

Subsidence ponded landforms and closure

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Abstract

This innovative study assessed the potential impacts (beneficial and adverse) associated with leaving subsidence-induced ponded landforms (ponded areas) in situ in comparison to reinstating free-draining landforms at Grosvenor Mine in Queensland. This included a risk-based comparison and identification of relevant post-mining land uses (PMLU) under the legislative framework of the Mineral and Energy Resources (Financial Provisioning) Act 2018.

An initial literature review identified that the most common contemporary industry standard for managing ponded areas is to reinstate free-draining landforms. However, technical studies including GoldSim water balance modelling, TUFLOW flood modelling, targeted flora and fauna surveys and groundwater, soil and geomorphology assessments determined that, in comparison to free-draining landforms, ponded areas may result in reduced erosion risk, reduced and/or differing vegetation and fauna habitat clearing, increased access to water sources for stock and native flora/fauna and reduction of sediment entering the receiving environment catchment. Ponded areas were found to reduce the average annual water volume reporting to the downstream waterways; however, the associated impact would be small in proportion to the broader regional flow in the Isaac River. The key risks of this initial study that were found to be less likely to support PMLU outcomes were associated with impacts to ecological communities as a result of long-term inundation and salt leaching in vertosol soils.

Ponded areas were shown to have the potential to support the PMLU of grazing and potentially other PMLUs, such as wetland environments. However, further site-specific monitoring and analysis is required to verify the PMLU outcomes for each individual ponded area.

Keywords: *post-mining land use, subsidence ponding, innovation, closure*

1 Introduction

Anglo American engaged Engeny Australia Pty Ltd (Engeny) to investigate the potential impacts (beneficial and adverse), risks and opportunities associated with leaving subsidence-induced ponded landforms (ponded areas) in situ, compared to reinstating free-draining landforms. The objective of the study was to compare the risk profiles of each scenario and verify the potential for post-mining land uses (PMLU) for ponded areas under the legislative framework of the Queensland *Mineral and Energy Resources (Financial Provisioning) Act 2018* (MERFP Act) (Government of Queensland 2018).

The study focused on the Grosvenor underground metallurgical coal mine near Moranbah in Central Queensland, Australia. Mining operations currently operate concurrently with cattle grazing within the tenement. All waterways that traverse the mine are ephemeral, with the key waterways being the Isaac River and Teviot Brook.

An initial review of available literature identified that the most common contemporary industry practice for management of ponded areas is to reinstate a free-draining landform. However, there are instances of underground coal mining projects in which the regulator accepted that backfilling was not feasible and that reinstating free-draining landforms was not always practicable. In these cases, the regulator was accepting of residual ponding with appropriate monitoring and treatment programs to address the risks (Department

of Environment and Resource Management 2010). Key risks identified through a review of environmental impact statements included submissions regarding mosquito populations in ponded areas (BHP Billiton Mitsubishi Alliance [BMA] 2014), requests for further information on ponded area impacts and mitigation measures (GHD Pty Ltd 2013) and concerns that (in-stream) ponding will reduce the natural stream flows during low-flow periods (BMA 2014). However, a study of the international, national, regional, environmental and socio-economic context of the Moranbah region and PMLUs supported ponded areas having a positive impact if they provided habitats for flora and fauna in a landscape that has lost many of its ephemeral wetlands (Côte et al. 2020). Multiple international studies outlined beneficial outcomes for retaining ponded areas, including the potential to transform these areas into artificial wetlands (Xu et al. 2020). Another study found subsidence wetlands provide important complementary habitats for a wide array of waterbird species (Li et al. 2018).

To further identify and assess the potential impacts of ponded areas, technical assessments were completed on a range of environmental aspects, including soil, groundwater, surface water, flooding, geomorphology and ecology. The results of these assessments informed a comparative risk assessment between the two closure scenarios, residual ponded areas and reinstating free-draining landforms, as well as identifying the potential for the ponded areas to support a PMLU. Recommendations were derived for ongoing monitoring during the operational mining phase to verify the PMLU outcomes for individual ponded areas.

2 Methodology

2.1 Identification of ponded areas

Existing and predicted future ponded areas were identified using 12D and QGIS software through a manual interrogation of the latest LiDAR survey, aerial and forecast post-subsidence surface (which is a function of the configuration of the approved underground mine plan). The assessment identified the location, volume, depth and surface area of each ponded area at the Grosvenor Mine. Ponded areas within the channel beds of waterways were not assessed as part of this study, as previous studies have identified that there is currently an excess of sediment within the Isaac River compared to the scale of the predicted waterway ponded areas (Alluvium 2008), and therefore ponded areas within waterways are expected to be infilled and were considered too temporary to maintain a PMLU in closure. Ponds with a depth less than 150 mm were also not included in the assessment due to the level of accuracy in elevation data within the topographical survey. Each pond was assigned a unique identifier number and all attribute data were captured in spatial datasets. Existing ponded areas (or a selection of) at Anglo American's other underground operations were also identified as comparative sites to benchmark longer-term behaviour of Grosvenor Mine's ponds.

2.2 Conceptualisation of free-draining landform

To achieve a free-draining landform, earthen drains would need to be constructed between each ponded area and the next closest ponded area or waterway. These were conceptualised assuming the optimised number and extent of drainage, ensuring drainage ultimately enters a formalised drainage path/watercourse and alignment with existing conceptual layouts. This conceptualisation provided an indicative extent of vegetation clearing required for the free-draining scenario by adopting a standard drainage corridor width of 20 m to allow for the earthworks machinery to access and construct the drain.

