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Angus Place Water Treatment Project and EPL 467 Licence Variation Application
Environmental Impact Assessment

1.0 Overview

Centennial Angus Place Pty Limited (Centennial Angus Place) operates Angus Place Colliery (Angus Place) under project approval PA 06_0021. Centennial Angus Place is proposing to increase mine water discharges through Angus Place licensed discharge point (LDP) 001 on Environment Protection Licence (EPL) 467 in a modification to the project approval. Consistent with the intent of Condition 11B Schedule 3 of PA 06_0021 Angus Place will treat all mine water using the desalination technology (reverse osmosis) to electrical conductivity (EC) of 350 µS/cm before discharge to the Coxs River catchment. A temporary water treatment plant (WTP) and ancillary infrastructure are required to be installed for this reason.

The need to increase discharges through LDP001 has arisen because Angus Place's underground mining area is currently flooding, and will be fully flooded in less than two years if changes to the existing mine water management systems are not implemented. The 'Do Nothing' option is unsustainable as the full flooding of the underground workings will result in sterilisation of the coal reserves in the unmined areas within the Angus Place Colliery holding boundary and strata failure in panels already developed. In the event, underground workings are allowed to fully flood it is likely the mine will never be re-opened.

Centennial Angus Place is seeking a variation to EPL 467 for the inclusion of a pollution reduction program (PRP) to allow the establishment and operation of a temporary WTP at the Angus Place pit top. Specifically, the licence variation application will seek:

- the establishment and operation of a temporary water treatment plant, utilising desalination techniques, and ancillary infrastructure comprising water transfer pipelines and a 1 ML Mine Water Tank
- the management of waste stream from the water treatment plant through emplacement within the underground workings at Angus Place.

These works fall within the scope of "pollution control works" in accordance with Clause 6(e) of *State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007* (Mining SEPP).

Clause 6(e) of the Mining SEPP states:

6. Development for any of the following purposes may be carried out without development consent:

…

(e) the construction, maintenance or use (in each case, outside an environmentally sensitive area of State significance) of any pollution control works or pollution control equipment required as a result of the variation of a licence under the Protection of the Environment Operations Act 1997, being a licence that applies to an extractive industry, mine or petroleum production facility in existence immediately before the commencement of this clause.

The inclusion of the PRP on EPL 467 will allow Centennial Angus Place to construct and operate the temporary water treatment plant without development consent.

The current LDP001 volumetric limit is 2 ML/day of mine water discharge, and there is no limit on the salinity of the mine water. The modification application to Angus Place's project approval (MOD 5) is seeking an increase in discharges from LDP001 to up to 10 ML/day, treated to a salinity of 350 µS/cm or 234.5 mg/L. The proposed modification will be assessed under Section 75W modification provisions of the *Environment Planning and Assessment Act 1979* (EP&A Act). An *Environmental Assessment* will support the modification application and will assess the impact of the increased treated mine water discharges with 350 µS/cm EC on the immediate and regional receiving environment comprising Kangaroo Creek, the Coxs River catchment and Lake Burragorang.

Centennial Angus Place representatives have discussed the proposal to apply for a licence variation to EPL 467 for the pollution reductions works and modification to project approval PA 06_0221 with the officers of the Environmental Protection Authority (EPA) on two occasions (13 December 2017; 09 March 2018). The matter has also been discussed with the Department of Planning and Environment (DP&E) officers a number of times including at the meeting on 09 March 2018. At the meeting on 09 March 2018 it was agreed that Centennial Angus Place will assess the impact of establishing and operating the temporary WTP in an environmental impact assessment. The impact assessment will allow the EPA to consider matters included in Section 45 of the *Protection of the Environment Operations Act 1997* concerning Centennial Angus Place's application to vary EPL 467.

This letter report forms the environmental impact assessment required to accompany the licence variation application to EPL467. It describes the rationale for establishing the temporary WTP, project alternatives considered and the necessary works for its establishment. It provides potential environmental impacts for the construction and operation of the WTP, and the mitigation measures to be implemented to minimise the potential impacts.

2.0 Project Justification and Timing

The Angus Place Water Treatment Project (the Project) comprises two components for which approvals are sought separately (**Section 1.0**) due to timing constraints:

- the establishment and operation of a water treatment plant and management of the residuals waste stream through a variation to EPL 467 for the inclusion of these works as a PRP such that these works can be undertaken in accordance with Clause 6(e) provisions of the Mining SEPP
- increasing discharges through LDP001 to up to 10 ML/day treated to an EC of 350 µS/cm via a modification (Modification 5) to project approval PA 06_0221.

As noted above the need to increase discharges through LDP001 has arisen because the Angus Place's underground mine water storage areas (800 and 900 Panel Areas) are flooding, and will be fully flooded in less than two years if changes to the existing mine water management systems are not implemented.

Underground flooding has been occurring since the Angus Place's EPL 467 was varied to reduce the volumetric limit at LDP001 to 2 ML/day in 2013. An additional constraint has been Angus Place's volumetric limit on the 940 Bore Water Access Licence from the Sydney Basin Richmond groundwater source (WAL 36449), which at a volumetric limit at 2523 ML/year has allowed only on average 6.9 ML/day of mine water from Angus Place 900 Panel Area to be transferred to the SDWTS for discharge via LDP009 on Springvale Mine's EPL 3607 to the Coxs River catchment. The combined mine inflow rates from the 800 Panel Area (1.3 ML/day) and 900 Panel Areas and Newcom Colliery workings (7.9 ML/day) exceed the extraction rate (8.2 ML/day), and as a result, the underground mine has been slowly flooding.

The underground workings will be fully flooded in less than 2 months if LDP001 discharges are not increased, and the current practice of transferring mine water (up to 6.9 ML/day) to the Springvale Delta Water Transfer Scheme (SDWTS) is not possible due to Springvale Mine's adaptive management practices to minimise impacts to shrub swamps, discussed in detail below.

The 800 and 900 Panel Areas currently used for underground mine water storage and the levels of flooding are shown in **Figure 1**.

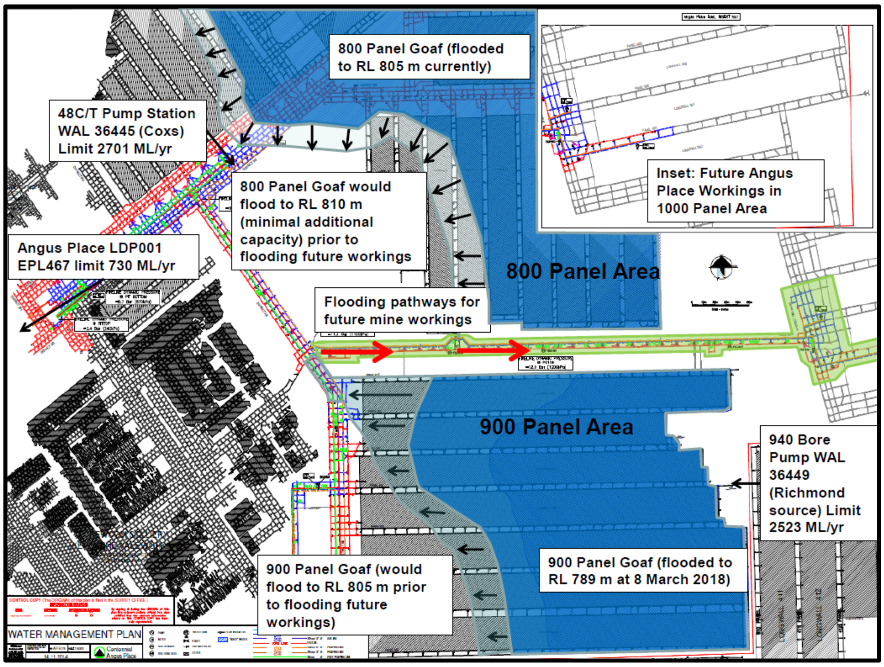

Figure 1 – The 800 and 900 Panel Areas at Angus Place Colliery

Springvale Mine has recently implemented adaptive management measures to minimise potential impacts to shrub swamps. The adaptive management in the northern longwall mining area, comprising the shortening of LW421, delay in the extraction of LW422, and not to mine LW423, has resulted in Springvale Mine commencing extraction of coal in the southern longwall blocks one year earlier than previously planned, that is in June 2018 rather than in June 2019. Operational experience at Springvale Mine and Angus Place indicate that mine inflows increase by 5 – 10 ML/day when mining commences in new virgin mining areas.

A consequence of Springvale's adaptive management is that the anticipated 'step change' in mine water make at Springvale Mine in June 2018 will increase the mine water that requires disposal from the underground workings from the current approximately 18±2 ML/day to up to 30 ML/day. It is expected this level of water make will be sustained in the long term. For Springvale Mine to keep operating, and given that there is very limited underground storage at Springvale Mine, the almost full 30 ML/day existing capacity of the SDWTS and the 30 ML/day volumetric discharge at LDP009 may be utilised by Springvale Mine. Mine water transfers from Angus Place to the SDWTS at the current level (6.9 ML/day) may not be possible from June 2018. The only option feasible available to Angus Place at present to prevent underground flooding is to seek an increase in mine water discharges through LDP001 to up to 31 December 2019.

The consequences of not increasing mine water discharges via LDP001 and allowing the underground mine to flood are as follows:

- **decommissioning of underground critical infrastructure** prior to inundation which is impractical and may not be possible

- **strata failure** in panels and mains headings already developed (first workings) for future extraction (LW910, LW1001)
- **coal sterilisation** in the remaining unmined areas and compromise the future Angus Place Extension Project.

It is very likely that the mine, once flooded, may never be re-opened.

When the Springvale Water Treatment Project becomes operational mine water from Angus Place will be transferred to that project for transfer to a water treatment plant at MPPS for treatment and beneficial reuse in the power station's cooling water system. At that point in time mine water discharges via LDP001 is being proposed to cease.

3.0 Water Treatment Plant and Ancillary Infrastructure

3.1 Site Location and Land Preparation

The WTP and the ancillary infrastructure will be installed at the Angus Place pit top. The WTP will be located in an isolated area of the pit top, shown in **Figure 2**. Angus Place's closest sensitive receptor (identified as Sharpe on project approval PA 06_0221) is located on Wolgan Road, approximately 1.5 km from the WTP site. There will be no visual impact due to the establishment of the WTP, given the isolated location and the densely vegetated areas between the WTP site and this nearest sensitive receptor. Any lighting from the site at night time will not be visible at the sensitive receptor because of the existing vegetation screen.

The WTP site is a redundant switchyard and a powerline easement (**Photograph 1**) which was constructed in 1976 for the Newcom Colliery to Angus Place Colliery transfer and has not been used for at least 10 years. The area is identified as laydown area in the *Angus Place Care and Maintenance Mining Operations Plan* (May 2016 – April 2023), and falls under Primary Rehabilitation Domain 1 – Infrastructure. The WTP site boundary, of approximately 0.25 ha in area, has been optimised to use only the previously disturbed areas.

Photograph 1 – Decommissioned Switchyard Compound at Angus Place Colliery Pit Top

The fenced switchyard building with power poles and cables has been decommissioned and is in the process of being rehabilitated. The ground surface has been levelled as part of the landform establishment phase. Topsoil recovered from the area will be used to create diversion drains on the periphery of the site to divert dirty water run-off to the downstream reed beds.

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DATE	15.03.2018
SEAM	LITHGOW
REFERENCE	SLR63012097_FIG1_APPB AngusPlaceShort_V4
SCALE	1:40000

Figure 2
Angus Place Pit Top Surface Infrastructure

0 60 120 M

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Erosion and sediment controls will be installed at appropriate locations to minimise high sediment loads in water being discharged to the reed beds. The disturbed areas will be covered with gravel (ballast material) prior to the WTP components and container units being mobilised to the site.

It is proposed to use the area for up to 18 months prior to progressing further with the rehabilitation works to create a free draining landform and ecosystem establishment using native vegetation consistent with the surrounding areas (**Section 5.0**).

3.2 Water Treatment Plant Components

A temporary WTP facility based on desalination technology will be constructed and will comprise the following processes:

- Pre-treatment or clarification of raw mine water to remove suspended solids
- Treatment of pre-treated water to reduce salinity by reverse osmosis (RO)
- Management of treated water meeting the nominated salinity limit of 350 µS/cm
- Management of waste stream comprising by-products of the pre-treatment (residuals) and desalination processes (salt stream (EC of ~4000 µS/cm) and Clean-in-Place (CIP) waste from the reverse osmosis membrane cleaning). This waste stream is referred to as residuals in this document and its composition is discussed further in **Section 4.2**.

The WTP will have the following components.

- Feed (raw) water system
- Low flow containers for reverse osmosis
- Residuals waste stream tank
- Permeate tanks – for storage of treated water
- Clean-in-Place facility
- Chemical storage area
- Pumping systems
- Electrical distribution network

The majority of the components noted above will be contained inside portable container units for safety as well minimisation of noise emissions. A sample portable containerised RO plant is shown in **Photograph 2**.

Photograph 2 – Sample Portable Containerised Reverse Osmosis Plant

3.3 Ancillary Infrastructure

The new ancillary infrastructure required is shown in **Figure 3**. A new mine water storage tank (1 ML capacity) will be installed for storage of mine water prior to transfer to the WTP feed water system. Mine water from this tank will also be used as process water. This tank replaces two existing Fire Fighting Tanks (**Figure 1**) currently used for storage of mine water for operations and for the discharge of excess mine water to the Aerating Ponds and reed beds and subsequent discharge offsite via the LDP 001 V-notch weir (**Photograph 3**). The V-notch weir discharges water to a tributary of Kangaroo Creek and, the water flows to Kangaroo Creek approximately 150 metres (m) downstream of the weir.

Photograph 3 – Existing V-Notch Weir at Angus Place LDP001

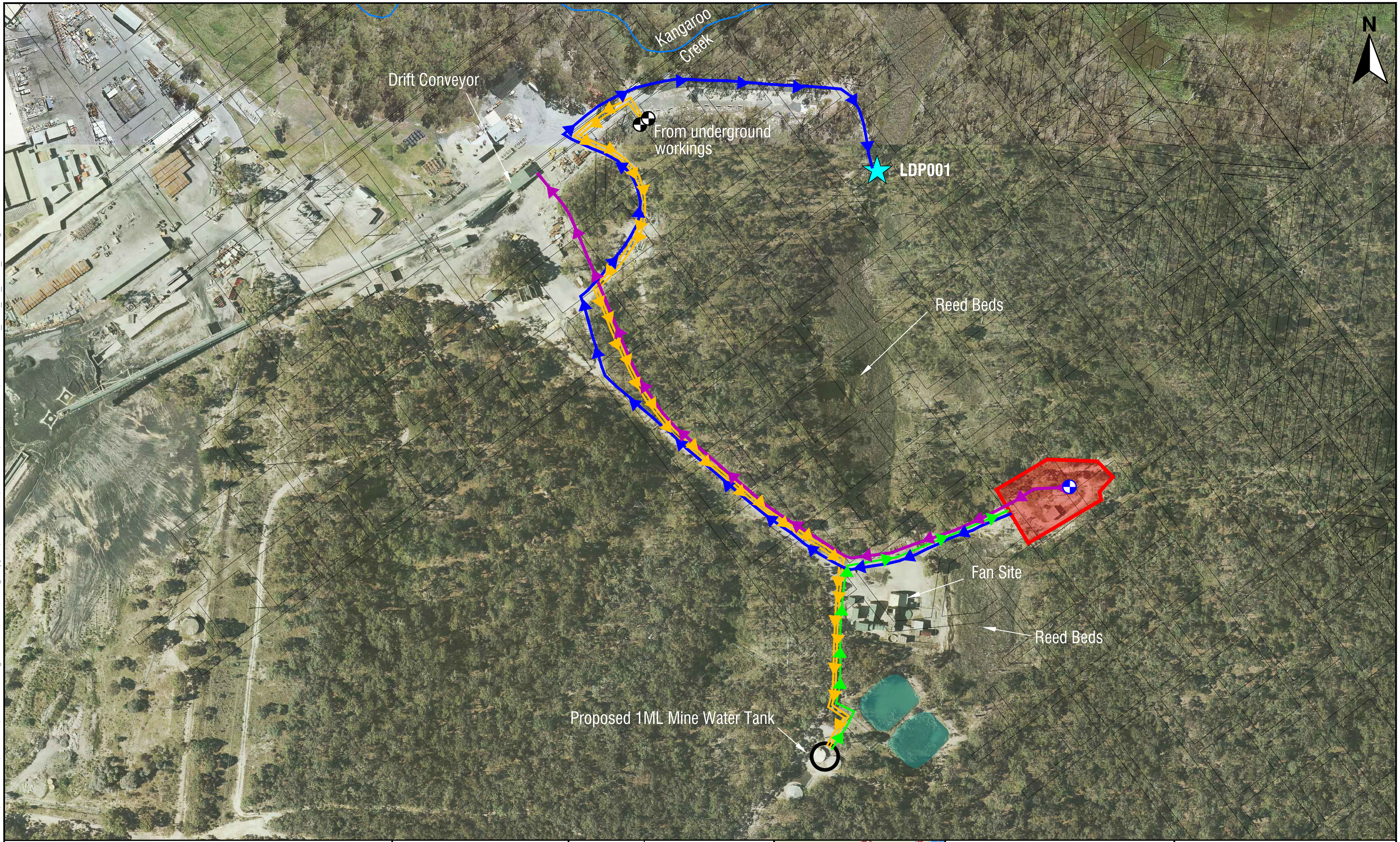
A number of temporary pipelines will be installed alongside existing tracks, and hence requiring no vegetation clearing, as follows.

- Two **mine water pipelines** (diameter 280 mm) will be installed to convey mine water from the underground to the 1 ML Mine Water Tank.
- A **feed water pipeline** (diameter 450 mm) will transfer mine water from the 1 ML Mine Water Tank to the WTP's feed water system.
- A **residuals pipeline** (diameter 200 mm) will transfer the residuals from the waste stream tank to the underground. This pipeline will connect to an existing pipeline running inside the drift conveyor to the underground workings. Alternatively, the residuals can be transferred to the Newcom Colliery workings (contingency) via a borehole located within the WTP site.
- A **treated water pipeline** (diameter 280 mm) will transfer the treated water from the WTP directly to the existing LDP001 V-notch weir pond (**Photograph 3**) for offsite discharge and flow to Kangaroo Creek (**Section 4.0**).

A power cable (415 V), using cable trays, from the nearby Fan Site to the WTP site will be installed above the surface to provide power to the WTP. Fibre optics cables will be installed with the power cable for communication purposes.

3.4 Site Access

The WTP site can be accessed via both site accesses on Wolgan Road shown in **Figure 1**. Heavy vehicles access to the site will only be via the northern Site Access. Light and heavily vehicles required for construction maintenance purposes will enter Wolgan Road from Castlereagh Highway.



LEGEND:

- Aeration Ponds
- Angus Place LDP
- Watercourse
- Proposed Water Treatment Plant Site
- Underground Workings
- Mine Water Pipeline
- Residual Pipeline
- Treated Water Pipeline
- Feed Water Pipeline
- Borehole to Newcom Colliery Workings
- Borehole from Underground Workings

DATE	16.03.2018
SEAM	LITHGOW
REFERENCE	SLR63012413_FIG2_AP_WTPI_V3
SCALE	1:3000

Figure 3
Angus Place Water Treatment Plant Infrastructure

0 50 100 M

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3.5 Workforce

An external company will undertake the construction and the operation of the WTP. Up to 8 external personnel (contractors) will be based at the site during the construction period (8 weeks) of the WTP and up to 1 external personnel (contractor) will be based at the site during the operational phase (June 2018 – December 2019), with up to 3 additional personnel working on the site on any day responding to maintenance requirements.

The installation of the ancillary infrastructure will be undertaken by the existing staff at Angus Place and using external contractors for specialist tasks as relevant.

3.6 Traffic

The construction of the WTP and ancillary infrastructure could take up to 8 weeks commencing in May 2018. It is anticipated that the transfer of the modular RO plant units could take up to 20 loads utilising heavy vehicles, resulting in an additional 40 vehicle trips on Wolgan Road and Castlereagh Highway over the first four weeks of the construction period, or on average 2 heavy vehicle movements per day Mondays to Fridays. For the entire 8 week construction period light vehicles will be utilised for transport of personnel and infrastructure components. This will result in additional 4 light vehicle movements per day.

During the up to 18-month operational life of the WTP, one personnel from the hire company will visit the site once a day resulting in additional 2 vehicle movements per day. On days when the WTP is undergoing maintenance, there will be up to additional 8 vehicles per day.

Angus Place Colliery is approved to employ up to 300 full-time equivalent (fte) personnel. Traffic impact assessments were undertaken as part of the original project approval and MOD 1 when the workforce was increased from 215 to 300 (fte) personnel including 75 contractors. Angus Place has been on care and maintenance since March 2015 and less than 40 personnel are working at the mine currently. The additional vehicle movements during the construction phase of the WTP will be within the previously assessed and approved traffic impacts of the mine. Similarly, during the operational phase of the WTP, the additional vehicle movements will fall within the assessed and approved traffic impacts of the mine, given that Angus Place will re-commence development in January 2020 and the mine will not be fully operational till 2024 when extraction is due to commence.

3.7 Construction Hours

The construction hours for the establishment of the WTP will be consistent with the recommended standard construction hours detailed in EPA's *Interim Construction Noise Guidelines* (DECC, 2009) as follows.

- Monday to Friday – 7 am to 6 pm
- Saturday – 8 am to 1 pm
- No work on Sundays and public holidays

Deliveries of materials and infrastructure components will not be undertaken outside of these hours.

4.0 Water Treatment Plant Operations and Waste Stream Management

Angus Place is approved to operate 24 hours a day, seven days per week. The WTP plant will be operated 24 hours a day unless maintenance works are required.

Up to 13.4 ML/day mine water (with EC of ~1000 µS/cm) will be drawn from the underground mine workings and transferred to the 1 ML Mine Water Tank prior to transfer to the feed water system within the WTP site. This rate of mine water extraction from existing workings was approved in Modification 4 to Angus Place's project approval PA 06_0221, approved on 27 October 2014.

Following the treatment of raw mine water by reverse osmosis and any blending within the WTP as applicable to achieve the 350 µS/cm EC, up to 10 ML/day of treated water will be transferred to the LDP001 V-notch weir pond using a poly-pipe. The V-notch weir (**Photograph 2**) currently collects mine water, discharged upstream from the weir into the reed beds, as well as environmental flows. In the future, appropriately sized diversion drains will be installed to divert environmental flows away from reaching the weir pond but instead will be diverted to a location downstream of the weir to discharge to the Kangaroo Creek tributary for subsequent flows to Kangaroo Creek. The water flow rate through the weir will continue to be undertaken using the existing flow monitoring arrangement in place.

The WTP will have facilities for monitoring both flow rate (using a calibrated flow meter) and water quality parameters and analyte concentrations. The WTP will also have facilities to collect treated water samples (i.e. 'grab sample' sampling methodology) for analyses at a NATA accredited laboratory, discussed further in **Section 4.1**.

The waste stream from the WTP, noted in **Section 3.2**, will be transferred to the underground workings for temporary storage and is discussed further in **Section 4.2**.

4.1 EPL467 Discharge Water Quality and Flow Monitoring

Following the approval of the modification (Modification 5) seeking increased mine water discharge at LDP001, Centennial Angus Place will seek a variation to EPL467 to increase the volumetric limit at LDP001 from the current 2 ML/day to 10 ML/day. In that licence variation application, Centennial Angus Place will nominate water quality pollutants to be monitored in the LDP001 discharge, and their 100^{th} percentile concentration limits.

Centennial Angus Place is currently required to monitor the pH and concentrations of Oil and Grease and Total Suspended Solids for LDP001 water discharges on a monthly basis using the Grab Sample sampling methodology. Centennial Angus Place will propose in the future licence variation application additional pollutants at 100^{th} percentile concentrations to be monitored at LDP001 from July 2018 (**Table 1**) following the installation and commissioning of the WTP.

The frequency of water quality monitoring will be monthly until December 2019, or earlier if the temporary WTP is removed from the site prior to 31 December 2019 and mine water discharges cease from LDP001.

Table 1 – Proposed Pollutants and Concentration Limits at LDP001

Pollutant	Unit	100^{th} percentile concentration limit
Aluminium (dissolved)	mg/L	0.45
Arsenic	mg/L	0.024
Boron (dissolved)	mg/L	0.37
Electrical conductivity	µS/cm	350
Copper (dissolved)	mg/L	0.007
Fluoride	mg/L	1.8
Iron (dissolved)	mg/L	0.4
Manganese (dissolved)	mg/L	1.7
Nickel (dissolved)	mg/L	0.047
Oil and grease	mg/L	10*
pH	pH unit	6.5 – 9.0*
Total suspended solids	mg/L	30*
Turbidity	nepholometric turbidity unit (NTU)	50
Zinc (dissolved)	mg/L	0.05

* Limits are unchanged from the current limits for these parameters on EPL 467.

4.2 Waste Stream Management

It is anticipated the residuals from the WTP will have the indicative composition included in **Table 2,** noting the values have been derived from the treatment of raw mine water with the existing water quality and without enrichment in the 800 Panel Area due to continuous emplacement of residuals in the underground workings over a maximum period of 18 months. As noted **Section 3.2**, the residuals waste stream comprises by-products of the pre-treatment (residuals) and desalination processes (reverse osmosis) and Clean-in-Place (CIP) waste from the reverse osmosis membrane cleaning.

With an EC of ~3400 µS/cm (TDS ~2500 mg/L) the residuals waste stream is considered to be brackish water. For a comparison, sea water has an EC of >52,000 µS/cm and the brine formed during desalination of seawater can be as high as 100,000 µS/cm. No by-product with an EC equal to brine will be formed in the WTP at Angus Place. The salt stream produced from the desalination process will be <4000 µS/cm and falls within brackish water EC range.

