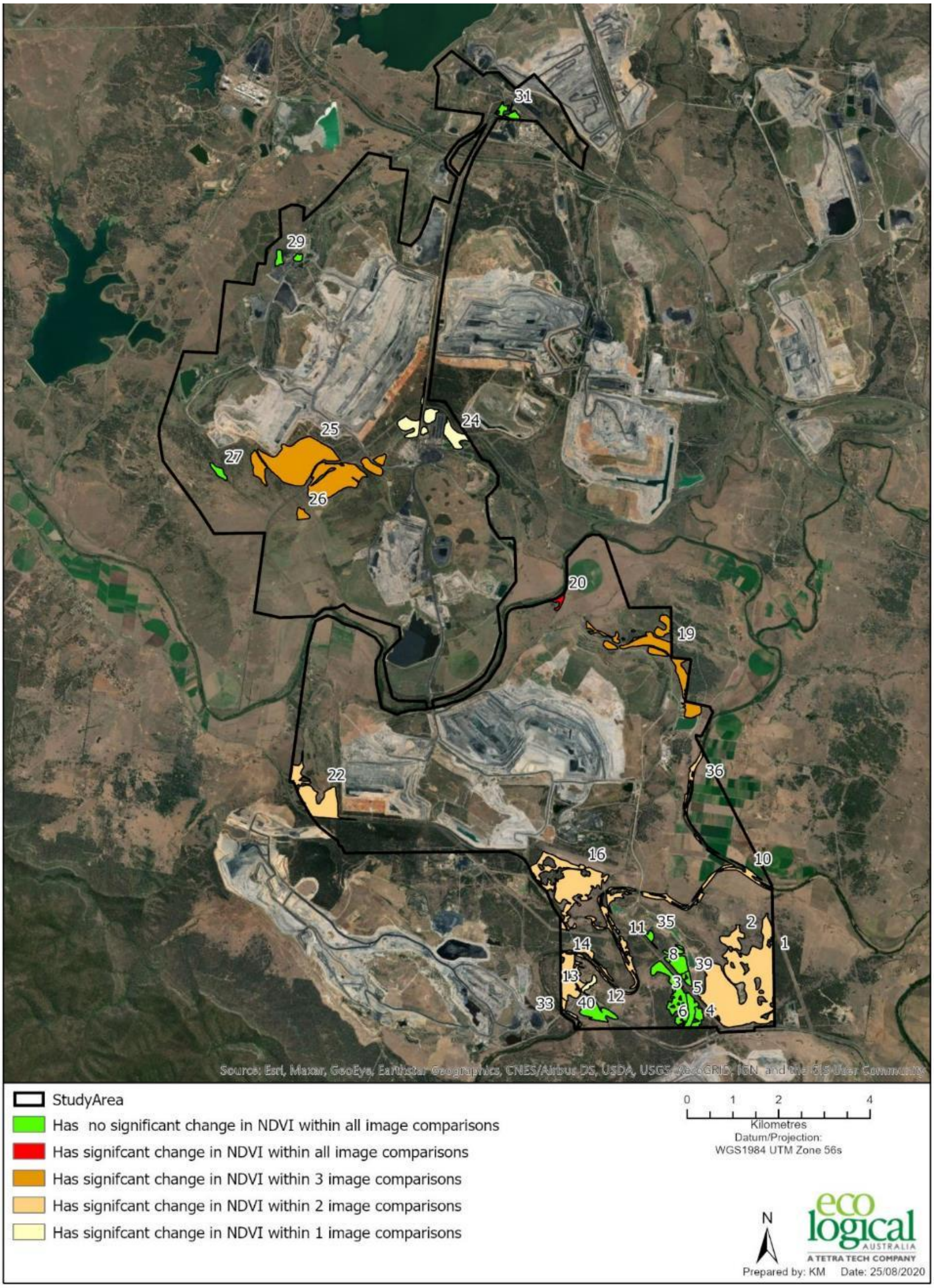


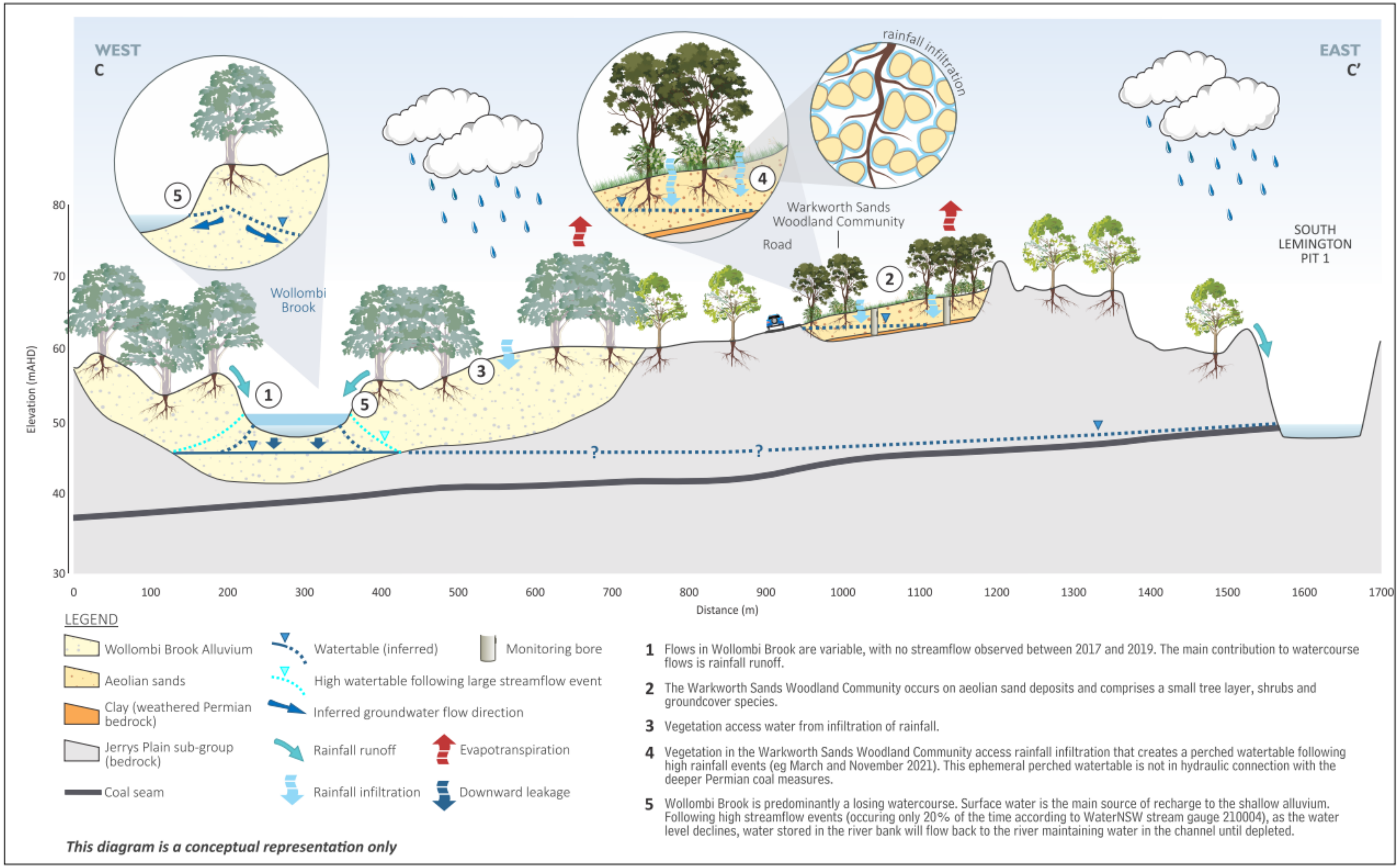
Figure 7: Summary of NDVI changes for images compared between 2013 and 2020. Numbers in map refer to locations of sites used in image analysis.

5.6 Other sources

HVO (2022) indicate that Carrington Billabong is considered a GDE, primarily because river red gums at the billabong are dependent on alluvial groundwater. Alluvial groundwater levels around Carrington Billabong have stayed relatively stable during mining of the Carrington Pit because of recharge from the regulated Hunter River, and to a lesser extent, the installation of a barrier wall through the unconsolidated sediments. Carrington Billabong has been significantly impacted over time from agricultural land use.

The *River Red Gum Rehabilitation and Restoration Strategy* (HVO 2022) outlines the management plans for river red gums of the Carrington Billabong, as well as along the Hunter River and Wollombi Brook.

The Warkworth Sands Woodland Community may potentially use perched groundwater following high rainfall events but remain dry otherwise (Figure 8), as evidenced by monitoring at groundwater bores installed in 2020 (EMM 2022b). Warkworth Sands Woodland communities are thought to access rainfall infiltration and perched groundwater when it occurs. Smaller patches occur at the northern, north-western, and western extents of HVO North.



Receptor Conceptual Diagram – Warkworth Sands and Wollombi Brook

HVO Continuation Project

Water Assessment

EMM creating opportunities

Figure 8. Conceptual representation of groundwater use in Warkworth Sands and Wollombi Brook (from EMM 2022b)

5.7 Stygofauna of the Hunter Valley

5.7.1 Hunter River Hyporheic Study

Stygofauna research in the Hunter Valley began in 2000, with a four-year survey investigating the impacts of river flow variation on groundwater adjacent to the Hunter River (Hancock 2004, 2006). During this survey, samples were collected from beneath the bed sediments and lateral bars of nine sites along the Hunter River, Goulburn River, and Wollombi Brook (Figure 9).

Hyporheic zones are the areas of river bed where groundwater and surface water mix, and often contain surface water, hyporheic, and groundwater taxa (Marmonier et al. 1993, Marmonier and Creuzé des Châtelliers 1991). The results from the survey validated such diversity in the invertebrate community, with groundwater representatives from Microturbellaria (flatworms), Oligochaeta (aquatic worms), and Ostracoda, Cyclopoida, and Harpacticoida (microcrustacea) recorded at all sites (Table 6). At the time of the survey, stygofauna taxonomy for microcrustaceans was poorly developed for eastern Australia, therefore it was not possible to identify specimens to species level; however, groundwater affinity was inferred by the presence of troglomorphic characteristics (e.g. blindness, elongation and depigmentation; Coineau 2000, Danielopol et al. 1994). This was later confirmed in consultation with international experts (Pierre Marmonier, Tom Karanovic, Ivana Karanovic *pers comm.*).

Two genera of Bathynellacea (an order of crustacean) were collected from the hyporheic zone. *Bathynella* sp. was collected from Hunter River sites at Bowmans Bridge, Dights Crossing, and Aberdeen, and from the Goulburn River at Sandy Hollow. *Notobathynella* sp. occurred at Denman, Dights Crossing, and Aberdeen. The largest stygofaunal taxon collected was a single species (Peter Serov *pers comm.*) of the undescribed Anaspidacean family, Family A. Specimens were collected at all Hunter River sites except Dights Crossing.

One species of the isopod *Heterias* sp. 1 was also collected at five sites along the Hunter River. The amphipod family, Paramaletidae, occurred at six hyporheic sites. It is often difficult to distinguish between amphipod species based solely on morphological characters (Finston et al. 2004) and until recently, molecular techniques were not sufficiently available to allow identification to species level. As a result, there is uncertainty about the number of species present in the Hunter hyporheic specimens.

A complete inventory of the species identified in the survey is shown in Table 6.

