Office of the **Queensland Mine Rehabilitation Commissioner**

# Review of open-cut coal mine void rehabilitation planning practices in Queensland

## Student project report

Queensland Government

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# Executive Summary

Open cut coal mining in Queensland underwent a period of expansion in the early 1970s. There are now over 90 large scale operational open-cut and underground metallurgical or thermal coal mines. While there are several proposals for greenfield coal mines or expansions to existing operations, many existing open cut coal mines are reaching maturity. Many of these mines will leave one or more residual voids in place at the end of mining. These structures typically fill with water after mining and ongoing evaporation and concentration can lead to poor water quality with limited practical use.

The most basic practices to rehabilitate residual voids have historically involved stabilising the high and low walls, bunding to provide flood protection, and preventing public access. Where residual voids are not properly rehabilitated, they may fail to achieve a post-mining land use (PMLU), pose a risk to the surrounding environment, and require ongoing monitoring and maintenance. Although there are a range of potential risks associated with residual voids, in some cases it can be possible to achieve a PMLU that can benefit local and regional communities. Examples include agriculture, native ecosystems, recreation and industrial uses (Keenan and Holcombe, 2021).

Regulatory reforms for mine rehabilitation were introduced in Queensland as part of the *Mineral and Energy Resources (Financial Provisioning) Bill 2018*. These reforms aimed to strengthen progressive rehabilitation planning, limit risks to the environment and improve outcomes for local and regional communities. Under the reforms, the goal for rehabilitation of residual mine voids is to achieve a safe, stable, and non-polluting landform (see section 111A of the *Environmental Protection Act 1994* for the definition of 'stable').

To work towards improved mine void rehabilitation outcomes, it is important to understand both the historic and current practices, identify possible PMLUs and the constraints that may limit their implementation. The objective of this study was to gain an understanding of how coal mine void rehabilitation practices have changed over time and identify the challenges and potential opportunities for residual coal mine voids to achieve a viable PMLU. This study describes current and historic approaches to rehabilitate mine voids in the Fitzroy Basin, a key coal mining region in Queensland. A review of practices being applied elsewhere in the world to rehabilitate open-cut mine voids was also undertaken and their suitability and potential limitations for application in the Fitzroy Basin are described. To assess their potential suitability for PMLUs, water quality guidelines for common uses were identified and compared with the water quality held in mine voids in the Fitzroy Basin. To achieve this the following steps were undertaken:

- describe mine void rehabilitation commitments in existing approvals (i.e. environmental authorities) for open-cut coal mines in the Fitzroy Basin,
- review proposed void PMLUs described in application documents and approved Progressive Rehabilitation and Closure (PRC) plans,
- report on void PMLU practices internationally and nationally,
- collate relevant water quality guidelines for different PMLUs in the Fitzroy Basin, and
- summarise available data describing water quality in coal mine voids of the Fitzroy Basin.

A review of historic approvals found that although many sites recognised that a residual void will remain after mining, most did not clearly describe a PMLU for them. However, a review of currently submitted and approved PRC plans found that there is a trend towards greater clarity in describing residual void rehabilitation outcomes in current rehabilitation plans. A review of the available data describing coal mine void water quality in Queensland showed that the water held in voids would typically be unsuitable for common PMLUs such as irrigation and stock watering without water treatment. In particular, elevated salinity is likely to limit PMLUs for many voids within the Fitzroy Basin. However, more detailed analysis would be needed to assess whether a broader range of potential uses for post-mining void water may be possible at a site level. Site level analysis was outside of the scope of this report. The analysis described here was based on publicly available data describing the quality of water in open-cut coal voids in Queensland. This relatively limited dataset highlights the need for improved water monitoring and reporting of void water quality to support more effective rehabilitation management and planning.

While various innovative PMLUs for voids have been implemented internationally and nationally, with beneficial outcomes for local communities (e.g., recreational use, floating solar, aquaculture), many of these may not be appropriate for the Fitzroy Basin. Feasibility studies and community consultation are needed to support the uptake of innovative PMLUs. Backfilling a void provides flexibility to achieve a range of PMLUs such as grazing or native ecosystems and can help to avoid or minimise risks associated with an open water body. However, it is recognised that residual voids left open to form a water body can potentially support a viable PMLU in some instances. Whatever PMLU is proposed, there is a need to demonstrate it will be viable, limit ongoing maintenance and environmental risks, and have a positive social impact into the future.

# 1. Introduction

Residual voids are depressed landform features resulting from open-cut excavation during mining. When excavation occurs to a level below the water table, the resultant voids are likely to receive groundwater inflow and fill with water once mining ceases. Water-filled residual voids (also called pit lakes in some jurisdictions) can act as terminal sinks where water losses due to evaporation exceed inputs from groundwater and precipitation (McCullough et al., 2013). Where groundwater with elevated salinity flows into a void it will mean that water bodies forming in these voids are expected to become increasingly saline over time. In the Fitzroy Basin, Queensland, mines with certain contaminants such as sulfate, aluminium, copper and zinc can also concentrate in voids. In the Fitzroy Basin, where the majority of open-cut coal mining in the state occurs, these compounds have been measured in concentrations above Australian toxicant guideline values (Jones et al., 2019). Consequently, the water quality of certain coal mine voids in Queensland, if not managed correctly, is likely to be unsuitable for PMLUs such as aquatic ecosystems, crop irrigation and stock watering. Residual voids that have been left to accumulate increasingly high levels of solutes in the water can impose a range of potential issues for local communities and wildlife, including through seepage or overtopping, leading to the contamination of surrounding areas (Blight and Fourie, 2005; Coffey Services Australia Pty Ltd, 2021).

In 2018 the Queensland Government introduced legislative reforms under the *Mineral and Energy Resources (Financial Provisioning) Act 2018* to improve rehabilitation outcomes in the resources sector. The *Environmental Protection Act 1994* requires all resource activities to have a PRC plan. Prior to the introduction of these legislative reforms, rehabilitation planning for voids in Queensland was often left until the final stages of mine life. Progressive rehabilitation, however, presents significant opportunities to deliver sustainable land outcomes; it can achieve good closure outcomes at reduced cost, reduces financial liability, and improves an operator's reputation (Australian Government, 2016).

One element of a PRC plan is a proposed schedule and subsequent steps to rehabilitate areas of disturbance, including residual voids, in a way that maximises the progressive rehabilitation of land to a "stable condition". Section 111A of the *Environmental Protection Act 1994* defines "stable condition" as land that is safe and structurally stable, not causing environmental harm and able to sustain a PMLU. Although achieving a PMLU is the goal, there are circumstances where a void may not be able to be rehabilitated to meet these requirements and a void may be proposed as a non-use management area (NUMA; see Table 2 for further explanation of NUMAs).

A void that can achieve a PMLU could benefit local communities, economies, and ecosystems. Various examples of PMLUs for mine voids that have been implemented nationally and internationally include agriculture, native ecosystems, recreation, and industrial uses (Keenan and Holcombe, 2021). In Queensland, only one open cut coal mine has officially been relinquished to date. Rehabilitation included backfilling and reshaping of the void and the site has achieved certification (Chan, 2022). In general, the lack of widespread rehabilitation and surrender of residual voids and other areas subject to mining is likely due to mining operations' *post-hoc* approach to closure (Cooper, 2019) and the technical difficulties associated with void rehabilitation.

This report aims to review open cut mine void rehabilitation practices both in Queensland and more broadly. Open cut coal mine voids of the Fitzroy Basin provide the focus of this review. This study also outlines the water quality guidelines in relation to a suite of proposed PMLUs, analyses void water quality data, and looks to local and global plans for voids post-mining.

# 2. Proposed PMLUs for open-cut coal mine voids in the Fitzroy Basin

## 2.1 Void PMLUs in EAs and Void Management Plans

A 2021 report prepared by Coffey Services Pty Ltd for the Office of Water Science on behalf of the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) found that there are 71 environmental authorities (EAs) for open-cut coal mines in Queensland (Coffey Services Australia Pty Ltd, 2021). A database of current open-cut coal pits in Queensland was produced as part of that study and included a review of the approval conditions describing coal mine void rehabilitation. This data was reviewed to define the number of voids, the area of voids and their PMLUs. Our analysis considered the sites reported as 'open-cut' or 'open-cut and underground mines' and excluded sites reported as 'underground' operations. It also included only those sites where mining was active and reported as 'operational'. Data from the IESC report was filtered to the Fitzroy Basin, grouped by PMLU and transposed to generate counts and the summed area of voids.

Our analysis found that of those sites, the EA conditions describe a residual void at the end of the life of mine for 85 voids in the Fitzroy Basin. These voids are expected to span a total area of ~140,000 ha. The proportion of PMLUs assigned to residual voids and the proportion of void area assigned to a PMLU are shown in Figure 1. Information shown in this figure is collated from EAs and void management plans and summarises the data reported in the 2021 IESC report on voids.

Figure 1 summarises the analysis and shows that of the 85 voids, the majority did not have a PMLU described (35.3% “not specified”) in the EA, and 23.5% were expected to be assigned a PMLU in a rehabilitation management plan that was not yet published. The most common PMLUs assigned to the voids in EAs included “water storage” (16.5%), “water body/native bushland” (8.2%), “native ecosystem, semi-evergreen vine thicket, hardwood plantation, agriculture” (7.1%), and “accessed by wildlife, used for a water supply or recreational facility” (4.7%). The proportion of the total surface area of the proposed PMLUs showed a different pattern. It was found that the majority of void area did not have a specified PMLU (84.0%, ~120,000ha), followed by ‘to be specified in the void management plan’ (6.4%, ~9,200 ha). The largest specified PMLU area was to be rehabilitated to ‘native ecosystem, semi-evergreen vine thicket, hardwood plantation, agriculture’ (2.8%), followed by water storage (2.1%). Backfilling was described as an end use for 3 out of 85 voids. The area of ‘backfilled’ voids covers ~328 ha which is equivalent to 0.3% of the total area of coal mine voids in the Fitzroy Basin (as reported by Coffey Services Australia Pty Ltd, 2021).