Table 2 – Indicative Residuals Waste Stream Quality

Parameter	Unit	100th percentile concentration limit*
pH	pH unit	7.0 – 8.5
Electrical conductivity	µS/cm	3391
Turbidity	NTU	7
Total suspended solids (TSS)	mg/L	18
Total dissolved solids (TDS)	mg/L	2511

* the 100th percentile limits in the residuals have been derived from the existing raw mine water quality with no enrichment in the 800 Panel Area

The residuals waste stream will be transferred to the underground workings for temporary storage. The 800 Panel Area will be used preferentially for this purpose using the residuals pipeline shown in **Figure 3**. However, in contingency situations, the Newcom Colliery workings could be utilised using the Newcom Colliery borehole within the WTP site and shown in **Figure 3**. Mine inflows from Newcom Colliery workings will dilute any residuals stored in the Newcom Colliery workings. The residuals will flow to the 900 Panel Area and will be further diluted with the raw mine water stored in that panel area.

The impact of the temporary storage of the residuals in the 800 Panel Area has been assessed in a Groundwater Assessment (JBS&G, 2018a), and discussed in **Section 7.1**.

5.0 Decommissioning and Rehabilitation

As noted above the WTP site is identified as laydown area in the *Angus Place Care and Maintenance Mining Operations Plan* (May 2016 – April 2023) (MOP), and falls under Primary Rehabilitation Domain 1 – Infrastructure and Secondary Rehabilitation Domain – Woodland in the final landform.

In preparation for siting the WTP components at the site, the area has been cleared of all infrastructure and the concrete pad (**Photograph 1**) and has been levelled. The site will be installed with erosion and sediment controls to ensure clean and dirty water run-offs are separated and managed appropriately prior to mobilisation of WTP infrastructure. The party rehabilitated area will remain in this condition until the WTP infrastructure is removed.

Following the removal of the WTP components, the site will be rehabilitated further to create a free draining landform with the pre-mining capacity and will be returned to ‘woodland’. This will be achieved through a series of conceptual phases – Growth Medium Development, Ecosystem Establishment, Ecosystem Development – described in detail in the MOP. Rehabilitation monitoring of the rehabilitated site will be undertaken until no longer required.

Revegetation of the WTP site with woodland species is consistent with the immediate surrounding land use and the pre-mining environment. The installed erosion and sediment controls will be retained if appropriate. Additional controls will be installed if required.

The 1 ML Mine Water Tank will not be decommissioned and will continue to be used for the storage of mine water from the underground for use as process water, both for surface operations and underground usage, the latter when the mine recommences development in 2020 and extraction in 2024.

The feed water and residuals pipelines to/from the WTP will be removed. The mine water transfer pipelines will be retained if required. The treated water pipeline from the WTP to LDP001 will be removed.

The Newcom Colliery borehole within the WTP site will be retained until the entire pit top is rehabilitated when mining operations cease and life of mine rehabilitation commences. It will be isolated and made safe using standard procedures prior to rehabilitation.

6.0 Analyses of Alternatives

6.1 Do Nothing Option

In the 'Do Nothing' option the proposed changes to the Angus Place mine water management will not be implemented. Angus Place will continue to discharge raw mine water at LDP001 at the rate of 2 ML/day. The following benefits / minor adverse impacts are not likely to be realised.

(i) Increasing the underground storage capacity to allow it to function as emergency storage area from June 2019 for Springvale Mine, Angus Place and the Springvale Water Treatment Project in the event the SDWTS is not available and / or the MPPS water treatment plant cannot take raw mine water.

(ii) The predicted reduction in salinity in Kangaroo Creek downstream from LDP001 and Upper Coxs River and the resulting improvements in macroinvertebrate community composition (**Section 7.2**) in these watercourses.

(iii) The increased flow rate in Kangaroo Creek downstream of LDP001 will not impact on the macroinvertebrate community that prefers slow-flowing water (**Section 7.2**).

(iv) There will not be a potential minor impact to the regional aquifer and Wolgan River in Wolgan Valley due to the temporary storage of residuals in the 800 Panel Area (**Section 7.1**).

Without an increase in the extraction rate of the mine water from the 800 and 900 Panel Areas, the underground mine workings in both the storage areas will continue to flood. The flooding will occur at a greater rate than the current rate (0.5 ML/day) given there may be a limited capacity in the SDWTS from June 2018 (**Section 2.0**) and Angus Place will not be able to transfer the up to 6.9 ML/day (WAL limit) of mine water to the SDWTS for discharge at LDP009 into Sawyers Swamp Creek. At the increased rate of flooding the underground workings will be fully flooded within two months. The consequences of the flooded underground workings comprise the following.

(i) Strata failure in panels already developed (e.g. 910N and 1001 Panels) and thus no access to the 1000 Panel Area (mining area for the Angus Place Mine Extension Project) will be available.

(ii) Impact on critical underground fixed machinery and infrastructure rendering them unusable in the future.

(iii) Sterilisation of coal reserves in the unmined areas within the Angus Place Colliery holding boundary and the viability of the Angus Place Mine Extension Project.

6.2 Alternatives for Waste Stream Management

A number of alternatives were investigated for the emplacement of residuals.

6.2.1 Emplacement of residuals within Newcom Colliery existing workings

Up to 2.8 GL of residuals plus mine inflows will be required to be managed if the WTP is operated for 18 months and up to 13.4 ML of raw mine water was treated in the WTP every day. The volume available within the Newcom Colliery existing workings for residuals storage is only 842 ML, which is not sufficient to store residuals and mine inflows from Newcom Colliery workings for the duration required. For this reason, the Newcom Colliery workings have not been considered as the primary storage area for residuals. However, the workings will be used for storage in contingency situations should the proposed 800 Panel Area be unavailable.

6.2.2 Transfer of Residuals to the Main REA at Springvale Coal Services Site

The option of transferring the residuals to the Main REA within the Springvale Coal Services Site (SCSS) (Western Coal Services Project SSD 5579) was considered for the maximum 18 months the WTP may be operated at the Angus Place pit top. This option was rejected for the following reasons.

a) *Issue with transfer of residuals to the Main REA*

There is no existing infrastructure (e.g. a pipeline and residuals storage tanks at Angus place pit top and the SCSS) to allow the onsite storage and transfer of residuals directly between Angus Place pit top and the SCSS. Any infrastructure development will require planning approvals (via modifications to approvals), in addition to requiring approvals by Angus Place to transfer residuals to an offsite location and for the Western Coal Services Project to accept the residuals. Obtaining approvals and development of the infrastructure could potentially take up to 18 months whereas the Angus Place Treatment Project is required to be operational by July 2018.

Transferring the residuals to the SCSS by road haulage using public roads (Wolgan Road and Castlereagh Highway) was also investigated. The time required to obtain approvals via modifications to consents precludes the road haulage of residuals as a viable option, and noting that road haulage would also have resulted in a minor traffic impact on public roads.

b) Issue of increased impacts to flow and water quality in Wangcol Creek

Whilst no impact assessments have been undertaken by specialist consultants, based on the water resources impact assessment undertaken for the WCS MOD 2 to receive residuals from the Springvale Water Treatment Project (GHD, 2016; Centennial Coal, 2016), it is likely the emplacement of residuals and in the main REA (potentially up to 3 ML/day) at an EC of ~4000 µS/cm) would have resulted in increases in minor increased in the salinity and flows in the LDP006 (SCSS) discharges and in Wangcol Creek downstream from LDP006.

7.0 Assessment of Natural Resources Impacts

7.1 Groundwater

The emplacement of the residuals (notionally 2 – 3 ML/day) within the 800 Panel Area, albeit for a maximum period of 18 months, has the potential to impact on the changes to groundwater quality within the 800 Panel Area and the regional aquifer, and changes to surface water/groundwater interaction. A Groundwater Assessment (JBS&G, 2018a), appended to this letter report as **Attachment 1**, has been prepared to assess the impact of the temporary storage of the residuals in the 800 Panel Area in the period 01 July 2018 to 31 December 2019. The impacts have been quantified through water balance modelling described in detail in (JBS&G, 2018a).

The following sections provide an overview of the key outcomes of the groundwater assessment, however, to gain a full understanding of the potential impacts of the storage of the residuals the groundwater assessment should be read in its entirety. The Groundwater Assessment also includes mitigation measures for minimising potential impacts during the post-emplacement stage when the mine water stored in the 800 and 900 Panel Areas will be transferred to the Springvale Water Treatment Project for treatment and the subsequent beneficial reuse at MPPS.

7.1.1 Existing Environment

Raw mine water from Angus Place underground workings has near neutral pH, is a Na-HCO_3 type water, with a salinity (measured as EC) of ~1,143 µS/cm or 766 mg/L. The mine water meets the requirements of the Australian Drinking Water Guideline (NHRMC, 2016) as well as the default guideline values for the 95^{th}% protection level of freshwater aquatic ecosystems (ANZECC, 2000), for pH and trace ions with the exception of salinity, which has a default value of 350 µS/cm (234.5 mg/L).

There are three main watercourses through the Angus Place Colliery holding boundary that have the potential to be impacted by the storage of the residuals within the 800 Panel Area – Kangaroo Creek, Lambs Creek and Wolgan River. Kangaroo Creek and Lambs Creek both flow from the east to the west to Coxs River and Sydney's drinking water catchment (and Lake Burragorang).

The Wolgan River flows from the southeast to the northwest, to the clifftop of the Wolgan Valley. It then cascades down the cliff face of the Wolgan Valley, continues to flow northwest within the Wolgan Valley and then feeds into Colo River and eventually Hawkesbury River.

7.1.2 Potential Impacts

a) Water Quality Changes

Water balance modelling results, presented in **Figure 4,** show there will be a steady increase in salinity in the 800 Panel Area to a maximum of~2541 mg/L (3790 µS/cm) at the end of the residuals emplacement period due to enrichment as residuals (up to 2 – 3 ML/day) are continually emplaced within the 800 Panel Area. When the Springvale Water Treatment Project commences and as the high EC water from the 800 Panel Area (blended with the water from the 900 Panel Area) is transferred to the water treatment plant at MPPS, the salinity in the 800 Panel will gradually decrease and will reach existing salinity levels after approximately five years of dewatering.

Geochemical modelling, using the US Geological Survey code, PHREEQCi, indicates there is a negligible expected change in pH of the mine water in the 800 Panel Area, and remains near neutral. The EC and concentrations of trace ions, such as dissolved metals in the 800 Panel mine water, due to the continuous transfer of residuals over an 18 month period, increases by a factor of 3.1. However, as noted below the trace ion concentrations and pH of the mine water will be consistent with the default guideline values at the 95th% protection level for slightly to moderately disturbed aquatic ecosystems.

In summary, the predicted water quality in the 800 District at the end of operation of the Project is a Na-HCO_3 type water, with near neutral pH, that is brackish but not saline. The high EC mine water will continue to meet the default guideline values at the 95th% protection level for slightly to moderately disturbed aquatic ecosystems, aside from EC, which is significantly exceeded from the 350 µS/cm default guideline value. It is noted this high EC mine water will not be discharged to the environment in the future without any treatment. The water from the 800 Panel Area will most likely be transferred to the water treatment plant at MPPS via the approved Springvale Water Treatment project for treatment and subsequent beneficial re-use in the power station’s cooling water system.

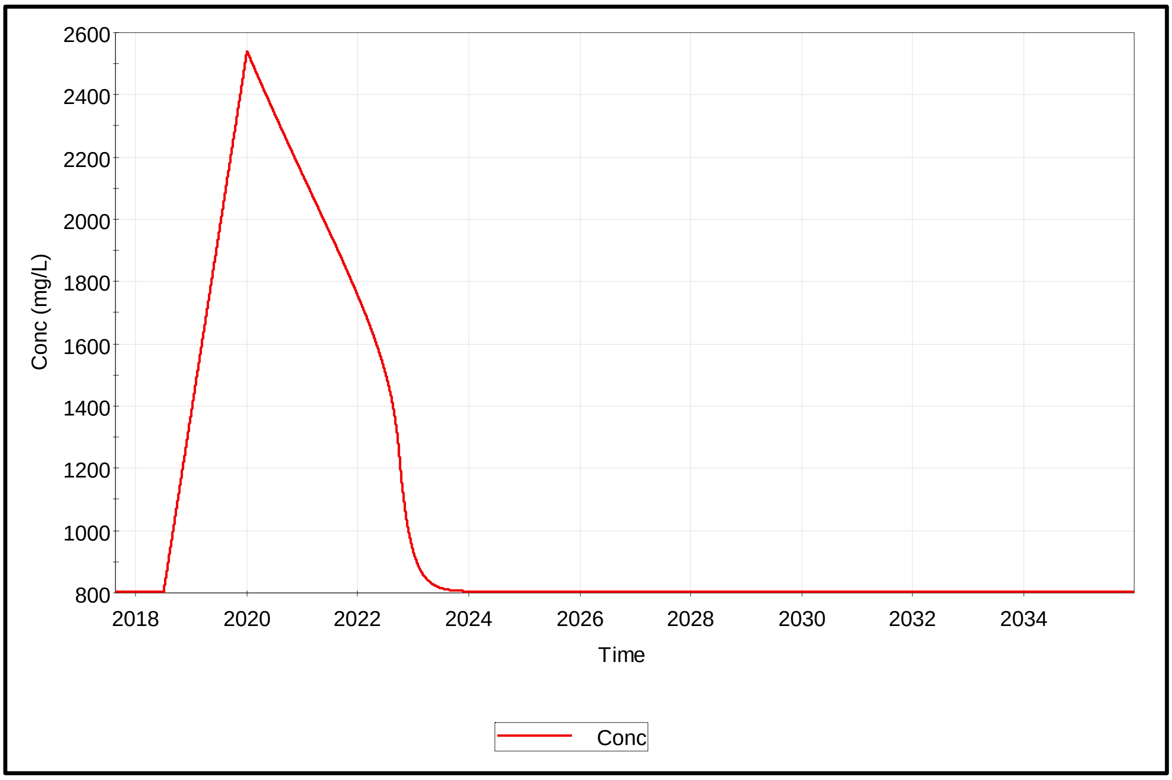

Figure 4 – Change in Salinity in the 800 Panel Area with Time

b) Surface Water / Groundwater Interaction

Comparison of the elevation of the floor of the Lithgow Seam and surface topography (ground level) indicates there is no direct connection between Lambs Creek and the 800 Panel Area (Lithgow Seam) because Lambs Creek lies significantly (52 to 296 m) above the Lithgow Seam. Similarly, because Kangaroo Creek lies significantly (75 to 326 m) above the Lithgow Seam, there is also no direct connection between Kangaroo Creek and the 800 Panel Area. There will be no seepage from the 800 Panel Area to these watercourses.

The Wolgan River flows from the Newnes Plateau to the Wolgan Valley. Where the Wolgan River is on the Newnes Plateau, there is no direct connection between it and the 800 Panel Area because the Wolgan River, when it is on the Newnes Plateau, lies significantly above the Lithgow Seam. Where the Wolgan River is within the Wolgan Valley the river is 2 – 126 m below the elevation of the Lithgow Seam. Due to the Lithgow Seam outcropping along the southern side of the Wolgan Valley, above the Wolgan River, there can be a connection (via seepage face) between the Wolgan River (in the Wolgan Valley) and the Lithgow Seam.

Analysis of the potential for seepage from the stored mine water in the 800 Panel Area into the Wolgan River (within the Wolgan Valley) indicates this is unlikely since average groundwater velocity (through the unmined Lithgow Seam, outside of the existing workings) has been calculated at 9.7 m/year. Accordingly, groundwater movement from the 800 Panel Area toward the Wolgan Valley, over the 5-year duration of high EC water storage will only be 48 m, compared to the shortest flow path to the Wolgan Valley being 750 m. The groundwater quality within this 48 m of the existing workings would be, at worst, the same as that predicted to occur (~2541 mg/L or 3790 µS/cm) within the 800 Panel Area itself. However, this assessed impact is conservative.

Dewatering of the 800 Panel Area, following commencement of the Springvale Water Treatment Project, will nullify the current hydraulic gradient between the 800 Panel Area and the Wolgan Valley. Nullifying the hydraulic gradient will facilitate recapture of potentially impacted groundwater.

In terms of cumulative groundwater impact with the nearest operation, Springvale Mine, it is noted that Springvale underground workings is located hydrogeologically up-gradient of Angus Place mine workings. Accordingly, transfer of residuals from the Project into stored mine water in the 800 Panel Area will have no impact on groundwater quality in Springvale Mine because the 800 Panel Area is down-gradient of Springvale Mine.

c) Neutral of Beneficial Effect on the Drinking Water Catchment

As noted above Kangaroo Creek and Lambs Creek traversing the Angus Place existing workings, both flow from the east to the west to Coxs River and Sydney's drinking water catchment (and Lake Burragorang). Given there are no direct connections between these watercourses and the 800 Panel Area there is no change to Lambs Creek or Kangaroo Creek due to the Project and hence there is no change to water quality within the Sydney Drinking Water Catchment.

d) Licensed Water Users

There are no non-mining groundwater users between Angus Place and the Wolgan Valley that may be potentially affected by the Project. Accordingly, there are no impacts to groundwater users due to the Project.

There are multiple surface water users within the Hawkesbury and Lower Nepean River Water Source, located downstream of Angus Place Colliery, within the Wolgan Valley and below.

There is potential for impact to these surface water users from seepage from stored mine water within 800 Panel Area into the Wolgan River within the Wolgan River (within the Wolgan Valley). As noted above the seepage of high EC water is unlikely to occur. However, any potential impact can be managed through dewatering of the 800 Panel Area following completion of the treatment phase of the Project.

7.1.3 Mitigation Measures

The main mitigation measure to be implemented to minimise potential impacts of the storage of the residuals in the existing workings is the dewatering of the 800 Panel Area as rapidly as practicable following the decommissioning of the WTP. This will nullify the current hydraulic gradient between the 800 Panel Area and the Wolgan Valley and facilitate the recapture of potentially impacted groundwater.

7.1.4 Conclusion

Site water balance modelling shows there will be an increase in salinity in the 800 Panel Area as a result of emplacement of residuals (up to 2 – 3 ML/day), increasing to 3790 µS/cm in the 18 months of emplacement. The EC will gradually decrease as the high EC water is transferred to the Springvale Water Treatment Project and will reduce to existing EC levels within a five year period.

There is a potential for seepage of impacted groundwater (which could have an EC as high as the EC in the 800 Panel Area) at the cliff-sides of the Wolgan Valley and thus impact on surface water users downstream of Wolgan Valley. The impact is unlikely given the seepage of the high EC water will occur through the unmined Lithgow Seam (and not Lithgow Seam) and will be slow. In the 5-year period the seepage of the high EC mine water will be approximately 48 m out of the 750 m distance to the Wolgan Valley cliff side. Seepage of the high EC mine water down the cliff side of Wolgan Valley is unlikely. This potential impact will be managed through dewatering of the 800 Panel Area when the Springvale Water Treatment Project becomes operational.

There will be no cumulative impact on Springvale Mine's mine inflows because Springvale underground workings is located hydrogeologically up-gradient of Angus Place mine workings. The transfer of residuals from the Project into stored mine water in the 800 Panel Area will have no impact on groundwater quality in Springvale Mine because District 800 is down-gradient of Springvale Mine.

7.2 Surface Water

There is potential for dirty water run-off from the WTP site to leave the site and reach Kangaroo Creek. As noted above diversion drains will be installed on the periphery of the WTP site. Erosion and sediment controls will also be installed to ensure that sediment/silt is removed from the dirty water run-off as much as possible before it is allowed to flow through the reed beds and towards Kangaroo Creek tributary within the pit top. The reed beds will further reduce the sediment load of the dirty water.

Surface water management at Angus Place pit top is managed and monitored in accordance with the *Western Region Water Management Plan*. The principal objective of surface water management at Angus Place is to ensure that the water quality leaving the site meets the appropriate quality standards outlined in EPL 467 (refer **Section 4.1**) and will continue to do so in the future.

The impact of discharging up to 10 ML/day of mine water treated to an EC of 350 µS/cm via LDP001 to Kangaroo Creek and the Coxs River catchment has been assessed in a surface water assessment (JBS&G, 2018b) prepared to support the proposed modification application (MOD 5). The key outcomes of that report relating to environmental impacts are presented in **Section 7.1** and environmental consequences in **Section 7.2**.

7.1 Environmental Impacts – Increased Mine Water Discharges (10 ML/day at 350 µS/cm)

The surface water assessment assessed the impact on flow/volume and salinity in downstream watercourses/dams, and the potential changes to geomorphology, flooding and drainage in Kangaroo Creek and Upper Coxs River.

- **Water flow and salinity impacts** are as follows.
  - A large increase (30%) in flow downstream of Angus Place LDP001 in Kangaroo Creek is predicted.
  - Large reductions in salinity downstream of LDP001 in Kangaroo Creek (39%) and Upper Coxs River (30%) are predicted
  - The magnitude of the reduction in salinity is predicted to diminish with distance downstream from Lake Wallace.
  - Negligible changes in volume and salinity in Lake Wallace, Lake Lyell and Lake Burragorang are predicted
- **Neutral or beneficial effect** – the modification meets:

    - the beneficial effect in Kangaroo Creek downstream of Angus Place LDP001 location
    - the neutral effect at Lake Wallace, Lake Lyell and Lake Burragorang.
- **Geomorphology** changes due to an increase in discharges at LDP001 from the current 2 ML/day to 10 ML/day shows:
    - no predicted change in the geomorphological state (scour) of Kangaroo Creek
    - no predicted change in the geomorphological state of Upper Coxs River downstream of Kangaroo Creek
- **Flooding** and **drainage** impacts due to an increase in discharges at LDP001 from the current 2 ML/day to 10 ML/day show:
    - negligible flooding in Kangaroo Creek and Upper Coxs River
    - no predicted change to drainage within Kangaroo Creek and Upper Coxs River.

7.2 Environmental consequences – Change in Flow and Salinity

There are potential environmental consequences on aquatic ecology (macroinvertebrates) due to:

- an increase in flow in Kangaroo Creek in the period 01 July 2018 – 31 December 2019
- a change in water quality of raw mine water to treated water with an EC of 350 µS/cm
- cessation of discharges from 01 January 2020 leading to a change in the hydrologic regime downstream of LDP001 from perennial to ephemeral

The environmental consequences can be summarised as follows.

- The reduced salinity in Kangaroo Creek and Upper Coxes River may result in improvements in macroinvertebrate community composition.
- The increased flow rate in Kangaroo Creek has the potential to impact on macroinvertebrate community:
    - Rheophilic taxa (those with a preference for fast flowing water) will become more dominant.
    - Lentic taxa (those that prefer slow flowing water) likely to result in reduced diversity.
- The change in the hydrologic regime of Kangaroo Creek downstream from LDP001 from perennial to ephemeral will result in the downstream macroinvertebrate community becoming similar to those present upstream from LDP001.

7.3 Downstream Surface Water Users

One downstream surface water user (WAL 25607) located upstream of Lake Wallace on Coxs River has the potential to be impacted as follows.

- The predicted median flow will decrease from 8.8 ML/day to 8.3 ML/day at the location (reduction in flow by 6%) however the predicted 95^{th} percentile flow will not change. It is noted the WAL is for 10 ML/day and the minor reduction in flow will not adversely impact on the surface water user.
- The predicted salinity of water at the location will decrease by 9%. This is a minor impact and will not degrade the usage category of the water. The WAL is for irrigation purposes and there will be negligible environmental consequences due to this minor reduction in salinity.

8.0 Assessment of Biological Impacts

Previously cleared areas have been utilised to delineate the footprint of the WTP site (**Section 3.1**). A flagging tape has been installed around the perimeter of the site to identify the extent of the WTP footprint. During installation of the WTP components, controls will be put in place to ensure that machinery will not impact on any vegetation outside of the defined WTP site boundary.

A due diligence ecology was undertaken over the WTP site and the surrounding areas. A vegetation community mapped as MU11 (DEC, 2006) was identified in the vicinity of the WTP site. This vegetation community is commensurate with an Endangered Ecological Community (EEC) – *Tablelands Snow Gum, Black Sallee, Candlebark and Ribbon Gum Grassy Woodland in the Sydney Basin Bioregion* listed under the *Biodiversity Conservation Act 2016*. The EEC will not be impacted by the Project.

9.0 Assessment of Aboriginal, Historical and Natural Cultural Heritage Impacts

As noted above the WTP site boundary is a previously disturbed area. A database search, comprising AHIMS, Heritage Register, World Heritage Register, National Heritage Register, State Heritage Register and *Lithgow Local Environment Plan 2014*, undertaken on 23 February 2018 did not identify any sites of Aboriginal and historical significance, within the WTP site boundary. The closest Aboriginal site is located over 900 m away to the east of the WTP site boundary.

The site was subject to a full cultural heritage assessment in 2013, including field surveys, undertaken as part of the Angus Place Mine Extension Project. There were no Aboriginal or European sites recorded within the WTP site during field surveys.

The WTP site is a previously disturbed area, and no landform of natural cultural heritage exists within the boundary.

Given no Aboriginal and historical cultural heritage sites or items are registered or have been recorded within the WTP site or its vicinity, no impacts are anticipated.

10.0 Assessment of Physical and Chemical Impacts

10.1 Noise

The nearest sensitive receptor is located approximately 1.5 km away from the WTP site. Noise impacts due to the Project will be negligible due to the distant location of the WTP, and also because the WTP components including the pumping gear will be enclosed and stored within portable container units and the sound power levels of noise sources within the WTP will be <85 dBA. The RO pumps (High-pressure pump, feed pump and CIP/backwash pump) will be the most significant sources of noise emissions. These pumps have sound power levels of < 85 dBA, and preliminary noise loss calculations to receptors 1.5 km away show noise levels <20 dBA, confirming that the WTP will have negligible noise impacts.