2.3 Soil

Landloch Pty Ltd investigated the impact of ponded areas on the physical and chemical condition of soils at the mine, through desktop review of site reports, existing soil data and published soil mapping. Water balance modelling was conducted using the HowLeaky software, with three varying soil concepts utilising 50 years of historical climate data for the site location obtained from the SILO climate database facility, hosted by the Queensland Department of Environment and Science, and HowLeaky generic model parameters for an actively growing grassy pasture (with a modification to reduce rootzone depth to 80 cm).

2.4 Groundwater

Pendragon Environmental Solutions Pty Ltd determined the potential impacts of ponded areas on groundwater through a desktop characterisation of the hydrogeological regime at the mine based on available data and reports, including existing hydrogeological cross-sections.

2.5 Surface water

A daily time step water balance model was created using the GoldSim software to model the inflows and outflows from each ponded area for the post-mining scenario, as well as the changes to volume and depth of water within each pond over time. This is a separate water balance model to the one referenced in the soil methodology above. The model was simulated for a 130-year period using historical climate data for the site location from the SILO database. The climate data indicated that the site receives an average rainfall of 550 mm/year but has an average evaporation rate of 1,811 mm/year, with the highest rainfall and evaporation rates occurring in the warmer summer months. Flushing inflows from regional flooding were conservatively excluded. Catchment areas for each pond were determined using CatchmentSIM with manual refinement using QGIS. Catchment runoff was simulated using the Australian Water Balance Model (AWBM).

A representative average seepage loss rate from the ponds of 0.2 mm/day was applied based on the soil assessment. The GoldSim water balance model was run with varying scenarios to provide a sensitivity assessment, using different natural runoff AWBM parameters and a low (0.02 mm/day) and high seepage rate (2 mm/day).

Total dissolved solids (TDS) and electrical conductivity (EC) were simulated as indicators of trends in overall water quality (e.g. concentration over time) to inform potential for stock water use and broad environmental impacts. Water quality was simulated for TDS and converted to EC based on an assumed conversion factor of 1 mg/L TDS = 1.49 μ S/cm EC. A representative TDS concentration of 77 mg/L was adopted for runoff inflow based on an average of two water quality samples taken from existing ponded areas at the mine in early January 2021. In the month preceding the samples (December 2020), 123 mm of rainfall was recorded, meaning the ponds had recently received rainfall and runoff. To analyse the EC results effectively, five depth thresholds were set at 0.15 m, 0.25 m, 0.5 m, 1 m and 2 m. The percentiles of daily EC values were then calculated using the water quality values when depth exceeded each of these thresholds. Model results were compared against the livestock (cattle) drinking water threshold of 4,000 mg/L TDS (which approximately equates to an EC of 5,960 μ S/cm and represents an upper threshold before stock production may be impacted [ANZECC 2000]).

The impacts on runoff volumes from the ponded areas were assessed relative to a simulation of catchment runoff from the pre-subsidence landform (i.e. no storage effects from ponding). The total catchment area was determined as the total of all the ponded catchment areas, at 3,431 ha.

2.6 Flooding

Flood modelling for the full range of events (39% annual exceedance probability to the probable maximum flood [PMF]) and reflecting the same post-mining conditions used to define the ponded areas for the mine was used to infer potential hydraulic impacts and risks associated with ponded areas. The outputs of the TUFLOW hydraulic model were extracted to identify the frequency and extent of inundation of the ponded areas resulting from regional Isaac River flooding. The hydraulic parameters (e.g. velocity, shear stress, stream power) were assessed to infer the potential for scour and erosion of the landform.

2.7 Geomorphology

Review of existing data and outcomes of the soils and flooding assessments was used to estimate sediment inflow rates and infill time frames and to comparatively assess the risks of erosion and incision of the ponded areas in comparison to free-draining landforms.

2.8 Ecological

Field investigations were conducted by the consultancy Ecological Survey & Management at the mine and another of Anglo American's underground mines between May and June 2021, as well as review of historical data and studies. The already subsided areas surveyed were stratified into (1) areas that experience short-term inundation and were not ponded at the time of the field survey and (2) areas that experience prolonged inundation and were ponded at the time of the field survey. A series of reference sites were also surveyed at sites as close as practical to the ponded survey sites within remnant vegetation that represented the same regional ecosystem (RE), to highlight potential variations in condition between subsided and intact communities.

For the short-term inundation ponds, seven subsidence and seven reference sites were assessed across both mines. Surveys were undertaken using the BioCondition methodology (Eyre et al. 2015). Each survey site involved a 100 m × 50 m transect (or 100 m × 20 m in wattle-dominated communities), in which a series of 10 ecological condition attributes were recorded. Data were collected on the soils, slope, aspect and landform observations, species richness describing stratum position and relative abundance using the Hurst & Allen (2007) interpretation of the Braun-Blanquet technique and photographs. An ecological score was calculated using the 10 BioCondition parameters monitored at each location. These scores and the most relevant individual parameters were then considered and compared between subsidence and reference sites.