Table 6: Stygofauna identified in the Hunter River Hyporheic Study (2000)

Location	Alluvial Aquifer Sampled	Oligochaeta	Microturbellaria	Bathynella sp.	Notobathynella sp.	Anaspid Family A sp. 1	Paramelitidae sp.	Heterias sp. 1	Ostracoda	Cyclopoida	Harpacticoida
Bowman Bridge	Hunter River	✓	✓	✓		✓	✓	✓	✓	✓	✓
Jerrys Plains	Hunter River	✓	✓			✓			✓	✓	✓
Moses Crossing	Hunter River	✓	✓			✓	✓	✓	✓	✓	✓
Denman	Hunter River	✓	✓		✓	✓	✓	✓	✓	✓	✓
Dights Crossing	Hunter River	✓	✓	✓	✓		✓	✓	✓	✓	
Warkworth	Wollombi Brook	✓	✓						✓	✓	✓
Sandy Hollow	Goulburn River	✓	✓	✓					✓	✓	✓
Aberdeen	Hunter River	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Maison Dieu	Hunter River	✓	✓			✓	✓		✓	✓	✓

5.7.2 Hunter Valley Alluvial Aquifer Study

The confirmation that stygofauna was present throughout much of the Hunter Valley led to further sampling between 2004 and 2008 of bores in the Hunter River, Pages River, Dart Brook, and Kingdon Ponds alluvial aquifers (Hancock and Boulton 2008, 2009; Watts *et al.* 2007). Samples were collected from 40 groundwater monitoring bores operated by mining companies and the then NSW Office of Water (Figure 9). The sampling program increased the number of known stygofauna taxa in the Hunter Valley to at least 26 groups with this number likely to rise as more of the collected taxa are formally described (Ana Camacho, Tom Karanovic, Ivana Karanovic *pers comm.*). To date, copepods and ostracods from Denman, Muswellbrook, Pages River, Dart Brook (north), and Kingdon Ponds samples have been identified to a species level.

Dart Brook, Pages River, and Kingdon Ponds alluvial aquifers each had similar diversity to the Hunter River alluvial aquifer at Denman. The Hunter River alluvial aquifer near Denman and the Pages River alluvial aquifer had 20 stygofauna taxa. The northern Dart Brook bores had 21 taxa, while Kingdon Ponds had 18 taxa and the Hunter River alluvial aquifer near Muswellbrook had only eight taxa.

A list of the species identified in the survey is shown in Table 7.

Of the stygofauna identified to species level in the survey, only four (*Notobathynella* sp. nov. 3, Anaspid Family A sp. 1, *Dyacyclops cryonastes*, and possibly *Eucyclops* cf *ruttneri*) out of 19 are known to occur at sites beyond the Hunter Valley. With the exception of a previously undescribed species of Hydrobiidae snail, all taxa collected from the Hunter River alluvial aquifer occurred in at least one alluvial aquifer of the tributary streams. Similarly, most species in aquifers of Dart Brook, Pages River and Kingdon Ponds bores were shared with at least one other aquifer. This suggests that approximately 80% of the species recorded are endemic to the region with many species typically occurring in more than one alluvial aquifer. Only four species are endemic to single aquifers: *Metacyclops* sp. 1, *Haplocyclops* sp. 1, *Hancockcamptus* sp. 1, and *Hydrobiidae* sp. nov.

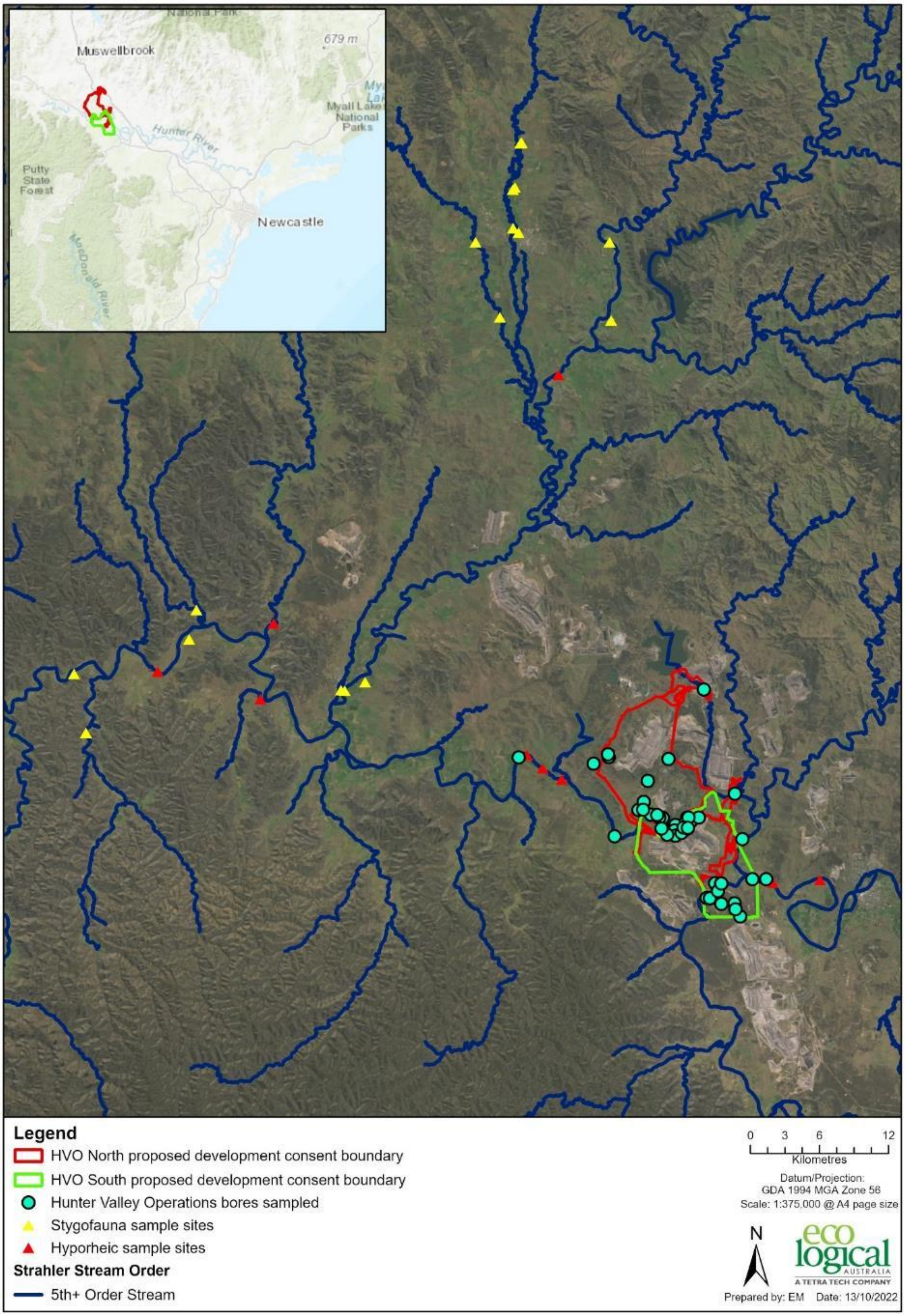


Figure 9. Sites sampled for stygofauna in the Hunter River Hyporheic Study and the Hunter Valley Alluvial Aquifer Study, showing HVO boundary and HVO survey sites.

Table 7. Stygofauna taxa collected during the Hunter River Hyporheic Assessment and the Hunter Stygofauna Assessment

Location	Alluvial aquifer	Oligochaeta	Microturbellaria	*Bathynella* sp.	*Notobathynella* sp.	Anaspid Family A sp. 1	Paramelitidae sp.	*Heterias* sp. 1	Ostracoda	Cyclopoida	Harpacticoida	*Eucyclops* cf. *ruttneri*	*Diacyclops cryonastes*	*Diacyclops* sp. 1	*Metacyclops* sp. 1	*Haplocyclops* sp. 1	*Elaphoidella* sp. 1	*Australocamptus* sp. 1	*Hancockcamptus* sp. 1	*Huntercamptus* sp. 1	*Huntercamptus* sp. 2	*Huntervallia* sp. 1	Aturidae sp 1	Elmidae sp 1	*Carabhydrus stephanieae*	*Limnobodesis* sp nov	Hydrobiidae sp nov
Denman	Hunter River	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓		✓	✓	✓		✓	✓		✓
Muswellbrook	Hunter River	✓	✓				✓		✓	✓		✓	✓	✓													
Dart Brook south	Dart Brook	✓	✓				✓		✓	✓	✓																
Goulburn	Goulburn River	✓		✓	✓					✓	✓																
Pages	Pages River	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓			✓	✓		✓		✓	✓	✓	✓	✓	
Dart Brook north	Dart Brook	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓		✓	✓	✓	✓	✓	✓	✓	
Kingdon Ponds	Kingdon Ponds	✓		✓	✓	✓	✓			✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓			✓	✓		

5.7.3 Other surveys

Other opportunistic sampling for stygofauna has been conducted by Dr Grant Hose (University of Technology, Sydney) from some of the bores sampled in the 2004 to 2008 Hunter Valley Alluvial Aquifer Study. No further taxa were found during these surveys.

ELA has conducted stygofauna surveys for several Hunter Valley mines, including Bengalla (ELA 2013a), Liddell Coal Operations (ELA 2013b), Bylong (ELA 2014) Mount Owen (ELA 2018), and Glendell (ELA 2019) (Table 8). All taxa collected during these surveys were previously known from the alluvial aquifers of the Hunter River or its tributaries, except for two. The exceptions were *Chilibathynella peelensis*, previously known only from near Tamworth, and an unknown species of Anaspidacea that occurred in two bores at Bylong.

During the Mount Owen survey, stygofauna were collected from alluvial aquifers in Yorks, Glennies, and Swamp Creeks, but none were endemic to that project area. Most taxa collected during the Liddell Coal Operations surveys were from the Bowmans Creek alluvium.

During sampling at Glendell, stygofauna were collected from the alluvium of Yorks Creek, Bowmans Creek, Glennies Creek, and Swamp Creek.

Table 8. Stygofauna from five surveys undertaken for mining operations in the Hunter Valley

Order	Family	Genus/ species	Bengalla	Liddell Coal Operations	Bylong	Mt Owen	Glendell
Mollusca	Hydrobiidae					✓	✓
Anaspidacea	Psammaspididae			✓	✓		
	Family A	Anaspidacea sp.			✓		
Bathynellacea	Parabathynellidae	*Notobathynella* sp.	✓	✓	✓	✓	✓
	Parabathynellidae	*Chilibathynella peelensis*			✓		
	Bathynellidae	*Bathynella* sp.	✓	✓	✓		✓
Isopoda	Janiridae	*Heterias* sp.		✓			
Amphipoda	Paramelitidae	*Chillagoe* sp.	✓	✓	✓		
Cyclopoida	Cyclopidae		✓	✓	✓	✓	✓
	Harpacticoida				✓		
Ostrocoda			✓	✓		✓	✓
Coleoptera	Dytiscidae	*Carabhydrus stephanieae*		✓		✓	✓
Coleoptera	Elmidae	*Austrolimnius* sp.		✓			✓
Oligochaeta			✓			✓	

5.7.4 Likelihood of stygofauna occurring in the Project Area

Stygofauna are already known from the alluvium of Hunter River, Bowmans Creek, and Glennies Creek, so occur in the Project area. Although the taxa collected to date are known from other parts of the Hunter Valley, there are potentially other stygofauna taxa in the aquifers that are not yet known.

Stygofauna are most likely in the alluvial aquifers that are well developed, with thick deposits of coarse sediment, and are connected frequently or continuously to the Hunter River alluvium. Where alluvial deposits are thin and the aquifer dries frequently, stygofauna will be unlikely.

The sedimentary rock and coal seam aquifers may also contain stygofauna. However, they are unlikely to occur in unfractured parts of the rock. Communities will be most diverse adjacent to alluvial aquifers such as the Hunter River and Wollombi Brook, from which they can colonise areas of secondary porosity. Stygofauna will extend into the rock and coal aquifers for as far as the network of fracturing or weathering allows. For this reason, the bores most likely to give access to stygofauna communities in the rock and coal aquifers will be relatively shallow (50 to 60 m below ground surface).

Although stygofauna are unlikely to occur in the underlying Permian coal seams due to increasing depth, low hydraulic conductivity and generally high salinity, there may be areas where EC is less than 5,000 µS/cm and weathering is likely to have increased the space available for stygofauna. As the Permian coal seams are the most likely to be impacted by the Project, samples were collected to confirm if stygofauna occur there.