Angus Place monitors and manages noise impacts in accordance with the *Western Region Noise Management Plan*. Given the potential noise sources from the pit top facilities are minimal because Angus Place is under care and maintenance (hence limited machinery operations occur) Angus Place will continue to meet the noise criteria included in the project approval PA 06_0221 (Schedule 3 Condition 17) at all sensitive receptors. It is noted there have been no exceedances at the nearest sensitive receptor on Wolgan Road in the last two years, or any complaints received relating to noise from any receptors.

Major material deliveries will be restricted to construction hours noted in **Section 3.7,** and hence traffic noise from the Project will be minimised, noting any traffic noise impact will be temporary.

No blasting or drilling will be required as part of the Project and there will be no vibration impacts.

10.2 Air Quality and Greenhouse Gas

Air quality at Angus Place is managed in accordance with the approved *Western Region Air Quality and Greenhouse Gas Management Plan*. This document outlines the dust management and monitoring that is undertaken by Angus Place to ensure compliance with the requirements of PA 06_0021 and EPL 467.

There is a potential for dust emissions to increase during the construction phase of the Project from unsealed traffic areas and un-vegetated areas. Dust controls including the use of water cart, water cannons/sprinklers will be used on unsealed or dirty traffic areas to ensure dust emissions will be managed.

Given the proposed implementation of dust suppression controls, and that the surface operations at the pit top are currently limited due to the mine being on care and maintenance, Angus Place will continue to meet the air quality criteria included in Schedule 3 Condition 14 of PA 06_0221 at all sensitive receptors.

The WTP will be operated using electricity, and therefore the operation of the WTP will contribute to the greenhouse gas emissions of the Angus Place operations. The greenhouse gas contributions from the

WTP will be negligible but will be reported in the Annual Review as required by Schedule 3 Condition 31 of PA 06_0221.

10.3 Chemicals and Hazardous Materials

The WTP operations will require ongoing use of chemicals during the operational phase of the Project. Chemicals to be used and stored on site include:

- Disinfectant / antifoulants (sodium hypochlorite 10.8%)
- Acids (concentrated hydrochloric acid 32%)
- Antiscalent (MDC714)
- Free chlorine neutraliser (sodium bisulphite 38%)
- RO membrane cleaning chemicals (MCT515, MCT103)

Potential impacts are mainly associated with storage and handling of the chemicals. The chemicals will be stored within a dedicated containerised unit at the WTP site using bunded tanks as required. Appropriate storage and handling procedures will be implemented. Any accidental spills of chemicals, including hydrocarbons, will be managed appropriately. Oil spill kits will be available at the site for managing accidental spills. Chemical impacts are predicted to be negligible.

All chemicals will be managed, during transport to site and whilst stored on site, in accordance with the relevant *Safety Data Sheets* (SDS), provided by the chemical supplier and/or manufacturers' guidelines. Centennial Angus Place has a standard protocol for managing the incoming SDSs. The company utilises Chemwatch's database for online chemical management and compliance solutions. The SDSs for the chemicals to be utilised in the WTP will be uploaded to the Chemwatch's database, and the standard protocols for the management of chemicals on site will be followed.

Chemicals remaining after the WTP is decommissioned will be removed from the site by the external contractor or licensed contractors as appropriate using approved procedures.

10.4 Land Contamination

Land contamination due to the construction and operation of the WTP and ancillary infrastructure will be negligible. Contractors and Angus Place site personnel have received the appropriate spill clean-up training and will be able to manage chemical spills should any accidental spills occur during the construction and operational phases of the Project. Spill kits are located around the pit top.

10.5 Bushfire

The risk of a bushfire from the Project is negligible as the WTP will be operated at a low voltage of 415 V. The power cables will be well insulated and appropriately installed using cable trays. The cables within the WTP components will similarly be well-insulated.

Angus Place operates in accordance with a *Bushfire Management Plan*. The protocols within this plan will be implemented for any bushfire events.

11.0 Assessment of Community Impacts

The WTP is not close to any residential or other community areas and will therefore not have any direct adverse social or environmental effects on the community. The WTP will not be visible from Wolgan Road and the nearest sensitive receptor on Wolgan Road.

Traffic impacts including traffic noise will be minimal and of short-term duration, and will be further mitigated by restricting the construction hours to the recommended standard construction hours detailed in EPA's *Interim Construction Noise Guidelines* (DECC, 2009) and included in **Section 3.7**.

The community has been provided information on the Project through the following the *Western Region Community Consultative Committee* (CCC) on a number of occasions.

- A letter regarding the proposed modification was provided via email to the members of the CCC on 22 January 2017. The letter:

  - communicated Centennial Angus Place's intention to submit a modification application to increase mine water discharges at LDP001 via modification to Angus Place's project approval
  - provided a rationale for the proposed increase in mine water discharges at LDP001 to up to 10 ML/day (treated to an EC of 350 µS/cm) from the current 2 ML/day (untreated) mine water discharges
  - requested an extraordinary CCC meeting in February to enable Centennial Angus Place to provide an overview of the proposed modification.
- An extraordinary CCC meeting was held on 13 February 2018 followed by a site visit to the Angus Place pit top. At the meeting, a presentation on the Project components was made.

The CCC members had no issue with either the proposed mine water discharges or the establishment and operation of a temporary water treatment plant at the Angus Place pit top.

Preliminary information on the Project was provided to the Lithgow Environment Group, Colong Foundation, Blue Mountains Conservation Society and the Colo Society on 24 January 2018. A briefing on the Project was offered. A meeting was held on 14 March 2018 in Lithgow with the Lithgow Environment Group. The Colo Society and Blue Mountains Conservation Society declined the opportunity to attend any meeting. A briefing with the Colong Foundation is scheduled to be held in Sydney on 23 March 2018.

12.0 Assessment of Cumulative Impacts

The Project will result in potentially minor to negligible impacts to the environment. However, the beneficial impacts of the Project will be significant. Water quality in Kangaroo Creek and in the regional Coxs River catchment will generally improve. No mine water discharges from Angus Place LDP001 will occur from 01 January 2020.

No other operations or projects are being undertaken close to the Angus Place pit top. Springvale Mine pit top is located more than 5.5 km to the southeast. Ridges and densely vegetated areas separate the two sites. As such the WTP construction and operation poses negligible impacts relating to air and noise and therefore would not contribute to the cumulative effects at sensitive receivers.

Given the Springvale Mine workings are hydrogeologically up-gradient from the Angus Place workings, including the 800 Panel Area where the residuals will be transferred to, there will be no cumulative impact on the Springvale mine inflows due to the high EC mine water stored in the 800 Panel Area.

13.0 Conclusion

The Project has been assessed to pose negligible impacts on biodiversity, cultural heritage, noise, air quality and greenhouse gas, and the community. There is a potential for a minor impact on the groundwater, however, is considered to be unlikely. The Project will improve the water quality in the Coxs River catchment, and this benefit will far outweigh any minor potential impact.

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Centennial Coal Company Limited

Encl.: Attachment A – *Angus Place Water Treatment Project: Groundwater Assessment*, (Report number: JBS&G54568-113824), JBS&G Australia Pty Ltd, March 2018

ATTACHMENT 1

Groundwater Assessment

Centennial Angus Place Pty Ltd

Angus Place Water Treatment Project: Groundwater Assessment

Angus Place Colliery
Lidsdale NSW

22 March 2018

JBS&G54568-113824 (R02_Rev0)

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Centennial Angus Place Pty Ltd
Angus Place Water Treatment Project: Groundwater Assessment

Angus Place Colliery
Lidsdale NSW

22 March 2018

JBS&G54568-113824 (R02_Rev0)
JBS&G

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Nomenclature

The following nomenclature has been adopted in this report when describing the magnitude of changes (numerical) due to the Project:

Term	Definition
Negligible	change 0 to <2%, that is, no different from background levels
Minor	change is 3 to 5%
Moderate	change is 5 to 15%
Large	change is >15%

The following nomenclature has been adopted in this report when describing the significance of impacts due to the Project.

Term	Definition[1]
Not Significant or Insignificant	Impact is so small or unimportant as to be not worth considering; insignificant.
Significant	Impact is sufficiently great or important to be worthy of attention; noteworthy

Notes. 1. The definition of significance can be, as appropriate, informed by statistical significance, with respect to statistical hypothesis testing, however, statistical significance does not imply importance. In this report, the definition of significance is based on importance and may, or may not, take into account statistical significance.

Executive Summary

The Angus Place Water Treatment Project (the Project), a Part 5 modification, seeks to:

- From 1 July 2018 to 31 December 2019, discharge mine water (treated to 350µS/cm and at a rate of up to 10ML/d), through Angus Place LDP001, into Kangaroo Creek
- From 1 July 2018, temporarily transfer residuals generated from the Project underground within the 800 Panel Area
- From 1 July 2018 to 31 December 2019, continue to discharge 'raw' mine water, at up to 6.9ML/d, which is the limit based on the current interpretation of the relevant Water Access Licence however may be revised in the future, to the Springvale Delta Water Transfer Scheme (SDWTS) through the Bore 940 facility, if required
- From 1 January 2020, or earlier, as relevant, up to 13.4ML/d of mine water from the underground workings (800 and 900 Panel Areas) will be transferred to the Springvale Water Treatment Project for treatment and beneficial re-use within the Mt Piper Power Station cooling water system. This may occur via transfers to the SDWTS using the 940 Bore or through a new pipeline to be installed from the Angus Place pit top to the raw water pipeline in the Springvale Water Treatment Project and which will run along the existing Wallerawang Haul Road.
- From 1 January 2020, or earlier, as relevant, cease to discharge mine water (raw or treated) to Kangaroo Creek through Angus Place LDP001.

This Groundwater Assessment has been prepared to support a licence variation application to Angus Place Colliery's Environment Protection Licence (EPL) 467 for the inclusion of a pollution reduction program comprising the establishment and operation of a temporary water treatment plant at the Angus Place pit top. This assessment assesses the impact of temporarily storing residuals generated from the water treatment plant into stored mine water within the 800 Panel Area. The assessment forms part of the Environment Impact Assessment to be submitted to the Environment Protection Authority to allow them to consider matters included in Section 45 of the *Protection of the Environment Operations Act* 1997 (NSW) in relation to Centennial Angus Place's application to vary EPL 467.

The proposed increase in mine water discharge through Angus Place LDP001 on EPL 467, to up to 10ML/d (treated to 350µS/cm), will be undertaken as a Section 75W modification to Angus Place Colliery's project approval PA 06_0221, Modification 5, and is not assessed in this assessment report.

Existing Conditions

Angus Place Colliery is located adjacent Kangaroo Creek within the Upper Coxs River catchment in the Western Coalfields of NSW, approximately 13 kilometres northwest of the town of Lithgow. The Coxs River eventually flows into Lake Burragorang, the primary drinking water catchment for Sydney.

Angus Place Colliery is currently in Care and Maintenance and there has been no mining at Angus Place since February 2015. Currently an average of 8.7ML/d is extracted from the existing workings, with expected and approved inflow being 13.4ML/d.

Mine water discharge from Angus Place Colliery has been restricted to 2ML/d since July 2013, with 1.3ML/d of 'raw' mine water, on average, being discharged to Kangaroo Creek. Currently 6.9ML/d of 'raw' mine water is being directed to the SDWTS through the existing Bore 940 facility to Springvale Mine, which is located immediately adjacent Angus Place Colliery. That 'raw' mine water is then discharged through Springvale Mine's Licensed Discharge Point (LDP) 009 to Sawyers Swamp Creek.

Given the above, approximately 0.5ML/d of mine inflows has been accumulated in the 900 Panel Area and that area is now full.

'Raw' mine water from Angus Place Colliery comprise, primarily, groundwater that flows into the underground workings. The water characteristic of groundwater is near neutral pH, a Na-HCO_3 type water, with salinity, as Electrical Conductivity (EC), of ~1,143µS/cm (766mg/L, assuming a 0.67 conversion factor between EC and Total Dissolved Solids).

'Raw' mine water meets the requirements of the Australian Drinking Water Guideline (NHRMC, 2016) as well as the default trigger values (Default Guideline Values) for the 95^{th}% protection level of freshwater aquatic ecosystems (ANZECC, 2000), with the exception of salinity, which has a default value of 350µS/cm (234.5mg/L).

Proposed Conditions

It is proposed to treat 'raw' mine water to 350µS/cm and discharge treated mine water through Angus Place LDP001, at a rate up to 10ML/d, between 1 July 2018 and 31 December 2019. Increased mine water discharge from Angus Place Colliery will prevent further flooding at Angus Place. Further flooding at Angus Place would lead to Care and Maintenance activities being unable to be completed safely as well as preventing recommencement of mining in the future.

During the treatment phase residuals (salt) from the treatment process will be temporarily transferred underground to the 800 Panel Area. Following completion of the treatment phase, mine water from the underground workings (800 and 900 Panel Areas) will be transferred to the Springvale Water Treatment Project for treatment and beneficial re-use within the Mt Piper Power Station cooling water system.

Environmental Consequences

The changes to the environment due to the Project, with respect to groundwater, include changes to site water management, changes to groundwater quality, changes to surface water/groundwater interaction as well as extraction of stored mine water (post treatment phase).

Given the above, potential impacts due to the Project may occur to the groundwater environment, neutral or beneficial effect to the drinking water catchment, groundwater dependent ecosystems, licensed water users and surface water/groundwater interaction.

<u>Cumulative Impact Assessment</u>

Significant projects in the vicinity of the Project include Springvale Mine, Springvale Water Treatment Project and the Angus Place Mine Extension Project (if approved).

With respect to Springvale Mine, Springvale is located hydrogeologically up-gradient of Angus Place Colliery. Accordingly, transfer of residuals from the Project into stored mine water in District 800 will have no impact on groundwater quality in Springvale Mine because District 800 is down-gradient of Springvale Mine.

With respect to the Springvale Water Treatment Project, water balance modelling undertaken in the Springvale Angus Place Residuals Management Model (SAPRMM), which is a new model developed during this assessment, indicates that the Project will not exceed the volumetric and water quality (salinity) contractual limitations of the Springvale Water Treatment Project.

With respect to the Angus Place Mine Extension Project, the Project will completed, including dissipation of residuals transferred into stored mined water in District 800, prior to the expected commencement of the Angus Place Mine Extension Project, if approved.

<u>Groundwater Environment</u>

Water balance modelling undertaken in the SAPRMM indicates that temporary transfer of residuals into stored mine water within the 800 Panel Area will lead to an increase in salinity within the

~2,000ML stored in those workings from 804mg/L (1,200µS/cm), which was the assumed salinity (conservative) in the model, to a maximum of 2,541mg/L (3,790µS/cm) over the 18 months (1 July 2018 through 31 December 2019) of operation of the water treatment plant.

Modelling indicates that the increased discharges via LDP001 will create contingency storage by dewatering existing flooded workings (District 900) from 1,600ML currently to 1,125ML by 1 July 2019, which is the date of commencement of the Springvale Water Treatment Project.

Following commencement of the Springvale Water Treatment Project, which has a contractual input water quality limit of 1,400µS/cm, the SAPRMM indicates that mine water in 800 Panel Area can commence being discharged to the Springvale Water Treatment Project.

Modelling indicates that stored mine water in the 800 Panel Area will be completely dissipated (return to background water quality, 99%) by August 2023.

The rate of extraction from District 800 and District 900 is shown to be less than, or equal to, the predicted mine inflow rate to existing operations of 13.4ML/d, which was presented and approved in the Surface Water and Groundwater Assessment for Modification 4 (RPS, 2014).

Geochemical modelling, using the United States Geological Survey code, PHREEQCi, indicates there is an insignificant expected change to pH during the 18 months of continuous transfer of residuals to the 800 District. However the concentration of trace ions, such as dissolved metals will increase by a factor of 3.133 in the same period.

The predicted water quality in the 800 District at the end of operation of the Project is a Na-HCO_3 type water, with near neutral pH, that is brackish but not saline. There are no exceedances of the default guideline values of the 95^{th}% protection level for slightly to moderately disturbed aquatic ecosystems, aside from EC, which is significantly exceeded. It is noted that water with elevated EC will not be discharged to the environment without treatment.

Neutral or Beneficial Effect to the Drinking Water Catchment

Lambs Creek and Kangaroo Creek are located within the Sydney Drinking Water Catchment.

As is discussed in detail below, there is no predicted change to Lambs Creek or Kangaroo Creek due to the Project, because the elevations along Lambs Creek and Kangaroo Creek lie well above the Lithgow Seam (800 Panel Area), and, as such, there is no direct hydraulic connection.

Because there is no change to water quality in tributaries to the Drinking Water Catchment, the Project meets the Neutral or Beneficial Effect on Water Quality test.

Groundwater Dependent Ecosystems

Groundwater dependent ecosystems reside on the Newnes Plateau (Temperate Highland Peat Swamps on Sandstone communities).

The Newnes Plateau is located well above elevation of the Lithgow Seam, and therefore there is impact to those ecosystems due to the Project.

Licensed Water Users

There are no non-mining groundwater users between Angus Place Colliery and the Wolgan Valley that may be potentially affected by the Project.

Accordingly, there are no impacts to groundwater users due to the Project.

There are multiple surface water users within the Hawkesbury and Lower Nepean River Water Source, located downstream of Angus Place Colliery, within the Wolgan Valley and below.

There is potential for impact to these users from seepage from stored mine water within 800 Panel Area into the Wolgan River within the Wolgan River (within the Wolgan Valley), however, this impact can be managed through dewatering of the 800 Panel Area following completion of the treatment phase of the Project, as discussed immediately below.

Surface Water/Groundwater Interaction

Comparison of the elevation of the floor of the Lithgow Seam and surface topography (ground level) indicates there is no direct connection between Lambs Creek and the Lithgow Seam (800 Panel Area), because Lambs Creek lies significantly above the Lithgow Seam. No seepage of high EC mine water from the 800 District to Lambs Creek will occur.

For the same reason, there is also no direct connection between Kangaroo Creek and the Lithgow Seam (800 Panel Area), because Kangaroo Creek lies significantly above the Lithgow Seam. No seepage of high EC mine water from the 800 District to Kangaroo Creek will occur.

The Wolgan River occurs both on the Newnes Plateau and within the Wolgan Valley. Where the Wolgan River is on the Newnes Plateau, there is no direct connection between it and the Lithgow Seam (800 Panel Area) because the Wolgan River, when it is on the Newnes Plateau, lies significantly above the Lithgow Seam. Where the Wolgan River is within the Wolgan Valley, due to the Lithgow Seam outcropping along the southern side of the Wolgan Valley, above the Wolgan River, there can be connection (via seepage face) between the Wolgan River (in the Wolgan Valley) and the Lithgows Seam.

Analysis of the potential for seepage from stored mine water in District 800 into the Wolgan River (within the Wolgan Valley) indicates this is unlikely, since average groundwater velocity (through the unmined Lithgow Seam, outside of the existing workings) has been calculated at 9.7m/year. Accordingly, groundwater movement from District 800 toward the Wolgan Valley, over the 5 year duration of storage will only be 48m, compared to the shortest flowpath to the Wolgan Valley being 750m. The groundwater quality within 48m of the existing workings would be, at worst, the same as that proposed to occur within District 800 itself (conservative).

Dewatering of District 800 following commencement of the Springvale Water Treatment Project, will nullify the current hydraulic gradient between District 800 and the Wolgan Valley. Nullifying the hydraulic gradient will facilitate recapture of potentially impacted groundwater.

In addition, the current groundwater model (CSIRO 2013) predicts there is a hydrogeologic divide at ~830mAHD between Longwall 11 to Longwall 13 of District 800 and the Wolgan Valley. A hydrogeologic divide at ~830mAHD, compared to the current groundwater elevation in District 800 of 805mAHD, would imply that the groundwater flow direction currently would be towards District 800, rather than towards the Wolgan Valley. If this were the case, then this would prevent seepage of temporarily impacted groundwater into the Wolgan Valley.

1. Introduction

This chapter presents the background to the request for approval, the water management strategy for the Project, expected changes and potential impacts due to the Project, as well as the purpose and layout of the report

1.1 Overview of Angus Place Colliery

Angus Place Colliery is an existing underground coal mine with the approval to produce up to 4 million tonnes per annum (Mtpa) of run-of-mine (ROM) high quality thermal coal for domestic markets, including for the Mt Piper Power Station which produces about 15% of the total electricity generated in New South Wales (NSW). The mine has been on care and maintenance since March 2015 and will recommence operations in 2020.

The mine is located 15 kilometres (km) northwest of the regional city of Lithgow and 120 km west northwest of Sydney in NSW. The Angus Place Colliery pit top is situated at the foot of the Newnes Plateau. Underground longwall coal mining commenced at Angus Place Colliery in 1979. Coal is extracted from the Lithgow Coal Seam.

The mine's current Project Approval (PA 06_0021) was granted in September 2006 under Part 3A of the *Environmental Planning and Assessment Act* 1979 (NSW) (EP&A Act), and the project approval has been modified on four occasions. The mine also operates under Environment Protection Licence (EPL) 467.

Angus Place Colliery is owned by Centennial Springvale Pty Limited (50%) and Springvale SK Kores Pty Limited (50%) as participants in the Springvale unincorporated joint venture. Angus Place Colliery is operated by Centennial Angus Place Pty Limited (Centennial Angus Place).

1.2 Water Management Strategy

1.2.1 Current Approach

Angus Place Colliery is currently operating under Care and Maintenance. Groundwater is continuously extracted from the Angus Place Colliery workings to prevent them from flooding. However, the water levels in the Angus Place Colliery workings are steadily increasing and, if extraction rates are not increased, the mine will be flooded to a degree that underground Care and Maintenance operations will not be able to be carried out safely, and the costs of recommencing mining will become prohibitive.

Currently, an average of about 8.7 megalitres per day (ML/d) of water is extracted from the workings. As presented in Table 8.5 of the Surface Water and Groundwater Assessment for Modification 4 (RPS, 2014), the expected and approved inflow from existing workings is 13.4ML/d.

Extracted groundwater is currently treated to remove suspended sediment and up to 2ML/day of 'raw' mine water is discharged from Angus Place licensed discharge point (LDP) No. 001, to Kangaroo Creek upstream of the Coxs River. 2ML/d is the current maximum permitted discharge volume from LDP001 under EPL 467. There is no restriction on the salinity of the discharged groundwater. The EC, a measure of salinity, of 'raw' mine water discharge is currently 1,033µS/cm (4 December 2017).

The remaining extracted groundwater is transferred to the Springvale Delta Water Transfer Scheme (SDWTS) via the Bore 940 facility, where it is discharged through the Springvale Mine Licensed Discharge Point LDP009 in accordance with the Springvale Mine EPL (EPL 3607).

A map presenting the extent of current workings at Angus Place Colliery is provided in **Figure 1.1**.

It is noted that, for the purpose of this report, District 700 is included in the definition of District 800. Further detail of the connection between District 700 and District 800 is provided in **Section 3.3.2**.

1.2.2 Future Changes

In order to prevent the full flooding of the underground workings, Centennial Angus Place is proposing to increase mine water discharges through LDP 001 in a modification to the Angus Place Colliery's project approval. Consistent with the intent of Condition 11B Schedule 3 of PA 06_0021 Angus Place will treat all mine water using the desalination technology (reverse osmosis) to an electrical conductivity (EC) of 350 µS/cm prior to discharge to the Coxs River catchment. A temporary water treatment plant and ancillary infrastructure is required to be installed for this reason.

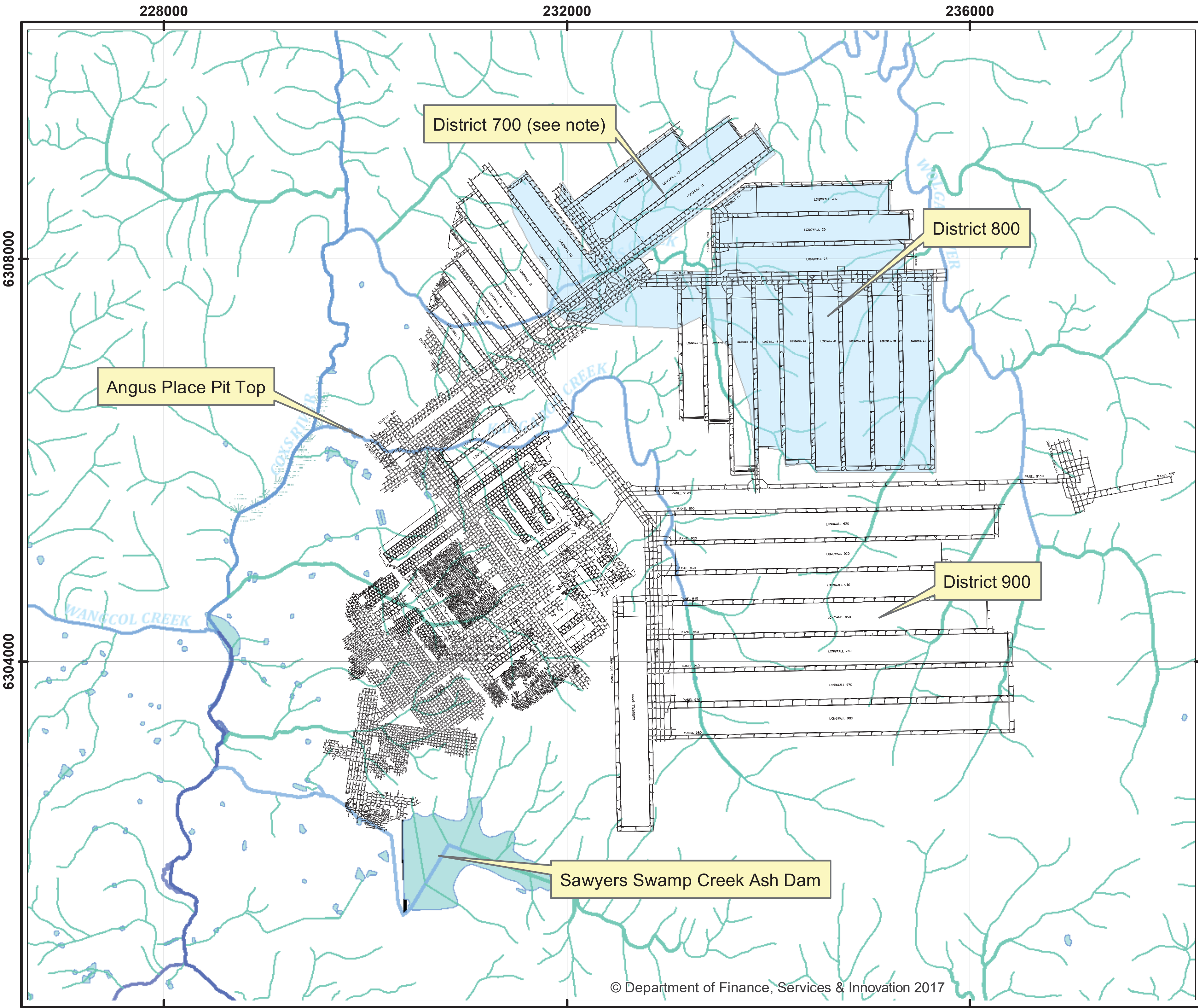
The proposed increased in mine water discharges and the construction and operation of the water treatment plant are two separate components of the Angus Place Water Treatment Project (the Project) for which approvals are sought separately, due to timing constraints:

- the establishment and operation of a water treatment plant and management of the residuals waste stream through a variation to EPL 467 for the inclusion of these works as a Pollution Reduction Program such that these works can be undertaken in accordance with Clause 6(e) provisions of State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007 (NSW)
- increasing discharges through LDP001 to up to 10 ML/day treated to an EC of 350µS/cm via modification (Modification 5) to project approval PA 06_0221 to be assessed under Section 75W provisions of the EP&A Act.