Some caveats associated with the data are that:

- the area of voids reported may be an overestimate area of the area of water because it includes “all currently visible excavated areas (e.g. including excavated areas for waste rock emplacements)” (Coffey Services Australia Pty Ltd, 2021),
- the number and area of voids that would be backfilled may also be an underestimate because the conditions reviewed may not directly state that a void will be backfilled, however, this may be described elsewhere in the rehabilitation management plan but not captured in the information presented in Coffey Services Australia Pty Ltd, 2021,
- the figures show current disturbance rather than the expected residual void areas and the location and number of pits at the end of mining may vary, and
- the Coffey Services Australia Pty Ltd, (2021) report digitised ‘current open-cut coal pits’ and as a result some historic pits may be excluded.

Figures reported here summarise the data as reported by Coffey Services Australia Pty Ltd, (2021) and any differences with the figures presented may reflect naming and categories used in that report. Further explanation of the uncertainty associated with the assignment of PMLUs is discussed in Table 1. Although there is some uncertainty in these figures, and the available information on the proposed PMLUs for many voids is limited, it does show that voids with PMLUs can be ill-defined in EAs. Planning for rehabilitation and stating clear rehabilitation objectives in relevant plans and approvals (i.e. from the conceptual phase in the life of mine), may enhance rehabilitation outcomes, as seen in the US (Skousen and Zipper, 2014; Keenan and Holcombe, 2021).

**Table 1. Explanation of uncertainty associated with Post-Mining Land Use categories**

| **Ill-defined Post-Mining Land Uses (PMLUs)** |
| --- |
| In the data presented by the IESC (Figure 1) and collected from PRC plans (Figure 2), various PMLUs were sometimes ill-defined. Examples include ‘water storage’, ‘water body’ and “either/or” PMLUs (e.g. “water body/native bushland”, “irrigation/livestock”).<br><br>Nominating ‘water storage’ as an outcome does not represent a PMLU. For void water to have a use, it would need to be suitable for a beneficial use such as crop irrigation, livestock watering, drinking water or providing habitat values.<br><br>Clear definition of the intended use for stored water is needed to ensure water quality will meet appropriate guidelines. This will allow both industry and the regulator to plan and implement strategies to achieve a designated PMLU. |

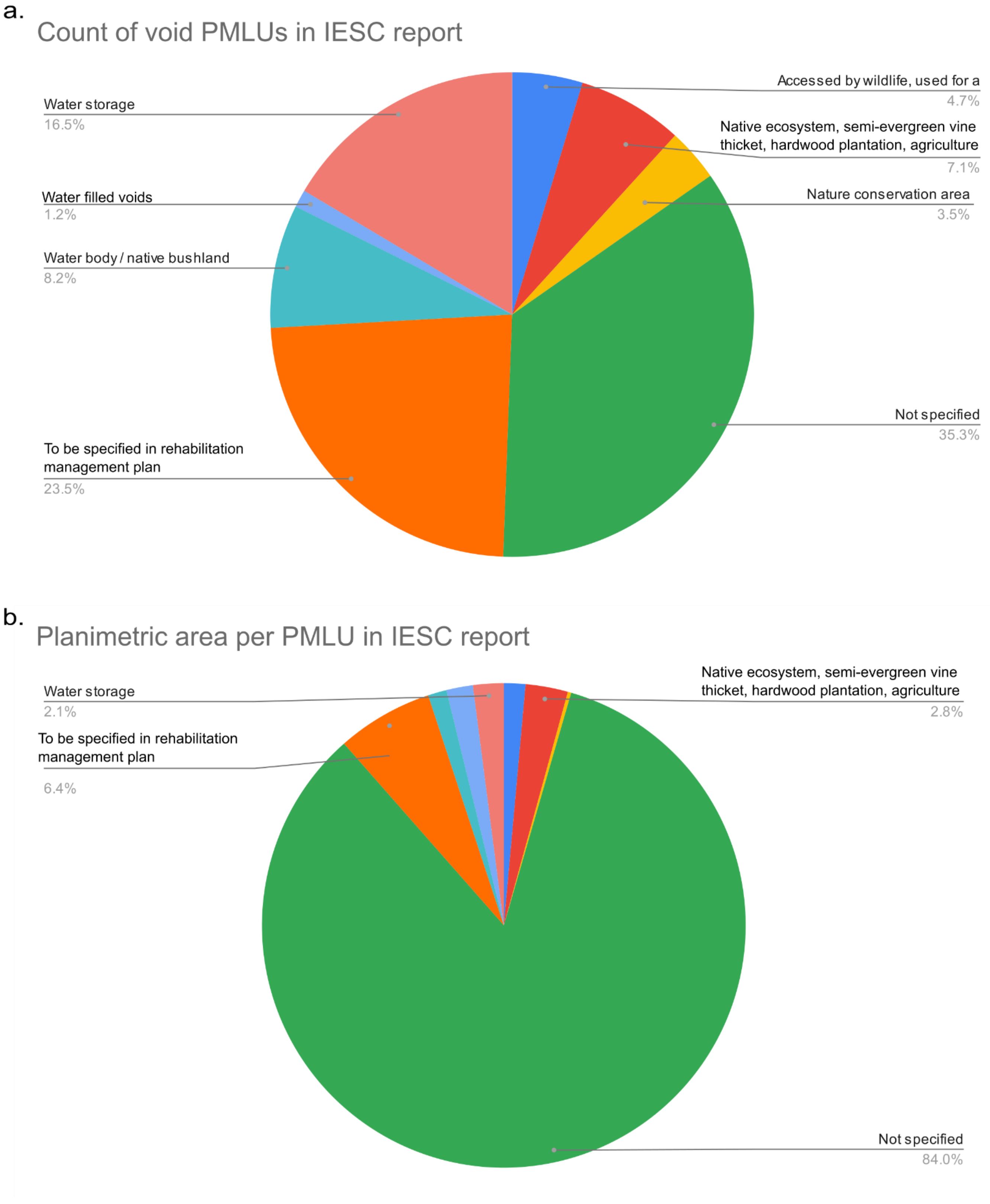


**Figure 1. Post Mining Land Uses (PMLUs) assigned to 85 residual voids of open cut coal mines of the Fitzroy Basin as reported in Coffey Services Australia Pty Ltd, 2021 a) Counts of PMLUs, b) Surface areas assigned to PMLUs**

## 2.2 Void PMLUs in PRC plans

The requirement for existing and new mines to develop PRC plans has caused an overhaul of the practices reported in the previous section. Resource activities subject to PRC planning requirements must identify PMLUs or NUMAs (discussed in Table 2) and prepare a rehabilitation schedule. The *Mineral and Energy Resources (Financial Provisioning) Act 2018* includes provisions requiring existing EA holders with EAs granted prior to November 2019 to be issued transitional notices by November 2022. These transitional notices require the preparation of PRC plans (Department of Environment and Science, 2021). So far, 90 open-cut coal mines have been identified as requiring a PRC plan[1]. At the time of preparation of this report, four PRC plans had been approved and six PRC plan proposals have been submitted (as available at https://apps.des.qld.gov.au/public-register/search/prc.php).

Analysis of approved and proposed PRC plans showed that 29 voids across the 10 projects (four approved and six proposed) are expected to be created during life of mine (Figure 2). Of these 29 voids, 10 are to be backfilled to above the water table, with PMLUs including water management areas (with mention of irrigation and stock watering) and grazing. However, 19 voids are proposed to be retained post closure, with 16 of these proposed as NUMAs. It is of note that of the four approved PRC plans, no NUMAs were proposed, and voids were committed to being backfilled above the water table. The distinction between 'grazing' and 'void backfilled to grazing' in Figure 2(a) is that the landform in 'grazing' may store rainwater temporarily. Many of the voids in Figure 2(a) are not present in Figure 2(b) as they are expected to be backfilled.

**Table 2. Explanation of Non-Use Management Areas.**

| **Non-Use Management Areas (NUMAs)** |
|---|
| • In the PRC plan framework, NUMAs are a category designed for areas of land where a PMLU cannot be achieved, or is unable to be made safe, stable and non-polluting.<br>• Voids cannot be proposed as NUMAs if they are located within a floodplain.<br>• In order to propose a NUMA, a Public Interest Evaluation must be carried out.<br>• A NUMA must achieve sufficient improvement of the land within the PRC plan schedule. In the context of voids this may mean minimising the amount of contamination generation due to evapo-concentration (see section on water quality below) and ensuring structural stability.<br>• It is possible that NUMA voids will pose public health risks and require considerable management after life of mine.<br>• Certain exemptions exist, such as removing the requirement for Public Interest Evaluation for mines "where a NUMA has already been identified in a land outcome document". |

[1] At the time of writing, there were approximately 52 operating thermal and metallurgical coal mines in Queensland. PRC plans are required for these mines, proposed new mines and certain mine infrastructure authorities which take the number to 90.