For the prolonged inundation ponds, 13 subsidence survey sites were assessed. Survey methodology varied from the short-term ponds as quadrats could not be appropriately and safely installed within the inundated ponded areas. Instead, the methodology comprised a 180° hemispherical sweep of the immediate edge of the inundated communities orientated into the inundated area. Similar ecological parameters to the short-term inundation ponds were estimated, including canopy, sub-canopy, shrub- and ground-layer height and cover, recruitment, scaled condition and disturbance observations, soils, slope, aspect and landform observations and photographs. The ecological parameters were averaged for each subsidence pond. This average for each parameter was then considered and compared to the corresponding BioCondition parameters that could be sampled at the most relevant reference site.

An incidental assessment of bird usage at each of the surveyed prolonged inundation ponds was undertaken and cross-referenced to a previous 2021 fauna survey of birds using the ponded habitats and corresponding non-ponded REs.

The field data were also considered and reviewed with the range of forecast physical characteristics for each subsided area, including depth, volume, duration of inundation, surface area of subsidence ponding and quality (EC) from the surface water assessment.

3 Results

3.1 Definition of ponded areas and conceptual free-draining landform

A total of 73 (either existing or forecast) ponded areas were identified at Grosvenor Mine based on the mine plan (Figure 1). The volume of individual ponded areas ranged from less than 1 to 127 ML, depth ranged from 0.25 to 3 m and surface area ranged from less than 1 to 15 ha. The ponded areas resulted in a total surface area of 290 ha and a combined capacity of 1.6 gigalitres.

Based on the drainage conceptualisation, the total disturbance area for the free-draining landform would be approximately 37 ha. However, this disturbance area is conceptual only and subject to change based on further detailed investigations and design.

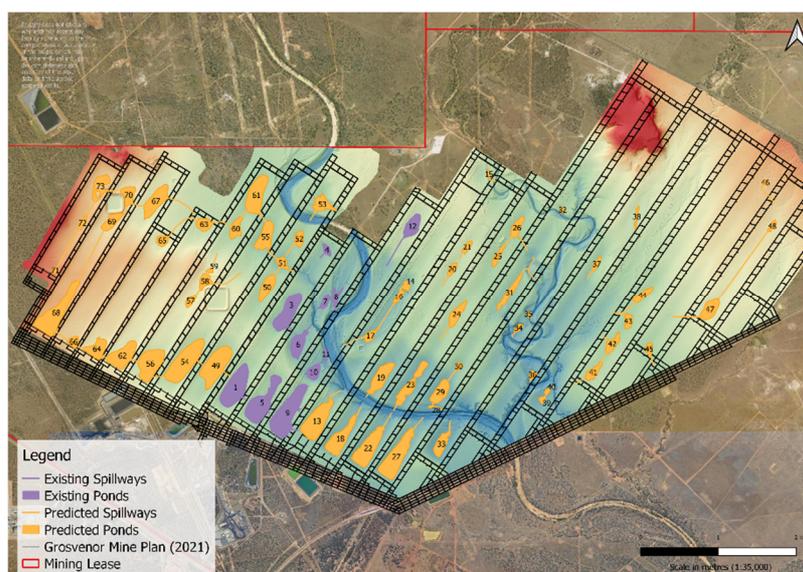


Figure 1 Identified ponded areas at Grosvenor Mine

3.2 Soils

The soil technical study determined that vertosols, sodosols, kandosols and rudosols are overlaid by the ponded areas, with the majority overlaid by vertosols and sodosols. However, given the low resolution of the existing soil sampling information, it was difficult to determine the proportions of the soils that will be affected. The HowLeaky water balance modelling provided indicators of deep drainage and runoff, which are presented in Table 1. The kandosol and sodosol soils had higher infiltration rates than vertosols, with a more obvious difference with higher rainfall events.

Table 1 Runoff and drainage results

Soil	Annual runoff (mm)			Annual deep drainage (mm)		
	Average	Median	Max	Average	Median	Max
Vertosol	25	2	220	11	0	100
Sodosol	9	3	61	58	5	410
Kandosol	7	2	50	100	60	470

3.3 Groundwater

The review of existing hydrogeological information found there to be no significant and/or sustainable groundwater aquifers and/or sources. The groundwater quality in those that contain small, sporadic and compartmentalised water supplies is mostly saline with elevated levels of heavy metals/metalloids.

3.4 Surface water

The GoldSim water balance model results determined that the ponded areas experience fluctuations in volume with cycles of substantial ponding over extended periods (depths greater than 1–2 m for months and years at a time), followed by extended dry periods with small residual pools (shallow depths of less than 0.5 m for months and years at a time).

Figure 2 demonstrates the percentage of days over the 130-year simulation that each pond was modelled to exceed various depth and volume thresholds. Figure 2a shows most ponds follow a similar trend, with the pond with the greatest depth remaining between 2.5 m to 3 m for 10% of the 130-year period. Figure 2b shows that almost all ponds were modelled as not empty for approximately 50% of the time or less.