Specifically, the Project seeks to:

- Construct a Temporary Water Treatment Plant at Angus Place Colliery by 30 June 2018
- Continue discharge of 'raw' mine water at up to 2ML/d, through Angus Place LDP001, into Kangaroo Creek, until 30 June 2018. Discharge of 'raw' mine water at 2ML/d is currently permitted
- Operate the Temporary Water Treatment Plant from 1 July 2018 until 31 December 2019
- From 1 July 2018 to 31 December 2019, discharge mine water (treated to 350µS/cm and at a rate of up to 10ML/d), through Angus Place LDP001, into Kangaroo Creek
- From 1 July 2018 to 31 December 2019, continue to discharge 'raw' mine water, at up to 6.9ML/d, which is the limit based on the current interpretation of the relevant Water Access Licence however may be revised in the future, to the SDWTS through the Bore 940 facility, if required
- From 1 July 2018, temporarily transfer residuals generated from the Project underground within the 800 Panel Area until 31 December 2019
- From 1 January 2020, or earlier, as relevant, up to 13.4ML/d of mine water from the underground workings (800 and 900 Panel Areas) at Angus Place Colliery will be, transferred to the Springvale Water Treatment Project for treatment and beneficial re-use within the Mount Piper Power Station cooling water system. This may occur via transfers to the SDWTS using the 940 Bore or through a new pipeline to be installed from the Angus Place pit top to the raw water pipeline in the Springvale Water Treatment Project and which will run along the existing Wallerawang Haul Road.
- From 1 January 2020, or earlier, as relevant, cease to discharge mine water (raw or treated) to Kangaroo Creek through Angus Place LDP001.

As noted above, the increase in mine water discharge through Angus Place LDP001, to up to 10ML/d (treated to 350µS/cm), will be undertaken as a Section 75W modification, Modification 5, and is not assessed in this assessment report.



Legend:

- Angus Place Workings
- District 800 - Stored Mine Water

NB. Nomenclature of Hydrology Layer is indicative only and is not Strahler Order.
Note 1. District 700 is included in definition of District 800 Stored Mine Water.

JBS&G

Job No: 54568	
Client: Centennial Angus Place Pty Ltd	
Version: R01RevC	Date: 07-Mar-2018
Drawn By: JRB	Checked By: JRB
Scale 1:50,000	

0 500 1,000
metres

Coor. Sys. GDA 1994 MGA Zone 56

Angus Place Colliery
LIDSDALE NSW

EXTENT OF CURRENT WORKINGS

FIGURE: 1-1

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\54568_WaterAssessmentMOD5\Figures\GIS\Delivery\R02RevB_D003_ExtentCurrentWorkings.mxd
Reference: Layer from NSW LPI Web Services, 2018

1.3 Expected Changes and Potential Impacts due to the Project

The assessment methodology adopted in this report was tailored based on expected changes and potential impacts due to the Project.

The following list of changes is expected due to the Project:

- change to site water management
- change to groundwater quality (salinity, as well as other analytes)
- change to surface water/groundwater interaction
- extraction of stored mine water (post treatment phase)

Given the above, potential impacts due to the Project, including cumulative impacts, may occur to:

- the Groundwater Environment
- Neutral or Beneficial Effect to the Drinking Water Catchment
- Groundwater Dependent Ecosystems
- Licensed Water Users
- Surface Water/Groundwater Interaction

1.4 Purpose of this Report

JBS&G Australia Pty Ltd (JBS&G) has been engaged by Centennial Angus Place to prepare a Groundwater Assessment to support a licence variation application to EPL 467 for the inclusion of a pollution reduction program comprising the establishment and operation of a temporary water treatment plant at the Angus Place pit top. This assessment assesses the impact of temporarily storing residuals generated from the water treatment plant into stored mine water within the 800 Panel Area. The assessment forms part of the Environmental Impact Assessment to be submitted to the EPA to allow them to consider matters included in Section 45 of the *Protection of the Environment Operations Act* 1997 (NSW) in relation to Centennial Angus Place's application to vary EPL 467.

The increase in mine water discharge through Angus Place LDP001 (**Section 1.2.2**), to up to 10ML/d (treated to 350µS/cm), is not part of the EPL 467 licence variation application, and has not been assessed in this assessment report.

This report has been prepared based on information current at the time of this report.

It is noted that this report is a technical appendix to the main text of the Environmental Impact Assessment. Assumptions made in the environmental model/s and in text in this report, for the purpose of preparing an impact assessment with respect to Groundwater are, necessarily, superseded by the dates, quantities and undertakings noted in the main text of the Environmental Assessment.

1.5 Layout of the Report

The layout of the report is as follows:

- Chapter 1 – presents the background to the request for approval, the water management strategy for the Project, expected changes and potential impacts due to the Project, as well as the purpose and layout of the report
- Chapter 2 – presents governing legislation, regulations, environmental planning instruments, guidance documents and policies relevant to the assessment
- Chapter 3 – presents a summary of the environmental and hydrogeological setting

- Chapter 4 – presents an analysis of proposed changes due to the Project to site water management, changes to groundwater quality, changes to surface water/groundwater interaction as well as extraction of stored mine water (post treatment phase)
- Chapter 5 – presents a summary of the environmental consequences of the Project, including cumulative impacts, with respect to the groundwater environment, neutral or beneficial effect to the drinking water catchment, groundwater dependent ecosystems, licensed water users and surface water/groundwater interaction
- Chapter 6 – presents an assessment of the impact of the Project against compliance with relevant governing legislation, regulations, environmental planning instruments, guidance documents and policies
- Chapter 7 – presents changes to licensing, management and monitoring due to the Project
- Chapter 8 – presents relevant references.

2. Legislation, Regulation and Policy

This chapter presents governing legislation, regulations, environmental planning instruments, guidance documents and policies relevant to the assessment.

2.1 Commonwealth Legislation

2.1.1 Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act* 1999 (Cth) is the main Commonwealth environmental legislation that provides the legal framework to protect and manage Matters of National Environmental Significance (MNES) including nationally and internationally important flora, fauna, ecological communities, cultural heritage and water resources.

The shrub swamps and hanging swamps on the Newnes Plateau are collectively referred to as the Temperate Highland Peat Swamps on Sandstone (THPSS). The THPSS are federally listed Endangered Ecological Communities (EECs) protected under the *Environment Protection and Biodiversity Conservation Act* 1999 (Cth) and occur within the Angus Place Colliery holding boundary. As noted in **Section 2.3.2** below, these communities are also listed in the Schedule of the relevant Water Sharing Plan.

Water resources are also an MNES and the potential impact of the Project is considered in this report through the Significant Impact Guidelines for Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources (DoE, December 2013), which are summarised in **Section 2.2.1** below.

An assessment of the Project against MNES (THPSS) is presented in **Section 6.1.1**.

2.2 Commonwealth Guidelines and Policy

Guidelines and policies relevant to the Surface Water Assessment are presented below.

2.2.1 Significant Impact Guidelines: Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources 2013

The guidelines have been prepared by the Department of the Environment of the Australian Government (DoE, 2013). DoE (2013) define a significant impact on hydrological characteristics as follows:

"A significant impact on the hydrological characteristics of a water resource may occur where there are, as a result of the action:

a) changes in the water quantity, including the timing of variations in water quantity

b) changes in the integrity of hydrological or hydrogeological connections, including substantial structural damage (e.g. large scale subsidence)

c) changes in the area or extent of a water resource

where these changes are of sufficient scale or intensity as to significantly reduce the current or future utility of the water resource for third party users, including environmental and other public benefit outcomes."

[Page 17 of DoE (2013)]

DoE (2013) define a significant impact on water quality as follows:

"A significant impact on a water resource may occur where, as a result of the action:

a) there is a risk that the ability to achieve relevant local or regional water quality objectives would be materially compromised, and as a result the action:

i. creates risks to human or animal health or to the condition of the natural environment as a result of the change in water quality

ii. substantially reduces the amount of water available for human consumptive uses or for other uses, including environmental uses, which are dependent on water of the appropriate quality

iii. causes persistent organic chemicals, heavy metals, salt or other potentially harmful substances to accumulate in the environment

iv. seriously affects the habitat or lifecycle of a native species dependent on a water resource, or

v. causes the establishment of an invasive species (or the spread of an existing invasive species) that is harmful to the ecosystem function of the water resource, or

b) there is a significant worsening of local water quality (where current local water quality is superior to local or regional water quality objectives), or

c) high quality water is released into an ecosystem which is adapted to a lower quality of water.

For water-dependent ecosystems, a significant impact is likely if the predicted change in water quality is greater than that required for 'moderately to slightly disturbed' systems as described in the relevant local or regional water quality objectives (typically the 80% to 95% ecosystem protection guideline values listed in ANZECC (2000)). Note that other thresholds may apply where changes in water quality may impact on other matters of national environmental significance, such as threatened species or ecological communities."

[Page 18 of DoE (2013)]

An assessment of the Project against the abovementioned guidelines is presented in **Section 6.2**.

2.2.2 Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000

The Australian and New Zealand Environment and Conservation Council and the Agriculture and Resource Management Council of Australia and New Zealand for the Australian and New Zealand Governments (ANZECC, 2000) present the water quality management framework that has been adopted nationally. That framework aims to:

- *"identify the environmental values that are to be protected in a particular water body and the spatial designation of the environmental values*
- *identify management goals and then select the relevant water quality guidelines for measuring performance, tailored to local environmental conditions. Based on these guidelines, set water quality objectives that must be met to maintain the environmental values*
- *develop statistical performance criteria to evaluate the resulting of the monitoring programs*
- *develop tactical monitoring programs focussing on the water quality objectives*
- *initiate appropriate management response to attain or maintain the water quality objectives."*

[Page 2-1 of ANZECC (2000)]

The selected water quality and river flow objectives for the Project are presented in the Surface Water Assessment (JBS&G, 2018). These objectives are relevant in the context of surface water/groundwater interaction, as identified in the NSW Groundwater Quality Protection Policy, presented in **Section 2.4.1** below.

An assessment against the objectives is discussed in **Section 6.2.2** and addressed in **Section 6.4.1**.

2.2.3 Australian Drinking Water Guidelines 2011

The guidelines are prepared by the National Health and Medical Research Council for the Australian Government (NHMRC, 2016) and are:

"…*intended to provide a framework for good management of drinking water supplies that, if implemented, will assure safety at point of use. The ADWG have been developed after consideration of the best available scientific evidence. They are designed to provide an authoritative reference on what defines safe, good quality water, how it can be achieved and how it can be assured. They are concerned both with safety from a health point of view and with aesthetic quality.*

The ADWG are not mandatory standards; however, they provide a basis for determining the quality of water to be supplied to consumers in all parts of Australia. These determinations need to consider the diverse array of regional or local factors, and take into account economic, political and cultural issues, including customer expectations and willingness and ability to pay.

The ADWG are intended for use by the Australian community and all agencies with responsibilities associated with the supply of drinking water, including catchment and water resource managers, drinking water suppliers, water regulators and health authorities."

[Page 2 of NHMRC (2016)]

The Australian Drinking Water Guidelines are potentially relevant in the circumstance of changes to surface water/groundwater interaction within the Coxs River. As noted in **Section 2.3.1** below, the Coxs River lies within the Sydney Drinking Water Catchment, however, the Wolgan River does not.

An assessment of the Project against the guidelines is discussed in **Section 6.2.3**.

2.3 NSW Legislation

2.3.1 Environmental Planning and Assessment Act 1979

2.3.1.1 State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011

The *State Environmental Planning Policy (Sydney Drinking Water Catchment)* 2011 (NSW) is an environmental planning instrument under the *Environmental Planning and Assessment Act* 1979 (NSW).

Surface water catchments within the Upper Nepean and Upstream Warragamba Water Source, of which Lambs Creek, Kangaroo Creek and the Coxs River are tributaries, are declared by the *State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011* (NSW) to be within the Sydney Drinking Water Catchment. Surface water catchments within the Hawkesbury and Lower Nepean Rivers Water Source, of which the Wolgan River is a tributary, are outside of the Sydney Drinking Water Catchment. Further detail on the above water sources is presented in **Section 3.1.3** below.

An assessment of the Project against the *State Environmental Planning Policy (Sydney Drinking Water Catchment)* 2011 (NSW) is presented in **Section 6.3.1**.

2.3.2 Water Management Act 2000

The *Water Management Act 2000* (NSW) presents the framework for sustainable and integrated water management in NSW and its objectives are as follows:

- "*to apply the principles of ecologically sustainable development, and*
- *to protect, enhance and restore water sources, their associated ecosystems, ecological processes and biological diversity and their water quality, and*
- *to recognise and foster the significant social and economic benefits to the State that result from the sustainable and efficient use of water, including:*

- *benefits to the environment, and*
- *benefits to urban communities, agriculture, fisheries, industry and recreation, and*
- *benefits to culture and heritage, and*
- *benefits to the Aboriginal people in relation to their spiritual, social, customary and economic use of land and water,*

- *to recognise the role of the community, as a partner with government, in resolving issues relating to the management of water sources,*
- *to provide for the orderly, efficient and equitable sharing of water from water sources,*
- *to integrate the management of water sources with the management of other aspects of the environment, including the land, its soil, its native vegetation and its native fauna,*
- *to encourage the sharing of responsibility for the sustainable and efficient use of water between the Government and water users,*
- *to encourage best practice in the management and use of water."*

[Chapter 1, Section 3 of the *Water Management Act* 2000 (NSW)]

The primary instruments applied in NSW to achieve these objectives are Water Sharing Plans.

Water Sharing Plans

Water Sharing Plans provide the basis for equitable sharing of surface water and groundwater between water users, including the environment, and are regulations under the *Water Management Act* 2000 (NSW).

The majority of NSW is now covered by Water Sharing Plans. If an activity leads to a take from a groundwater or surface water source covered by a Water Sharing Plan, then an approval and/or licence is required.

In general, the *Water Management Act* 2000 (NSW) requires:

- a water access licence to take water
- a water supply works approval to construct a work
- a water use approval to use the water.

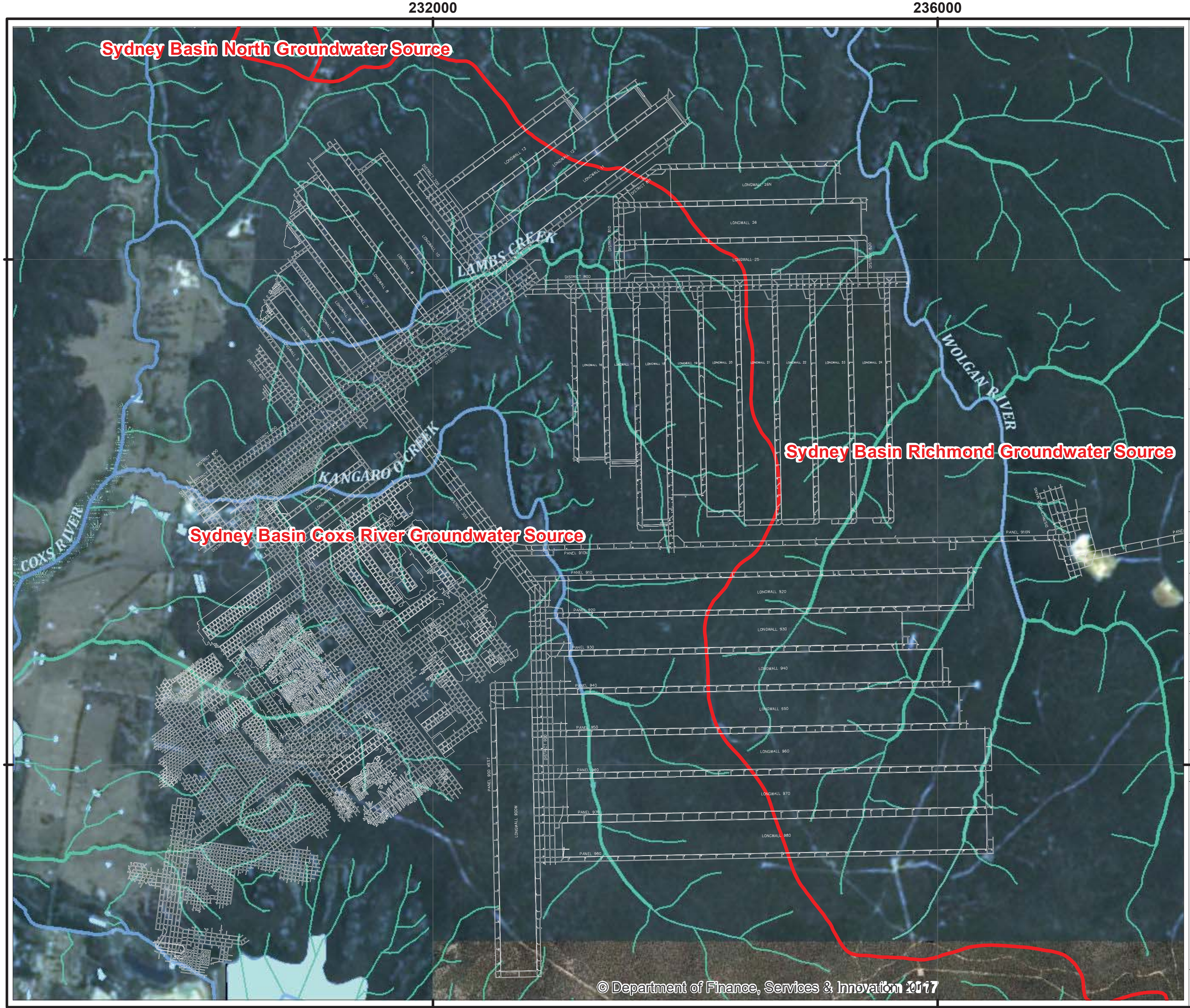
For groundwater, the Project lies on the boundary of the Sydney Basin Coxs River Groundwater Source and the Sydney Basin Richmond Groundwater Source within the *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources* 2011 (NSW).

Figure 2.1 presents the location of the Water Sharing Plans in the vicinity of Angus Place Colliery.

There are groundwater licences held by Angus Place Colliery in both the Sydney Basin Coxs River and the Sydney Basin Richmond Groundwater Sources. **Table 2.1** presents a summary of these licences.

Table 2.1 : Centennial Angus Place Groundwater Water Access Licences (WALs)

WAL No.	Licence Class and Entitlement	Owner
Sydney Basin Coxs River Groundwater Source		
36445	Aquifer (2701ML)	Centennial Angus Place
Total held in Water Source is 2701ML.		
Sydney Basin Richmond Groundwater Source		
36449	Aquifer (2523ML)	Centennial Angus Place
Total held in Water Source is 2523ML		



Legend:

Angus Place Workings

JBS&G

Job No: 54568	
Client: Centennial Angus Place Pty Ltd	
Version: R02RevA	Date: 13-Feb-2018
Drawn By: JRB	Checked By: JRB
Scale 1:40,000	

0 400 800
metres

Coor. Sys. GDA 1994 MGA Zone 56

Angus Place Colliery
LIDSDALE NSW

WATER SHARING PLAN BOUNDARIES (GROUNDWATER)

FIGURE: 2-1

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\54568_WaterAssessmentMOD5\Figures\GIS\Delivery\R02RevA_D002_WaterSharingPlanBoundaries.mxd
Reference: Aerial Imagery and Hydrology Layer from NSW LPI Web Services, 2018

High priority groundwater dependent ecosystems are listed in Table D of Schedule 4 of the *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources* 2011 (NSW). **Table 2.2** presents the relevant entry with respect to the THPSS communities.

Table 2.2 : High Priority Groundwater Dependent Ecosystems (after Table D of Schedule 4 of the *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources* 2011 (NSW)).

High Priority Groundwater dependent ecosystem	Location	Conservation Status at the commencement of this Plan
Temperate Highland Peat Swamps on Sandstone Note. Temperate Highland Peat Swamps on Sandstone includes Blue Mountains Sedge Swamps, Butler's Swamp, Newnes Plateau Swamps, Paddy's River Swamps and Wingecarribee Swamp.	Numerous small wetlands located in the Blue Mountains and Newnes Plateau regions. Note. A current list of Temperate Highland Peat Swamps on Sandstone is provided on the Office of Environment and Heritage's website.	Part of the Montane peatlands and swamps of the Sydney Basin Bioregion, which is an endangered ecological community listed in the Threatened Species Conservation Act 1995; listed as an endangered ecological community under section 181 of the Environment Protection and Biodiversity Conservation Act 1999 (Cth).

An assessment of the Project against the *Water Management Act* 2000 (NSW) is presented in **Section 6.3.2**.

2.3.3 Biodiversity Conversation Act 2016

The *Biodiversity Conservation Act* 2016 (NSW) is NSW state legislation that is intended to maintain a healthy, productive and resilient environment for the greatest well being of the community, now and into the future, consistent with the principles of ecologically sustainable development.

The THPSS on the Newnes Plateau, located above previous mining at Angus Place Colliery, are listed as under EECs (Montane Peatlands and Swamps of the Sydney Basin Bioregion) in the *Biodiversity Conservation Act* 2016 (NSW).

An assessment of the impact of the Project on THPSS communities is presented in **Section 6.3.3**.

2.4 NSW Guidelines and Policy

2.4.1 NSW Groundwater Quality Protection Policy

The objectives of the NSW Groundwater Quality Protection Policy (DLWC (now NSW Lands and Water), 1998) are the basis of the objectives of the *Water Management Act* 2000 (NSW).

The NSW Groundwater Quality Protection Policy encourages ecologically sustainable management of groundwater resources to:

- *"slow and halt, or reverse any degradation of groundwater resources*
- *ensure sustainability of groundwater dependent ecosystems*
- *maintain the full range of beneficial uses of these resources*
- *maximise economic benefit to the Region, State and Nation."*

[Page 7 of DLWC (1998)]

DLWC (1998) state that the objectives of the NSW Groundwater Quality Protection Policy will be met through the following management principles:

1. *"All groundwater systems should be managed such that their most sensitive identified beneficial use (or environmental value) is maintained.*
2. *Town water supplies should be afforded special protection against contamination.*
3. *Groundwater pollution should be prevented so that future remediation is not required.*

4. *For new developments, the scale and scope of work required to demonstrate adequate groundwater protection shall be commensurate with the risk the development poses to a groundwater system and the value of the groundwater resource.*
5. *A groundwater pumper shall bear the responsibility for environmental damage or degradation caused by using groundwaters that are incompatible with soil, vegetation or receiving waters.*
6. *Groundwater dependent ecosystems will be afforded protection.*
7. *Groundwater quality protection should be integrated with the management of groundwater quantity.*
8. *The cumulative impacts of developments on groundwater quality should be recognised by all those who manage, use, or impact on the resource.*
9. *Where possible and practical, environmentally degraded areas should be rehabilitated and their ecosystem support functions restored."*

[Page 7 and 8 of DLWC (1998)]

An assessment of the Project against the above principles is presented in **Section 6.4.1**.

2.4.2 NSW Aquifer Interference Policy

The NSW Aquifer Interference Policy (NSW Office of Water (now NSW Lands and Water), 2012), presents the requirements for assessment of aquifer interference activities administered under the *Water Management Act* 2000 (NSW).

The key components of the policy are:

- all water must be properly accounted for
- the activity must address minimal impact considerations with respect to water table, water pressure and water quality
- planning measures are to be presented to manage the circumstance that actual impacts are greater than predicted and, accordingly, that sufficient monitoring is in place to identify this circumstance.

Table 2.3 presents the Level 1 Minimal Harm Considerations for the Water Sources relevant to the Project. It is noted that NSW Lands and Water have designated the Sydney Basin Coxs River Groundwater Source as a Less Productive Porous Rock groundwater source and the Sydney Basin Richmond Groundwater Source as a Highly Productive Porous Rock groundwater source. The Level 1 Minimum Harm Considerations are, however, the same for Less Productive and Highly Productive Porous Rock groundwater sources.

An assessment of the impact of the modification against the NSW Aquifer Interference Policy is presented in **Section 6.4.2**.