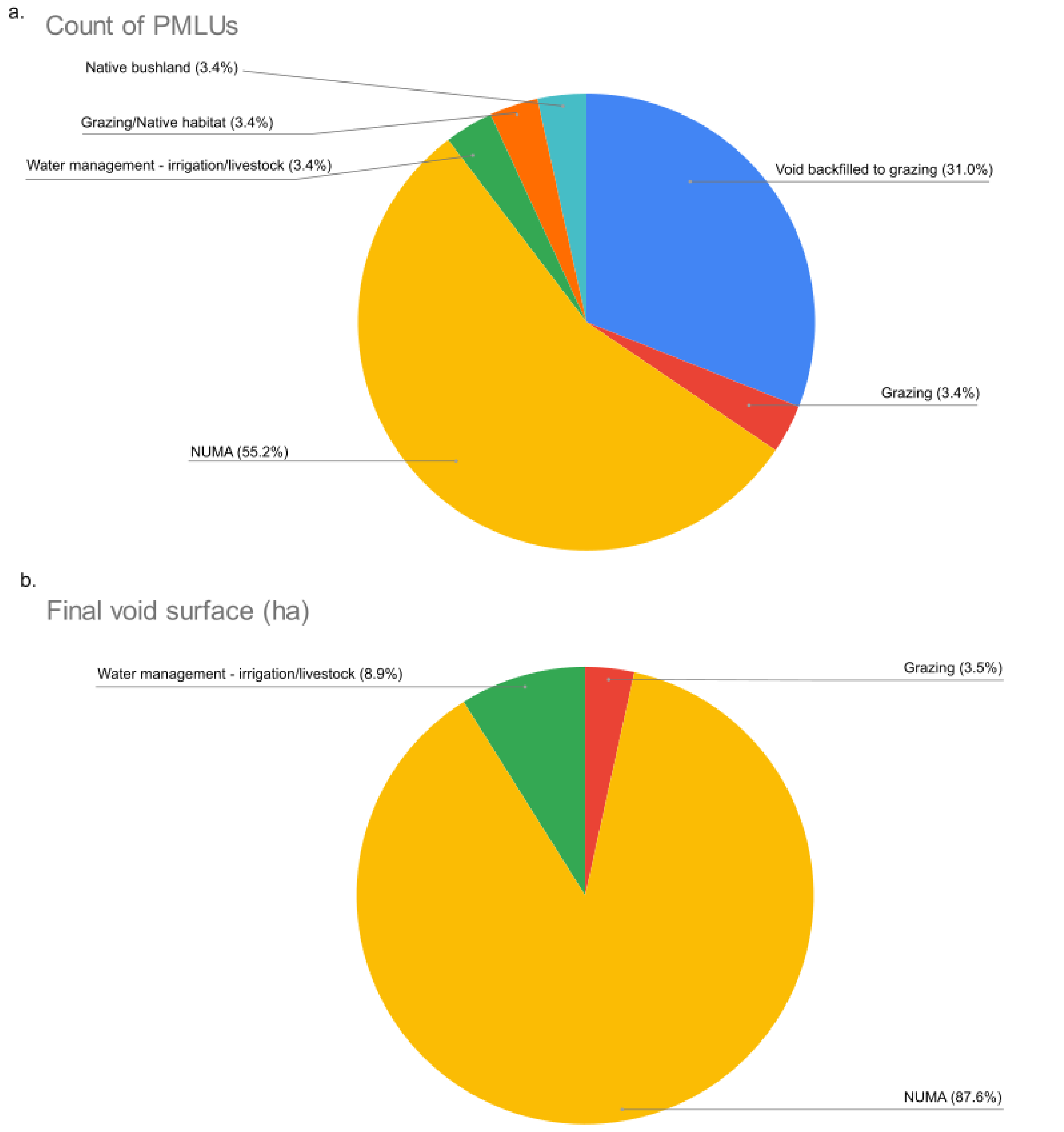


**Figure 2. Post Mining Land Uses (PMLUs) assigned to 29 residual voids within proposed and approved PRC plans as of 24/05/2022 for open cut coal mines of the Fitzroy Basin a) Counts of PMLUs within PRC plans, b) Surface areas assigned to PMLUs within PRC plans**

# 3. National and international void PMLUs

Void rehabilitation practices across Australia and internationally were reviewed. Based upon the available literature describing PMLUs for coal and mineral mine voids, there were 11 different PMLUs recorded across three national and 10 international locations. Examples of practices and case studies for void PMLUs are summarised in Table 3 from a search of the available literature for coal and mineral mine voids. While the review covered the information available to give a general indication of PMLUs, it was not an exhaustive search of industry or grey literature and there may be further examples not mentioned here. The information presented in the table describes practices outside of Queensland and does not directly include local practices. Instead, local practices are described below when making comparisons. Sources for the heatmap include Veolia Environmental Services, (2016); Land Rehabilitation Society of Southern Africa et al., (2018); Smith, (2019); McCullough and Vandenberg, (2020); McCullough et al., (2020); Ruth Fraňková, (2020); Cox et al., (2021); Jiang et al., (2021); Explore Parks Westeran Australia, (2022); Wang et al., (2022); Premier Coal,(2022); Veolia, (2022).

International examples where mine voids have achieved a PMLU included locations across Europe, North America, Oceania, Africa and Asia. It is noted that references to these in the literature are likely to represent the biases in available documentation in the English language (McCullough et al., 2013). Examples of conventional PMLUs for voids such as backfilling to livestock grazing land, aquatic ecosystems, water storage for grazing or crop irrigation were recorded. A range of innovative uses have also been trialled including aquaculture, recreation, pumped storage hydroelectricity and floating solar. Legislation may encourage the diversification of PMLUs: void PMLUs in the USA span various traditional and innovative uses (Table 3). This range is potentially due to the requirement to backfill mine voids to “approximate original contour” in the *Surface Mining Control and Reclamation Act (SMCRA) 1977* (section 515 (b) 3 and 2, U.S. Government, 1977), thus priming the land for future usage.

Nationally, proposals for innovative PMLUs and successful implementation were found although these were more the exception than the rule. Lake Kepwari is an example where a coal mine void in the Collie region of Western Australia has been rehabilitated to a lake that is now used for recreational purposes after it became hydraulically connected to the surrounding river system (McCullough et al., 2020). Although Lake Kepwari is used for recreational purposes, other surrounding residual voids have highly acidic water (Sakellari et al., 2021).

A current example of an innovative PMLU for voids in Queensland is the Kidston pumped storage hydroelectricity project (Genex Power Ltd, 2018). Other examples of innovative uses for mine voids in Queensland appear limited. Although many mines are in various stages of rehabilitation planning with many sites yet to nominate or revise plans for PMLUs of their mine voids, common designated PMLUs across Queensland tend to be stock watering or grazing, requiring backfilling.

**Table 3. Instances of post mining land uses internationally and across Australia (excluding Queensland)**

| Location | Agriculture | Building site | Aquaculture | Floating solar | Forestry | Pumped Hydro | Recreation | Waste | Water Storage | Wetland or wildlife |
|---|---|---|---|---|---|---|---|---|---|---|
| USA | ✓ | ✓ | ✓ | | ✓ | | ✓ | | ✓ | ✓ |
| Spain | | | | | | | ✓ | ✓ | | |
| South Africa | ✓ | | | | | | | | | ✓ |
| Poland | | | ✓ | | | | | ✓ | | ✓ |
| New Zealand | | | ✓ | | | | ✓ | | | ✓ |
| Netherlands | | | | ✓ | | | | | | |
| Germany | | | ✓ | | | | ✓ | ✓ | | ✓ |
| Czech Republic | | | ✓ | | | | ✓ | ✓ | ✓ | ✓ |
| China | ✓ | | | ✓ | | ✓ | | | | |
| Canada | | | ✓ | | | | ✓ | ✓ | | ✓ |
| Western Australia | | | ✓ | | | | ✓ | | | |
| Victoria | | | | | | | ✓ | | | |
| NSW | | | | | | | | ✓ | ✓ | |

## 3.1 Backfilling – United States of America

As discussed earlier, legislation in the USA requires open-cut mines to return disturbed areas to “approximate original contour” under the *Surface Mining Control and Reclamation Act (SMCRA) of 1977* (section 515 (b) 3 of U.S. Government, 1977). This legislation essentially mandates backfilling and ensures that no residual voids are left, except where there is insufficient material to completely backfill. The SMCRA (see section 515 (b) 2 of U.S. Government, 1977) also requires that the land be restored to a condition capable of supporting a use equivalent to the pre-mining use or better. This has allowed various PMLUs to be achieved, including prime farmland, hay land and pasture, biofuel crops, forestry, wildlife habitat, and building site development (Skousen and Zipper, 2014).

## 3.2 Recreational lakes - Germany and Western Australia

In the east of Germany a former coal mining region has been transformed into a recreational district containing 26 lakes, including one of over 1800 ha (Transition in Coal Intensive Regions, 2019). Old lignite mines were reshaped and filled with water from four nearby rivers (Schultze et al., 2010). Recreational lakes are earmarked for swimming, boating, water sports, and riparian activities such as art, music, camping, picnicking and cycling, and have been reported to draw over 500,000 visitors per year (Worker, 2016). Recreation in rehabilitated voids sees economic returns to the Lusatia region in Germany, while also having cultural and societal benefits (Deshaies and Michel, 2020).

The highly acidic waters of the old lignite mines still require treatment, which is performed *in situ* with a mobile treatment vessel (Benthaus et al., 2020). Lake Kepwari, a Western Australian recreational lake in an old coal mine void, has combated water quality issues through a different approach: riverine flow through. The inputs from the local river system have been recorded to improve water quality in the lake by "*adding carbon matter, improving acidity and reducing soluble metal concentrations*", at a "*low risk to the downstream environment*" (Premier Coal, no date).