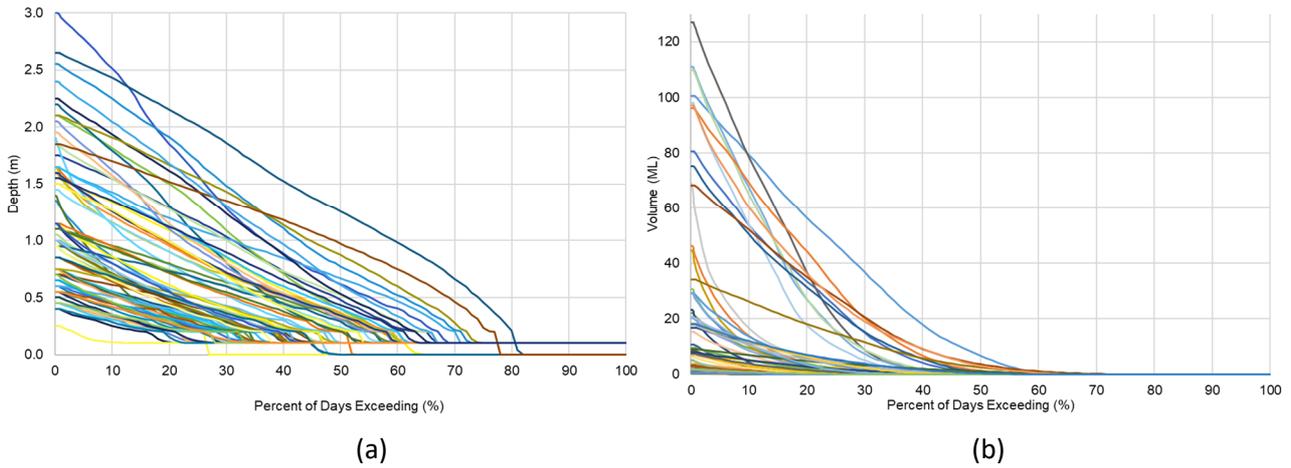


Figure 2 (a) Percentage of days that each pond exceeds depth thresholds; (b) Percentage of days that each pond exceeds volume thresholds

The annual overflow frequency of each pond is presented in Figure 3. The results show that only eight ponds had an overflow frequency of less than 20% of years.

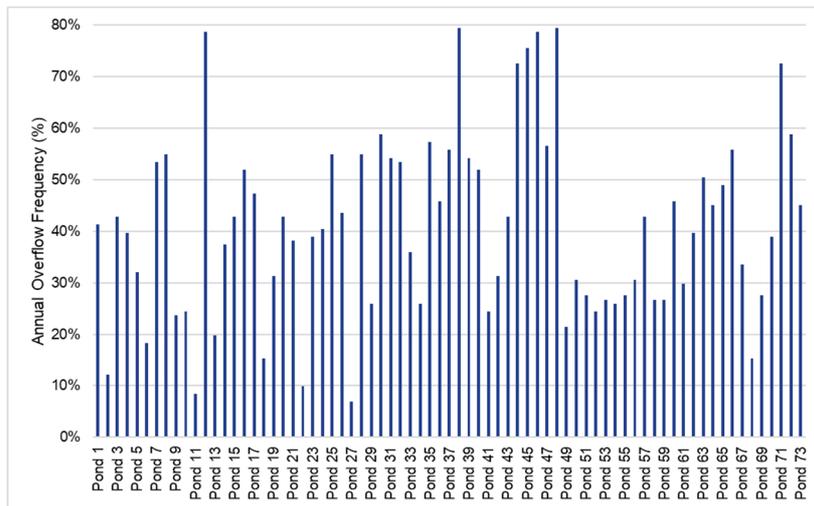


Figure 3 Annual overflow frequency of each pond

The EC percentile results for the minimum and maximum adopted depth thresholds are shown in Figure 4. These results demonstrate that when ponds have a higher volume, the EC is reduced.

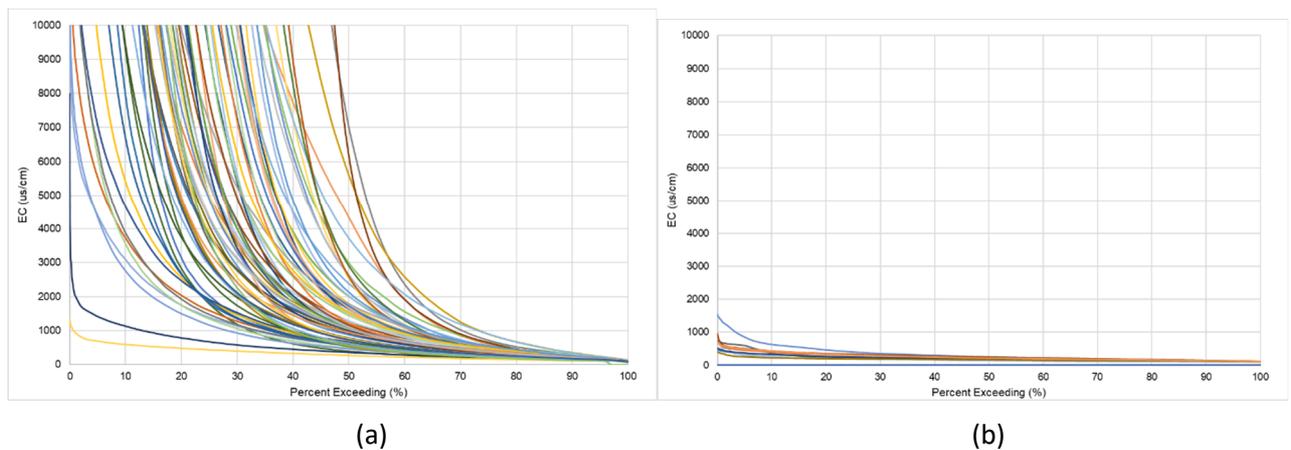


Figure 4 (a) EC percentile when depth is >0.15 m; (b) EC percentile when depth is > 2 m

The comparison of runoff from the local catchment to the Isaac River from pre- and post-subsidence is shown in Figure 5. A total average annual water loss of approximately 640 ML was forecast.