Table 2.3 : Level 1 Minimal Harm Considerations (NSW Office of Water, 2012)

Water Source	Level 1 Minimal Harm Consideration
Sydney Basin Coxs River Groundwater Source	**Water table:** • less than 10 per cent cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 metres from any high priority groundwater dependent ecosystem or high priority culturally significant site listed in the Schedule of the relevant water sharing plan • a maximum of a 2 metres decline cumulatively at any water supply work **Water pressure:** • a cumulative pressure head decline of not more than a 2 metres decline, at any water supply work **Water quality:** • any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.
Sydney Basin Richmond Groundwater Source	As above

3. Hydrogeological Setting

This chapter presents a summary of the environmental and hydrogeological setting of the Project.

3.1 Environmental Setting

3.1.1 Climate

The climate at Angus Place Colliery is typical of a cool temperate mountain climate, characterised by cold winters and warm summers.

The highest temperatures occur throughout December, January and February, with the coolest temperatures occurring in July. Snow and/or sleet are common in winter months.

3.1.2 Topography

The topography around Angus Place Colliery comprises narrow gorges with high ridgelines, and steep sided slopes of sandstone cliffs. The cliffs rise above incised valleys, and hilly areas with relatively flat crests and some spurs with moderately sloped ephemeral drainage lines occur within the valleys. Rivers and streams in the vicinity of Angus Place Colliery include Kangaroo Creek, Lambs Creek and the Coxs River.

3.1.3 Hydrology

Angus Place Colliery encompasses two adjacent sub-catchments. The divide between the two catchments runs in a northwest-southeast direction.

To the southwest lies the Upper Nepean and Upstream Warragamba Water Source (Wywandy Management Zone). Locally, this comprises Lambs Creek, Kangaroo Creek and the Upper Coxs River.

To the northeast lies the Hawkesbury and Lower Nepean Rivers Water Source (Colo River Management Zone). Locally, this comprises of the Wolgan River.

Figure 1.1 presents the location of surface water features in the vicinity of Angus Place Colliery.

3.1.4 Historical Mining

There has been extensive mining in the vicinity of Angus Place Colliery for more than 100 years, with mining in the Western Coalfields commencing at Fernbrook / Hermitage Colliery in 1886.

There are several active mines in the region, the closest to Angus Place Colliery being the adjacent Centennial operation at Springvale Mine. There is no active mining currently at Angus Place Colliery, with Angus Place currently in Care and Maintenance following completion of Longwall 900W in February 2015.

The adjacent Springvale Mine, is currently mining Longwall 421.

3.1.5 Ecology

Temperate Highland Peat Swamps on Sandstone

Temperate Highland Peat Swamps on Sandstone

THPSS comprising Newnes Plateau Shrub Swamps (Mapping Unit MU 50, DEC (2006)) and Hanging Swamps (Mapping Unit MU51, DEC (2006)) listed under the *Environment Protection and Biodiversity Conservation Act* 1999 (Cth) as EECs reside on the Newnes Plateau above the previous workings at Angus Place Colliery, as well as above the mining area at the adjacent operation at Springvale Mine. The Newnes Plateau shrub swamps are also listed as an EEC under the *Biodiversity Conservation Act* 2016 (NSW).

3.1.6 Geology

Angus Place Colliery is located in the southwest corner of the NSW Western Coalfields.

The geological sequence at Angus Place Colliery is Palaeozoic (Carboniferous) through to Mesozoic (Triassic).

The Illawarra Coal Measures are of Late Permian age, and in the vicinity of Angus Place Colliery are relatively thin, with an average thickness of 110m from the Katoomba to the Lithgow Seam.

Underlying the Illawarra Coal Measures is the Shoalhaven Group (Early Permian) and below that is Carboniferous bedrock. Overlying the Illawarra Coal Measures is the Narrabeen Group (Triassic).

Within the geological sequence, from ground to seam, the following units are of hydrogeological significance:

- Burralow Formation
- Banks Wall Sandstone
- Mt York Claystone
- Burra-Moko Head Sandstone
- Caley Formation

These formations, except for the Mt York Claystone, comprise interbedded siltstone, sandstone and conglomeratic sandstone, with occasional claystone bands, as observed in the characteristic cliffs that occur throughout the area.

3.2 Hydrogeological Environment

3.2.1 Conceptual Model

RPS (2014) presents a description of the conceptual hydrogeological model at Angus Place Colliery. This has been refined in light of recent changes observed at the adjacent Springvale Mine, in regard to the potential role of geological lineaments and groundwater behaviour.

The key elements of the conceptual model are:

- stacked and segregated groundwater systems recharged by rainfall – locally in the case of shallow and perched systems and regionally in the case of the deeper systems
- deep regional flow essentially isolated from the shallow and perched groundwater systems
- perched water systems, supported on low permeability aquitard layers
- shrub swamps fed partially by groundwater originating from the perched groundwater systems and partially from surface water run-off
- the Mount York Claystone, and to a lesser extent, the Denman Formation, act as significant regional aquitards isolating (in part) the shallow and perched groundwater systems from the deep groundwater system
- the deep interbedded and interbanded aquitard (mudstones) and aquifer (sandstone and coal) units present beneath the Mount York Claystone strongly influence the deep regional groundwater flow pattern at depth
- groundwater flow is dominated by both porous media flow (dominantly horizontal) and to a much lesser extent, fracture flow associated with the joint, fracture and fault conduits
- variably enhanced groundwater flow through the lithological pile affected by subsidence induced permeability zones
- extensive aquifer interference in the deep regional groundwater system aquifers due to subsidence-induced goaf formation, collapse and fracturing affects. These observed aquifer changes are now understood to extend above the Mount York Claystone

- shallow formation sagging, induced by subsidence, gives rise to enhanced horizontal permeability in the shallow groundwater system (permeability enhancements decreasing closer to the ground surface)
- disconnected vertical permeability enhancements are inferred in the shallow surface zones
- reactivation of geological lineaments which occur coincident with the location of Newnes Plateau Shrub Swamps (orientation and strike) are now considered to play a more significant role in the hydrogeologic response to mining than previously understood.

Further detail of the hydrogeological system at Angus Place Colliery is presented in RPS (2014).

3.2.2 Groundwater Environment

There are three groundwater systems described in the conceptual model presented in **Section 3.2.1**.

Mining occurs in the deep groundwater system, within the Lithgow Coal Seam. Groundwater flow within that deep groundwater system is toward the north east, at a similar hydraulic gradient to the dip of the Lithgow Coal Seam, which is approximately 2 to 3 degrees. The groundwater flow direction within the deep groundwater system is locally disrupted because of the effect of depressurisation that is required ahead of mining.

Above the Mount York Claystone, which is a regionally significant clay aquitard, groundwater flow direction within the shallow groundwater system starts to reflect the influence of the topographic ridge, the catchment divide that bisects both Angus Place Colliery and Springvale Mine.

Within the Burralow Formation, groundwater flow is significantly influenced by local topographic and geological features. Vertical percolation of rainfall is retarded by the sequence of aquitard plies within the Burralow Formation. The retarded rainfall recharge is, in the majority, transmitted laterally, appearing as cascading seeps, coinciding with the location of the THPSS.

3.2.3 Neutral or Beneficial Effect to the Drinking Water Catchment

As identified in **Section 2.3.1**, surface water catchments within the Upper Nepean and Upstream Warragamba Water Source, of which Lambs Creek, Kangaroo Creek and the Coxs River are tributaries, are declared to be within the Sydney Drinking Water Catchment.

Accordingly, it is necessary to demonstrate that the Project will have a Neutral or Beneficial Effect on Water Quality with respect to the Lambs Creek, Kangaroo Creek and the Coxs River.

3.2.4 Groundwater Dependent Ecosystems

Temperate Highland Peat Swamps on Sandstone

As presented in **Section 3.1.5**, THPSS reside on the Newnes Plateau above the previous workings at Angus Place Colliery, as well as above the current workings at the adjacent operation at Springvale Mine.

Kangaroo Creek Swamp, West Wolgan Swamp and Narrow Swamp South and Narrow Swamp North lie above the District 900 area. There are three unnamed shrub swamps above or adjacent to District 800.

3.2.5 Licensed Water Users

Surface Water Users

The NSW Water Register (http://www.water.nsw.gov.au/water-licensing/registers) was reviewed to obtain details of licensed water use (holders of a Water Access Licence (WAL)) in both the Upper Nepean and Upstream Warragamba Water Source (refer **Table 3.1**) and Hawkesbury and Lower Nepean Rivers Water Source (refer **Table 3.2**) in the water year, 2016/17.

It is noted that data presented in **Table 3.1** and **Table 3.2** is with respect to the whole water source.

Table 3.1: WALs – Upper Nepean and Upstream Warragamba Water Source (2016/17)

Access Licence Category	No. of WAL's	Total Share Component	Share Component Unit	Cumulative AWD	Cumulative AWD Unit	Water made Available (ML)	Usage YTD (ML)
DOMESTIC AND STOCK	19	110.5	% of Share Component	1	100	110.5	1.1
DOMESTIC AND STOCK [DOMESTIC]	16	21.3	% of Share Component	1	100	21.3	1
DOMESTIC AND STOCK [STOCK]	14	65	% of Share Component	1	100	65	0
DOMESTIC AND STOCK [TOWN WATER SUPPLY]	4	1839	% of Share Component	1	100	1839	146.4
LOCAL WATER UTILITY	2	6000	% of Share Component	1	100	6000	2905.1
MAJOR UTILITY [POWER GENERATION]	1	25000	ML per share	1	1	25000	8147
MAJOR UTILITY [URBAN WATER]	1	620000	ML per share	1	1	620000	530885
UNREGULATED RIVER	350	15663	ML per share	1	1	15663	380.3
UNREGULATED RIVER (A CLASS)	1	0	ML per share	1	1	0	0

Table 3.2: WALs – Hawkesbury and Lower Nepean Rivers Water Source (2016/17)

Access Licence Category	No. of WAL's	Total Share Component	Share Component Unit	Cumulative AWD	Cumulative AWD Unit	Water made Available (ML)	Usage YTD (ML)
DOMESTIC AND STOCK	75	746	% of Share Component	1	100	746	69.4
DOMESTIC AND STOCK [DOMESTIC]	56	88.7	% of Share Component	1	100	88.7	0
DOMESTIC AND STOCK [STOCK]	37	287.5	% of Share Component	1	100	287.5	12
LOCAL WATER UTILITY	1	1293	% of Share Component	1	100	1293	0
MAJOR UTILITY [URBAN WATER]	2	26075	ML per share	1	1	26075	10481
UNREGULATED RIVER	1337	92803.2	ML per share	1	1	92222.8	8290.3

From **Table 3.1**, there are 351 unregulated river WALs in the Upper Nepean and Upstream Warragamba Water Source in the 2016/2017 water year.

From **Table 3.2**, there were 1337 unregulated river WALs in the Hawkesbury and Lower Nepean Rivers Water Source in the 2016/2017 water year.

Details of individual WALs (surface water) for the Hawkesbury and Lower Nepean Rivers Water Source were not readily available, due to the very large number of WALs in the water source.

Groundwater Users

Table 3.3 presents the details of licensed water use in the Sydney Basin Coxs River Groundwater Source in the 2016/17 water year and **Table 3.4** presents the equivalent data from the Sydney Basin Richmond Groundwater Source.

It is noted that data presented in **Table 3.3** and **Table 3.4** is with respect to the whole water source. Details of WALs held by Centennial Angus Place are presented in **Table 2.1**.

Table 3.3: WALs – Sydney Basin Coxs River Groundwater Source (2016/17)

Access Licence Category	No. of WAL's	Total Share Component	Share Component Unit	Cumulative AWD	Cumulative AWD Unit	Water made Available (ML)	Usage YTD (ML)
AQUIFER	17	7421.5	ML per share	1	1	7421.5	0

Table 3.4: WALs – Sydney Basin Richmond Groundwater Source (2016/17)

Access Licence Category	No. of WAL's	Total Share Component	Share Component Unit	Cumulative AWD	Cumulative AWD Unit	Water made Available (ML)	Usage YTD (ML)
AQUIFER	84	16605.5	ML per share	1	1	16605.5	11312
DOMESTIC AND STOCK [TOWN WATER SUPPLY]	2	29	% of Share Component	1	100	29	0

A review of the NSW PINNEENA database indicates there are no non-mining groundwater works between District 800 and the Wolgan Valley.

3.2.6 Surface Water/Groundwater Interaction

Upper Nepean and Upstream Warragamba Water Source (Wywandy Management Zone)

Lambs Creek and Kangaroo Creek are presented in **Figure 3.1**, together with topographic contours (mAHD) and the elevation of the floor of the Lithgow Seam (mAHD). The Lithgow Seam is the coal seam that is being mined at Angus Place Colliery.

<u>Lambs Creek</u>

Lambs Creek flows from east to west.

From **Figure 3.1**, the elevation of the thalweg, which is the minimum channel elevation, along Lambs Creek ranges between 915mAHD, at the confluence of Lambs Creek and the Coxs River, to 1130mAHD, at the headwater of Lambs Creek. In comparison, the elevation of the floor of the Lithgow Seam, at equivalent locations, ranges between 840mAHD and 804mAHD. As such, Lambs Creek is 75m to 326m above the floor of the Lithgow Seam.

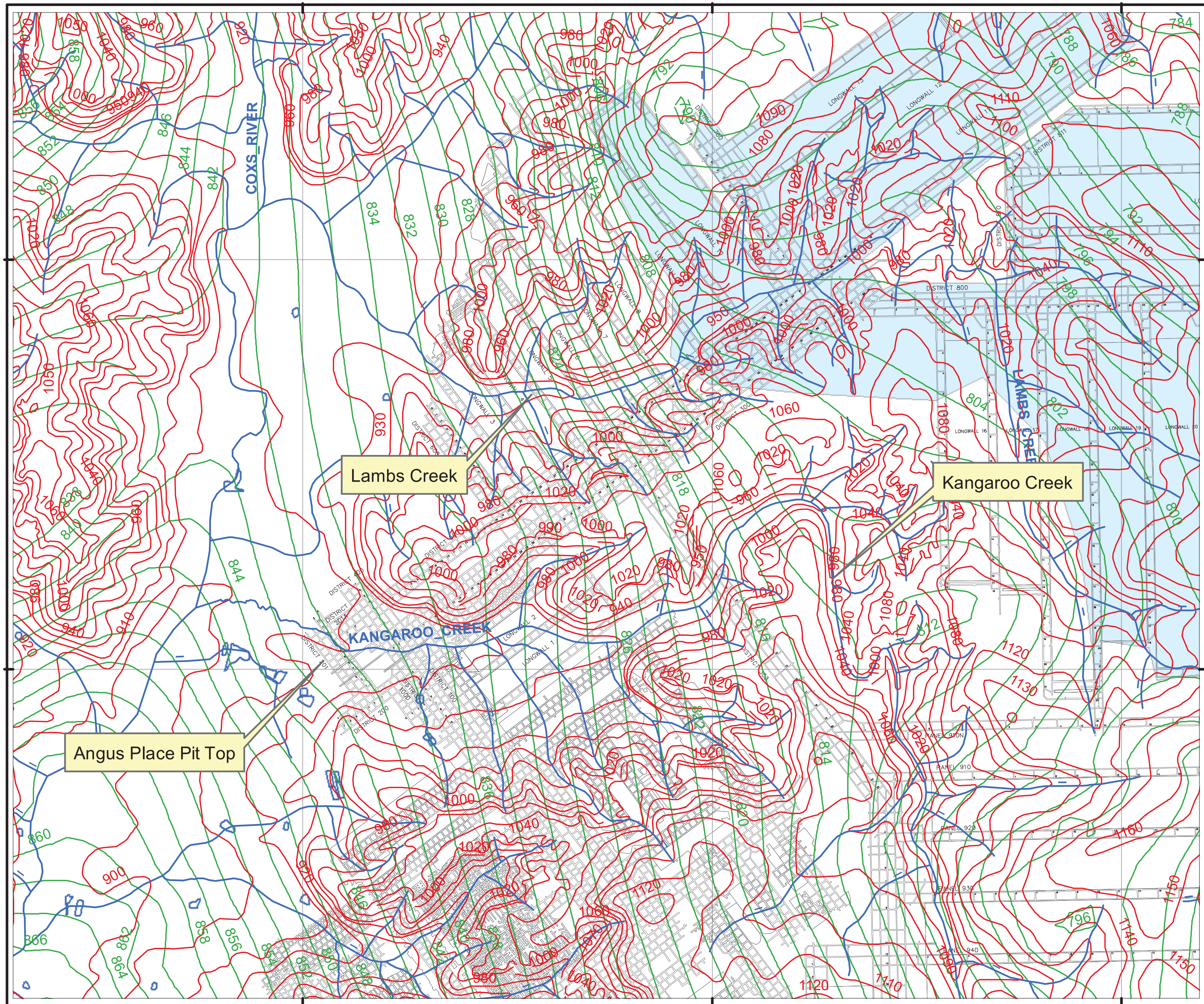
Accordingly, there is no direct connection between Lambs Creek and the Lithgow Seam, because Lambs Creek lies significantly above the Lithgow Seam. It is unlikely that seepage from the mine water stored in 800 District to Lambs Creek will occur.

<u>Kangaroo Creek</u>

Kangaroo Creek flows from east to west.

From **Figure 3.1**, the elevation of the thalweg of Kangaroo Creek ranges between 898mAHD, at the confluence of Kangaroo Creek and the Coxs River, to more than 1100mAHD, at the headwater of Kangaroo Creek. In comparison, the elevation of the floor of the Lithgow Seam, at equivalent locations, ranges between 846mAHD and 804mAHD. As such, Kangaroo Creek is 52 to 296m above the floor of the Lithgow Seam.

Accordingly, there is no direct connection between Kangaroo Creek and the Lithgow Seam, because Kangaroo Creek lies significantly above the Lithgow Seam. It is unlikely that seepage from the mine water stored in 800 District to Kangaroo Creek will occur.



Legend:
- Ground Surface (mAHD)
- Lithgow Seam Floor (mAHD)
- Angus Place Workings
- District 800 - Stored Mine Water

Job No: 54568	
Client: Centennial Angus Place Pty Ltd	
Version: R02RevB	Date: 07-Mar-2018
Drawn By: JRB	Checked By: JRB
Scale 1:25,000	

0 400 800
metres

Coor. Sys. GDA 1994 MGA Zone 56

Angus Place Colliery
LIDSDALE NSW

GROUNDWATER AND SURFACE WATER INTERACTION LAMBS AND KANGAROO CREEK

FIGURE: 3-1

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\54568_WaterAssessmentMOD5\Figures\GIS\Delivery\R02RevB_D001_GroundwaterSurfaceWaterInteraction.mxd
Reference: Hydrology Layer from NSW LPI Web Services, 2018

Hawkesbury and Lower Nepean Rivers Water Source (Colo River Management Zone)

The Wolgan River is presented in **Figure 3.2**, together with topographic contours (mAHD) and the elevation of the floor of the Lithgow Seam (mAHD).

The Wolgan River occurs both on the Newnes Plateau and within the Wolgan Valley.

The Wolgan River flows from southeast to the northwest, to the clifftop of the Wolgan Valley. The Wolgan River cascades down the cliff face of the Wolgan Valley and then continues to flow northwest within the Wolgan Valley.

<u>Wolgan River (on the Newnes Plateau)</u>

From **Figure 3.2**, for the Wolgan River on the Newnes Plateau, its thalweg ranges between 920mAHD at the clifftop of the valley, to more than 1040mAHD at its headwaters on the Newnes Plateau. In comparison, the elevation of the floor of the Lithgow Seam, at equivalent locations, ranges between 768mAHD and 770mAHD. As such, the Wolgan River (on the Newnes Plateau) is 152 to 270m above the floor of the Lithgow Seam.

Accordingly, there is no direct connection between the Wolgan River (on the Newnes Plateau) and the Lithgow Seam, because the Wolgan River (on the Newnes Plateau) lies significantly above the Lithgow Seam.

<u>Wolgan River (within the Wolgan Valley)</u>

For the Wolgan River within the Wolgan Valley, the thalweg of the river ranges from 680mAHD in **Figure 3.2** to 780mAHD. As indicated in **Figure 3.2**, the Lithgow Seam outcrops along the southern cliffside of the Wolgan Valley at between 806mAHD and 782mAHD. As such, the Wolgan River (within the Wolgan Valley) is 126 to 2m below the floor of the Lithgow Seam.

Accordingly, there can be connection (via seepage face) between the Wolgan River (within the Wolgan Valley) and the Lithgow Seam, because the Wolgan River (within the Wolgan Valley) lies below the Lithgow Seam.

3.3 Hydrogeological Investigation

3.3.1 Groundwater Monitoring Network

There is an extensive network of groundwater level and quality monitoring piezometers installed at Angus Place Colliery.

Groundwater extracted from the 900 Panel Area via the Bore 940 facility is subject to regular water quality testing and routine testing is also undertaken on mine water discharge to Kangaroo Creek.

Mine water discharge to Kangaroo Creek is administered under Angus Place LDP001.

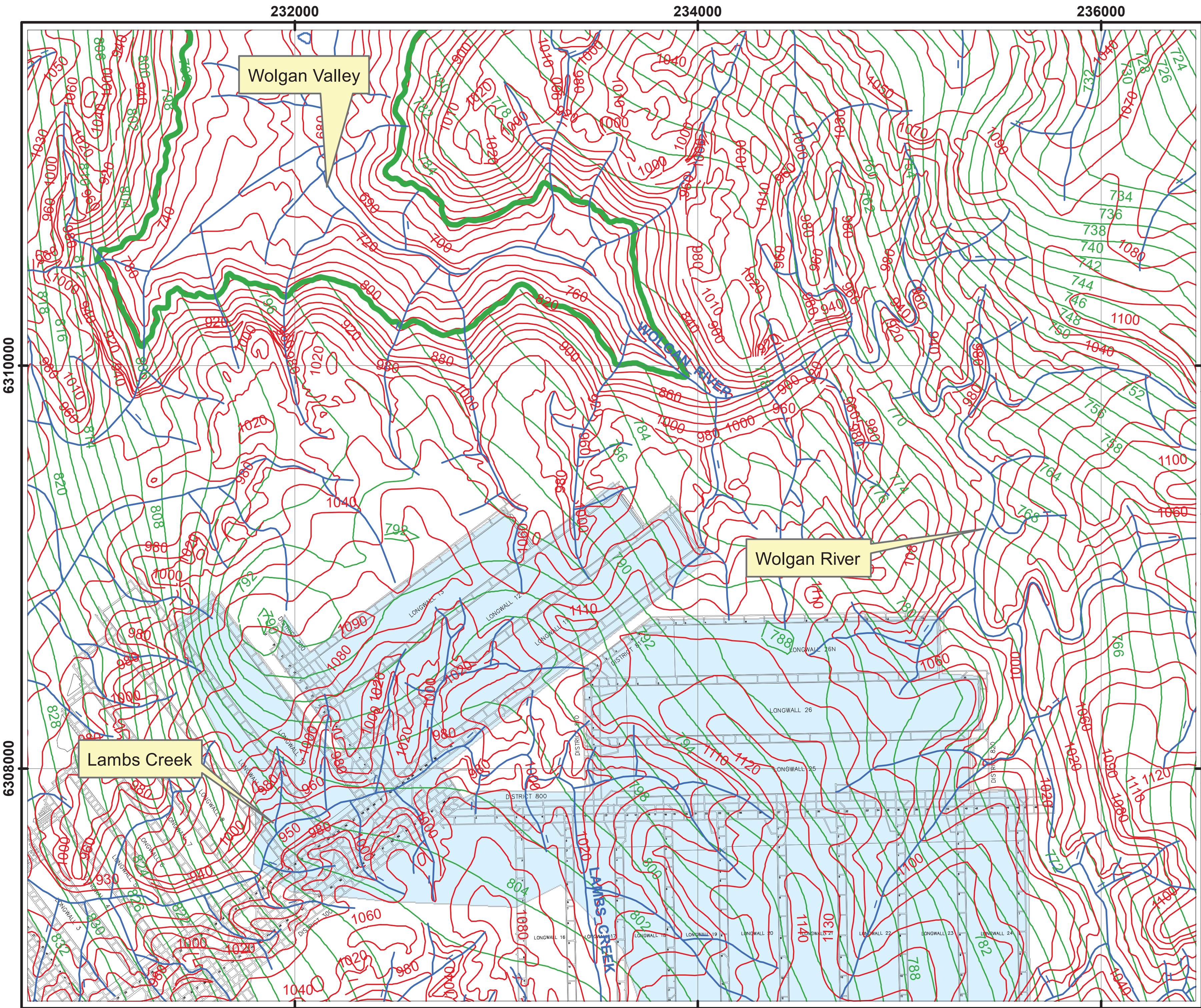
Further details of groundwater monitoring at Angus Place Colliery is presented in RPS (2014).

3.3.2 Groundwater Levels

Figure 3.3 presents the predicted groundwater elevation in the Lithgow Seam (Layer AQ1 of CSIRO (2013) in 2015).

The contours presented in **Figure 3.3** were obtained from the current version of the numerical groundwater model at Angus Place Colliery, which was developed by the CSIRO (CSIRO, 2013, 2016). That numerical groundwater model is in the process of being updated as part of on-going work on the potential role of geological lineaments on groundwater behaviour at Springvale Mine.

From **Figure 3.3**, the modelled groundwater elevation between Longwall 11 to Longwall 13 in District 800 and the Wolgan Valley is approximately 830mAHD, compared to between 790 and 800mAHD in Longwall 11 to Longwall 13, and less than 800mAHD in the Wolgan Valley.