6. Results of field surveys

6.1 Groundwater Dependent Ecosystems

6.1.1 Groundwater dependent vegetation condition

The condition of the vegetation in potential GDE areas was assessed using BAM plots to obtain a vegetation integrity score. A total of four plots were completed. The vegetation integrity score (out of a maximum of 100) represents the degree to which the composition, structure and function of the vegetation at the site differs from the best-on-offer condition (i.e. benchmark) of the vegetation class and formation of the Plant Community Type (PCT). BAM plot data collected at each site was entered into the Biodiversity Assessment Method Calculator (BAM-C) to obtain vegetation integrity scores (Table 9).

Plot 1 (Central Hunter Swamp Oak Riparian Forest) scored 24.8, representing low condition vegetation. This result was strongly driven by a low species composition and structure scores, indicating that vegetation in this area has relatively low diversity and cover of native plant species. As this site was on a large gravel bar beside the Hunter River, it is likely that only shallow alluvial groundwater sourced from the river supports this community.

Plot 2 (Namoi-Upper Hunter River Red Gum Forest) scored 51.9, representing moderate condition vegetation. Minimal cover of native shrub and ground layer vegetation contributed to lowering the overall score. River red gums potentially use groundwater that has recharged the aquifer from the Wollombi Brook at this location (refer Figure 5).

Scores for plots 3 and 4 were combined as they represent the same potential GDE area (Central Hunter Ironbark Grassy Woodland). This area scored 45.2, representing moderate condition vegetation. Minimal cover of native shrub and ground layer vegetation contributed to lowering the overall score.

Table 9: Results of BAM surveys at GDE sites at HVO North and South.

Plot	Plant Community Type	Composition (native plant species richness)	Structure (native plant foliage cover)	Function	Vegetation integrity score
GDE 1	Central Hunter Swamp Oak Riparian Forest	12.1	25.2	50	24.8
GDE 2	Namoi-Upper Hunter River Red Gum Forest	60.8	42	54.8	51.9
GDE 3 and 4	Central Hunter Ironbark Grassy Woodland	54.7	28.8	65.2	45.2

6.1.2 Aquifer ecosystems assessment

Groundwater physico-chemistry

Water quality samples were collected from 14 of the 25 bores visited in April 2020, 2 of the 6 bores sampled in September 2020, and all 5 of the bores sampled in January 2022 (Table 10). EC was between 311 and 9,158 µS/cm across all the bores sampled, with all but two bores having EC less than 5,000 µS/cm. DO concentration was between 27.1 and 83.6% saturation, so all within concentrations tolerated by stygofauna (Hancock and Boulton 2008). pH was between 6.23 and 8.33.

Table 10: Physico-chemical variables measured from bores at HVO North and South (April and September 2020, and January 2022)

Bore ID	EC (µS/cm)	pH	DO (%Sat)	DO (mg/L)	Temperature (°C)	Groundwater level (m below datum)	Notes
4037P	1250	8.33	50.4	4.49	20.03	12.49	Sampled April 2020. Alluvium.
4037P	919	7.38	52.5	4.68	21.29	*	Sampled January 2022. Alluvium.
4040P	937	8.12	48.7	4.16	19.96	10.71	Sampled April 2020. Alluvium.
4040P	882	7.19	47.1	4.13	21.78	*	Sampled January 2022. Alluvium.
4051c							Sampled fauna only April 2020. Alluvium.
Appleyard Farm	347	6.60	83.6	7.41	21.90	6.14	Sampled April 2020. Alluvium.
B334(BFS)	7642	7.49	27.1	2.36	20.80	52.00	Bowfield Seam. Sampled in April 2020.
BZ1-1							Bore diameter was too small to sample. Visited in April 2020. Alluvium.
BZ4A(2)							Bore diameter was too small to sample. Visited in April 2020. Alluvium.
C919(ALL)							Bore was dry (depth 12.03 m). Visited in April 2020. Alluvium.
CFW57	2882	7.44	32.8	3.87	20.69	12.10	Sampled April 2020. Alluvium.
CFW57	4557	7.30	43.1	3.63	21.51	*	Sampled in January 2022

Bore ID	EC (µS/cm)	pH	DO (%Sat)	DO (mg/L)	Temperature (°C)	Groundwater level (m below datum)	Notes
CGW47a							Visited April 2020. Bore was dry. Not sampled. Alluvium
CGW47	4576	7.64	48.1	4.04	21.43	*	Visited January 2022
CGW52a	1984	6.92	52.0	4.49	20.60	12.57	Sampled April 2020. Alluvium.
CGW52a	1672	8.16	52.3	4.16	21.99	*	Sampled January 2022. Alluvium.
CHPZ10A	907	8.61	38.7	38.7	20.15	9.12	Base of casing washed out to depth of 50 cm so may contain surface water. Sampled in April 2020. Alluvium.
CHPZ8D	1476	6.68	31.2	2.69	21.33	6.60	Sampled April 2020. Alluvium.
G1							Bore was dry. Visited April 2020. Alluvium.
G3							Bore was dry. Visited April 2020. Alluvium.
GW101							Bore was dry. Visited April 2020. Alluvium.
GW106	9158	6.67	48.6	4.17	20.89	23.44	Sampled April 2020. Alluvium.
Hobdens Well							Sampled April 2020. No water quality. Alluvium.
HV3(2)	814	6.35	45.8	4.05	20.59	10.92	Sampled April 2020. Alluvium.
PBO1(ALL)							Bore is dry. Visited April 2020. Alluvium.
PZ2CH400	311	6.74	23.2	2	21.92	3.18	Sampled April 2020. Alluvium.
PZ4CH1380	974	7.35	30.1	2.71	20.07	9.42	Sampled April 2020. Alluvium.
HG2	3662	6.23	42.5	3.74	20.56	12.67	Sampled April 2020. Alluvium.
D317(all)							Bore was dry. Visited April 2020. Alluvium.
GA3	918	6.28	31.9	2.84	21.14	10.15	Sampled April 2020. Alluvium.
4119P							Rehabilitated alluvial lands bore. Dry. Visited September 2020.
DM4							Rehabilitated Alluvial Lands bore. Dry. Visited September 2020.
MB14HVO04							Rehabilitated Alluvial Lands bore. Dry. Visited September 2020.
MB14HVO01							Rehabilitated Alluvial Lands bore.

Bore ID	EC (µS/cm)	pH	DO (%Sat)	DO (mg/L)	Temperature (°C)	Groundwater level (m below datum)	Notes
							Dry. Visited September 2020.
MB14HVO03							Rehabilitated Alluvial Lands bore. Sampled September 2020. Water quality not measured.
MBHVO02							Rehabilitated Alluvial Lands bore. Sampled September 2020. Water quality not measured

** Water level not measured in Jan 2022 because depth tape was stolen*

Stygofauna communities

A total of five stygofauna taxa were collected over two survey periods: four taxa from four bores in April 2020, and four taxa from January 2022 (Table 11). No stygofauna were collected in September 2020. All samples came from the Hunter River alluvium.

The Parabathynellidae *Onychobathynella bifuricata* was the most abundant species, with 189 individuals in bore GW106 in April 2020. Another member of the Parabathynellidae family, *Notobathynella* sp. was collected from CHP8D in April 2020, and from CGW52a and CGW47 in January 2022. Twenty-three *Notobathynella* sp. were collected from CHP8D, but only single specimens occurred in each of the other bores. Surface-dwelling aquatic invertebrates Acarina (mite) and Chironomidae (midge larvae) were also collected from CHP8D, indicating that this bore may have been covered by flood water or connected to temporary water such as a puddle.

Three individuals of the stygofaunal amphipod family Paramelitidae were collected from 4040P, along with 8 Cyclopioda (Table 11). This bore also yielded copepods, ostracods, and the stygofaunal family Psammaspidae in January 2022.

Paramelitidae was collected as a single individual in HV3(2) along with an oligochaete worm. A single cyclopoid was also collected from GA3.

The Harpacticoid family Parastenocaridae was collected only in January 2022. One individual was collected from CGW52a, and five from CGW47.

Oligochaeta worms, which could either be stygofauna, soil fauna, or members of the surface aquatic fauna, were collected from 4040P, HV3(2), 4037P, and CGW47. Apart from 4037P, the communities from which these individuals were collected was dominated by stygofauna, so it is reasonable to assume that these are also stygofauna.

Three other bores had taxa that were either from surface water or soil origin (Table 11).

Two bores were sampled in the rehabilitated Alluvial Lands, but neither of these had stygofauna in them.

Table 11: Invertebrate taxa collected from bores at HVO

	GW106	CHPZ8D	PZ2CH400	GA3	4040P		HV3(2)	CGW52a	4037P	CGW47
	Apr-20	Apr-20	Apr-20	Apr-20	Apr-20	Jan-22	Apr-20	Jan-22	Jan-22	Jan-22
Stygofauna										
Anaspidacea, Psammaspididae						2				
Parabathynellidae, *Onychobathynella bifurcata*	189									
Parabathynellidae, *Notobathynella* sp.		23						1		1
Amphipoda, Paramelitidae					3		1			
Harpacticoida, Parastenocaridae								1		5
Possible stygofauna										
Cyclopoida				1	8	1				
Oligochaeta						2	2		1	9
Surface aquatic										
Acarina		7								
Chironomidae		15	15							
Baetidae			4							
Soil fauna										
Collembola			4	1						

6.2 Aquatic ecology assessment

Overview of habitat assessment

At the time of the April and September 2020 surveys, the seven Hunter River sites all consisted of deep pools and had shallow riffles over a sand and gravel bed. The sites all had emergent and submerged macrophytes around the edges or in backwaters, and most contained large woody debris. Lateral sand and gravel bars lined the river, and these contained a mixed riparian zone of River Oak (*Casuarina* sp) and Willows (*Salix* sp). Debris from recent flooding was deposited along banks and in riparian vegetation. These sites had diverse range of aquatic habitats (Figure 10).

Figure 10: Hunter River at HVO1 (Bowmans Crossing) showing riffle, backwater and run habitat, as well as submerged and trailing bankside vegetation (April 2020)

Between the September 2020 and January 2022 surveys, the Hunter River had experienced several large flow events, which caused scouring along the banks and removed some of the macrophyte beds (Figure 11). Flow was still high during September 2020 surveys. Woody debris was washed up along the banks at many sites, and sand and gravel beds experienced erosion and deposition in many places.

Both Wollombi Brook sites (HVO5 and HVO6), consisted of a sand-bed channel approximately 10 to 20 m wide. In April and September 2020, there was a moderate amount of water and turbidity was high.

The banks were fringed with dense stands of *Phragmites australis* and *Casuarina* sp. There was a moderate amount of woody debris in the channel, but no submerged macrophytes were seen. At HVO6, the river was crossed by a concrete causeway containing pipe culverts. Conditions were similar in January 2022, although there was more flow.

Figure 11: Recent bank erosion due to flooding at HVO12 on the Hunter River (photo taken during January 2022).

Bowmans Creek (HVO7) had a narrow, well-defined channel of standing water with cobble and gravel bed. Water was shallow, and was in isolated pools in April and September 2020. The site is fringed with *Phragmites australis,* and has a riparian zone of *Casuarina* sp. The creek was flowing in January 2022, and was approximately 3 m wide when sampled. Riffle habitat was present, as were vegetated banks. Pools contained dense stands of the macrophyte *Potamogeton* sp.

Bayswater Creek (HVO9) was dry in April and September 2020. The channel was full of terrestrial weeds and lined with *Casuarina* sp. This creek constitutes poor aquatic habitat and is only likely to flow following periods of high rainfall or when there is discharge from Lake Liddell. The site was not visited in January 2022.

Carrington Billabong (HVO10) had no standing water in April and September 2020. Vegetation in the billabong consisted of river red gums and exotic groundcovers. The river red gums have potential to be aquatic habitat during periods when there is water in the billabong.