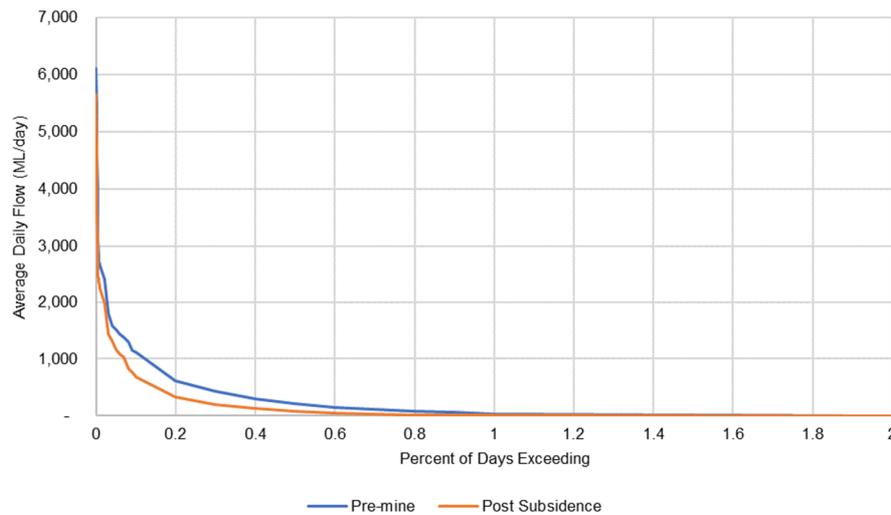


Figure 5 Average daily flow pre- and post-subsidence from local catchment (flow duration)

3.5 Flooding

The comparison of flood extents and pond locations determined up to 49 ponds are inundated from the Isaac River and/or Teviot Brook in a range of regional flood event magnitudes. Figure 6 shows the ponded areas that are overlaid by the PMF event.

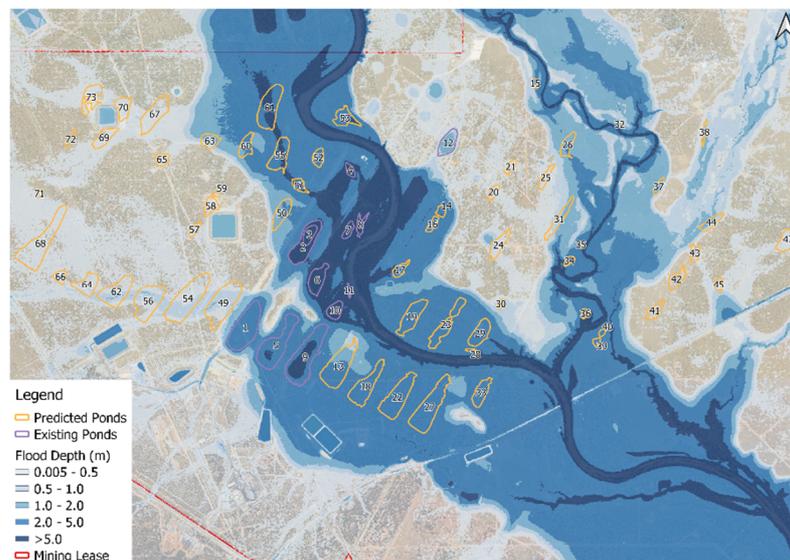


Figure 6 Ponded areas overlaid by the PMF depth results

3.6 Geomorphology

Using predicted sediment rates for the Isaac River catchment upstream of Deverill (Alluvium 2008), the catchments for the ponded areas were estimated to generate between 1,064 to 4,289 tonnes of sediment per year (worst-case), which is around 3% of the sediment load calculated for the total Isaac River catchment upstream of the mine using the same rates. Infilling timeframes for each pond were conservatively estimated based on the sediment input rates, assumed density of 1.6 g/cm³ and pond volumes and catchments.

3.7 Ecology

The ecological condition scores were calculated for the short-term inundation sites and are provided in Table 2.

Table 2 Ecological condition scores for short-term inundation survey sites

Regional ecosystem (RE)	Ecological condition score – subsidence site	Ecological condition score – reference site	Difference (%)
RE 11.3.2 – <i>Eucalyptus populnea</i> woodland on alluvial plains	53	60	-11.7
RE 11.4.9 – <i>Acacia harpophylla</i> shrubby woodland with <i>Terminalia oblongata</i> on Cainozoic clay plains	51	43.5	17.2
RE 11.5.3 – <i>Eucalyptus populnea</i> +/- <i>E. melanophloia</i> +/- <i>Corymbia clarksoniana</i> woodland on Cainozoic sand plains and/or remnant surfaces	53	55.5	-4.5
	52.5	58	-9.5
	50.5	58	-12.9
RE 11.5.3b – <i>Eucalyptus populnea</i> woodland on closed depressions	49	45.5	7.7

4 Discussion

4.1 Soils

Vertosols and sodosols are sodic soils with high dispersion risk, and exposed subsoils of these soil types would require amelioration. Erosion was identified as an ongoing risk where inadequate vegetation cover exists, with an increased risk along the edges of subsidence. Once started, erosion of dispersive soils can be difficult to stabilise and would likely continue to erode unless stabilised through intervention. However, sediment that is detached from erosion areas along the edges of subsidence is likely to be deposited locally (i.e. within the subsidence pond), reducing the amount of sediment entering the receiving environment. In addition, pasture grasses are likely to benefit from the increase in moisture availability. Erosion risks for ponded areas were considered to be less than the free-draining landform scenario, which is more likely to expose these materials.