Legend:

- Lithgow Seam Extent
- Ground Surface (mAHD)
- Lithgow Seam Floor (mAHD)
- Angus Place Workings
- District 800 - Stored Mine Water

Job No: 54568	
Client: Centennial Angus Place Pty Ltd	
Version: R02RevB	Date: 07-Mar-2018
Drawn By: JRB	Checked By: JRB
Scale 1:25,000	

0 400 800
metres

Coor. Sys. GDA 1994 MGA Zone 56

Angus Place Colliery
LIDSDALE NSW

GROUNDWATER AND SURFACE WATER INTERACTION WOLGAN RIVER

FIGURE: 3-2

File Name: N:\Projects\CentennialCoal\AngusPlaceColliery\54568_WaterAssessmentMOD5\Figures\GIS\Delivery\R02RevB_D002_GroundwaterSurfaceWaterInteraction.mxd
Reference: Hydrology Layer from NSW LPI Web Services, 2018

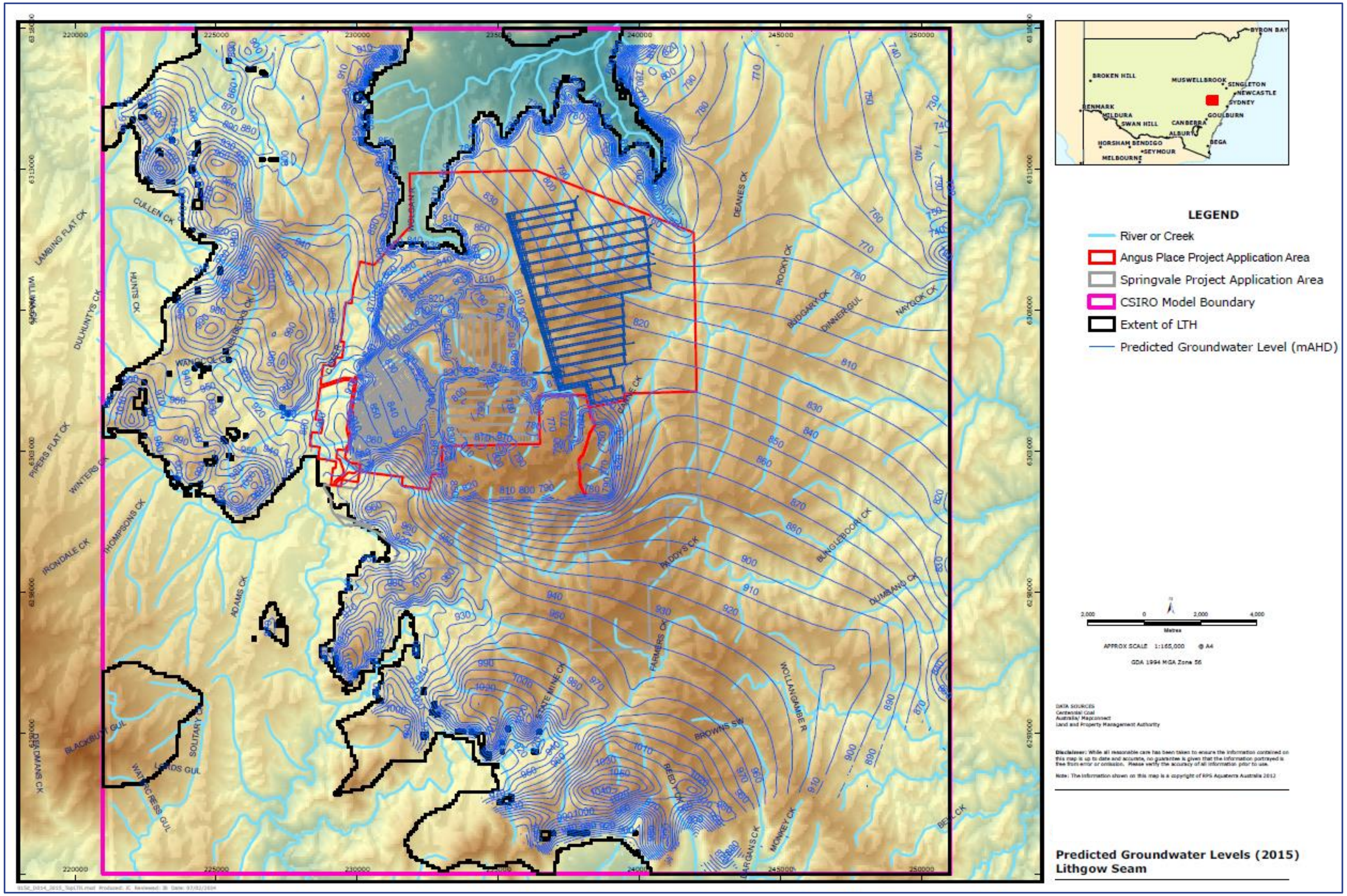


Figure 3.3: Predicted Groundwater Levels (2015) – Lithgow Seam

Modelled groundwater elevations imply there may be a hydrogeologic divide between District 700/800 and the Wolgan Valley. If a hydrogeologic divide exists, then the groundwater flow direction is toward District 800 (with a current groundwater elevation of 805mAHD, maintained by pumping), rather than toward the Wolgan Valley.

Figure 3.4 presents the current underground storage levels in District 800 and District 900. It is noted that District 700 and District 800 are hydraulically connected above 802mAHD. Given that District 700/800 are going to be maintained 'full' at 805mAHD, for the purpose of this report, District 700 is included in the definition of District 800.

From **Figure 3.4**, the current groundwater elevation in District 800 is 805mAHD and the current groundwater elevation in District 900 is 800mAHD. It is highlighted, as noted in **Figure 3.4**, that District 800 is 'full' and that District 900 is almost 'full'.

3.3.3 Groundwater Quality

Groundwater is currently being extracted from Angus Place Colliery to maintain the current stored level of 805mAHD in District 700/800 and 800mAHD in District 900.

Table 3.5 presents the concentrations of various analytes obtained from Bore 940 in December 2017, as well as the concentration of analytes at Angus Place LDP001, which is the licensed discharge point (currently volumetrically limited to 2ML/d). Median water quality in the period 2013-2017 is presented in **Table 3.6**. Data presented in **Table 3.6** was extracted from the draft Water Management Plan for Angus Place Colliery (GHD, 2018).

Bore 940

Physiochemical Parameters

pH of mine water discharge from Bore 940 is 7.7 in December 2017 and is 7.6 in median (2013-2017) and therefore is neutral pH.

Electrical Conductivity (EC) is 1,143µS/cm in December 2017 and is 1,246µS/cm in median (2013-2017).

Total Suspended Solids (TSS) is negligible, being <5mg/L, in both the December 2017 sample and in median (2013-2017).

Dissolved Oxygen (DO) is moderate to high at 5.6mg/L in December 2017 and is 6.5mg/L in median (2013-2017).

Major Ions

Sodium (Na) is 247mg/L in December 2017 and is 267mg/L in median (2013-2017).

Bicarbonate alkalinity (HCO_3) is 644mg/L in December 2017 and is 609mg/L in median (2013-2017).

Other major ions, such as Calcium (Ca), Magnesium (Mg), Chloride (Cl) and Sulphate (SO_4), are small compared to Na and HCO_3 both in the December 2017 sample and in median (2013-2107).

Trace Ions

Aluminium (Al) is <0.01mg/L in December 2017 and in median (2013-2017).

Arsenic (As) is 0.067mg/L in December 2017 and is <0.0001mg/L in median (2013-2017). It is noted that **Table 3.6** data is obtained from the range 16 January 2013 to 9 May 2017. The default guideline value for As is 0.024mg/L as As(III).

Boron (B) is 0.07mg/L in the sample from December 2017 and is 0.06mg/L in median (2013-2017).

Copper (Cu) is <0.001mg/L, being the detection limit, and is <0.001mg/L in median (2013-2017).

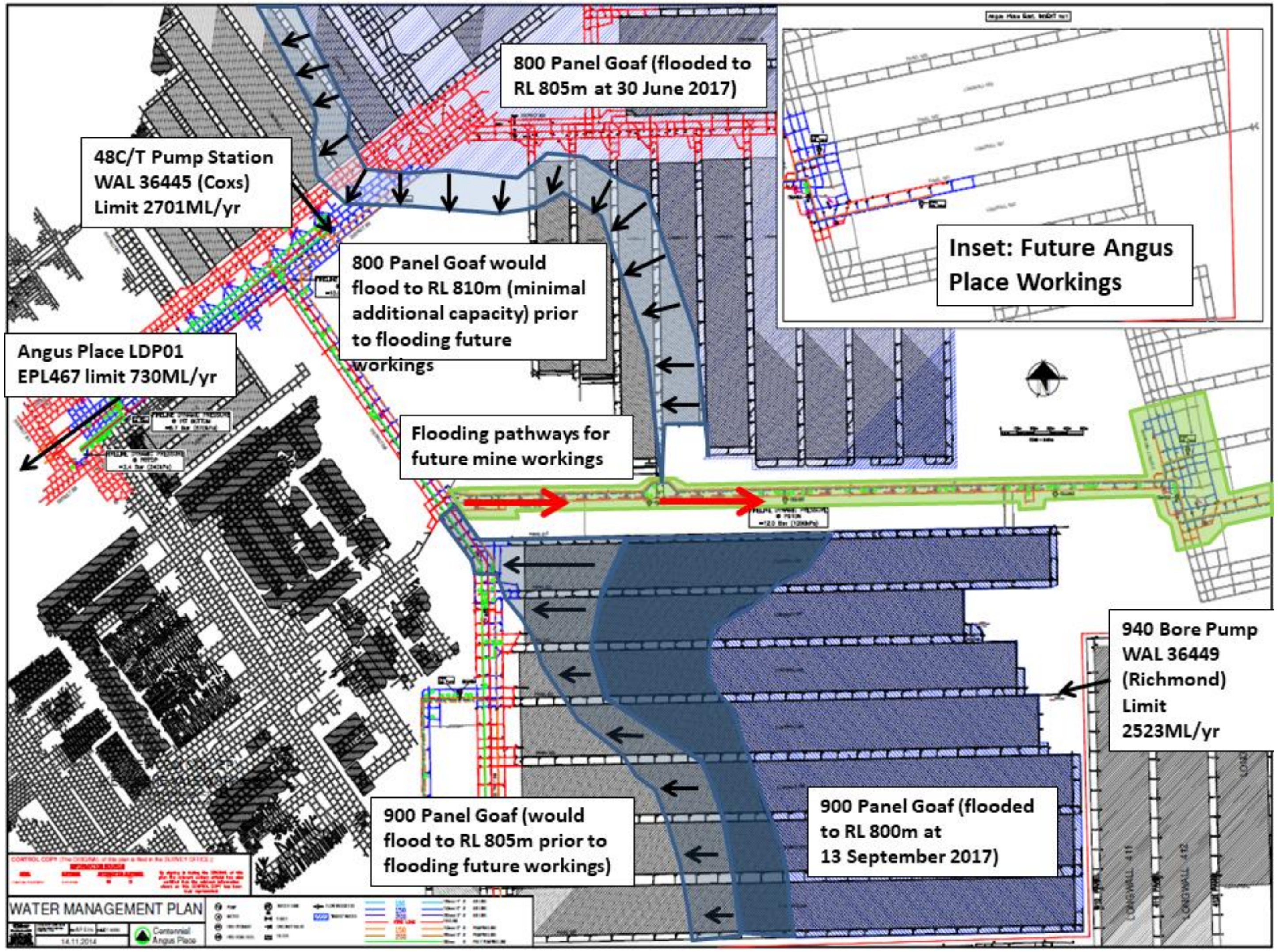


Figure 3.4: Current Underground Storage Levels (mAHD) – Angus Place Colliery (District 800 and District 900)

Table 3.5: Groundwater Quality – Bore 940 and Angus Place LDP001 (December 2017)

Parameter	Units	95th% Prot. (ANZECC, 2000)	EPL 467 LDP 001, 002[3]	ADWG Health (NHRMC, 2016)	ADWG Aesthetic (NHRMC, 2016)	Angus Place LDP001	Bore 940
Date of Sample						4/12/2017 9:40	7/12/2017 9:30
Physical Parameters							
pH		6.5 – 8.0	6.5 – 9.0	c	6.5 – 8.5	7.9	7.7
EC[1]	µS/cm	350	-	-		1033	1143
TDS[1]	mg/L	234.5	-	f	Based on taste: < 600 good quality 600 – 900 fair quality	686	700
Hardness as $CaCO_3$	mg/L	-	-	f	< 60 soft but possibly corrosive 60 – 200 good quality 200 – 500 increasing scaling problems >500 severe scaling	129	45
TSS	mg/L	-	30	-	-	<5	<5
Turbidity	NTU	2 – 25	-	c	5	0.8	1.4
Oil and Grease	mg/L	-	10	-	-	<5	<5
Dissolved Oxygen	mg/L					7.5	5.6
Major Ions							
Na	mg/L	-	-	f	180	173	247
Ca	mg/L	-	-	-	-	22	8
Mg	mg/L	-	-	-	-	18	6
K	mg/L	-	-	-	-	34	18
Alkalinity[4]	mg/L	-	-	-	-	622	644
Cl	mg/L	-	-	c	250	5	8
SO_4	mg/L	-	-	500	250	12	11
Trace Ions							
Al	mg/L	0.055 for pH>6.5	-	c	0.2	<0.01	<0.01
As	mg/L	0.024 as As III	-	0.01	-	<0.001	0.067
B	mg/L	0.37	-	4	-	<0.05	0.07
Ba	mg/L	-	-	2	-	0.229	0.069
Cd	mg/L	0.0002	-	0.002	-	<0.0001	<0.0001
Cr	mg/L	0.001 as Cr VI	-	0.05 as Cr VI	-	<0.001	<0.001
Cu	mg/L	0.0014	-	2	1	<0.001	<0.001
F	mg/L	-	-	1.5	-	0.9	Not Tested
Fe	mg/L	ID	-	c	0.3	<0.05	0.23
Li	mg/L	-		-	-	0.33	0.202

Parameter	Units	95th% Prot. (ANZECC, 2000)	EPL 467 LDP 001, 002[3]	ADWG Health (NHRMC, 2016)	ADWG Aesthetic (NHRMC, 2016)	Angus Place LDP001	Bore 940
Mn	mg/L	1.9	-	0.5	0.1	0.012	0.015
Ni	mg/L	0.011	-	0.02	-	0.002	0.005
Pb	mg/L	0.034	-	0.01	-	<0.001	<0.001
Se	mg/L	0.011 as Total Se	-	0.01	-	Not Tested	Not Tested
Si	mg/L	-	-	-	37.4[5]	4.45	4.15
Sr	mgL	-	-	-	-	0.117	0.048
Zn	mg/L	0.008	-	c	3	<0.005	<0.005
Nutrients							
NH_3 as N	mg/L	0.013	-	c	0.4	<0.01	1.48
NO_3 as N	mg/L	0.015[2]	-	11.3	-	<0.01	0.02
Total N as N	mg/L	0.25	-	-	-	0.2	1.5
Total P as P	mg/L	0.02	-	-	-	<0.01	0.02

Notes: 1. The assumed conversation factor is EC (µS/cm) x 0.67 = TDS (mg/L) from Section 4.3.3 of ANZECC (2000). If laboratory determination of TDS has occurred, results are provided; 2. NOx (oxides of N); 3. 100th% limit; 4. Bicarbonate alkalinity; 5: Limit is 80mg/L as Silica; ID. Insufficient data to derive a reliable trigger value; c. Insufficient data to set guideline value based on health considerations; f. No health-based value considered necessary.

Table 3.6: Groundwater Quality – Bore 940 and Angus Place LDP001 Median Results (2013 to 2017)

Parameter	Units	95th% Prot. (ANZECC, 2000)	EPL 467 LDP 001, 002[3]	ADWG Health (NHRMC, 2016)	ADWG Aesthetic (NHRMC, 2016)	Angus Place LDP001	Bore 940
Date of Sample						16/1/2013 to 9/5/2017	16/1/2013 to 9/5/2017
Physical Parameters							
pH		6.5 – 8.0	6.5 – 9.0	c	6.5 – 8.5	8.1 (n=66)	7.6 (n=211)
EC[1]	µS/cm	350	-	-		1,040 (n=66	1246 (n=208)
TDS[1]	mg/L	234.5	-	f	Based on taste: < 600 good quality 600 – 900 fair quality	642 (n=60)	745 (n=60)
Hardness as $CaCO_3$	mg/L	-	-	f	< 60 soft but possibly corrosive 60 – 200 good quality 200 – 500 increasing scaling problems >500 severe scaling	129 (n=59)	44 (n=58)
TSS	mg/L	-	30	-	-	<5[5] (n=65)	<5[5] (n=206)
Turbidity	NTU	2 – 25	-	c	5	2 (n=65)	2 (n=207)
Oil and Grease	mg/L	-	10	-	-	<5[5] (n=66)	<5[5] (n=203)
Dissolved Oxygen	mg/L					8.75 (n=56)	6.50 (n=60)
Major Ions							
Na	mg/L	-	-	f	180	180 (n=59)	267 (n=58)
Ca	mg/L	-	-	-	-	22 (n=59)	6 (n=58)
Mg	mg/L	-	-	-	-	18 (n=59)	7 (n=58)
K	mg/L	-	-	-	-	34 (n=59)	20 (n=58)
Alkalinity[4]	mg/L	-	-	-	-	518 (n=59)	609 (n=59)
Cl	mg/L	-	-	c	250	7 (n=59)	6 (n=58)
SO_4	mg/L	-	-	500	250	21 (n=59)	44 (n=58)
Trace Ions							
Al	mg/L	0.055 for pH>6.5	-	c	0.2	<0.01[5] (n=59)	<0.01[5] (n=203)
As	mg/L	0.024 as As III	-	0.01	-	<0.001[5] (n=61)	<0.001[5] (n=203)
B	mg/L	0.37	-	4	-	0.07 (n=59)	0.06 (n=203)
Ba	mg/L	-	-	2	-	0.181 (n=59)	0.065 (n=59)
Cd	mg/L	0.0002	-	0.002	-	<0.0001[5] (n=59)	<0.0001[5] (n=59)
Cr	mg/L	0.001 as Cr VI	-	0.05 as Cr VI	-	n/a	n/a
Cu	mg/L	0.0014	-	2	1	<0.001[5] (n=59)	<0.001[5] (n=203)
F	mg/L	-	-	1.5	-	1.0 (n=59)	1.2 (n=196)
Fe	mg/L	ID	-	c	0.3	<0.05[5] (n=61)	0.20 (n=203)
Li	mg/L	-		-	-	0.265 (n=59)	0.176 (n=58)

Parameter	Units	95th% Prot. (ANZECC, 2000)	EPL 467 LDP 001, 002[3]	ADWG Health (NHRMC, 2016)	ADWG Aesthetic (NHRMC, 2016)	Angus Place LDP001	Bore 940
Mn	mg/L	1.9	-	0.5	0.1	0.005 (n=61)	0.013 (n=203)
Ni	mg/L	0.011	-	0.02	-	0.002 (n=59)	0.007 (n=202)
Pb	mg/L	0.034	-	0.01	-	<0.001[5] (n=59)	<0.001[5] (n=59)
Se	mg/L	0.011 as Total Se	-	0.01	-	n/a	n/a
Si	mg/L	-	-	-	37.4[6]	n/a	4.38 (n=58)
Sr	mgL	-	-	-	-	0.119 (n=59)	0.043 (n=59)
Zn	mg/L	0.008	-	c	3	0.009 (n=59)	0.008 (n=202)
Nutrients							
NH_3 as N	mg/L	0.013	-	c	0.4	<0.01[5] (n=58)	1.31 (n=59)
NO_3 as N	mg/L	0.015[2]	-	11.3	-	0.40 (n=59)	0.01 (n=58)
Total N as N	mg/L	0.25	-	-	-	0.5 (n=59)	1.4 (n=59)
Total P as P	mg/L	0.02	-	-	-	<0.01[5] (n=59)	0.03 (n=59)

Notes: 1. The assumed conversation factor is EC (µS/cm) x 0.67 = TDS (mg/L) from Section 4.3.3 of ANZECC (2000). If laboratory determination of TDS has occurred, results are provided; 2. NOx (oxides of N); 3. 100th% limit; 4. Bicarbonate alkalinity; 5. GHD (2018) note that where a parameter was less than the detection limit (Level of Reporting, LOR), the detection limit was adopted when calculating the statistical summary. A "less than sign" has been added to highlight this assumption; 6: Limit is 80mg/L as Silica; ID. Insufficient data to derive a reliable trigger value; c. Insufficient data to set guideline value based on health considerations; f. No health-based value considered necessary.

Fluoride (F) was not tested in the December 2017 sample, however, is 1.2mg/L in median (2013-2017).

Iron (Fe) is 0.23mg/L in December 2017 and is 0.20mg/L in median (2013-2017).

Manganese (Mn) is 0.015mg/L in the December 2017 sample and is 0.013mg/L in median (2013-2017).

Nickel (Ni) is 0.015mg/L in Bore 940 in December 2017 and is 0.007mg/L in median (2013-2017).

Zinc (Zn) is <0.0005mg/L in December 2017 and is 0.008mg/L in median (2013-2017).

The concentration of dissolved metals is below the default guideline value for the 95^{th}% protection level of slightly to moderately disturbed aquatic ecosystems, with the exception of As.

Nutrients

Ammonia (NH_3 as N) is 1.48mg/L in the December 2017 sample and is 1.31mg/L in median (2013-2017). These concentrations are in excess of the default guideline value of 0.013mg/L.

Nitrate (NO_3 as N) is 0.02mg/L in December 2017 and is 0.01mg/L in median (2013-2017). As noted in **Table 3.6**, in the calculation of medians, where the concentration was below the detection limit, the value of the detection limit was used. Further detail of this calculation is presented in GHD (2018).

Total Phosphorous (TP) is 0.02mg/L in December 2017 and is 0.03mg/L in median (2013-2017).

Discussion

In summary, groundwater from Bore 940 is fresh (being sufficiently dilute to be potable, less than 1,000mg/L TDS), near neutral pH and is a Na-HCO3 type water.

Angus Place LDP001

Physiochemical Parameters

pH of mine water discharge from Angus Place LDP001 is 7.9 in December 2017 and is 8.1 in median (2013-2017) and therefore is neutral pH, as between the range 6.5 and 9.0.

EC is 1,033µS/cm in the December 2017 sample and is 1,040µS/cm in median (2013-2017). The EC of mine water discharge exceeds the default guideline value of the 95^{th}% protection level for slightly to moderately disturbed aquatic ecosystems, which is 350µS/cm.

TSS is negligible, being <5mg/L, which is the detection limit.

DO is high at 7.5mg/L, being fully oxygenated in the December 2017 sample and is also high, at 8.75mg/L in median (2013-2017).

Major Ions

Na is 173mg/L in the December 2017 sample and is 180mg/L in median (2013-2017).

HCO_3 is 622mg/L in December 2017 and is 518mg/L in median (2013-2017).

The concentration of other major ions are low in comparison to Na and HCO_3.

The water type is Na-HCO_3, which is the same as Bore 940.

Trace Ions

Al is not detected in the December 2017 sample or in median (2013-2017).

As is <0.001mg/L, which is the detection limit, in December 2017 and is also not detected in the median (2013-2017).

B is <0.05mg/L in December 2017 and is 0.07mg/L in median (2013-2017).

Cu is not detected in the December 2017 sample and is also not detected in median (2013-2017).

F is 0.9mg/L in December 2017 and is 1.0mg/L in median (2013-2017).

Fe is <0.05mg/L in December 2017, which is the detection limit, and is also not detected in median (2013-2017).

Mn is 0.012mg/L in December 2017 and is 0.005mg/L in median (2013-2017).

Ni is 0.002mg/L in the December 2017 sample and is 0.002mgL in median (2013-2017).

Zn is <0.005mg/L in December 2017 and is 0.009mg/L in median (2013-2017).

In summary, the concentration of dissolved metals is less than the default guideline value for the 95^{th}% protection level of slightly to moderately disturbed aquatic ecosystems.

<u>Nutrients</u>

NH_3 as N is <0.01mg/L in December 2017, which is the detection limit, and is <0.01mg/L in median (2013-2017).

NO_3 as N is <0.01mg/L in December 2017 and is 0.40mg/L in median (2013-2017). The default guideline value for NO_3 as N is 0.015mg/L.

TP is less than the detection limit, <0.01mg/L, in December 2017 and is also less than the detection limit in median (2013-2017).

<u>Discussion</u>

Mine water discharge is fresh, being sufficiently dilute to be potable. Bore 940 and Angus Place LDP001 meet the health-based criteria of the Australian Drinking Water Guideline (NHMRC, 2016). Salinity, as TDS, is an aesthetic-based criteria in the Australian Drinking Water Guideline. Mine water discharge has neutral pH and is a Na-HCO_3 type water. The concentration of trace ions is less than the default guideline value for the 95^{th}% protection level of slightly to moderately disturbed aquatic ecosystems.

4. Hydrogeological Analysis

This chapter presents an analysis of proposed changes due to the Project to site water management, changes to groundwater quality, changes to surface water/groundwater interaction as well as extraction of stored mine water (post treatment phase).

4.1 Angus Place Water Treatment Project

The Project seeks to:

- Construct a Temporary Water Treatment Plant at Angus Place Colliery by 30 June 2018
- Continue discharge of 'raw' mine water at up to 2ML/d, through Angus Place LDP001, into Kangaroo Creek, until 30 June 2018. Discharge of 'raw' mine water at 2ML/d is currently permitted
- Operate the Temporary Water Treatment Plant from 1 July 2018 until 31 December 2019
- From 1 July 2018 to 31 December 2019, discharge mine water (treated to 350µS/cm and at a rate of up to 10ML/d), through Angus Place LDP001, into Kangaroo Creek
- From 1 July 2018 to 31 December 2019, continue to discharge 'raw' mine water, at up to 6.9ML/d, which is the limit based on the current interpretation of the relevant Water Access Licence however may be revised in the future, to the SDWTS through the Bore 940 facility, if required
- From 1 July 2018, temporarily transfer residuals generated from the Project underground within the 800 Panel Area until 31 December 2019
- From 1 January 2020, or earlier, as relevant, up to 13.4ML/d of mine water from the underground workings (800 and 900 Panel Areas) at Angus Place Colliery will be, transferred to the Springvale Water Treatment Project for treatment and beneficial re-use within the Mt Piper Power Station cooling water system. This may occur via transfers to the SDWTS using the 940 Bore or through a new pipeline to be installed from the Angus Place pit top to the raw water pipeline in the Springvale Water Treatment Project and which will run along the existing Wallerawang Haul Road.
- From 1 January 2020, or earlier, as relevant, cease to discharge mine water (raw or treated) to Kangaroo Creek through Angus Place LDP001.