The only water present at HVO13, on Farrells Creek, was in an excavated hole approximately 20 m x 20 m. No macrophytes or other habitat features were seen in the water. Banks consisted of sand and had been graded. There was no vegetation around the dam, so very little aquatic habitat. This was the case for all three survey periods.

Surface water physico-chemistry

EC was below 1,000 µS/cm for all sites except HVO7 (Bowmans Creek) in April 2020 and HVO3 (Hunter River at Lemington Road realignment) in September 2020 (Table 12). DO concentration in April 2020 was below ANZG 2018 guidelines for all sites except HVO3, but was only low at four sites each in September 2020 and January 2022 (Table 12). At many sites, pH was high in April 2020 and low in September 2020. In January 2022, pH was slightly above recommended guideline value at 8 sites (Table 12). Turbidity for all Hunter River sites exceeded recommended guidelines in April 2020, with measurements exceeding 100 NTU. Most of the Hunter River sites were still relatively turbid in September 2020 and January 2022, due to high river flow (Table 12).

Table 12: Water quality variables at surface sites for three field surveys.

	Temperature (°C)			EC (µS/cm)			DO (% saturation)			DO (mg/L)			pH			Turbidity (NTU)			Alkalinity		
ANZG (2018):				125-2,200			85-110						6.5-8.0			6-50					
Survey date:	Apr-20	Sep-20	Jan-22	Apr-20	Sep-20	Jan-22	Apr-20	Sep-20	Jan-22	Apr-20	Sep-20	Jan-22	Apr-20	Sep-20	Jan-22	Apr-20	Sep-20	Jan-22	Apr-20	Sep-20	Jan-22
HVO 1	19.2	19.6	24.1	687	887	617	78.7	126.8	83.9	7.14	11.48	7.07	7.1	5.84	8.08	138	30.7	64.2	217	231	NA
HVO 2	19.6	19.7	24.4	832	884	580	81.9	129.1	86.4	8.19	11.7	7.22	7.2	5.86	8.08	154	50.2	81.4	212	216	NA
HVO 7	21.0	18.2	23.7	3849	848	836	80.2	88.5	89.2	6.99	8.32	7.58	6.59	6.42	7.86	9.3	48.1	16.5	300	207	NA
HVO 8	17.4	19.5	23.1	677	877	579	75.7	114.2	86.3	7.24	10.43	7.43	8.51	6.28	8.15	293	36.8	77.8	206	218	NA
US Parnells *			23.8			594			95			7.95			8.17			73.8			NA
DS Parnells *			NA			NA			NA			NA			NA			NA			NA
US Farrells *			NA			NA			NA			NA			NA			NA			NA
HVO13	20.2	16.6	25.7	217	264	326	63.3	75.9	73.4	5.71	7.35	5.96	6.9	7.28	8.17	19.1	7.46	137	160	87	NA
DS Farrells *			NA			NA			NA			NA			NA			NA			NA
HVO 3	19.7	16.9	24.7	762	1,680	621	86.2	58.8	86.5	7.92	5.67	7.1	6.52	7.97	8.15	103	3.88	88.8	202	157	NA
HVO 11 (US Lake James)	16.2	19.9	NA	710	856	NA	72.2	89.4	NA	7.08	8.14	NA	9.05	7.84	NA	150	55.3	NA	200	195	NA
DS Lake James *			23.7			641			85.6			7.29			8.05			87.1			NA
HVO 5	16.95	16.73	23.31	563	545	521	64.7	75.3	77.6	6.25	7.27	6.67	6.13	6.23	7.95	23.8	12.5	11	67	39	NA
HVO6	16.99	23.72	24	564	244	578	70	93.7	84.5	6.7	7.92	7.13	6.6	7.06	7.6	26	74.9	10.6	67	33	NA

	Temperature (°C)			EC (µS/cm)			DO (% saturation)			DO (mg/L)			pH			Turbidity (NTU)			Alkalinity		
HVO 12	17.4	17.4	23.7	362	554	637	83.6	82.8	95.9	8.01	7.93	8.1	8.82	7.07	8.02	135	8.16	75	172	43	NA
HVO 4a *	16.7	18.7	NA	645	771	NA	76	90.2	NA	7.38	8.38	NA	8.43	6.79	NA	130	25.5	NA		154	NA

Sites marked with * were established in January 2022. Data marked with NA were not collected in January because of a faulty water quality meter

Macroinvertebrate communities

A total of 43 invertebrate taxa were collected during the surveys at HVO across the three survey dates. Taxonomic richness at each site was between 8 and 15 in April 2020 (average 10.4 ± 2.4), 9 and 15 in September 2020 (average 12.7 ± 2.1), and 6 and 11 in January 2022 (average 8.5 ± 1.8). Richness was generally higher at the Hunter River sites than at tributary sites (Figure 12).

Average SIGNAL score was used as an indicator of ecosystem condition, and was fairly consisted across all times sampled. SIGNAL scores in April 2020 for the Hunter River were between 2.7 and 4.8, and 3.3 to 3.8 for the tributaries sampled (Figure 13). In September 2020, SIGNAL scores were 3.8 to 4.6 for the Hunter River and 3.6 to 3.9 for tributaries. January 2022 SIGNAL score was between 3.3 and 4.8 at Hunter River sites, and 3.6 to 3.9 at tributaries.

The lowest scoring site was HVO11 in April 2020 (Figure 13). This is a Hunter River site approximately 3 km downstream of Glennies Creek confluence, and in April 2020 had a SIGNAL score of 2.7. It remained low (3.6 and 3.5) for the subsequent surveys. SIGNAL scores for individual survey periods were highest at USP (Hunter River upstream of Parnells Creek) (4.8) and HVO12 (Hunter River, H3) (4.7). HVO1 (Bowmans Crossing) and HVO2 (Moses Crossing) were the most consistently highest-scoring sites across all three surveys, with values between 3.8 and 4.5 across all surveys (Figure 13).

SIGNAL scores below 4 indicate severe pollution, while scores between 4 and 5 indicate moderate pollution. All the sites sampled were either severely or moderately polluted.

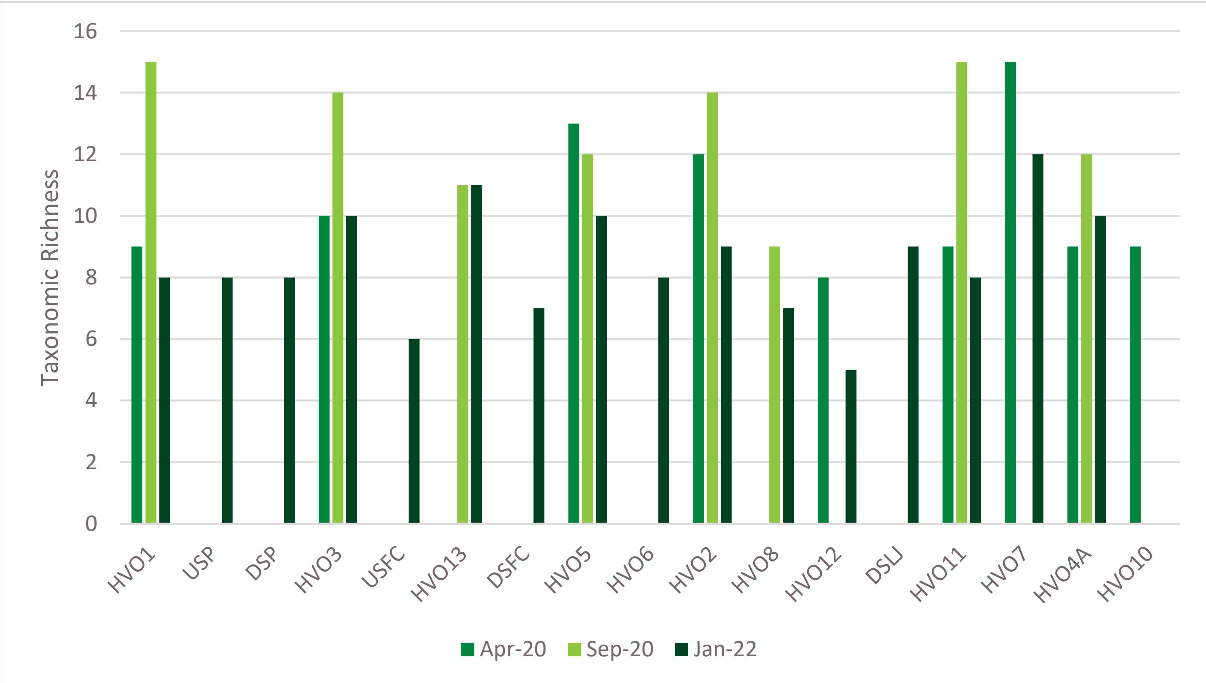


Figure 12. Macroinvertebrate taxonomic richness at surface sites along the Hunter River and tributaries (sites are graphed in order from upstream to downstream. Refer to Figure 5 for location)

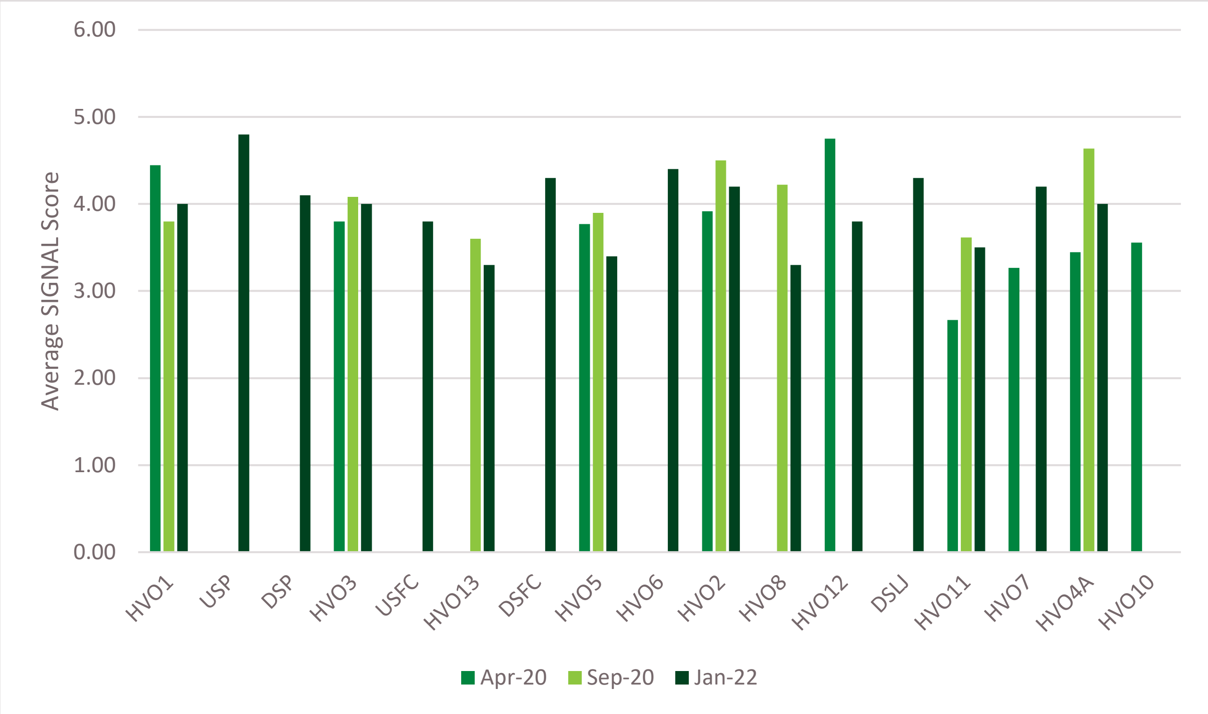


Figure 13: Average SIGNAL scores for aquatic sites along the Hunter River and tributaries (sites are graphed in order from upstream to downstream. Refer to Figure 5 for location)

Macroinvertebrate communities differed between dates (ANOSIM R= 0.45, P<0.01, Figure 14). The difference in communities is shown in the MDS plot in Figure 14 by the lack of overlap between the three clusters of sites representing the three survey dates. Atyidae, Leptoceridae, Ceratopogonidae and Cyclopoida were more common in September 2020 than April 2020, while in April the sites were characterised by Palaemonidae and Culicidae. In January 2022, sites were dominated by Atyidae, Leptoceridae, and Micronectidae.