The HowLeaky water balance modelling results of kandosols and sodosols reflect impacts of leaching of salts from the soil profile as a result of deep drainage. Vertosols exhibit strong subsoil water movement, resulting in small deep drainage events leaching salts from a small portion of the soil. Higher inputs of water from rainfall or ponding are likely to increase the deep drainage and leaching of salt in all soil classes. The results suggest that deep drainage and consequent leaching of soil salts is likely to be significantly increased in ponded areas for all soil classes. The salinity levels of vertosol soils that are subject to periodic ponding are likely to reduce over time, more than the other soil classes. The salt load of the surface soils is generally low and the amount of salt that may run off into the ponded areas and accumulate through overland flow was considered to be insignificant compared to the increased leaching that takes place. More detailed soil testing and modelling is required to further investigate the risks and potential pathways and receptors of any salt leaching and therefore the significance of this impact.

Pasture grasses may be negatively impacted during short periods of inundation; however, it was noted that the ponded areas will supply a source of water for stock (under a grazing PMLU), and this may be of higher value than a localised impact to grasses within the ponded area footprint.

4.2 Groundwater

Based on the groundwater assessment results, the groundwater technical study determined that, for Grosvenor Mine, the ponding of water will not have an impact on the hydrogeological regime, other than the potential recharge of water that may assist in the recovery of dewatered strata and improve water quality.

4.3 Surface water

The ponded areas were modelled to reduce the frequency of runoff flows from the local catchment into the downstream receiving environment. However, it was noted that the frequency of flows from the local catchment under pre-subsidence conditions is already low and the associated impact would be small in proportion to the broader regional flow in the Isaac River (the contributing catchments to the ponded areas are less than 3% of the size of the Isaac River catchment upstream of the mine). The average annual water loss forecast could increase by up to 40% based on the sensitivity assessment using alternative runoff parameters, which demonstrated the benefit of ongoing water level monitoring in existing ponds to allow improved calibration of the runoff parameters. However, the relative impact of ponded areas on these flows appears to remain relatively consistent regardless of the runoff parameters adopted.

The change in seepage rates indicated generally minimal or negligible impact on the overflow frequency, water quality of the ponds and the annual flows for the ponded areas. The decrease in seepage rate resulted in a 6 ML reduction in the average annual water loss (less than 1% change). The increase in seepage rate resulted in a reduced occurrence of overflows and a 41 ML increase in average annual water loss (6% increase).

The GoldSim water quality modelling results demonstrated a clear inverse relationship between EC and depth over time – that is, when pond depth decreases, the EC increases via evapo-concentration. The majority of ponds demonstrated a seasonal cyclic pattern, with salinity being diluted and/or flushed as a result of catchment runoff and no long-term trend was observed for concentration of salts over multiple seasonal cycles. The EC results demonstrated that the water quality within ponds will be heavily diluted as a result of fresh runoff inflows that fill ponds prior to resulting in overflows. All ponds were forecast to overflow frequently and only eight ponds had an overflow frequency of less than 20% of years. When overflows coincide with regional flows in the Isaac River, the discharges from the ponds would be further diluted within the much larger flows in the receiving environment.

The comparison of water quality against the livestock drinking water threshold found that when pond depths exceed 2 m and also when ponds overflow as a result of localised rainfall with no flow in the Isaac River, the water quality within all ponds is forecast to be well below stock watering limits. These limits begin to be exceeded on occasion for some ponds as depths decrease to 1.5 m. It is noted that this evapo-concentration behaviour would similarly occur within naturally occurring pools within waterways and water bodies, where a reduction in rainfall would result in water bodies increasing in EC as depth and volume decreases. Further water quality and level monitoring of existing ponds will allow for calibration and verification of modelling.

4.4 Flooding

The identified interaction between ponded areas and the floodplain is considered to have a beneficial impact on water quality, with more regularly flushed ponds expected to have improved water quality outcomes relative to less frequently flushed ponds further from these waterways.

Post-mining flood model results were compared to pre-subsidence results to assess changes to the flood depths, velocities, shear stress and stream power as a result of subsidence with a focus on changes resulting from or impacting on ponded areas. Any increases in flow velocities, shear stress and stream power as a result of subsidence were observed to be generally localised across pillars, on the banks of waterways or within waterways or new/altered flow paths (which are impacts typically managed during operations through specific subsidence controls – i.e. rock chutes/checks, pile fields, etc.) and not seen to be attributed to the

ponded areas in isolation. In fact, flow velocities, shear stress and stream power were found to generally reduce within the ponded areas.

4.5 Geomorphology

Previous geomorphic assessments have found that ponded areas at the mine will generally spill in similar locations to the pre-subsidence overland flow paths due to the panel alignment and nature of topography onsite (Alluvium 2019). Geomorphic instability such as incision and increased risk of erosion may occur where minor tributaries and overland flow paths drop into the subsided panel catchments, at newly formed confluences or over pillar zones (Alluvium 2019); however, the outcomes of the flooding assessment and analysis of the change in hydraulic parameters between the pre- and post-subsidence landforms confirms these impacts are much less of a risk for the ponded areas in isolation.