In the event that the Project is not approved:

- Continue discharge of 'raw' mine water at up to 2ML/d, through Angus Place LDP001, into Kangaroo Creek, until 18 August 2024, coincident with the expiration of the current Angus Place Colliery's Project Approval.
- If the proposed Angus Place Mine Extension Project does not proceed, continue to discharge 'raw' mine water at up to 2ML/d, through Angus Place LDP001, until 18 August 2029, reflecting 5 years for completion of mine rehabilitation.

The increase in mine water discharge through Angus Place LDP001, to up to 10ML/d (treated to 350µS/cm), will be undertaken as a Section 75W modification, Modification 5, and is not assessed in this assessment report.

4.2 Water and Salt Balance Modelling of Stored Mine Water

4.2.1 Proposed Change

The proposed change to site water management and groundwater quality (salinity) with the Project consists of:

- transfer of residuals into stored mine water within the 800 Panel Area
- extraction of stored mine water within the 800 Panel Area (post treatment phase)

4.2.2 Results of Analysis

4.2.2.1 Model Approach

Model Description

A new water balance was developed for this assessment.

This new model is referred to as the Springvale-Angus Place Residual Management Model (SAPRMM) and was prepared using GoldSIM, Version 12.0.379 (10 February 2017).

A new model was needed, which included Angus Place Colliery, the adjacent Springvale Mine and the Springvale Water Treatment Project, in order to address the model objectives provided below.

Whilst the Regional Water Quality Impact Assessment Model (RWQIAM) is presented in the Surface Water Assessment for the Project (JBS&G, 2018 of the S75W modification), that model is focussed on downstream impacts of mine water discharge, rather than internal detail at Angus Place Colliery.

Model Objectives

The objectives for this new model were as follows:

- maximise utilisation of available discharge capacity
- assess the time-series change in salinity in the existing flooded workings in District 800
- assess the time-series change in storage in the existing flooded workings in District 900
- create contingency storage for the Project
- create contingency storage for the, soon to commence, Springvale Water Treatment Project
- demonstrate that the proposed EPL limit on Angus Place LDP001 of 350µS/cm at up to 10ML/d (volumetric discharge) is plausible
- demonstrate that the current EPL limit on Springvale LDP009 of 1,200µS/cm at up to 30ML/d (volumetric discharge) can be met
- demonstrate that the contractual limitation on the salinity of discharge to the Springvale Water Treatment Project of 1,400µS/cm and volumetric limit of 42ML/d can be met
- confirm modelled, combined, take from District 800 and District 900, is less than 13.4ML/d, which was the predicted mine inflow for existing operations, as presented in RPS (2014).

Model Setup

<u>Containers</u>

The layout of containers within the SAPRMM is presented in **Figure 4.1**. Containers are primarily used in GoldSIM to assist in organising the layout of a model.

<u>Water and Mass Stores</u>

There are several Water and Mass Stores in the model:

Figure 4.1: Model Structure – Container Layout

- District 800 (used for transfer of residuals and feed (partial) to the water treatment plant)
  - Initial Water Storage Volume is 1,980ML
  - Upper Water Storage Bound is 2,000ML
  - Lower Water Storage Bound is 100ML
  - Initial Mass Storage Volume is 1,980ML * 1,200µS/cm * 0.67
- District 900 (used as a feed (all)[1] to the water treatment plant)
  - Initial Water Storage Volume is 1,600ML
  - Upper Water Storage Bound is 1,880ML
  - Lower Water Storage Bound is 100ML
  - Initial Mass Storage Volume is 1,600ML * 1,300µS/cm * 0.67
- District Angus Place East (District APE)
  - Initial Water Storage Volume is 200ML[3]
  - Upper Water Storage Bound is 2,000ML[3]
  - Lower Water Storage Bound is 100ML
  - Initial Mass Storage Volume is 200ML * 1,300µS/cm * 0.67
- Springvale
  - Initial Water Storage Volume is 200ML[3]
  - Upper Water Storage Bound is 2,000ML[3]
  - Lower Water Storage Bound is 100ML
  - Initial Mass Storage Volume is 200ML * 1,250µS/cm * 0.67

Notes. 1. From 1 July 2018 to 31 December 2019, continue to discharge 'raw' mine water, at up to 6.9ML/d, which is the limit based on the current interpretation of the relevant WAL, however, may be revised in the future, to the SDWTS via the Bore 940 facility, if required; 2. The lower threshold for turning off the water treatment plant in the model was set at

150ML; 3. There is no physical storage capacity at Springvale (due to being an operational mine) or District APE (District APE is the Angus Place Mine Extension Project, which is yet to be approved). For Springvale and District APE, inflow to Water and Mass Stores was made to equal outflow, so the Initial Water and Mass Volume and Upper Water Storage Bound do not have meaning, however, are required to be specified in a GoldSIM.

It is highlighted that whilst the Angus Place Mine Extension Project (referred to in this model as Angus Place East) is included in the SAPRMM, it is not a currently approved project.

Each potential water source (groundwater inflow) comprised a Water and Mass Store.

An example of the layout of the Water and Mass Store, from District 800, is presented in **Figure 4.2**.

The Water and Mass Store in District 800 and District 900 reflect the current flooded state of these workings. The location of these workings and a graphical representation of their flooded state is presented in **Figure 3.4**.

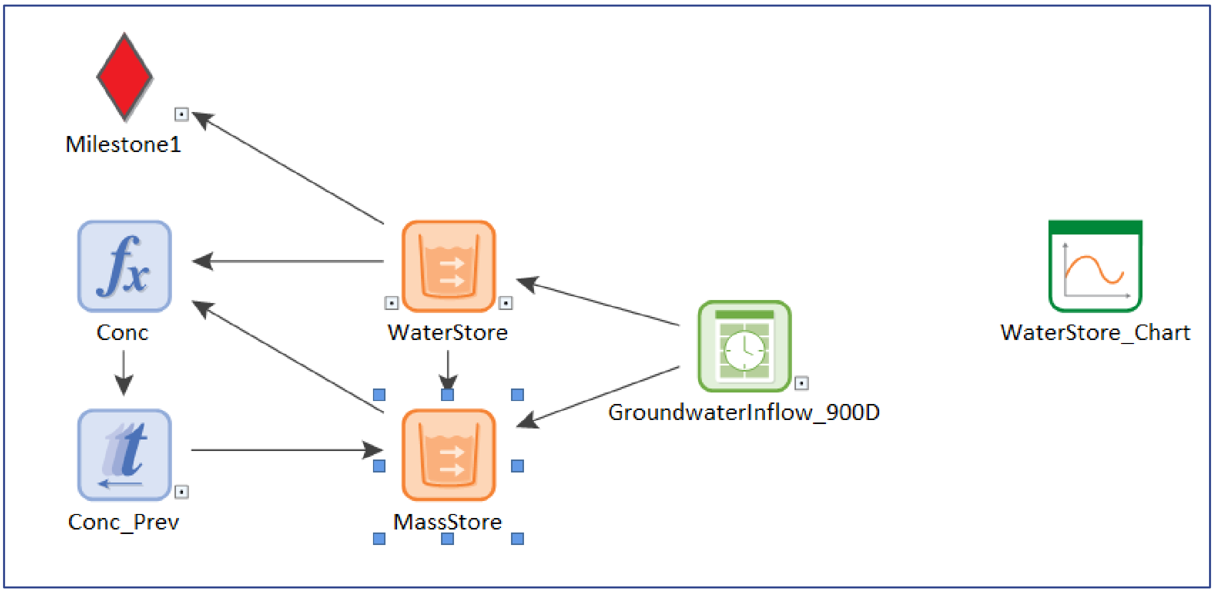


Figure 4.2: Model Structure – Example of Water and Mass Store – District 900

For each Water and Mass Store, there is groundwater inflow.

The simulation duration of the SAPRMM was set to 18 August 2017 through to 31 December 2035, and the model was configured to run on a daily basis.

It is noted that the unscheduled update option in GoldSIM was disabled, such that the time step was locked at daily. This assumption was not significant with respect to the SAPRMM and was only potentially relevant at the point in the simulation where a Water Store reached its lower bound. Even in that circumstance, the implication of the assumption was insignificant.

For the SAPRMM, the following groundwater inflows were assumed.

- District 800
  - Groundwater inflow at a constant rate of 1.3ML/d
  - Groundwater inflow would continue from present (18 August 2017) through to end of the simulation (31 December 2035)
- District 900
  - Groundwater inflow at a constant rate of 7.4ML/d
  - Groundwater inflow would continue from present (18 August 2017) through to end of the simulation (31 December 2035)

- Springvale
  - Groundwater inflow adapted from groundwater modelling presented in CSIRO 2016
  - Groundwater inflow to Springvale is assumed, in the model, to continue from present (18 August 2017) through to 19 March 2025
- District APE
  - Groundwater inflow adapted from groundwater modelling presented in CSIRO 2016

Groundwater inflow to District APE is assumed, in the model, to commence on 20 March 2025 and continue through to the end of the simulation (31 December 2035).

Figure 4.3 presents the times-series distribution of groundwater inflows assumed in the SAPRMM.

It is noted that concentration of material flows in the model was calculated using Mass Flux / Water Flux and that concentration in material stores was calculated using Mass / Volume.

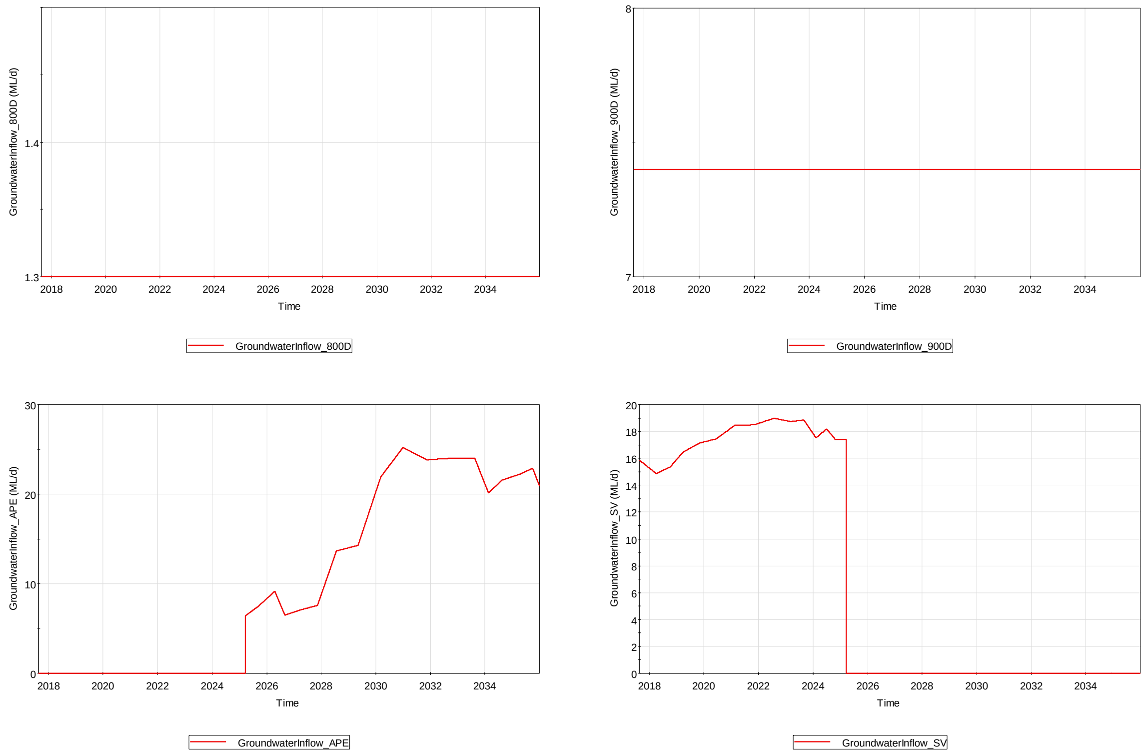


Figure 4.3: Assumed Groundwater Inflow to the SAPRMM (ML/d)

<u>Angus Place Water Treatment Project</u>

The Project will result in a treated water (permeate and ‘raw’ water blended) and a residual stream.

For the purpose of the SAPRMM, it was assumed that:

- water treatment plant efficiency (which is calculated by treated water divided by water fed into the plant, expressed as a %) may range between 70% and 85%, depending on the design
- volumetric flux (Feed Water)[1] through the treatment media/method will be spilt as follows:
  - 63% Permeate and 37% Residual (water treatment plant efficiency – 70%)
  - 69% Permeate and 31% Residual (water treatment plant efficiency – 75%)
  - 75% Permeate and 25% Residual (water treatment plant efficiency – 80%)
  - 80% Permeate and 20% Residual (water treatment plant efficiency – 85%)

- mass flux (Feed Mass) through the treatment media/method will be split 1% Permeate and 99% Residual
- residual stream will be temporarily transferred to District 800
- District 800 will be maintained in its currently ‘full’ state throughout the period of operation of the Project
    - to prevent overtopping, this requires treatment of Groundwater Inflow to District 800 and Residual Input to District 800 (recirculation)
    - because residuals are being recirculated (partly), salinity in District 800 will increase more quickly over time
- following commencement of the Springvale Water Treatment Project, dewatering of District 800 will commence and continue until the mine water store is completely dissipated

Notes. 1. Due to the design of the temporary water treatment plant not being final, several water treatment efficiencies were simulated.

The layout of the ‘calculation’ component of the SAPRMM is presented in **Figure 4.4** and **Figure 4.5** presents the mass balance check for the model.

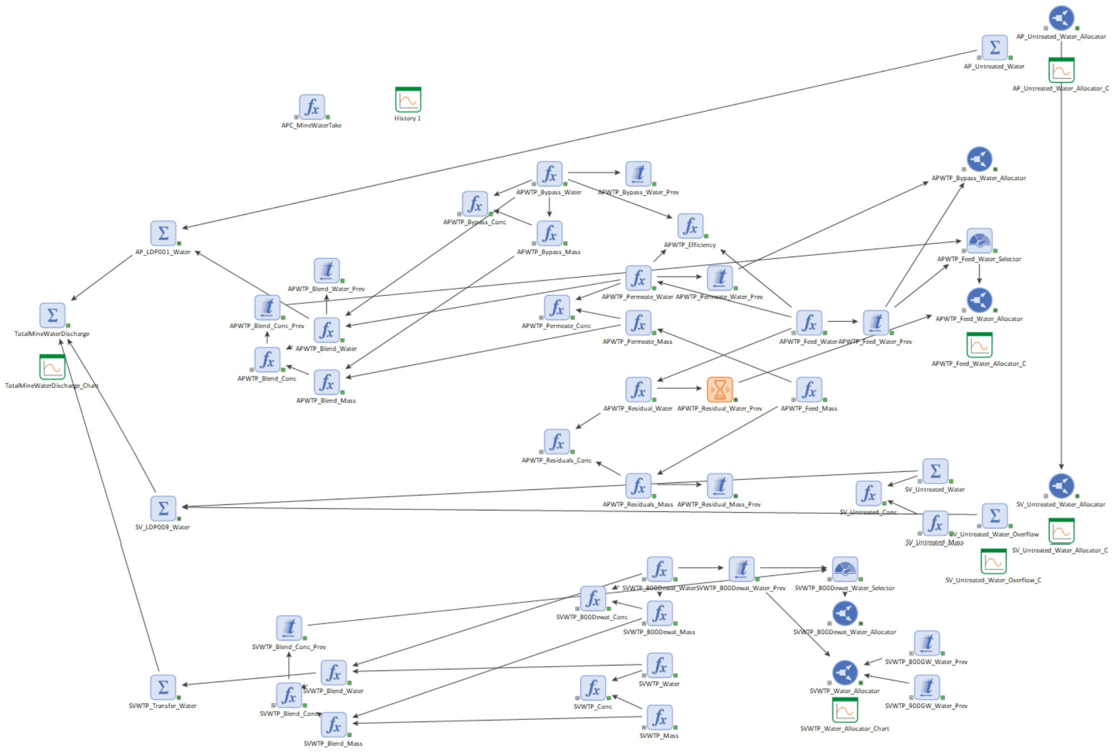


Figure 4.4: Model Structure – ‘Calculation’ Component

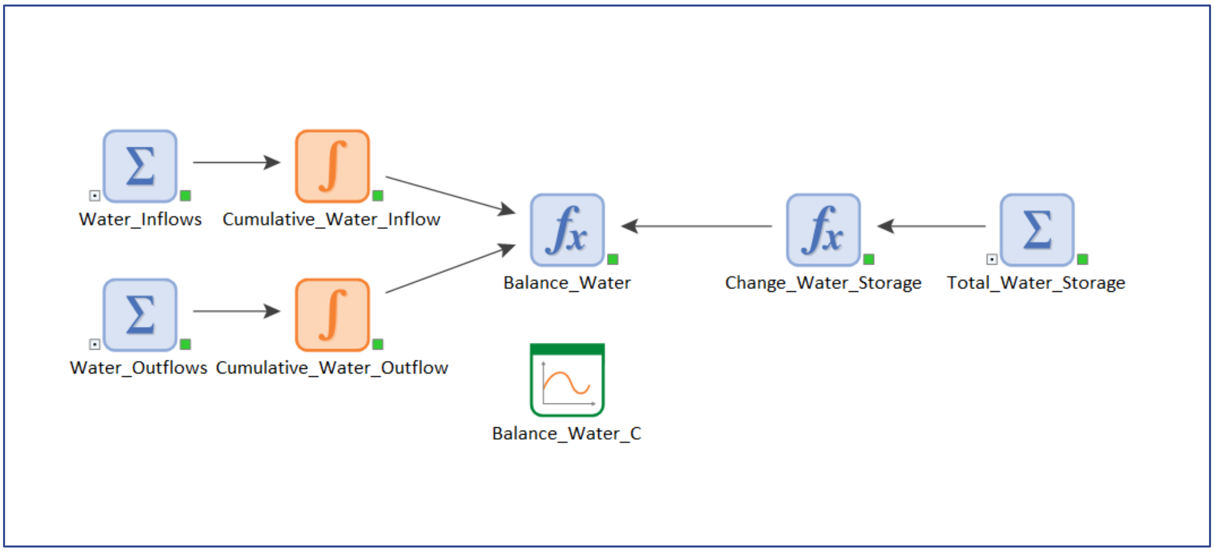


Figure 4.5: Model Structure – Mass Balance Check

<u>Model Demands</u>

The approach undertaken in the model was to assign demands (both volume and salinity) with respect to each of the Licensed Discharge Points (LDPs) at Angus Place Colliery and Springvale Mine, and the, soon to be commissioned, Springvale Water Treatment Project.

Demands were used in GoldSIM, rather than fixed values, since demands have the flexibility of not being met.

Angus Place LDP001

There were three phases in the model for Angus Place LDP001:

- 2ML/d and no limit to salinity (18 August 2017 through to 30 June 2018)
- 10ML/d and 350µS/cm limit to salinity (1 July 2018 through to 31 December 2019)
- 0ML/d onward (from 1 January 2020 onward)

Springvale LDP009

There were two phases in the model for Springvale LDP009:

- 30ML/d and 1,200µS/cm limit to salinity (18 August 2017 through to 30 June 2019)
- 0ML/d onward (from 1 July 2019 onward)
  - Commissioning of the Springvale Water Treatment Project was assumed to occur on 30 June 2019

Springvale Water Treatment Project

There were two phases in the model for the Springvale Water Treatment Project:

- 0ML/d (18 August 2017 to 30 June 2019)
- 42ML/d at 1,400µS/cm limit to salinity (from 1 July 2019 through to 31 December 2035). This includes extraction of mine inflows from Angus Place Colliery up to 13.4ML/d via the SDWTS through the Bore 940 facility, if required.

<u>Model Priorities</u>

The assignments of priorities, in order of priority, were as follows, with respect to each point of discharge.

Angus Place LDP001

- 2ML/d with no salinity limit (18 August 2017 to 30 June 2018)
  - District 800 Groundwater Inflows (1.3ML/d)
- 10ML/d with 350µS/cm limit (1 July 2019 to 31 December 2019)
  - District 800 Groundwater Inflows (1.3ML/d)
  - District 800 Residual Transfer (variable, but, notionally 2-3ML/d)
  - District 900 Groundwater Inflows (all) (constant at 7.4ML/d)
  - District 900 Feed Top Up (dewatering of District 900, as capacity permits)

Springvale LDP009

- 30ML/d with 1,200µS/cm salinity limit (18 August 2017 to 30 June 2019)
  - Springvale Groundwater Inflows
  - District 900 Groundwater Inflows (excess) (until 30 June 2018, then 0ML/d[1])
  - District 800 Groundwater Inflow (after 1 July 2018, from the date that District 900 is dewatered, if that occurs)
  - District 900 Groundwater Inflow (after 1 July 2018, from the date that District 900 is dewatered, if that occurs)[1].

Springvale Water Treatment Project

- 0ML/d (18 August 2017 to 30 June 2019)
- 42ML/d with 1,400µS/cm salinity limit (1 July 2019 to 31 December 2035).

Notes. 1. During this period, although not presented in this report, up to 6.9ML/d may continue to be transferred to the SDWTS via the Bore 940 facility, if required. 6.9ML/d is the limit based on the current interpretation of the relevant Water Access Licence, however, may be revised in the future.

4.2.2.2 Model Results

The model control file pertaining to the prediction simulation is:

- R02RevB_PRD_03a.gsm

Results from the simulation are presented with respect to points of discharge, both flow and concentration (salinity) and then with respect to water store volume and concentration (salinity).

As noted above, due to the design of the temporary treatment plant not being final, several treatment efficiencies were simulated, however, as will be shown below, the different treatment efficiencies did not lead to significantly different results.

Angus Place LDP001

Figure 4.6 presents the discharge rate (ML/d) through Angus Place LDP001 (Untreated). As noted above, discharge (untreated) through Angus Place LDP001 is proposed to cease on 1 July 2018.

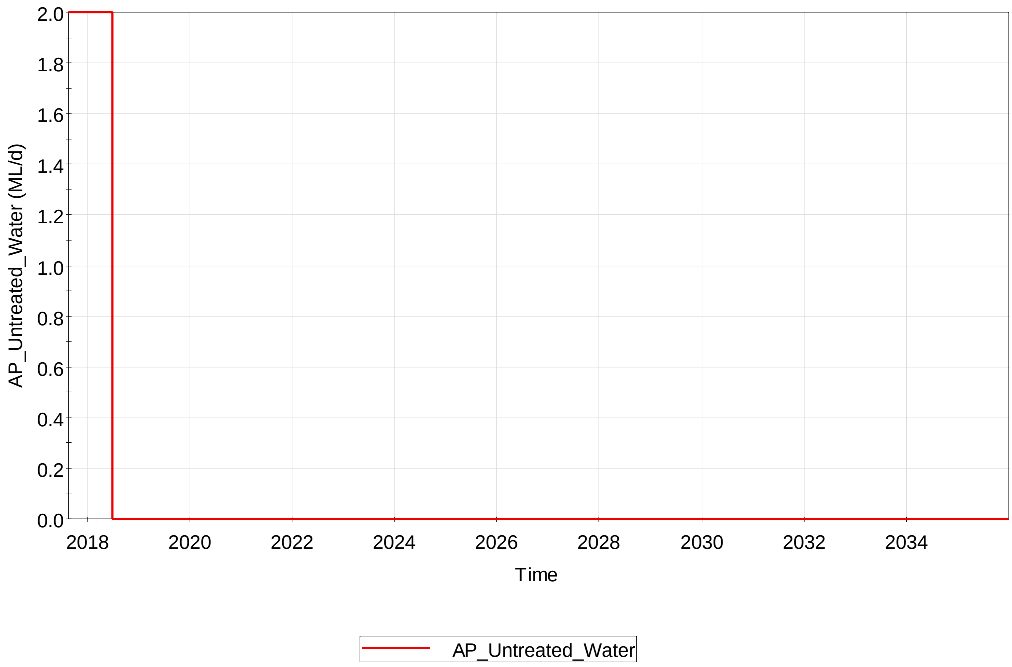


Figure 4.6: Angus Place LDP001 (Untreated) – Discharge Rate (ML/d)

Figure 4.7 presents the discharge rate (ML/d) through Angus Place LDP001 (Treated) and **Figure 4.8** presents the modelled concentration (salinity, mg/L).

The results presented in **Figure 4.7** and **Figure 4.8** were, essentially, identical for each treatment efficiency, therefore only the results from the 75% efficiency simulation were presented.

The reason that the results were, essentially, the same, and are also the same further below, was because, for the lower efficiency simulation, this led to a relatively higher residual volumetric transfer to District 800 (~4.35 to 4.45ML/d), but at a lower relative concentration (~2,240 to 4,450mg/L). Conversely, for the higher efficiency simulation, this led to a relatively lower residual volumetric transfer rate to District 800 (~1.85 to 1.86ML/d), but at a relatively higher concentration (~4,200 to 7,100mg/L). Because the volume of stored mine water in District 800 is very large at 2,000ML, the difference in efficiency did not become significant in the 18 month period of operation.

As presented in **Section 4.2.2.1**, treatment is proposed to commence on 1 July 2018 and continue through to 31 December 2019. It is noted that whilst the model indicates operation of the temporary treatment plant for the entire 18 month period, the plant may not be need to be operated for the entire duration of the Project.

It is highlighted that GoldSIM uses SI units, therefore concentration is required to be presented in mg/L rather than µS/cm. For example, in **Figure 4.8**, a concentration of 234.5mg/L is equivalent to 350µS/cm.