There was no difference between invertebrate communities at control (upstream) and impact (downstream) sites during April 2020 (ANOSIM R=-0.20, P=0.86, Figure 15), September 2020 (ANOSIM R=0.18, P=0.18, Figure 16), or January 2022 (ANOSIM R=-0.16, P=0.86, Figure 17).

January 2022 was the first survey period where data was collected for sites upstream and downstream of HRSTS discharge sites (Table 13). Differences in taxonomic richness were minor, with only one family more occurring at the downstream site than upstream for the Dam 11N on Farrells Creek and Lake James HRSTS sites (Table 13). SIGNAL scores were higher at the sites downstream of Farrells Creek and Lake James than for the upstream sites, but were lower at the site downstream of Parnells Creek.

Table 13. Aquatic invertebrate data for sites upstream and downstream of HRSTS sites

	Site code:	USP	DSP	USFC	DSFC	HVO11	DSLJ
	HRSTS sampling site:	Upstream Parnells Ck	Downstream Parnells Ck	Upstream Farrells Ck	Downstream Farrells Ck	Upstream Lake James	Downstream Lake James
Number of Taxa	Apr-20					9	
	Sep-20					15	
	Jan-22	8	8	6	7	8	9
SIGNAL	Apr-20					2.67	
	Sep-20					3.62	
	Jan-22	4.8	4.1	3.8	4.3	3.5	4.3

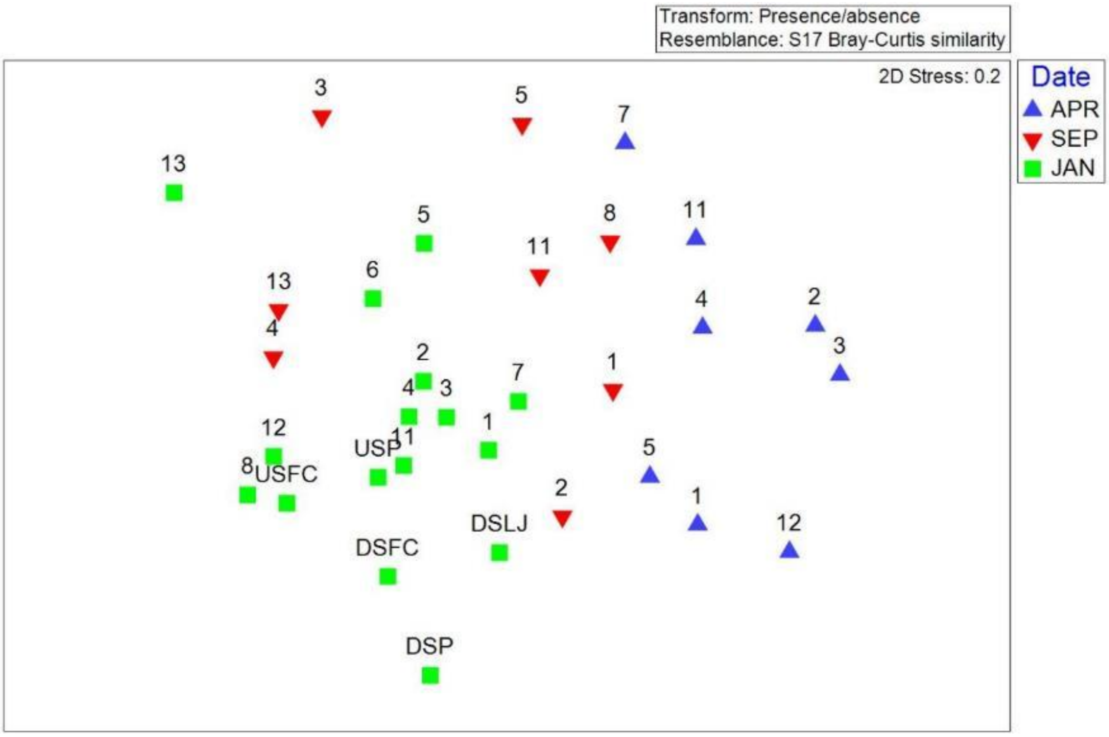


Figure 14: Non-metric multidimensional scaling plot of macroinvertebrate community data at each site for April 2020 (blue triangles), September 2020 (red triangles), and January 2022 (green squares)

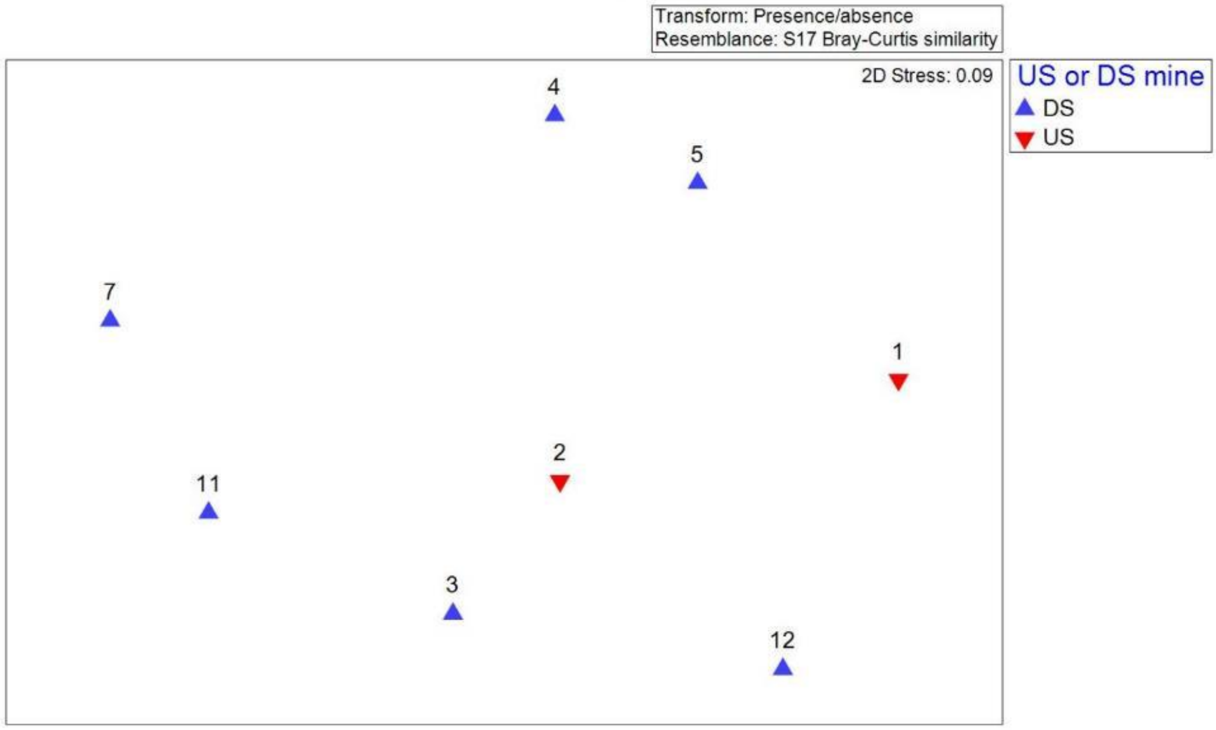


Figure 15: nMDS plot of macroinvertebrate communities at control (red triangles) and impact (blue triangle) sites during April 2020

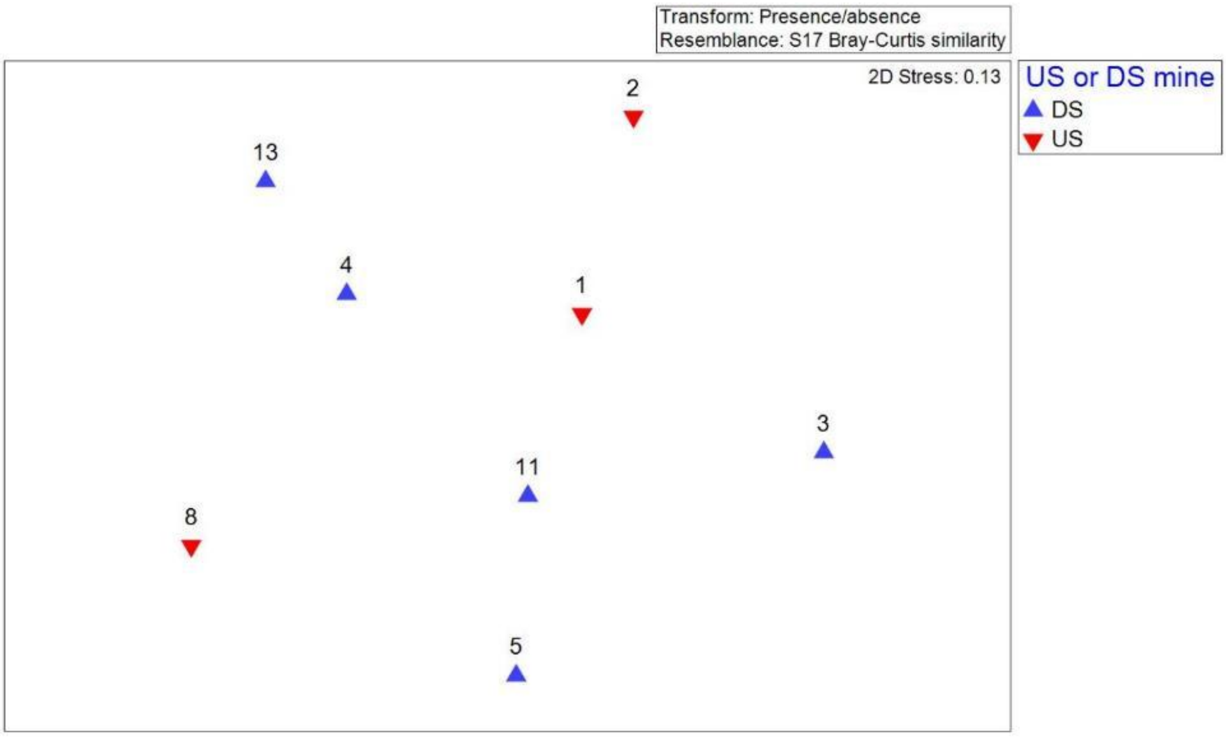


Figure 16: nMDS plot of macroinvertebrate communities at control (red triangle) and impact (blue triangle) sites during September 2020