## 3.3 Floating Solar – China, the Netherlands and South Korea

Floating photovoltaics have previously been rolled out in Asian economies, and various European countries are now implementing the technology for use in mine voids. For example, The Netherlands has recently set up a floating solar array in a former quarry (Bellini, 2021), and there are plans for the roll out of floating solar in old coal mines in Germany. Floating solar has been used in remote areas in China (Pouran, 2018). Floating solar is attractive, as while the costs of construction for floating solar are higher than those of conventional photovoltaics, the water's cooling capacity allows for a high density of photovoltaics in an area, mitigating costs over time. A case study of a potential floating solar farm in Korea estimated that the project would pay for itself in the 12th year of the project, whilst reducing $CO_2$ emissions by 471.23 t/year (Song and Choi, 2016). Whilst floating solar is expected to cause changes to mine void ecosystems (de Lima et al., 2021), some of these may be positive given the impact of evaporation on mine water quality. Nonetheless, the effect of floating photovoltaics on water quality within Queensland mine voids would need careful assessment and monitoring to analyse the chemical and ecological outcomes of such a system's implementation.

## 3.4 Aquaculture - Western Australia

The Ngalang Boodja Mine Lake Aquaculture Project in Western Australia was developed in a dam neighbouring an old open-cut coal mine. It uses treated mine lake water before being pumped into a dam where the ponds are situated (Fitzgerald, 2014). Ponds are stocked with marron and the operation provides employment for Aboriginal aquaculturists (Government of Western Australia, 2009; Fitzgerald, 2014).

## 3.5 Benefits and limitations of national and international PMLUs in Queensland coal mines

Whilst certain examples of PMLUs have been beneficial for local communities, the implementation of similar plans in the Fitzroy Basin must be carefully considered. The successful development of PMLUs need to be assessed for whether they will add significant value to the region, reduce environmental risks associated with voids (contamination, regional water security) and be sustainable over extended timeframes (Maest et al., 2020). Queensland's climate means that water quality is an issue for PMLUs in water-filled voids, while the remoteness of many of the open cut coal mines in Queensland may be problematic with respect to the development of infrastructure for certain uses, as well as for the economic appetite for uses such as energy generation (see Table 4 for further description of potential limitations of void PMLUs in Queensland).

Addressing water quality and water level issues by diverting water into voids from other sources has been suggested as a way to minimise solute concentration arising from evapo-concentration, however, communities in Victoria and New South Wales have been concerned about the impact on activities of other water users (Beer et al., 2022). These issues may also be relevant in the Fitzroy Basin, where water tends to be scarce and annual rainfall has been decreasing over the past decades (BOM, 2020). Alternative PMLUs for water-filled residual voids can include provision of habitat for wildlife and agriculture, although these may require reshaping and backfilling.

Mine void rehabilitation has in some instances not been properly implemented. An example is the rehabilitation of the Misima mine in Papua New Guinea, which was intended to function as a hydroelectricity generation project but failed due to limited maintenance (Macintyre, 2018). The result of this apparently well-intentioned project was the abandonment of a void with acidic water which posed an ongoing risk (Keenan and Holcombe, 2021). Care should be taken to ensure that a post mining use is sustainable and able to be implemented into the long term without negatively impacting surrounding communities.

**Table 4. Considerations that may limit implementation of PMLUs for coal voids in the Fitzroy Basin.**

| PMLU | Remoteness/Need for maintenance | Water quality/levels | Requires backfilling |
|---|---|---|---|
| Aquaculture and Fisheries | ✓ | ✓ | |
| Arable/Grazing land | ✓ | | ✓ |
| Building site development | ✓ | | |
| Floating solar | ✓ | | |
| Forestry | | | ✓ |
| Pumped Hydro (Feasibility study) | ✓ | | |
| Recreation | ✓ | ✓ | |
| Recreation in a flow through lake | ✓ | ✓ | |
| Source/Water storage* | ✓ | ✓ | |
| Waste | ✓ | | |
| Wetland | | ✓ | ✓ |
| Wildlife habitat (terrestrial) | | | ✓ |
| Aquatic ecosystem/Wildlife | | ✓ | ✓ |
| Wildlife habitat | | ✓ | ✓ |
| Waste Bioreactor | ✓ | | |

Table note: *crop irrigation/potable water/stock watering

# 4. Water quality in mine voids and suitability for PMLUs

The successful rehabilitation of water-filled mine voids depends upon their long-term water quality. Water quality guidelines differ for each PMLU. Seven common PMLUs for water-filled voids were identified from the literature including water storage for drinking water, water storage for crop irrigation, water storage for livestock watering, freshwater aquaculture, marine aquaculture, electricity generation, and aquatic ecosystems (Keenan and Holcombe, 2021). While these PMLUs have been discussed in the literature, their inclusion in this document is not an endorsement of their implementation or an indication of feasibility.

The water quality guidelines listed here were obtained from a range of sources, including federal, state, and sub-basin policies (ANZECC & ARMCANZ, 2000; DEHP, 2011; NHMRC, 2011). Their inclusion in this document follows the hierarchy of water quality guidelines as shown in Figure 3.

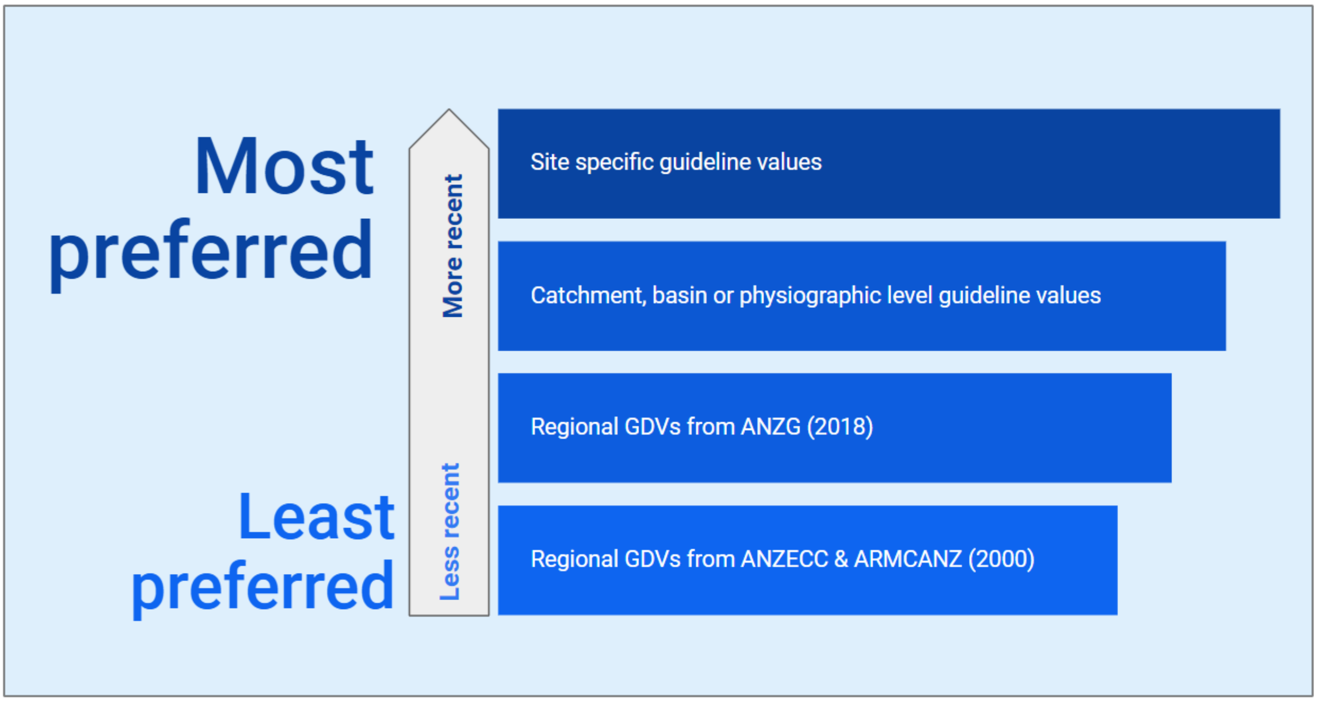


**Figure 3. Hierarchy for applying water quality guidelines (adapted from Figure 3.1.2 ANZECC & ARMCANZ, 2000)**

A subset of water quality guidelines were assessed in this study. It is of note that site specific guidelines are the preferred method, and where available, these may override the guidelines described below. Indicators assessed here included salinity, aluminium, zinc, copper, sulfate and pH. These were selected for analysis as they are recognised in the literature as being key water quality indicators associated with coal mining (Jones et al., 2019; Coffey Services Australia Pty Ltd, 2021). To give an indication of the appropriateness of proposed PMLUs, reported void water quality was compared to water quality guidelines associated with different PMLUs proposed for Fitzroy River Basin coal mine voids in PRC plans and EAs.

The methodology for this assessment was as follows:

- Extract water quality data from water storages for open-cut coal mining activities of the Fitzroy River Basin from the Regulatory Information, Visualisation, Estimation and Reporting System (RIVERS) database (DES, 2022).
- Identify sample points as representing mine voids by overlaying locations with the location of void shape files described by Coffey Services Australia Pty Ltd.
- Select a sub-set of data for the parameter of interest (see above for rationale describing which parameters were considered and why).
- Manually remove potential outliers if necessary.
- Visualise smoothed data overlaid on median water quality guidelines for aquatic ecosystems (except for metals), crop irrigation and livestock watering.