The soils technical study confirmed that erosion has potential to accelerate along the edges of subsidence where the slopes steepen, especially where sodic and dispersive soils are present. These areas may increase sediment transportation until the erosion is stabilised by vegetation growth; however, the soils are likely to be deposited locally (i.e. within the pond). It was considered that the risks associated with erosion and vegetation establishment would likely be greater for clearing associated with the free-draining landform scenario.

Another impact associated with ponding that affects the geomorphology is the potential for the ponds to interrupt overland flow and cause an increase in water storage on the floodplain. From a geomorphic perspective, this creates deposition environments where sediment infills and can result in a change in balance between sediment storage and transport (Alluvium 2011). The catchments for the ponded areas were estimated to generate approximately 3% of the sediment load calculated for the total Isaac River catchment upstream of the mine. In comparison to the free-draining landform scenario, the ponded areas would be expected to gradually infill with sediment from their local catchment, resulting in a reduction in the total volume of sediment entering the Isaac River and, more broadly, the Great Barrier Reef (GBR) catchments. This form of informal sediment control and reduction in sediment entering the GBR catchment is considered a beneficial outcome of the ponded areas. The majority of infilling time frames were estimated to be extremely long-term; however, some ponds with small volumes and comparatively large catchments had minimum time frames of less than two years, which may influence their feasibility of supporting PMLUs.

4.6 Ecology

In comparison with the free-draining landform, the short-term inundation of subsidence may not result in significant direct impacts and loss of habitat, whereas the impact of prolonged inundation on vegetation and habitat is similar to the free-draining landform scenario in that both will result in impacts and changes to vegetation and habitats. However, the drainage footprint will result in a direct loss of vegetation (i.e. through clearing), whereas direct or long-term impacts to vegetation may not occur for the full extent of the ponded area footprints.

4.6.1 Flora

The field data at the mine did not show a distinct lack of ecological condition in areas subjected to short-term subsidence ponding versus the reference sites and therefore there was potential for short-term inundation ponding to not permanently or significantly alter the vegetation communities present, particularly the remnant structure. While the ecological condition scoring was generally lower for subsidence sites in comparison to reference sites, the difference was not considered substantial at this stage, noting that a single survey event does not provide conclusive evidence.

Adverse impacts for areas of prolonged inundation included dieback of existing vegetation in all strata and a permanent loss of ground-layer cover and habitat features and possible loss of canopy layer habitat features for threatened species. However, it is noted that this impact could be managed and considered acceptable

where there are existing approvals, offsets and/or opportunities for the creation of other habitats (e.g. wetlands).

4.6.2 *Fauna*

Similarly to flora, areas of short-term inundation may not have significant or long-term impacts to fauna due to the brief and temporary nature of the inundation. However, prolonged inundation does have potential for causing loss of existing habitat. Beneficial outcomes include the potential to provide refuge for wetland species, including resident water birds and potentially migratory bird species (e.g. Australian Painted Snipe [*Rostratula australis*]). Wetland indicator bird species were observed and frogs were recorded calling in areas of prolonged inundation at the mine and were not observed in other drier areas. Previous studies at other Anglo American mines recorded the threatened Australian Painted Snipe using subsidence ponding.

It was concluded that subsidence ponding has the potential to provide at least foraging habitat opportunities for a limited number of species, particularly wetland birds. Foraging and possibly shelter habitat for some reptiles is possible at the periphery of ponded areas, as inundation will remove ground-layer micro-habitat features within the ponds, which are required by these species for shelter.

4.7 Risk assessment

A risk assessment was completed, based on the outcomes of the technical studies, that compared the likelihood and severity of impacts for ponded areas to the free-draining landform scenario. Key outcomes included:

- There is a higher likelihood of loss of ecological value to a smaller area due to clearing for the free-draining landform scenario. Ponded areas create additional risks to ecological values due to inundation; however, it is noted that this impact could be acceptably managed under existing approvals and/or opportunities for offsets. Ponded areas with short-term inundation were assessed with a lower risk compared to those with prolonged inundation.
- Risks associated with erosion and sediment generation were assessed as higher for the free-draining landform scenario.
- Construction of drainage alignments will result in a direct loss of vegetation, whereas the risk of vegetation impacts and change is less certain for ponded areas depending on their inundation time frames.
- The ponded areas do have a risk of leaching of soil salts; however, this risk is likely to make little difference to most soil classes except vertosols. It's noted that further studies are required to determine the potential pathways and receptors of any salt leaching and therefore the significance of this impact.
- Ponded areas were assessed with a marginally greater likelihood of potential to change surface water quality compared to a free-draining landform due to evapo-concentration and risk of increased salinity; however, conversely, they were assessed with less likelihood of increasing sediment generation into the receiving environment.
- Ponded areas had a higher likelihood of reducing quantity of water entering the receiving environment; however, the associated impact would be small in proportion to the broader regional flow in the Isaac River.

4.8 PMLUs

There is no definitive list of PMLUs under the MERFP Act 2018 (Government of Queensland 2018); however, examples provided that are relevant for ponded landforms are native ecosystem, grazing, agriculture or water storage (Department of Environment and Science [DES] 2021).