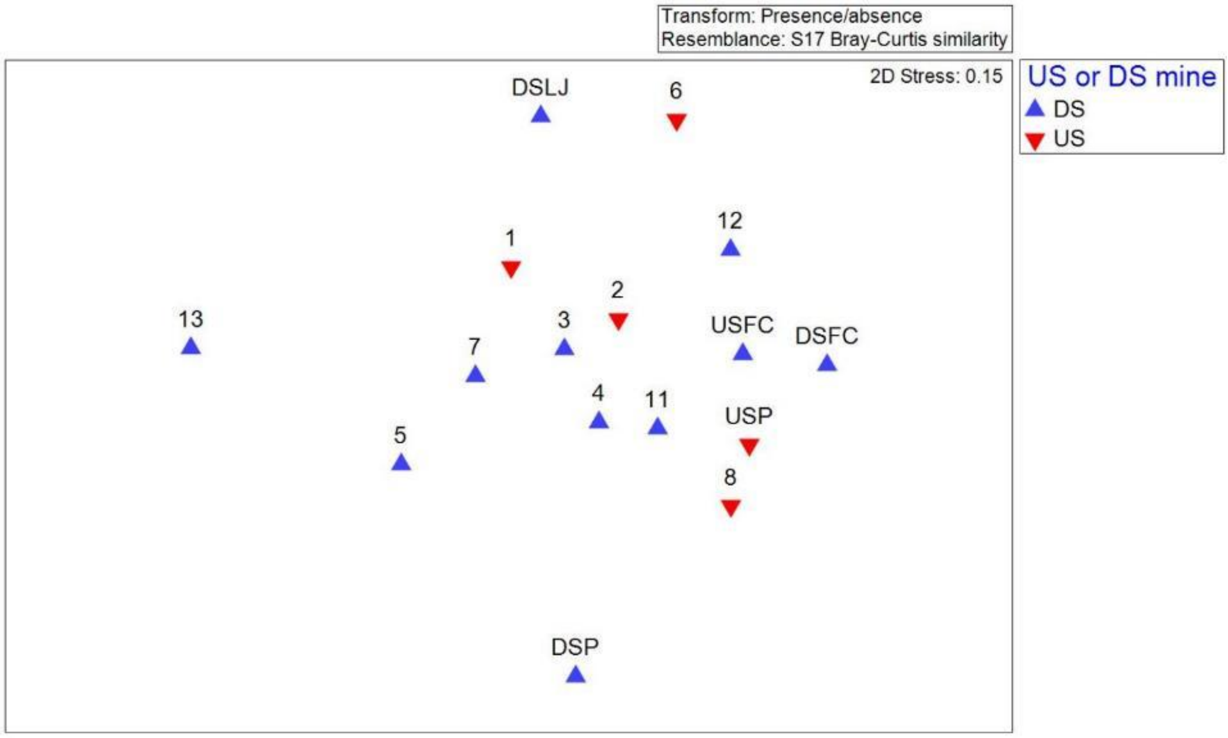


Figure 17: nMDS plot of macroinvertebrate communities at control (red triangle) and impact (blue triangle) sites during January 2022

7. Impact assessment

7.1 Overview of potential impacts

7.1.1 Impacts to Hunter River Alluvium

The Project proposes mining through the remnant paleochannel located between Mitchell/West Pit and Carrington West Wing area. This area is known to contain stygofauna from sampling at GW106 and CGW47, which will be removed by the project. Mining has already occurred in the Carrington extension area, removing part of the western arm of the paleochannel sediments and limiting connection to the Hunter River and connected alluvium. Mining in the Carrington West Wing area is already approved. Low permeability barrier walls in the Alluvial Lands and eastern arm of the paleochannel (Carrington Pit barrier) have been put in place to reduce the extent of drawdown in the alluvium though they do not stop it completely, as depressurisation of the interburden and coal strata underlying the alluvium allows depressurisation to occur beneath the barrier wall. A barrier wall is proposed for installation in the western arm of the paleochannel (the approved but not yet constructed Carrington West Wing Barrier Wall) as part of the Project, and this is expected to limit drawdown in the alluvium in a similar manner to the existing low permeability barrier walls.

Modelling completed by EMM (2025a) predicted groundwater levels and drawdown in response to the proposed mine plan. Some incremental drawdown in the Hunter River alluvium is predicted near HVO North, but this is only minor during operations, being 0.5 m at a small area (approximately 50 x 50 m) on the northern edge of the alluvium near Carrington Billabong, and then 0.2 m across a larger area beyond that. Cumulative drawdown affects a slightly larger area near Carrington Billabong, and a section further east, although only to a drawdown extent of 0.2 m. The southern margin of Hunter Alluvium adjacent to HVO South has a negligible section of alluvium that will experience 0.5 m cumulative drawdown and a slightly larger section 80 m wide that will experience 0.2 m drawdown. Water levels in the alluvium would be buffered against excessive drawdown because it has limited connection with the underlying Permian aquifer and alluvial aquifer water levels will be supplemented by recharge from the Hunter River and rainfall recharge (EMM 2025b).

Post-closure cumulative drawdown is predicted to be more widespread through the aquifer, with the 0.2 m drawdown contour from HVO North occurring beneath much of the northern section of alluvium west of Carrington Pit and extending south under the Hunter River. A very small, narrow section of aquifer immediately south of the Carrington Pit barrier wall is predicted to experience 2 m of drawdown (EMM 2025b). Cumulative drawdown in the alluvium south of the Hunter River is predicted to be mostly 0.2 m, apart from a narrow section of marginal sediments with 0.5 m drawdown north of Cheshunt Pit. Predicted drawdown post-closure is due to ongoing evaporative losses from the final voids as the groundwater system gradually adjusts to a new post-mining equilibrium.

Drawdown between 0.2 and 0.5 m extends from the Wollombi Brook alluvium into a 4 km reach of the Hunter River alluvium. Over most of the dewatered area, the alluvium is thick enough that the impact of 0.5 m drawdown is negligible. Only the marginal sediments would potentially go dry, although the impact of this would be negligible because this is only a very small fraction of the Hunter alluvial aquifer.

Negligible cumulative drawdown (less than 0.2 m) is predicted at CGW52a, which had *Notobathynella* and Parastenocaridae. Despite the modelled drawdown, the alluvium will remain saturated due to leakage of surface water through the bed of the regulated Hunter River (AGE 2022; EMM 2025b). There is no incremental drawdown predicted at HV3(2), GA3, or CHPZ8D.

The extent and magnitude of the predicted cumulative drawdown in the Hunter River alluvium is less than that predicted for the EIS (AGE 2022) and as presented as part of responding to submissions. This is due to the changes to the mine plan and the HVO North pit being shallower than and ceasing further from the Hunter River in the Carrington area than that proposed in the EIS.

Saturated aquifer thickness has been modelled for Hunter alluvium between HVO North and HVO South for the operational period of the amended project (EMM 2025). Over most of the aquifer there is little change in saturated thickness between 2020 and 2045. For the duration of the project, this indicates that there should be a sufficient amount of saturated sediments for stygofauna to inhabit.

7.1.2 Impacts to Wollombi Brook Alluvium

Consistent with the EIS and AGE (2022) predictions, most of the Wollombi Brook Alluvial Aquifer between South Lemington Pit 1 and Lemington Underground is modelled to experience between 0.2 and 2 m of drawdown from the cumulative impacts of depressurisation. The greatest magnitude drawdown is predicted to occur near Lemington Underground, affecting just a 100 m expanse of alluvium. Much of the alluvium west of South Lemington Pit 1 and east of the southern extent of Lemington Underground is predicted to experience 1 m of cumulative drawdown. The alluvium west of the confluence of Wollombi Brook and Hunter River is predicted to experience up to 0.5 m drawdown (cumulative), and there is a finger of drawdown north of this along the western edge of the alluvium. The 0.2 m drawdown contour east of Lemington Underground and north of South Lemington Pit 1, extends beneath the Hunter River and beneath much of the floodplain east of the Hunter River.

There is no incremental drawdown predicted in the Wollombi Brook alluvium, given mining is no longer proposed at South Lemington Pit 1 or 2 (i.e. the Project is predicted to have a positive impact in this area compared to the Approved Project).

7.1.3 Impacts to surface water

The HVO Complex is within the catchments of some tributaries of the Hunter River, including Parnells, Farrells, Pikes, and Bayswater Creeks, Hobden Gully, Wollombi Brook, and five unnamed tributaries (Engeny 2025). The Project will not intercept new catchments.

Based on data provided from groundwater modelling (EMM 2025a), maximum impacts to baseflow from the Approved Project have already occurred (Engeny 2025). Changes to stream flow resulting from the Amended Project would be due to altered surface catchment areas and/or changes to surface water-groundwater interaction that are caused by watertable drawdown. Reductions in baseflow from less groundwater interaction are expected in Hunter River and Parnells Creek, while small changes to catchment landscape would occur in most tributaries and have a small downstream impact on Hunter River (Engeny 2025). These changes range from changes to haul roads, road realignments, increases in stockpile areas, increases in mining area, and rehabilitation areas.

Flow sequencing analysis indicates that, for most of the waterways in the catchment of the Project will result in minimal or no changes to the number of zero flow days compared to those already expected from approved operations. For the analysis, a ‘dry’ day for the Hunter River is classified as having a flow of less than 100 ML/day. For all other creeks, the ‘dry’ day is classified as having a flow of less than 0.1 ML/day. The number of expected no flow days, and the average duration of dry periods, are also shown in **Error! Reference source not found.**.

The Hunter River has an average of 24 dry days per year under the current flow regime, and the average duration of the dry periods are 5 days (Table 14). These do not change for the amended project in the operational phase, and after project closure (Engeny 2025). Likewise, the average number of dry days in Wollombi Brook remains the same for all modelled scenarios, with an average of 52 dry days per year, and average dry duration of 5 days (Table 14). There will be negligible impacts on aquatic ecology for these two waterways because there are no differences in the modelled number of dry days. For the Hunter River, even though there are 24 dry days modelled per year, these are unlikely to be realised because flow is be mitigated through regulated releases from Glenbawn Dam (via HVO’s existing entitlements). Percent changes for each of the long term flow scenarios are shown in Table 15

Many of the ungauged, ephemeral streams will experience some level of change to their average annual number of flow days under the Amended Project plan. There will be more dry days per year under the Amended Project operations for Parnells Creek, Pikes Creek, Unnamed Tributary 1, and Farrells Creek, and fewer dry days for Unnamed Tributaries 2, 5, and 6 (Table 14). For most creeks, the difference between Approved and Amended Project is less than 7 days, but for Unnamed Tributary 1 there are 39 more dry days per year under the Amended Project during operations (Table 14). The expected decline in flow to this creek results from the loss of its upper tributaries and their catchments during excavation of West Pit. These are similar to the results modelled for the EIS.

All ungauged ephemeral streams will have fewer dry days at project closure under the amended plans, than for the currently approved operations, except for Parnells Creek, which will have 4 more dry days on average per year (Table 14). The differences range from 1 fewer dry day at Pikes Creek, to 53 fewer dry days at Unnamed Tributary 5. The biggest change influencing catchment area at Pikes Creek is the removal of the Lemington Rail Loop at project completion (Engeny 2025). There is also a large increase in the number of flow days at Hobden Gully after closure of the amended project, with 44 fewer dry days. Average duration of dry period remains between 61 and 64 across all of the ungauged streams and all three modelled scenarios (Table 14).