Data was extracted from the RIVERS database (DES, 2022) on the 13/4/2022. The RIVERS database is a data visualisation and extraction tool that provides access to monitoring data submitted by industry to the Water Tracking and Electronic Reporting System (WaTERS). The monitoring data held in this database represents data submitted to the Department of Environment and Science for regulated activities in Queensland. Data was extracted for coal mining activities in the Fitzroy River Basin. The data was further refined to represent 'on-site storages'. This data only reflects current and historic conditions at sample points nominated as 'on-site storages' and does not delineate the type of storage (e.g., whether the location is a catchment dam, environmental dam, active or closed pit or other storage). The data provides an indication of conditions at the time of sampling for a nominal sample point. In some instances, water storages may be used to temporarily store both mine affected and unaffected water for operational purposes. Water quality at a point in time may not relate to the water quality that would remain in those storages after mine closure. To obtain an indication of prevailing water quality conditions in mine voids, the location of sample points were overlaid with void locations described by Coffey Services Australia Pty Ltd (Coffey Services Australia Pty Ltd, 2021) to verify whether they are likely to represent a water-filled mine void sampling location. Only those locations identified as water-filled mine void sampling locations were used for further analysis. Although care has been taken to identify those locations likely to represent a sub-set of void sampling locations, the information should not be considered as representative of all coal void conditions that occur across Queensland.

The data analysis presented in this section represents total fraction of metals and metalloids and is not representative of the bioavailable or filtered fraction. An analysis of requirements for metals in aquatic ecosystems requires further analysis and is outside the scope of the current report. Marine aquaculture was not considered in further analyses as inland aquaculture of marine fish stocks has only been discussed and not trialled within mine voids to the author's knowledge (Otchere et al., 2004), and there are no documented national or international cases of implementation of this putative PMLU. Freshwater aquaculture was not proposed in Queensland EAs and PRC plans and is therefore not shown in the plots of this analysis.

## 4.1 Salinity

The data in Figure 5 and summarised below shows salinity is observed at elevated concentrations in many coal mine pits of the Fitzroy Basin. Many voids are expected to become terminal sinks (Coffey Services Australia Pty Ltd, 2021) due to saline soils and an arid climate. A highly saline water body limits the viability of many PMLUs. Some of the challenges associated with saline water in voids include the prevention of the establishment of autochthonous ecological communities (Nielsen et al., 2003) and result in sub-par outcomes if used as a water source for crops or livestock (Zörb et al., 2019). Figure 4 shows general water quality guidelines for salinity within the Fitzroy Basin, model mining conditions and national guidelines (ANZECC & ARMCANZ, 2000; DEHP, 2011; NHMRC, 2011; DES, 2017). These range from 210 µS/cm for aquatic ecosystems of the Comet Basin to 15,000 µS/cm for stock watering of sheep.

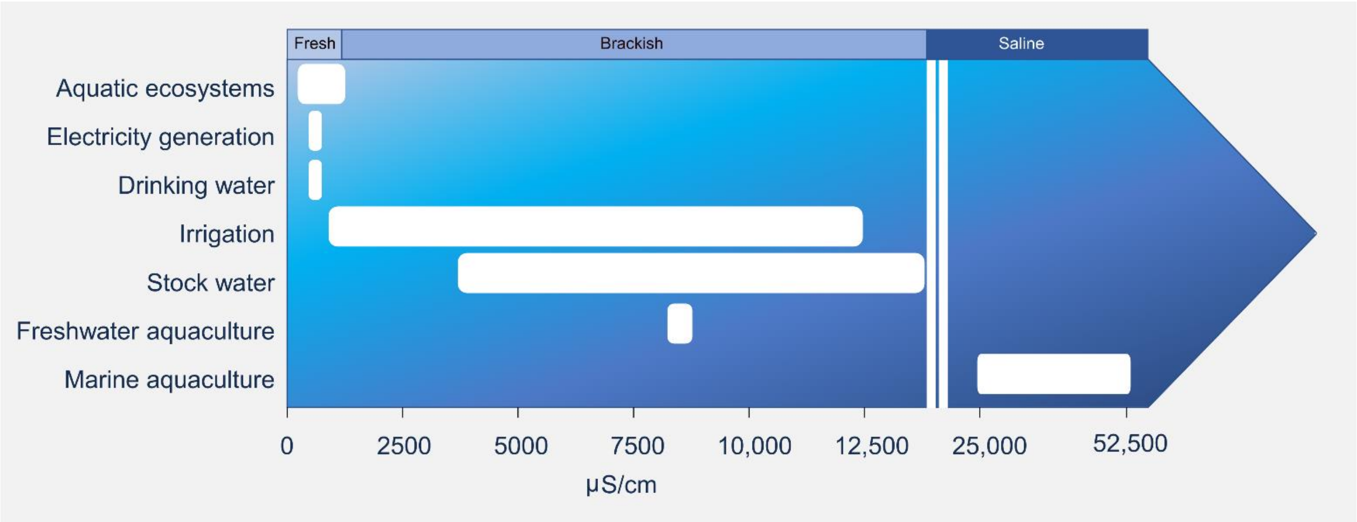


**Figure 4. Sliding scale of salinity trigger values within the Fitzroy Basin, Queensland**

Figure 5 shows electrical conductivity (in µS/cm) data overlaid with water quality trigger values for livestock watering, crop irrigation and aquatic ecosystems. Fluctuations in values over time may be due to a range of factors including rainfall events and water movements to facilitate mining. Data on electrical conductivity, a measure of salinity, was recovered for 12 voids of the Fitzroy Basin. Values ranged between 750 µS/cm and 18,000 µS/cm (outliers of 62.2 µS/cm, 43,000 µS/cm and 46,000 µS/cm removed from plot). Measured electrical conductivity in void waters was sufficiently good over the whole of the reporting period to support livestock watering for half the voids; crop irrigation for a quarter of the voids; and aquatic ecosystems for no voids (where water quality objectives are available).

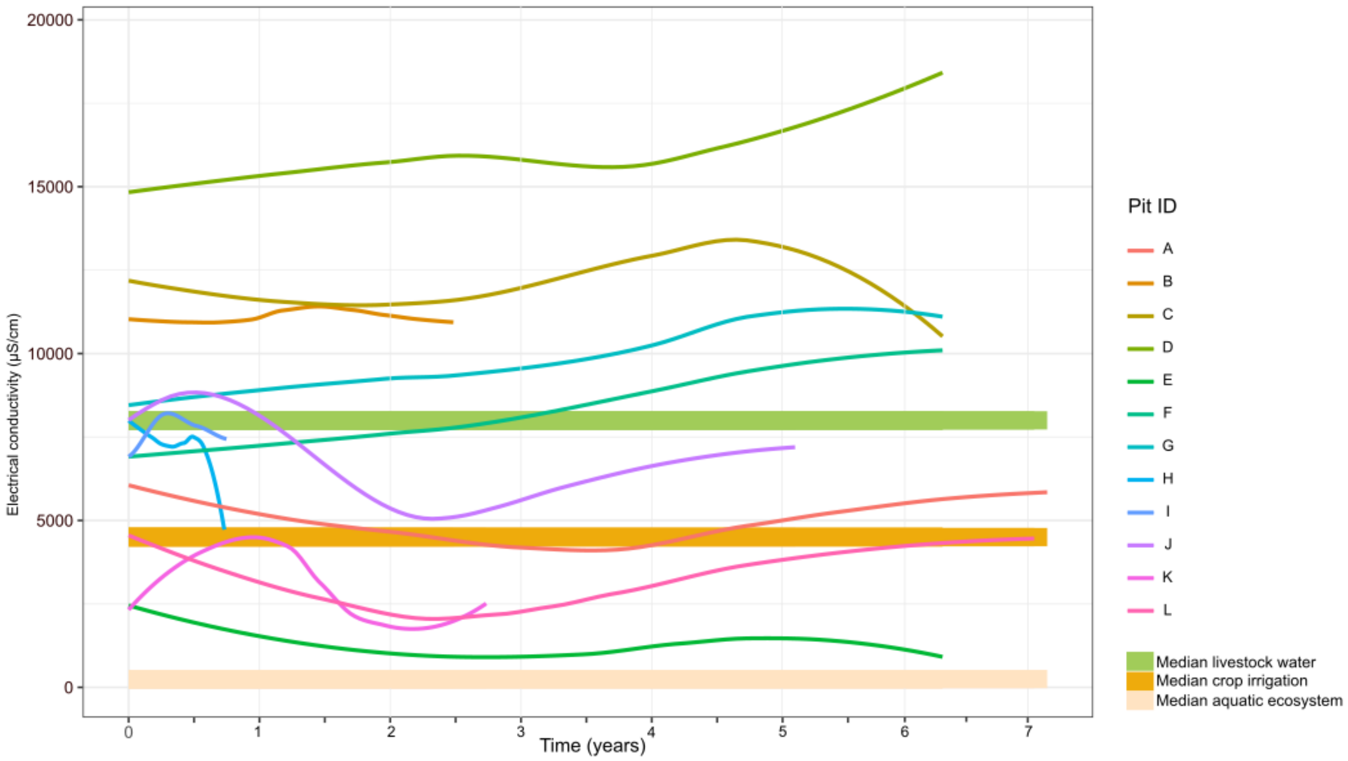


**Figure 5. Electrical conductivity (µS/cm) for 12 open-cut coal mines of the Fitzroy Basin, Queensland compared with trigger values for beneficial use**

We have assumed for the purpose of this study that water storage as a PMLU will be for livestock watering and crop irrigation, although the end use of that water is undefined in most void management plans and EAs. Electrical conductivity in mine voids in the semi-arid Fitzroy Basin is expected to increase after the cessation of mining due to evapo-concentration, a trend already seen in many of the pits for which data is presented here. Additionally, the results of this analysis already predict that crop irrigation, livestock watering and aquatic ecosystem PMLUs are incompatible with the current water quality in some or all voids. Consequently, it is likely that many voids in the Fitzroy Basin will not be able to sustain a PMLU without amendment or water treatment to reduce salinity.