Other published relevant examples of PMLUs recommended for the Moranbah region included re-establishment of native ecosystems, grazing, agricultural options irrigated using mine water, hydroponics or protected horticulture, and livestock production (Côte et al. 2020).

Another potential PMLU, as discussed previously, is wetlands. If the ponded areas were shown to be able to sustain a wetland environment, particularly within such a dry region with ephemeral waterways, this could be justified as satisfying one of the PMLU requirements in delivering a ‘beneficial environmental outcome’.

Table 3 outlines an assessment of a grazing PMLU (of which ponded areas would be a feature within this PMLU) and a wetlands PMLU and environmental factors that were found to be more or less likely to support them.

Table 3 PMLU options assessment

PMLU	Beneficial environmental outcomes of ponded areas	Assessed features more likely to support PMLU suitability/sustainability	Assessed features less likely to support PMLU suitability/sustainability
Grazing	Increase access to water sources for stock. Integrate with the surrounding grazing land use to provide more reliable access to water supplies for grazing and native flora/fauna.	Ponding on kandosol and rudosol soils – least impacted from leaching and at risk of dispersion. Both short- and long-term inundation will support grazing and availability of water supply. Pond located within floodplain will have increased flushing from floodwaters, further improving water quality. Ponds that maintain higher volumes/depths of water were modelled as maintaining water quality (EC) below thresholds for stock water for longer.	Ponding on vertosol soils – salt leaching and erosion risk increased. Ponds that consistently dry out or have small volumes of water may exceed water quality (EC) thresholds for stock water more frequently (However, it is noted this would be similar to any water body, pond or dam in the region).
Wetlands	Integrate with the surrounding land use to provide more reliable access to water supplies for native flora/fauna. Due to their carbon storing potential (DES 2020), wetlands could increase carbon sequestration and storage.	Ponding on kandosol and rudosol soils – least impacted from leaching and at risk of dispersion. Long-term inundation – more likely to form wetland environment than short-term and attract wetland indicator bird species. Ponds with long-term infill time frames.	Ponding on vertosol soils – salt leaching and erosion risk increased. Short-term inundation. Ponds with short sediment infill time frames might be precluded from achieving a wetland PMLU.

4.9 Monitoring

A monitoring program was recommended to address existing knowledge gaps identified through the technical studies and to further inform and support individual ponded areas sustaining a PMLU (Table 4).

Table 4 Proposed monitoring program requirements

Aspect	Monitoring/management requirement	Objectives
Soil	Soil sampling and analysis to determine soil types and depths for each pond. At least one soil sample per pond; however, it would be useful to confirm both the soil types within the centre of each pond (where ponding is greatest) and along the edges (where erosion risks are greater). Subsidence monitoring programs should continue to identify existing exposed dispersive subsoils within ponded areas.	This information can be used to develop an in-depth soil classification map to accurately confirm the soil types throughout the ponded areas and therefore the varying risks and site-specific soil characteristics for each pond.
Surface water	Increased water quality samples taken at regular intervals from existing ponds. Monthly water quality sampling was recommended as a minimum from as many existing ponds as possible. Both electrical conductivity and total suspended solids (TSS) should be sampled. Increased monitoring of pond depths (i.e. water levels) at monthly intervals was recommended in the short-term in as many existing ponds as possible.	This data will assist in understanding seasonal influences on the ponds and assist with calibration and verification of modelling. Routine TSS sampling over time will aid in better quantifying the behaviour of sediment within the ponded water during both wet and dry seasons.
Topography	At least annual collection of survey over ponded areas during the dry season, particularly in the centre of each pond.	This information can be used to assess over time the infilling rates of ponds that dry out on an annual basis and to better quantify the overland flow sediment transport rates for the ponded area catchments and verify infill time frames.
Ecology	Collection of detailed baseline data/plot at each subsidence pond prior to inundation. Monitor physical parameters and water quality (including macroinvertebrate presence) and collect plot-based ecological data throughout period of inundation, including presence or absence of key species of tree, shrub and groundcover of the predominant regional ecosystem, species richness, evidence of dieback (using a scale and photos), weed richness and cover, recruitment and ground and canopy cover parameters sampled when subsidence pond is largely dry.	The data will be able to be used in the medium term to confirm that short-term ponding is not significantly detrimental to species and communities and identify where additional management actions may be required to ensure a positive environmental outcome.

5 Conclusion

The technical assessments and comparative risk assessment demonstrated that ponded areas have potential to support PMLUs such as grazing and wetland environments and may, in some instances, present less environmental risk than the alternative free-draining landform scenario, particularly with regard to erosion and direct clearing of vegetation. However, the technical studies identified that some parameters, especially the duration of inundation and soil class, will have a greater influence on the ability for ponded areas to support a PMLU. Some parameters present a higher risk of environmental impacts occurring, particularly prolonged inundation to existing vegetation and reduction in salinity levels of vertosol soils due to increased salt leaching, although further studies are required to determine the potential pathways and receptors of any salt leaching and therefore the significance of this impact. This information may assist in informing a case-by-case assessment of which ponded areas are more suitable to be proposed as supporting a PMLU (in comparison to a free-draining landform scenario); however, further monitoring data is required to address existing knowledge gaps and to further inform assessments to verify the PMLU outcomes for individual ponded areas.

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