Table 14. Long term average annual flow characteristics (Engeny 2025)

Waterway		Average Annual Flows (ML/year)			Average Annual Dry Days			Average duration of dry period (days)		
		Approved	Amended Project Operations	Amended Project Closure	Approved	Amended Project Operations	Amended Project Closure	Approved	Amended Project Operations	Amended Project Closure
Gauged streams	Hunter River	409,800	409,400	411,000	24	24	24	5	5	5
	Wollombi Brook	172,300	172,300	173,000	52	52	52	32	32	32
Ungauged streams	Parnells Creek	630	630	1,220	252	256	256	63	63	64
	Unnamed Trib 1	480	140	680	264	303	250	63	61	63
	Unnamed Trib 2	110	130	140	310	305	302	60	61	61
	Hobden Gully	70	70	360	318	318	274	62	62	61
	Farrells Creek	420	340	680	269	276	249	62	61	63
	Pikes Creek	400	390	410	270	271	269	62	62	62
	Bayswater Creek	880	880	1,230	238	238	221	64	64	63
	Unnamed Trib 3	380	380	550	272	272	259	62	62	63

Waterway		Average Annual Flows (ML/year)			Average Annual Dry Days			Average duration of dry period (days)		
		Approved	Amended Project Operations	Amended Project Closure	Approved	Amended Project Operations	Amended Project Closure	Approved	Amended Project Operations	Amended Project Closure
	Unnamed Trib 5	100	110	550	312	309	259	60	60	63
	Unnamed Trib 6	50	70	70	325	320	320	63	62	62

Table 15. Change in long term annual flow characteristics (Engeny 2025)

Waterway		Average Annual Flows (ML/year)		Average Annual Dry Days		Average duration of dry period (days)	
		Amended Project Operations vs Approved Operations	Amended Project Closure vs Approved Operations	Amended Project Operations vs Approved Operations	Amended Project Closure vs Approved Operations	Amended Project Operations vs Approved Operations	Amended Project Closure vs Approved Operations
Gauged streams	Hunter River	-0.1%	0.3%	0%	0%	0%	0%
	Wollombi Brook	0%	0%	0%	0%	0%	0%
Ungauged streams	Parnells Creek	0%	94%	2%	-12%	0%	2%
	Unnamed Trib 1	-71%	42%	15%	-5%	-3%	0%

Waterway		Average Annual Flows (ML/year)		Average Annual Dry Days		Average duration of dry period (days)	
		Amended Project Operations vs Approved Operations	Amended Project Closure vs Approved Operations	Amended Project Operations vs Approved Operations	Amended Project Closure vs Approved Operations	Amended Project Operations vs Approved Operations	Amended Project Closure vs Approved Operations
	Unnamed Trib 2	18%	27%	-2%	-3%	2%	2%
	Hobden Gully	0%	414%	0%	-14%	0%	-2%
	Farrells Creek	-19%	62%	3%	-7%	-2%	2%
	Pikes Creek	-3%	3%	0%	0%	0%	0%
	Bayswater Creek	0%	40%	0%	-7%	0%	-2%
	Unnamed Trib 3	0%	45%	0%	-5%	0%	2%
	Unnamed Trib 5	10%	450%	-1%	-17%	0%	5%
	Unnamed Trib 6	40%	40%	-2%	-2%	-2%	-2%

7.2 Likelihood of significant impacts to GDEs

7.2.1 Groundwater dependent vegetation

Four potentially groundwater dependent vegetation communities were visited during the field survey, although none of these occur in areas of modelled incremental drawdown (EMM 2025a).

All sites were in moderate or low ecological condition and would be considered as having Poor Ecological Value (Serov et al 2012). GDE 3 and 4 are on shallow sandy substrate near Warkworth, and vegetation communities may use water in the sands. These vegetation communities showed very little change in their NDVI, even during dry periods, so are likely to have some dependence on subsurface water from rainfall infiltration and in the perched aquifer when it occurs after high rainfall events. In this location, the geology is dominated by Warkworth Sands, which are disconnected from the aquifers likely to be impacted by approved development at HVO South.

GDE 1 and 2 were close to the Hunter River and Wollombi Brook respectively, and much of the groundwater at these sites would contain high proportions of surface water. No drawdown (cumulative or incremental) is modelled for either site. GDE 1, which is on a sand and gravel bar beside the Hunter River between HVO North and South and is buffered from drawdown by the groundwater barrier in place between Carrington Pit and leakage from the river. Additionally, there will be no increase in the number of dry days, nor the duration of dry periods at Wollombi Brook or the Hunter River, so there would not be an impact on these GDEs. Given no drawdown is predicted and the connection to surface water at these sites, the vegetation will not be impacted by the Project.

River red gum communities mapped by HVO (2022) are thought to be groundwater dependent, so are potentially impacted by changes to groundwater regime. Modelling predicts some drawdown in the Quaternary alluvium of the Hunter River near the riparian river red gum sites, however, the incremental drawdown is predicted to be less than 0.5 m and no widespread dewatering will occur. Minor drawdown of 0.2-0.5 m is modelled for below Carrington Billabong during operations, and 1-2 m cumulative drawdown post-operations (EMM 2025a). Any decline in the water table due to mining activities in other parts of the aquifer is likely to be replaced by the leakage of surface water through the bed of the Hunter River (EMM 2025b). River red gum populations close to the Hunter River will continue to have access to groundwater due to drainage from the Hunter River, and no significant impact is expected.

The river red gum community of the Hunter Valley is considered a threatened population under the BC Act, but at HVO it is highly disturbed so is classified in the GDE Assessment Guidelines as having a moderate ecological value. Under the Risk Matrix, the ecosystem is classified as D (moderate ecological value, low risk).

7.2.2 Aquifer ecological communities

Most of the larger alluvial aquifers in the Project area are confirmed as stygofauna habitat and have diverse stygofauna communities, meaning they are considered High Ecological Value. These include the alluvial aquifers of Hunter River and Wollombi Brook. All stygofauna taxa collected during the HVO surveys are widespread throughout the Hunter Valley. *Onychobathynella bifuricata* has previously been collected from the Hunter River alluvium near Aberdeen (Camacho and Hancock 2012), while *Notobathynella* sp. and Paramelitidae are known to occur along the Hunter River alluvium between Aberdeen and Singleton (Hancock and Boulton 2008).

Drawdown is only predicted for small sections of the alluvial aquifer during operations, and cumulative drawdown is predicted to be around 0.2 m in the alluvium between HVO North and South. Bore 4040P, which contained amphipods, occurs just south of the section of paleochannel planned for mining as part of the already approved Carrington West Wing and in the approximate location of the approved but not yet constructed barrier wall. The Carrington West Wing barrier wall will be installed prior to mining, and no incremental drawdown is predicted above what is already approved. The small magnitude of drawdown would have negligible impact on the stygofauna community.

Consistent with the EIS, the remnant paleochannel at and around GW106 and CGW47a will be mined as part of Amended Project. GW106 had large numbers of *Onychobathynella bifuricata*, making it one of the most sensitive parts of the aquifer sampled during the current survey. CGW47a had *Notobathynella* sp. and Parastenocaridae, both of which also occurred in CGW52a, closer to the Hunter River and outside of the area planned for excavation. The paleochannel is partially connected to the Hunter River alluvium, and all the taxa occurring in the paleochannel have previously been collected from this aquifer, which shares similar stygofauna communities. Nevertheless, there will be some impact to the local stygofauna community in the paleochannel, as they will not be able to migrate out of the impact area prior to excavation. These impacts would occur under the current approval, and there may also be an impact to the stygofauna community of the surrounding aquifer due to local drawdown during operations near Carrington Billabong.

Under the GDE Assessment Guidelines, the Hunter River alluvial aquifer is a Category 1- High Ecological Value GDE because there were several stygofauna taxa collected from the site, and the broader aquifer is known to have a diverse stygofauna community. The risk associated with the Project is low because there will be no additional excavation to the alluvium that has already been approved. However, the cumulative risk to the stygofauna community from already-approved mining to the section surrounding GW106 is high and is categorised in the Risk Matrix (summarised in Section 4.6) as C (High Ecological Value, High Risk).

7.3 Impacts to aquatic ecology

The aquatic ecosystems surveyed during this assessment all appear to be in poor ecological condition based on the macroinvertebrate community and water quality. Macroinvertebrate communities were dominated by sensitive taxa that are not tolerant to pollution and poor environmental conditions.

Hunter River fish communities are mapped as being in good condition by DPI Fisheries, which suggests the community is dominated by native species and that recruitment is at a sustainable level. The site is mapped as having potential habitat for purple-spotted gudgeon (*Mogurnda adspersa*), but there are no records of the species in the Hunter River and it is not likely to occur in the Project area.

Australian bass, longfinned eels, and several other species of fish living in the Hunter River require access to estuarine reaches to spawn. It is important that river levels do not fall to the extent where this migration is impaired for long periods of time. However, this is not critical as Australian bass can remain in upstream reaches for up to three years during periods of drought or low flow (Butler et al. 2019), and longfinned eels are able to move overland (McDowall 1996). Flow in the Hunter River is mostly determined by releases from Glenbawn Dam, rainfall-runoff and inflow from tributaries, rather than from contribution from groundwater. Therefore, river levels are not expected to fall as a result of the Project, as the Project-induced stream losses will be offset using existing WAL entitlements.

Depressurisation of the Permian strata is expected to have only minimal impact on the Hunter River and its alluvial aquifer beyond any already approved operations (AGE 2022).

Consistent with the EIS, conservative flow sequence analysis of the Hunter River indicates that, under the Project, there will be an average of 24 days per year where flow will be less than 100 ML/day, and that the average duration of dry periods will be 5 days (Engeny 2025). This is the same as the already approved operations and represents results from conservative modelling where flows in the Hunter River decline due to changes in baseflow. As flow in the Hunter River is regulated, the actual number of dry days is likely to be less as this will be mitigated by releases from Glenbawn Dam (using HVO's existing WAL entitlements). There will be no additional impact to aquatic ecology for the Hunter River.

Wollombi Brook will have more dry days than the Hunter River, with 52 predicted by modelling for the currently approved operations. However, there will be no change in the number of dry days for the amended project during operations and closure.

Of the ungauged ephemeral tributaries, change in the number of dry days varies, with more dry days during operational phase at four creeks, fewer at three creeks, and the same at three creeks. In most cases, the difference is only small and would have little significant impact on the aquatic ecology of these creeks. This is because the creeks are dry for most of the year (>250 days) so for much of this time function as terrestrial ecosystems rather than aquatic ecosystems.

Once the amended project moves into the closure period, all of the ephemeral streams (except Parnells Creek) have fewer dry days modelled than under the approved project, sometimes by up to 53 days. Again, this is unlikely to have a significant impact on the aquatic ecology of most of these waterways, all of which are likely to be dry for between 250 and 320 days of the year.

7.4 Mitigation measures and recommendations

Modelled drawdown contours (EMM 2025a) indicate that small sections of the Hunter River alluvial aquifer between HVO North and HVO South will be impacted by already approved operations. Cumulative drawdown in this area is currently expected to be less than 1 m in most locations, with some areas closer to Carrington Pit barrier wall experiencing 2 m post-closure. Groundwater level should continue to be monitored, and models updated so that any increase in the maximum drawdown in the alluvium can be predicted.

Although the stygofauna communities in this location are not endemic, impacts to aquifer communities should be minimised as much as possible. There are no experimentally tested mitigation measures to reduce impacts to stygofauna communities. However, given what is known about stygofauna ecology, and their adaptation to living in a relatively stable environment, it is possible to monitor for changes in groundwater level and quality, and use environmental thresholds that trigger a management response. Following Project approval, the existing Water Management Plan (WMP) will be updated, including review of trigger levels approved by NSW Government.

Consistent with the current WMP and as documented in the EIS, the Project WMP will include trigger levels for groundwater levels and EC in the Hunter River alluvium south of the Carrington West Wing barrier wall. Trigger Action Response Plans (TARPs) will be established for the bores, and bores will be monitored regularly. If there are exceedances in trigger values, or impacts exceed those that have been modelled, mitigation measures will be implemented.

Groundwater quality trigger values will be reviewed and adjusted as necessary when baseline data is collected prior to mining. These will be used to set trigger values for a range of water quality variables including EC. Groundwater level trigger values will be determined for selected bores based on both baseline data and levels predicted from modelling at different stages of the Project.

Trigger values in groundwater level and groundwater quality are appropriate for mitigating impacts to stygofauna and groundwater dependent vegetation communities. This is because, if monitored frequently enough, changes to groundwater can be detected prior to any serious impact to the receptor community.

Mitigation measures for the river red gum communities of Carrington Billabong and the Hunter River are given in detail in the *River Red Gum Rehabilitation and Restoration Strategy* (HVO 2022). The strategy proposes a tiered management approach based on the level of impact and the probability of success. Carrington Billabong has been listed as a High Priority because it has one of the largest remnant examples of river red gum communities in the Hunter Valley. The Hunter River and Wollombi Brook sites have been allocated an Intermediate Priority because of the relatively high ecological integrity of the sites, and because management outcomes are likely to have positive outcomes (HVO 2022).

Restoration and rehabilitation strategies were mainly focussed on the terrestrial aspects of the river red gum communities, rather than on groundwater. For Carrington Billabong these include:

- Fencing and stock access control,
- Weed and pest management,
- Support of naturally recruited natives to boost natural regeneration, and supplement with assisted regeneration of groundcover and understorey species,
- Assisted revegetation of river red gum tubestock and seeding using locally collected material
- Artificial flooding with clean water to promote natural plant recruitment,
- Ecological monitoring of recruitment.