## 4.2 Total aluminium

Aluminium can be present in coal mine voids and mine affected water releases in the Fitzroy Basin (Jones et al., 2019). A water body with high levels of aluminium presents various challenges for PMLUs, including toxicity to various aquatic species (Gensemer and Playle, 1999), crops (Panda et al., 2009), livestock, and humans (Shaw and Tomljenovic, 2013). Water quality guidelines for aluminium within the Fitzroy Basin range from 55 µg/L for aquatic ecosystems to 5,000 µg/L for stock watering and crop irrigation.

Total aluminium data was available for 12 voids of the Fitzroy Basin (Figure 6). Values ranged between 10 µg/L and 15,000 µg/L (an outlier of 87,000 µg/L was removed). Total aluminium concentrations in void waters were sufficiently low over the whole of the reported period to support livestock watering and crop irrigation for 11 of the 12 voids. Residual voids may be able to sustain livestock watering and crop irrigation into the future, but to do so will require regular monitoring and possibly treatment, especially given that these voids are expected to undergo evapo-concentration. Furthermore, aluminium trigger values vary depending on pH, temperature, hardness, fluoride, citrate and humic substances (ANZECC & ARMCANZ, 2000). These parameters should be concomitantly evaluated and factored into assessing whether a void's water quality can support a proposed PMLU and be instrumental in devising management strategies. The data presented here represents the total fraction and does not represent the risks to aquatic ecosystems and a separate analysis would be required to assess this.

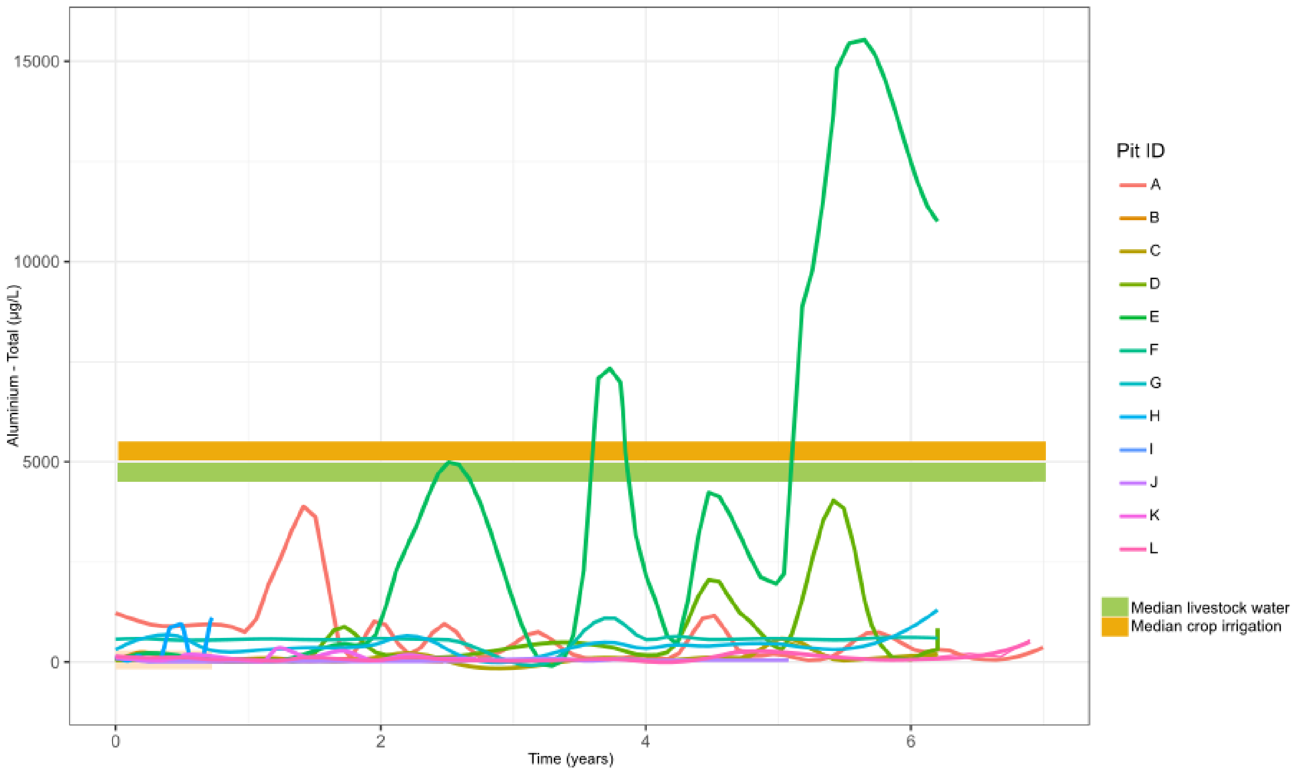


**Figure 6. Total aluminium (µg/L) for 12 open-cut coal mines of the Fitzroy Basin compared with trigger values for beneficial use**

## 4.3 Total zinc

Zinc is present in coal mine voids and mine affected water releases in the Fitzroy Basin (Jones et al., 2019). A water body with high levels of zinc presents various challenges for PMLUs, including toxicity for certain freshwater species, bioaccumulation in animal tissues (ANZECC & ARMCANZ, 2000), and cytotoxicity to plants (Rout and Das, 2009). Whilst zinc is an essential trace element for many aquatic organisms (ANZECC & ARMCANZ, 2000), it is also able to elicit toxic responses. Zinc toxicity is modulated by water hardness and complexation with organic matter (Tessier et al., 1996). Water quality guidelines for zinc within the Fitzroy Basin are 2,000 µg/L for crop irrigation and 20,000 µg/L for stock watering.

Total zinc data was recovered for 12 voids of the Fitzroy Basin (Figure 7). Values ranged between 2 µg/L and 1,410 µg/L. Total zinc concentrations in void waters were sufficiently good over the whole of the reported period to support livestock watering and crop irrigation for all 12 of the voids. Based on zinc values, residual voids may be able to sustain livestock watering and crop irrigation into the future, but in order to do so may require regular monitoring and possibly treatment.

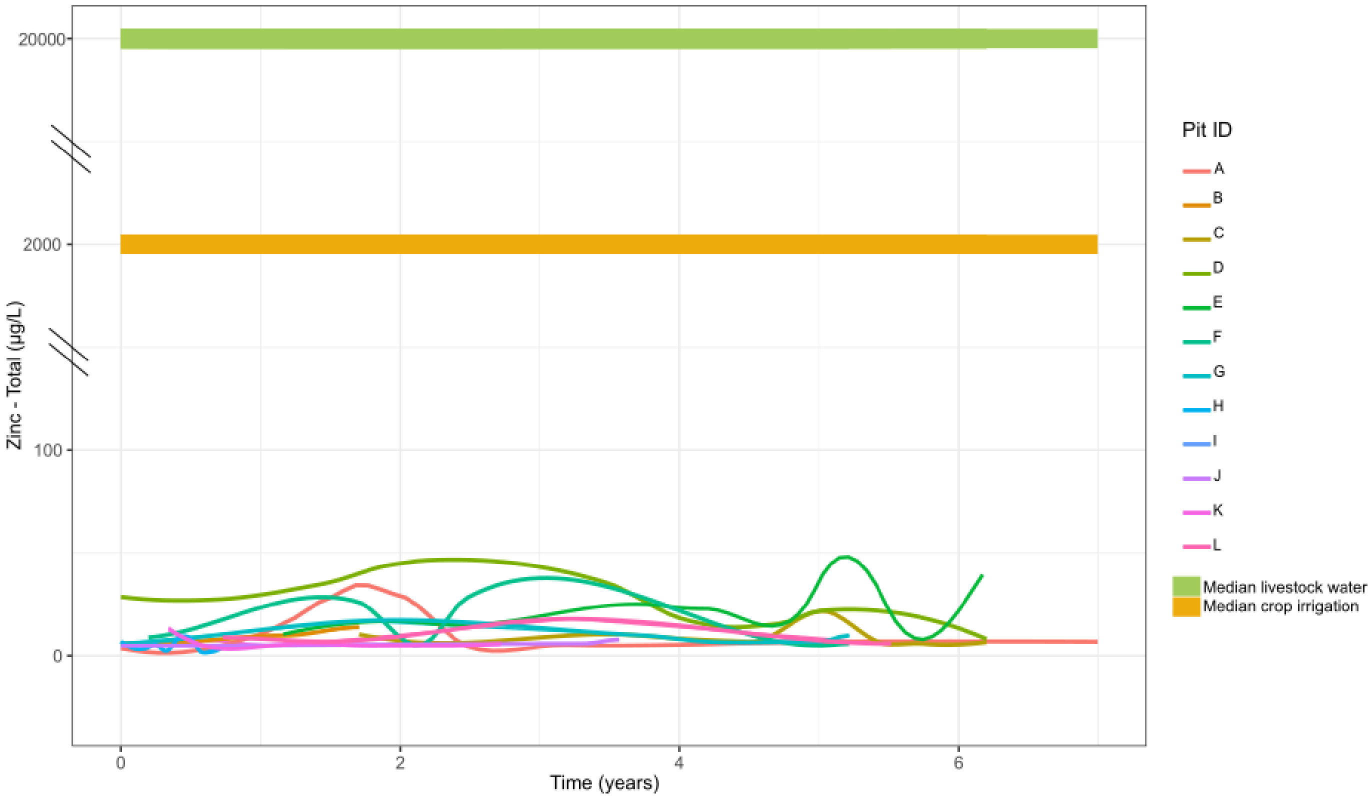


**Figure 7. Total zinc (µg/L) for 12 open-cut coal mines of the Fitzroy Basin compared with trigger values for beneficial use**

## 4.4 Total copper

Copper is present in coal mine voids and mine affected water releases in the Fitzroy Basin (Jones et al., 2019). Copper is an essential trace element which is found in most natural water bodies (ANZECC, 2000). Low concentrations of copper are required for the growth of most aquatic organisms, however, many of these are highly sensitive to even small increases (Nor, 1987), which is problematic for certain PMLUs. Water quality guidelines for copper within the Fitzroy Basin range from 0.4 µg/L for stock water for sheep, and 20,000 µg/L for primary recreation.

Total copper had the least available data points, both in terms of sites (n=4) and timepoints (two years of reported monitoring maximum, Figure 8). Accordingly, the information provides a limited representation of actual concentrations in coal mine voids across the Fitzroy Basin and care should be taken with its interpretation. Given that copper can be toxic to aquatic life, and previous research has described elevated copper concentrations in mine voids (Jones et al., 2019), monitoring of copper is important in achieving beneficial outcomes for mine voids. Copper concentrations in void water were sufficiently good over the whole of the reported period to support crop irrigation for three of the four voids, and livestock watering for all four voids.

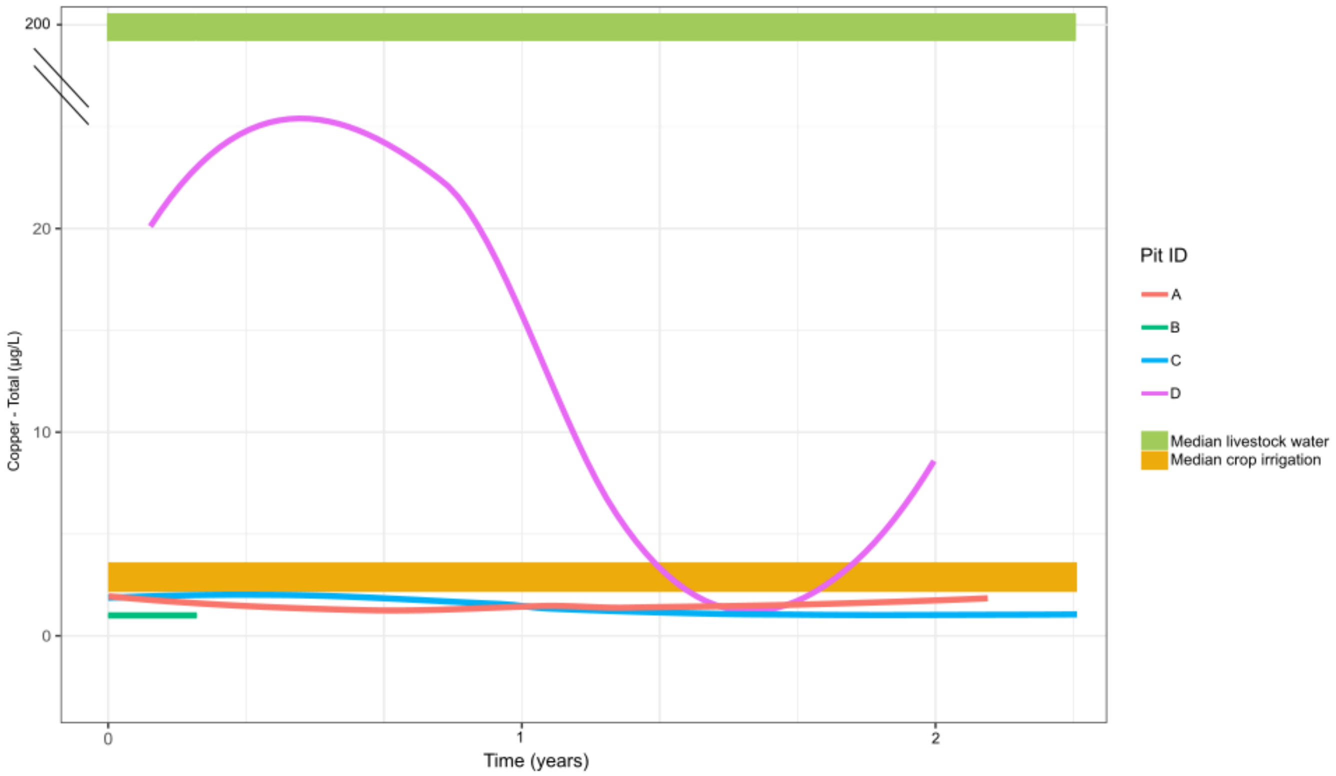


**Figure 8. Total copper (µg/L) for four open cut coal mines of the Fitzroy Basin compared with trigger values for beneficial use**

## 4.5 Sulfate

Sulfate is often found in high concentrations in pit lakes (McCullough and Lund, 2010) and can present various issues such as toxicity to aquatic biota and negative impacts on human health (Zak et al., 2021). Water quality guidelines for sulfate within the Fitzroy Basin range from 5 mg/L for aquatic ecosystems to 5,000 mg/L for recreation.

Sulfate data was available for 12 voids in the Fitzroy Basin (Figure 9). Values observed ranged between 20 mg/L and 7,800 mg/L. Sulfate concentrations in void waters were sufficiently good over the whole of the reporting period to support livestock watering for seven of the 12 voids.

Crop irrigation water quality guidelines could not be identified for sulfate as soils for cropping are often sulphur limited (Scherer, 2001). However, sulfate can be toxic to plants, and potentially crops. An ecotoxicology study that evaluated sulfate in test waters relevant to the Fitzroy Basin found that a freshwater plant species endemic to the Fitzroy Basin (*Lemna disperma*) had a chronic effect concentration (EC10) of 1,250 mg/L (Dunlop et al., 2016), a level surpassed in five of the 12 mine voids. That study suggested a preliminary toxicity guideline for sulfate of 355 mg/L for the Fitzroy Basin for the protection of 95% of species. While this threshold gives an indication of potential impacts, it is not a recognised water quality objective. Certain residual voids may be able to sustain livestock watering and crop irrigation into the future, but to do so will require regular monitoring and possibly treatment, especially given that these voids are expected to undergo evapo-concentration, concentrating solutes. Furthermore, sulfate toxicity thresholds are modulated by physicochemical parameters such as hardness, and it is therefore recommended that these parameters be measured concomitantly (Zak et al., 2021). Simultaneous evaluation of these parameters should be factored into assessing whether the quality of water in voids can support a proposed PMLU.

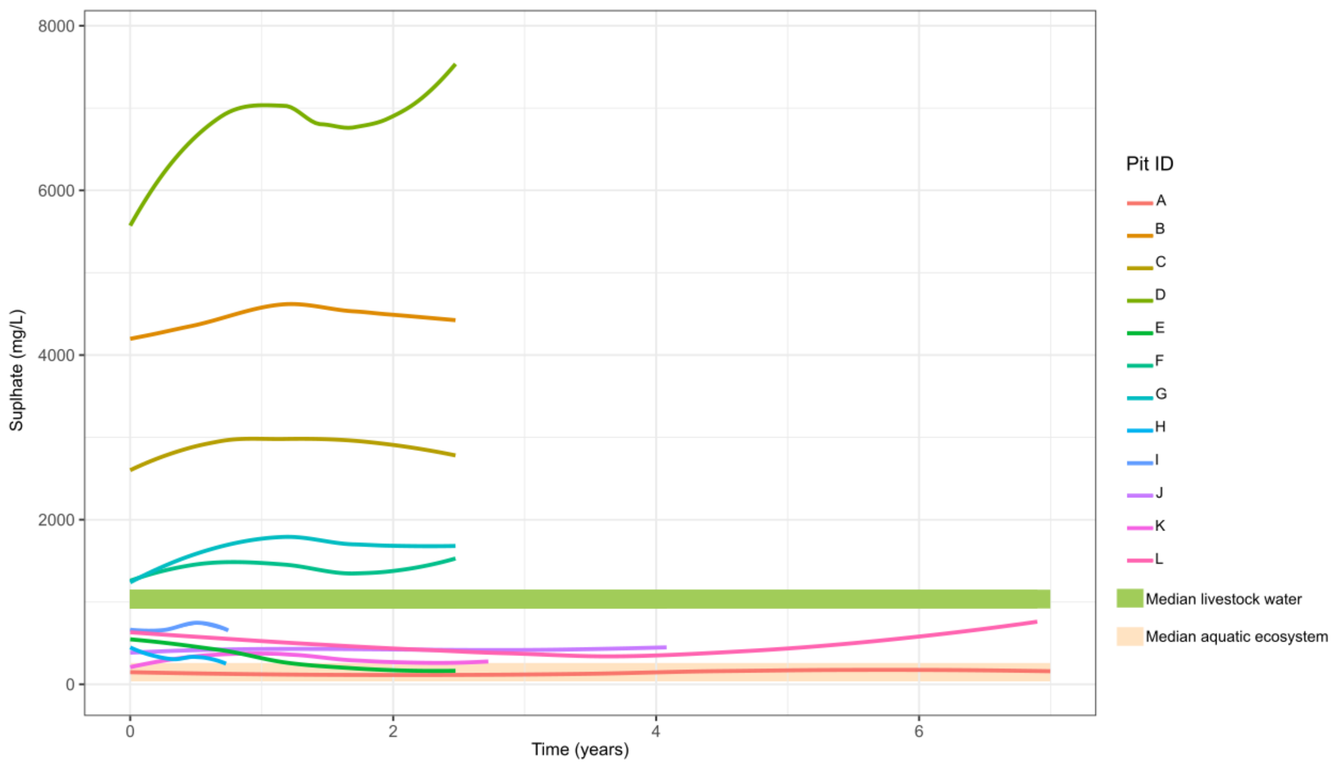


**Figure 9. Sulfate (mg/L) for 12 open-cut coal mines of the Fitzroy Basin compared with trigger values for beneficial use**

## 4.5 pH

Low pH can be a concern for water in some mine voids. Low pH can be caused by the disturbance of acidic soils and inflow of mine waste leachate (Thomas and John, 2006). Acidic water can be toxic for aquatic life and corrode industrial or agricultural equipment. Water quality guidelines for pH within the Fitzroy Basin range from six to nine for irrigation to six and a half to eight for aquatic ecosystems. pH data was available for 12 voids of the Fitzroy Basin (Figure 10). Interestingly, no void was too acidic for the proposed PMLUs. Voids were instead relatively alkaline, above trigger values for aquatic ecosystems for all 12 of the voids and crop irrigation for one of the 12 voids. This is likely due to the high carbonate concentrations in minerals of the Bowen Basin (Golding et al., 2000) where samples included in this analysis originated.