Additional recommendations are given for other priority sites in the *River Red Gum Rehabilitation and Restoration Strategy* (HVO 2022) and include:

- Establish and maintain appropriate fencing,
- Review data from existing groundwater monitoring sites are nearby,
- Regular ecological monitoring
- Appropriate weed and pest control
- Monitor response of river red gums after flooding
- Encourage natural recruitment of river red gums through weed control and management of grazing
- Encourage natural regeneration of other native species

7.4.1 Risk management actions

The GDE Assessment Guidelines provide a list of recommended management actions for GDEs based on the Risk Matrix classification determined above. A classification of C was determined for cumulative impacts to the alluvial aquifer, since a section of high value stygofauna habitat will be excavated during mining in the approved Carrington West Wing area. In the risk management matrix, this results in the recommendation of protection measures for the aquifer, as well as ongoing monitoring and annual assessments of mitigation effectiveness. It will not be possible to avoid impact to stygofauna in alluvium where excavation is to occur. However, as this is connected to the greater Hunter River alluvial aquifer, and the community in the impacted area also extends along the aquifer, mitigation measures should be applied to parts of the aquifer where excavation will not occur. In these areas, groundwater level and water quality will be monitored as part of regular groundwater monitoring.

Mitigation measures are already in place through the *River Red Gum Rehabilitation and Restoration Strategy*, which specifies monitoring requirements for the river red gum populations, and the WMP, which outlines a monitoring program and sets trigger values for surface and groundwater parameters.

The current WMP, which will be updated following approval of the Project, specifies that bores located near recognised GDE communities adopt a $5^{th}/95^{th}$ percentile of available validated data record for standing water level for each site as a trigger guideline. These bores also have trigger values for EC and pH that are based on the $5^{th}/95^{th}$ percentile of available data. It is recommended that bores where stygofauna were collected during the current study, excluding those within the Carrington West Wing disturbance area, be included in the groundwater monitoring network. This includes bores CGW52a, CHPZ8D, HV3(2) already in the monitoring program, but not GW106, CGW47a and 4040P. Consistent with the EIS, additional bores have been recommended to be installed in the Carrington West Wing area (EMM 2025b). Appropriate triggers will be assigned to these bores in the updated WMP and the *River Red Gum Rehabilitation and Restoration Strategy*.

8. References

Australian Groundwater and Environmental Consultants Pty Ltd. 2022. Hunter Valley Operations Continuation Project- groundwater impact assessment. Report for HV Operations Pty Ltd.

ANZECC. 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality https://www.waterquality.gov.au/sites/default/files/documents/anzecc-armcanz-2000-guidelines-vol2.pdf

ANZG. 2018. Australian and New Zealand Guidelines for Fresh and Marine Waters https://www.waterquality.gov.au/anz-guidelines

Bureau of Meteorology, 2022. Groundwater Dependent Ecosystems Atlas. http://www.bom.gov.au/water/groundwater/gde/

Butler, G., Brooks, S. & Raadik, T. 2019. *Percalates novemaculeata*. *The IUCN Red List of Threatened Species* 2019: e.T83130397A129086006. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T83130397A129086006.en. Downloaded on 16 March 2021.

Chessman, B.C. 2003. New sensitivity grates for Australian river macroinvertebrates. *Marine and Freshwater Research*, 54, 95-103.

Clarke, K.R. and Gorley, R.N. (2015) PRIMER v7: User Manual/Tutorial. PRIMER-EPlymouth

Coineau, N. 2000. Adaptations to interstitial groundwater life. In 'Subterranean Ecosystems'. (Eds H. Wilkens, D. C. Culver and W. F. Humphreys) pp. 189–210. (Elsevier: Amsterdam, The Netherlands.)

Danielopol, D.L., Creuzé des Châtteliers, M., Mösslacher, F., Pospisil, P. and Popa, R., 1994. Adaption of Crustacea to interstitial habitats: a practical agenda for ecological studies. Pp. 218–244 *in* Groundwater Ecology ed by J. Gibert, D. L. Danielopol and J. A. Stanford. Academic Press, San Diego California.

Department of Planning, Industry and Environment (2020) Biodiversity Assessment Method 2020-Operational Manual.

Doody, T.M., Hancock, P.J. and Pritchard, J.L. 2018. Assessing Groundwater-Dependent Ecosystems: IESC Information Guidelines Explanatory Note. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy.

Eco Logical Australia, 2013a. Continuation of Bengalla Mine – Stygofauna Assessment. Report prepared for Hansen Bailey and Bengalla Mining Company Pty Ltd.

Eco Logical Australia, 2013b. Liddell Coal mine Modification 5 – Aquatic Ecology and Groundwater Dependent Ecosystem Assessment. Report Prepared for Liddell Coal Operations Pty Ltd.

Eco Logical Australia, 2014. Bylong Coal Project Environmental Impact Statement- Stygofauna Impact Assessment. Report for Hansen Bailey

Eco Logical Australia, 2018. Mount Owen Continued Operations- Modification 2, Stygofauna Assessment. Report for Umwelt (Australia) Pty Ltd

Eco Logical Australia, 2019. Glendell Continued Operations Project- Stygofauna Assessment

Ecoplanning, 2021. River Red Gum Monitoring Report. Annual monitoring report 2020 prepared for HVO

Engeny 2022. HVO Continuation Project Surface water Impact Assessment, Prepared for EMM Consulting Pty Ltd. November 2022

Engeny, 2025. HVO Streamflow Assessment. Prepared for EMM Consulting Pty Ltd. June 2025

Environmental Protection Authority, 2003. Guidance for the Assessment of Environmental Factors: Consideration of Subterranean Fauna in Groundwater and Caves During Environmental Impact Assessment in Western Australia. Guidance Statement No. 54, Western Australian Environmental Protection Authority, Perth, Australia.

EMM, 2022a. HVO Continuation Project Environmental Impact Statement. Prepared for HV Operations Pty Ltd. November 2022.

EMM, 2022b. HVO Continuation Project Water Assessment. Prepared for HV Operations Pty Ltd. November 2022.

EMM, 2025a. *Hunter Valley Operations Continuation Project - Amended Project, Groundwater Modelling.* Prepared for HV Operations Pty Ltd. July 2025.

EMM, 2025b. Hunter Valley Operations – Amended Project, Water Assessment. Prepared for HV Operations Pty Ltd. July 2025.

Environmental Protection Authority, 2007. *Sampling methods and survey considerations for subterranean fauna in Western Australia*. Draft Guidance Statement No 54a (Technical Appendix to Guidance Statement No 54). Environmental Protection Authority, Perth.

Fairfield, S. 2013. *Fisheries NSW Policy and Guidelines for Fish Habitat Conservation and Management (2013 Update)*. NSW Department of Primary Industries.

Finston, T. L., and Johnson, M. S. 2004. Geographic patterns of genetic diversity in subterranean amphipods of the Pilbara, Western Australia. *Marine and Freshwater Research* 55, 619–628.

Gooderham, J. and Tsyrlin, E. 2002. The Waterbug Book. CSIRO Publishing. Collingwood, Victoria.

Hancock, P. 2004. Hyporheic and parafluvial ecology of the regulated Hunter River. Refereed report for NSW Department of Land and Water Conservation – Hunter Region.

Hancock, P.J. 2006. The response of hyporheic invertebrate communities to a large flood in the Hunter River, New South Wales. *Hydrobiologia* 568, 255-262.

Hancock, P.J. and Boulton, A.J. 2008. Stygofauna biodiversity and endemism in four alluvial aquifers in eastern Australia. *Invertebrate Systematics* 22, 117-126.

Hancock, P.J. and Boulton, A.J. 2009. Sampling groundwater fauna: efficiency of rapid assessment methods tested in monitoring wells in eastern Australia. *Freshwater Biology,* 54, 902-917.

HVO. 2018. Hunter Valley Operations Water Management Plan.

HVO. 2022. River Red Gum Rehabilitation and Restoration Strategy.

Marmonier, P., Vervier, P., Gibert, J. and M.-J. Dole-Olivier, 1993. Biodiversity in ground waters. *Trends in Ecology and Evolution*. 8, 392-395.

Marmonier, P. and M. Creuzé des Châtelliers, 1991. Effects of spates on interstitial assemblages of the Rhone River. *Hydrobiologia*, 210:243-251.

McDowall, R. 1996. *Freshwater Fishes of South-eastern Australia*. Reed Publishers.

Riches, M., Gilligan, D., Danaher, K., Pursey, J. 2016. Fish Communities and Threatened Species Distributions of NSW. NSW Department of Primary Industries.

Serov P, Kuginis L, Williams J.P., May, 2012. Risk assessment guidelines for groundwater dependent ecosystems, Volume 1 – The conceptual framework, NSW Department of Primary Industries, Office of Water, Sydney.

Umwelt. 2010, Hunter Valley Operations River Red Gum Rehabilitation and Restoration Strategy. Report for Hunter Valley Operations

Umwelt. 2022, Biodiversity Development Assessment Report for Hunter Valley Operations Continuation Project. Report for Hunter Valley Operations

Appendix A : Assessment of Significance for *Mogurnda adspersa*

This assessment of significance considers the potential impacts of reduced groundwater contributions to baseflow in the Hunter River. Drawdown in the alluvium around the river may cause leakage of river water through the bed, but this will be complemented by releases from Glenbawn Dam so is unlikely to have a major impact on aquatic ecology.

The factors of assessment for Purple-spotted Gudgeon (*Mogurnda adspersa*)

In the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction

The Purple-spotted gudgeon is listed as an endangered species in NSW. No specimens are known from the Hunter River catchment, despite many years of fish surveys. The Hunter River and its larger tributaries are mapped as Purple-spotted gudgeon habitat. There is suitable habitat along the Hunter River in the form of deep pools with aquatic vegetation, and while flow velocity can he high at times, there are periods when it is slow, or the water is still.

River regulation, increased turbidity, and a loss of habitat are key threatening processes for this species (NSW DPI 2017). All of these impacts are likely to have been occurring in the Hunter River since the completion of Glenbawn Dam in 1957. River regulation, agricultural and mining activity, and an increased human population in the Hunter Valley have all likely resulted in an increase in turbidity, a loss of habitat structure, and the loss of natural flow that included periods when flow was absent.

The Project is modelled to reduce baseflow contributions from groundwater by up to 230 ML per year during operations. This is only a small proportion of flow in the Hunter River, which is subject to irrigation flows and so experiences a highly variable flow regime. To compensate for this loss, HVO hold sufficient water entitlement for the predicted take, including the Hunter Regulated River, where releases from Glenbawn Dam will ensure surface flow continue. Should Purple-spotted gudgeon live in the Hunter River, the change to streamflow is very unlikely to have a significant impact on the population. The small loss in flow would not alter fish passage between upstream and downstream reaches.

In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction

Not applicable

In the case of an endangered ecological community or critically endangered ecological community, whether the action proposed:

- is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or
- is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction

Not applicable

In relation to the habitat of a threatened species, population or ecological community:

- the extent to which habitat is likely to be removed or modified as a result of the action proposed, and

The Project is unlikely to cause a significant reduction or modification in habitat in the Hunter River. As flow in the Hunter River has been regulated for more than 60 years, the proposed change to flow volume will have no significant impact to purple spotted gudgeon habitat.

- whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action, and

The predicted changes to flow in the Hunter River are not likely to cause fragmentation or isolation of purple spotted gudgeon habitat.

- the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality

There are no plans to remove, modify or fragment any purple spotted gudgeon habitat, so there will be no long-term impact to the survival of the species.

Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly)

There will be no adverse effect on critical purple-spotted gudgeon habitat.

Whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan

The proposed activities do not contradict the objectives or actions of the purple spotted gudgeon recovery plan.

Whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process

The minor reduction in streamflow does not constitute a key threatening process.

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