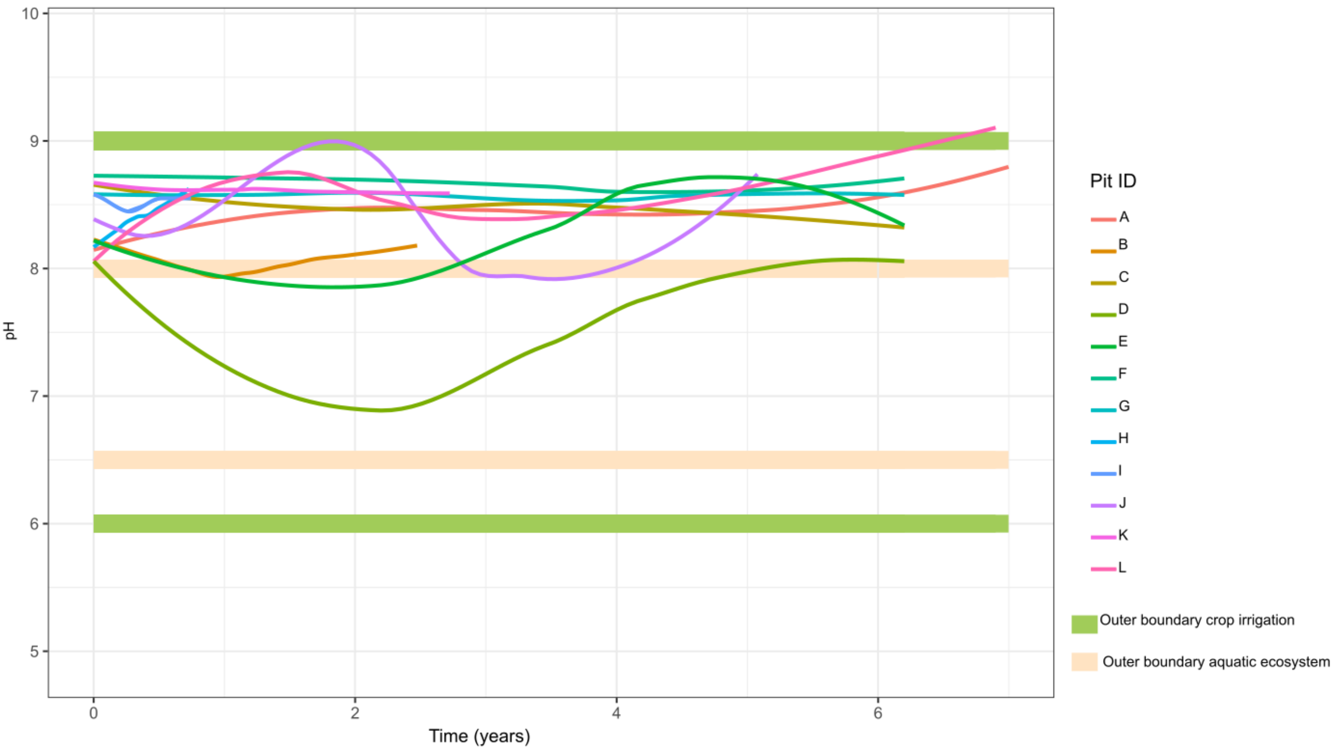


**Figure 10. pH for 12 open-cut coal mines of the Fitzroy Basin compared with trigger values for beneficial use**

# 5. Discussion

This review of the current state of open-cut mine voids of the Fitzroy Basin highlights common practices for rehabilitation planning. It finds that historic approvals describing final rehabilitation outcomes for residual mine voids either do not adequately define a PMLU or deferred the finalisation of rehabilitation planning objectives to the final stages of mine life. There were many instances where residual voids were nominated as a 'water storage' in EAs without defining a specific use for the water.

The requirement to develop a PRC plan aims to combat this issue by ensuring a PMLU is nominated upfront in the planning process and that land disturbed by mining is progressively rehabilitated to achieve that outcome during the life of a mine (Cooper, 2019). Analysis of proposed and approved PRC plans (n = 10 as of 24 May 2022) show an improvement in planning for void rehabilitation. Encouragingly, from a review of the (albeit limited) number of PRC plan documents either approved or submitted for consideration by the regulator at the time of this review, it was found that where a residual void was described in the final landform, a specific plan was stated for its rehabilitation.

Although historic approvals show backfilling of residual voids is rarely undertaken in Queensland, the review of currently proposed and approved PRC plans found some examples where voids were proposed to be backfilled. While the number of rehabilitation plans reviewed here does not provide a complete picture of the industry, it does indicate that backfilling is suitable in some instances, exemplified by the certified rehabilitation of the backfilled Chuwar coal mine. Backfilling mine voids can help to avoid or mitigate risks associated with a water-filled residual void and allow for the establishment of PMLUs such as grazing and native bushland. Such uses are expected to have benefits to local economies and ecosystems (Skousen and Zipper, 2014; Bainton and Holcombe, 2018). The US *Surface Mining Control and Reclamation Act 1977* requires re-establishment of a suitable PMLU and for the land to be returned to its ‘‘approximate original contour’’ (section 515(b)(3)). As shown by examples in the US, progressive backfilling to above the water table is likely one of the simplest ways to minimise risk and achieve a PMLU for a void (Skousen and Zipper, 2014). This option removes the possibility of leaving a contaminated water body in the area after mining has ceased and is considered suitable in the absence of a considerably beneficial PMLU.

Despite the advances in planning for voids under the PRC plan framework, NUMAs were still commonly proposed. This reflects both the number of historically approved NUMAs and potentially the difficulty to rehabilitate voids to achieve a viable PMLU where planning is undertaken late in mine life. While the PRC plan framework allows for the proposal of a residual void as a NUMA in some situations, the PRC plan guideline states that “*applicants should be planning for the rehabilitation of all areas to PMLUs as a priority with NUMAs as a last resort*” (Department of Environment and Science, 2021). Nevertheless, many voids with little prospect of a PMLU are authorised in Queensland.

Various innovative PMLUs for voids have been achieved globally (e.g. recreational use, floating solar, and aquaculture). Some of these innovative uses, such as floating solar and pumped storage hydroelectricity, also have goals of cutting carbon emissions with potential to provide a range of benefits to post-mining communities. Although such PMLUs may have potential for application in the Fitzroy Basin, many can be difficult or impractical to achieve on open-cut coal mines in Queensland. A precursor to any PMLU is the need to achieve a safe, stable and non-polluting landform, and therefore, innovative PMLUs must be assessed with great care in order to ensure that the rehabilitation to these PMLUs does not create further environmental or safety issues. Potential limitations to the uptake of innovative PMLUs include the remoteness of sites, the need for ongoing management, health and safety requirements, water quality constraints and the need for complex regulatory approvals. However, international and interstate examples do demonstrate that innovative PMLUs can potentially provide both environmental and social benefits.

Where residual voids are left open beyond mining it is likely that many will be unsuitable to support a PMLU without improving water quality. None of the water-filled voids for which data could be recovered could sustain a PMLU with compliant water quality over the monitoring timeframe. Mining was still in operation during monitoring, meaning that these measurements are not representative of what residual void water quality may be at the end of mining and that the data is from a limited sub-set of voids for which data was publicly available. However, while not broadly representative, these data show that in many cases where water-filled voids are left as such, they would likely not be able to sustain a PMLU into the future without water treatment to remove contaminants. Currently, in the Fitzroy Basin, water treatment is not common, and in perpetuity may be unfeasible and costly (Firth et al., 2002). Furthermore, the analysis undertaken here was hindered by the paucity of the available dataset, with data available for only 12 voids, and certain parameters being measured only sporadically. Robust reporting of water quality in voids would help to support the success of a PMLU or aiding PMLU decision making for similar voids. This opinion is echoed by the IESC scoping study on coal mine voids in Queensland that called for “*a comprehensive database (and accompanying spatial files) of key details for approved residual coal mine voids in Queensland*” (Coffey Services Australia Pty Ltd, 2021).

# 6. Conclusion

To conclude, a review of past and current information available describing rehabilitation planning for coal mine voids shows an industry which is in transition. Historically, planning for voids has often lacked clear outcomes, schedules, and methods. However, regulatory changes in Queensland appear to be enhancing rehabilitation planning for mine voids which may improve the achievement of void PMLUs. Although it may not be required or be feasible in some instances, backfilling voids to create a safe, stable and non-polluting landform that supports a viable PMLU can help to avoid or mitigate risks that can be associated with water-filled voids. The quality of water held in residual voids may exceed relevant guidelines and limit whether a PMLU can be sustained into the long term. In some instances, it may be necessary to improve long term water quality via water treatment to actively manage risks to the community and environment. The analysis presented here also demonstrates the limitations of current void water quality reporting with little data publicly available on mine void water quality. The available data showed that none of the voids would have water of a quality sufficient to sustain a PMLU when considering current water quality guidelines. This report also highlights that there is likely to be a substantial number of voids that may be proposed as NUMAs. Further guidance is required to ensure there are adequate approaches in place to plan and manage these structures in a way that will minimise the risk to the community and the environment.

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