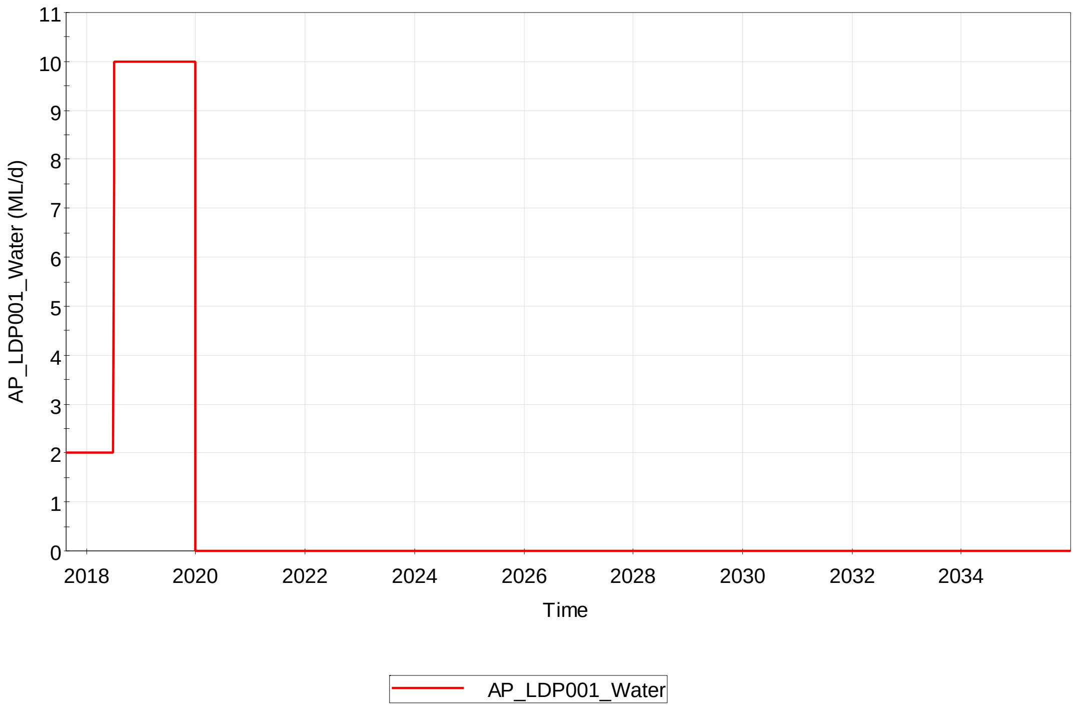


Figure 4.7: Angus Place LDP001 (Treated) – Discharge Rate (ML/d)

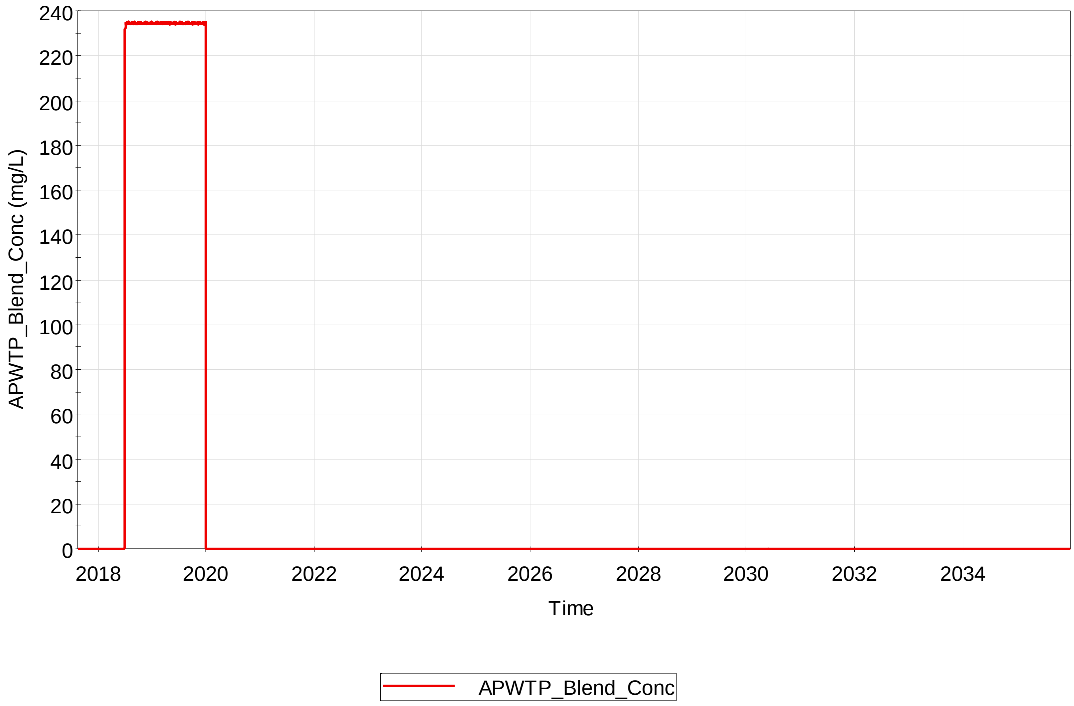


Figure 4.8: Angus Place LDP001 (Treated) – Water Quality (Salinity, mg/L)

From **Figure 4.7** and **Figure 4.8**, discharge through Angus Place LDP001 is approximately 10ML/d at 234.5mg/L (350µS/cm) until 31 December 2019.

Springvale LDP009

Figure 4.9 presents the modelled discharge rate (ML/d) through Springvale LDP009. **Figure 4.10** presents the modelled concentration (salinity, mg/L). The results presented in **Figure 4.9** and **Figure 4.10** were identical for each treatment efficiency, therefore only the 75% efficiency simulation was presented.

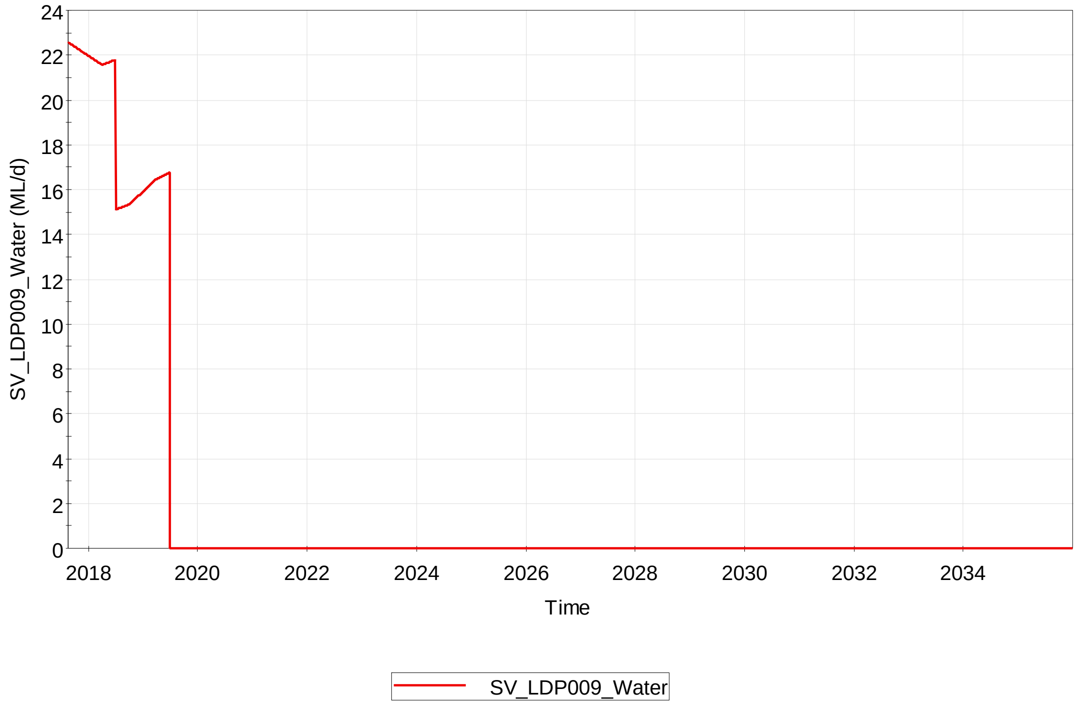


Figure 4.9: Springvale LDP009 (Untreated) – Discharge Rate (ML/d)

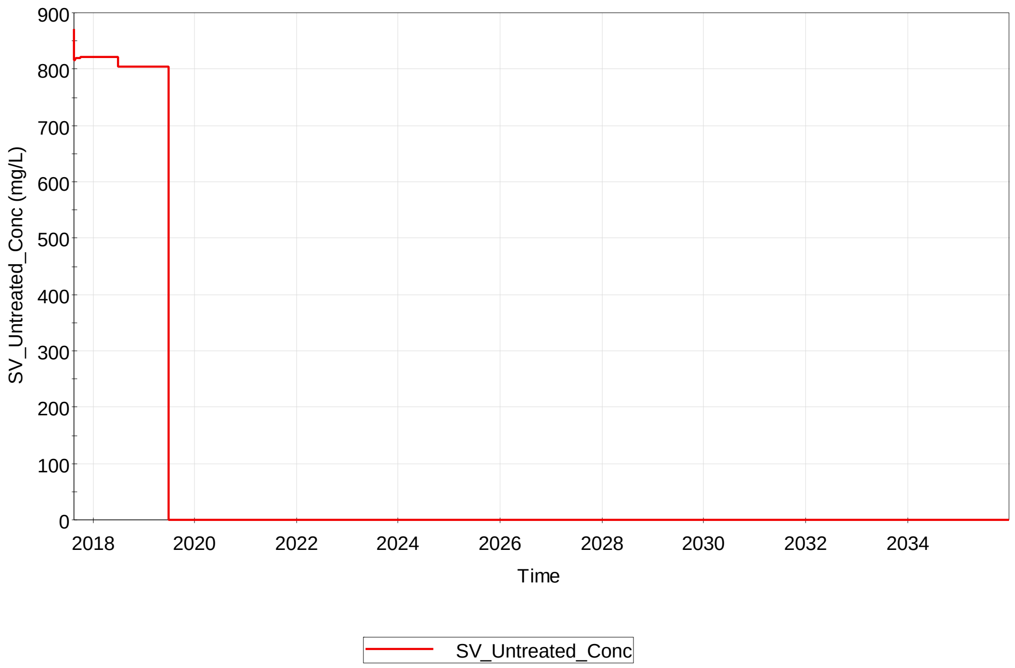


Figure 4.10: Springvale LDP009 (Untreated) – Water Quality (Salinity, mg/L)

From **Figure 4.9** and **Figure 4.10**, untreated discharge through Springvale LDP009 will cease on 1 July 2019.

Springvale Water Treatment Project

Figure 4.11 presents the transfer rate to the Springvale Water Treatment Project and **Figure 4.12** presents the modelled concentration (salinity, mg/L).

It is noted that the upper limit (contractual) on transfer to the Springvale Water Treatment Project is 1,400µS/cm (equivalent to 938mg/L) and 42ML/d.

The results presented in **Figure 4.11** and **Figure 4.12** were, essentially, identical for each treatment efficiency, therefore only the results from the 75% efficiency simulation were presented.

Figure 4.11: Springvale Water Treatment Project (Transfer) – Transfer Rate (ML/d)

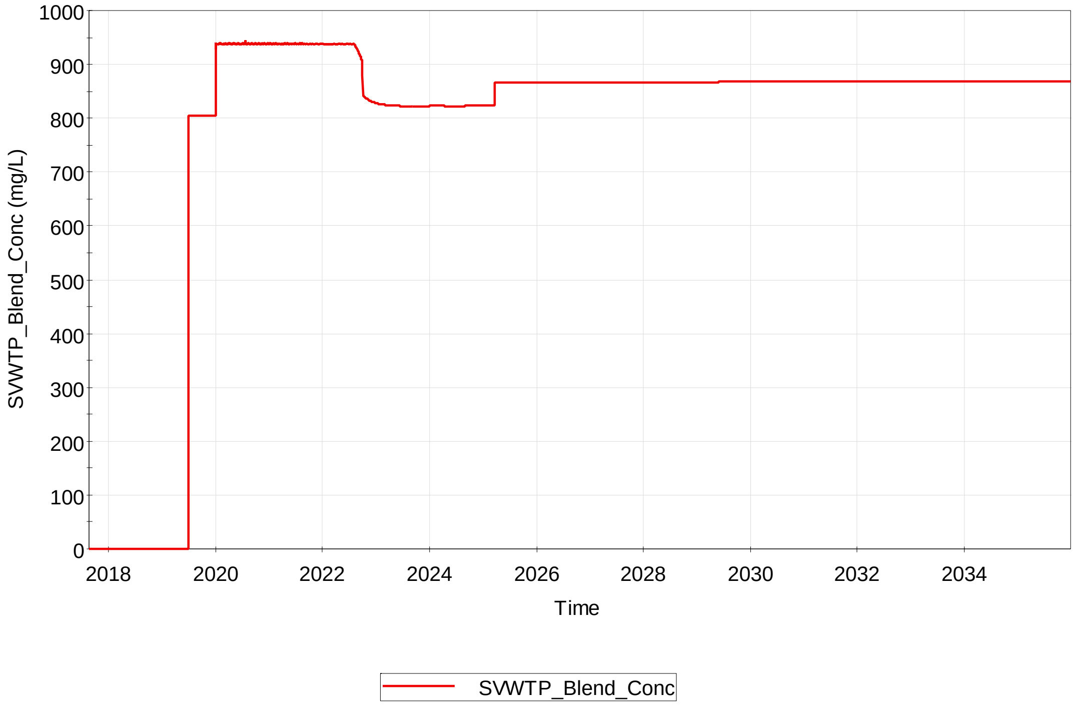


Figure 4.12: Springvale Water Treatment Project (Transfer) – Water Quality (Salinity, mg/L)

From **Figure 4.12**, the model optimises the blend of discharge with respect to the water quality limit of 1,400µS/cm (938mg/L) and demonstrates that the limits (contractual) both with respect to quality and transfer rate can be met.

District 800

Figure 4.13 presents the modelled storage volume in District 800. **Figure 4.14** presents the modelled concentration (salinity, mg/L).

As above, the results from the different treatment efficiency simulations were, essentially, identical, therefore only the 75% efficiency simulation was presented.

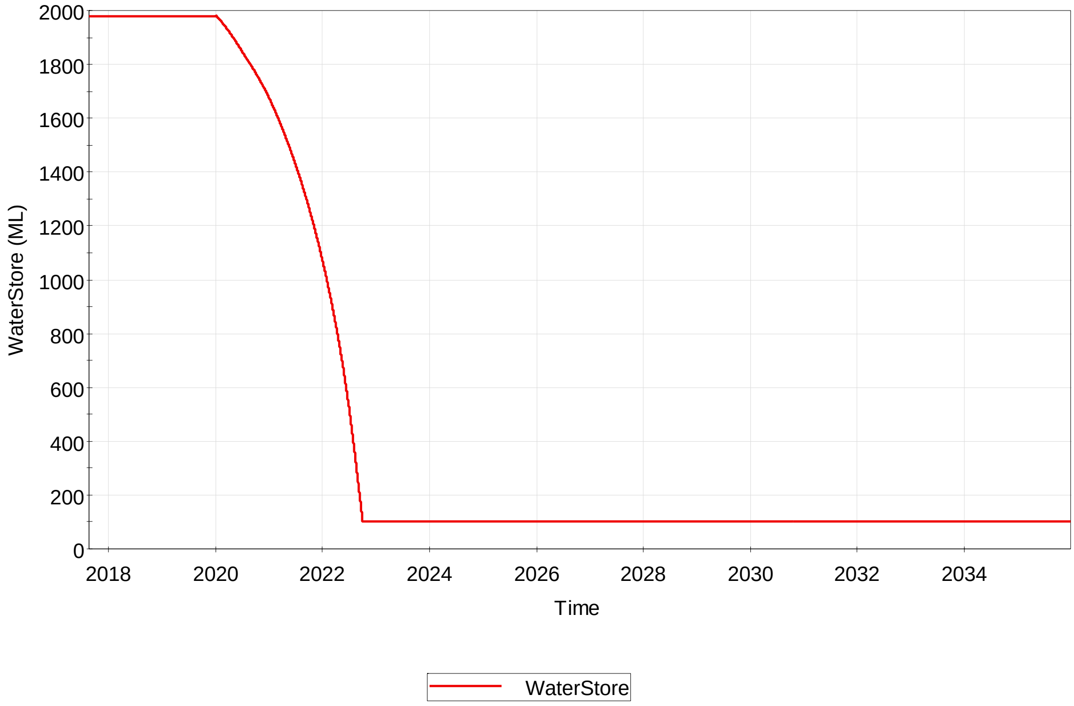


Figure 4.13: District 800 – Storage Volume (ML)

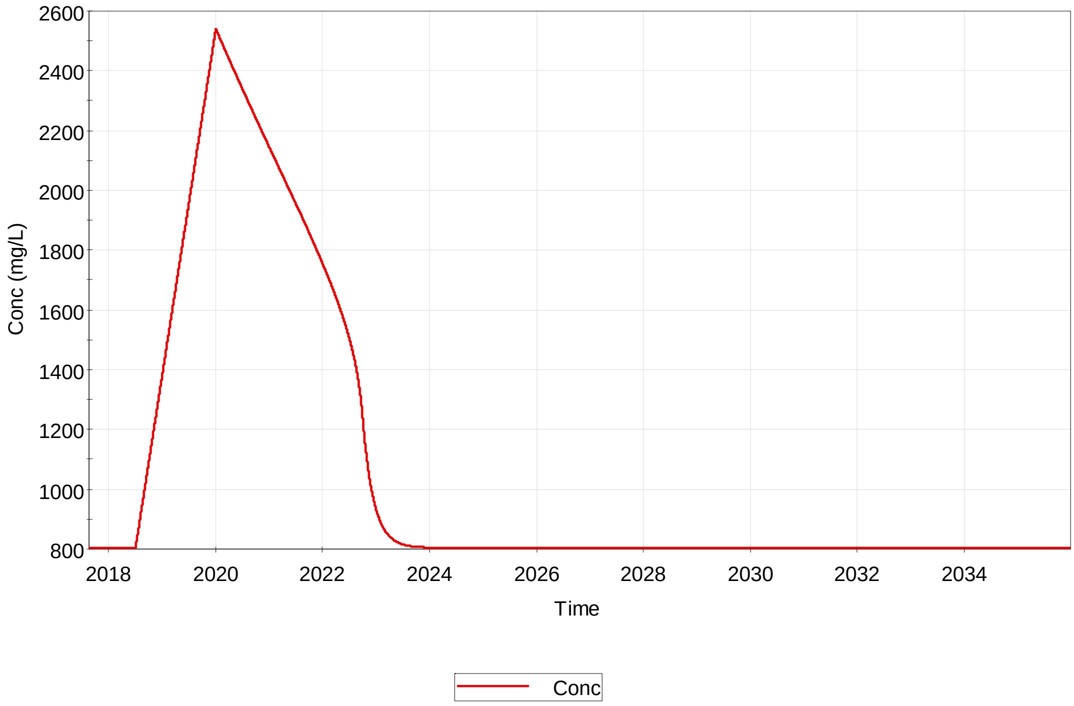


Figure 4.14: District 800 – Water Quality (Salinity, mg/L)

From **Figure 4.14**, the modelled concentration (salinity) increases from 804mg/L (1,200µS/cm) on 1 July 2018 to 2,541mg/L (~3,792µS/cm) on 2 January 2020 (75% efficiency simulation).

It is noted that, due to the need to avoid a recursive loop in the model, there is a one day delay in transfer of residuals between the Project and District 800.

The peak salinity from the other treatment efficiency simulations were:

- 2,539mg/L (2 January 2020) – 70% efficiency simulation
- 2,542mg/L (2 January 2020) – 80% efficiency simulation
- 2,545mg/L (2 January 2020) – 85% efficiency simulation

District 900

Figure 4.15 presents the modelled storage volume (ML) in District 900 and **Figure 4.16** presents the modelled water quality (salinity, mg/L).

As above, the results from the different treatment efficiency simulations were, essentially, identical, therefore only the 75% efficiency simulation was presented.

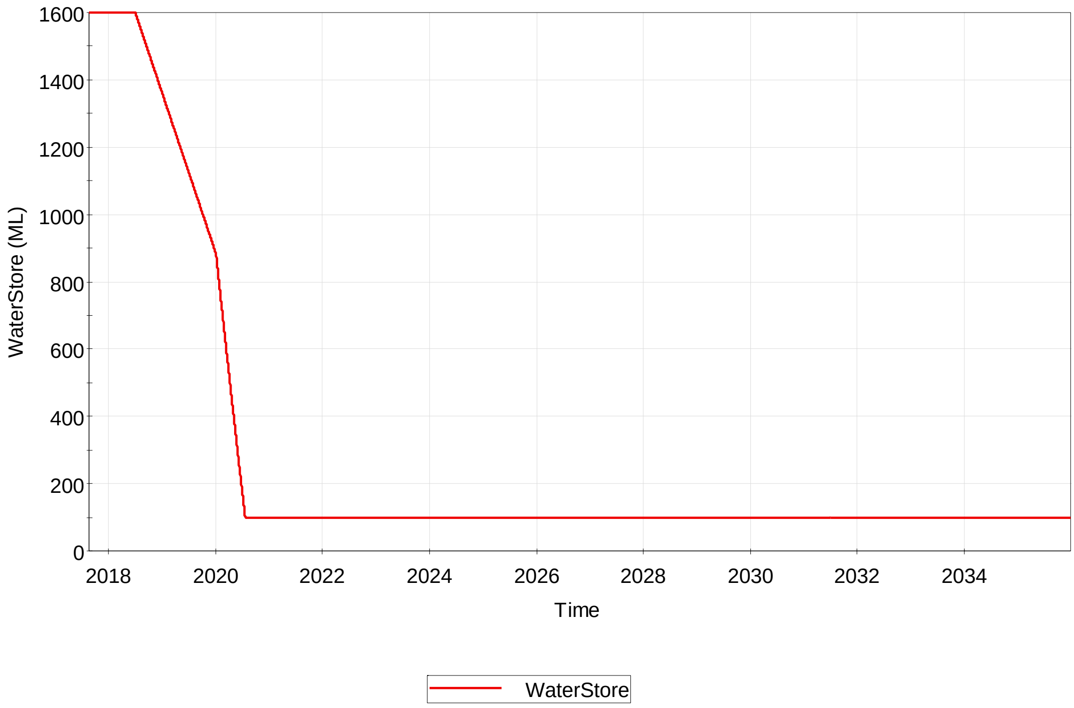


Figure 4.15: District 900 – Storage Volume (ML)

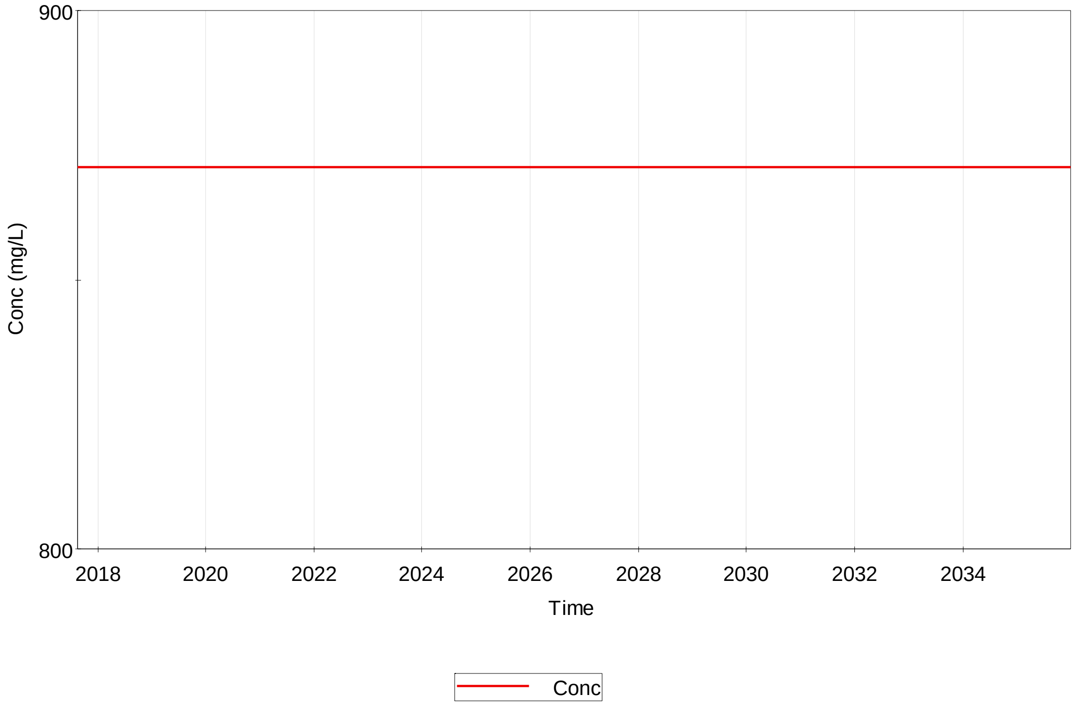


Figure 4.16: District 900 – Water Quality (Salinity, mg/L)

From **Figure 4.15**, the store of groundwater in District 900 is modelled as being dissipated by 21 July 2020. From **Figure 4.16**, the modelled salinity is constant, since only groundwater inflow occurs into District 900, at an assumed concentration of 871mg/L (1,300µS/cm).

Combined Take from Angus Place Colliery

Figure 4.17 presents the combined modelled take from District 800 and District 900, including extraction of stored mine water in District 800 following completion of the treatment phase.

The results from each of the treatment efficiency models are different and each is presented.

From **Figure 4.17**, it is noted that the 70% efficiency simulation marginally exceeds 13.4ML/d, which was the predicted and approved mine inflow rate for existing operations, as presented in RPS (2014).

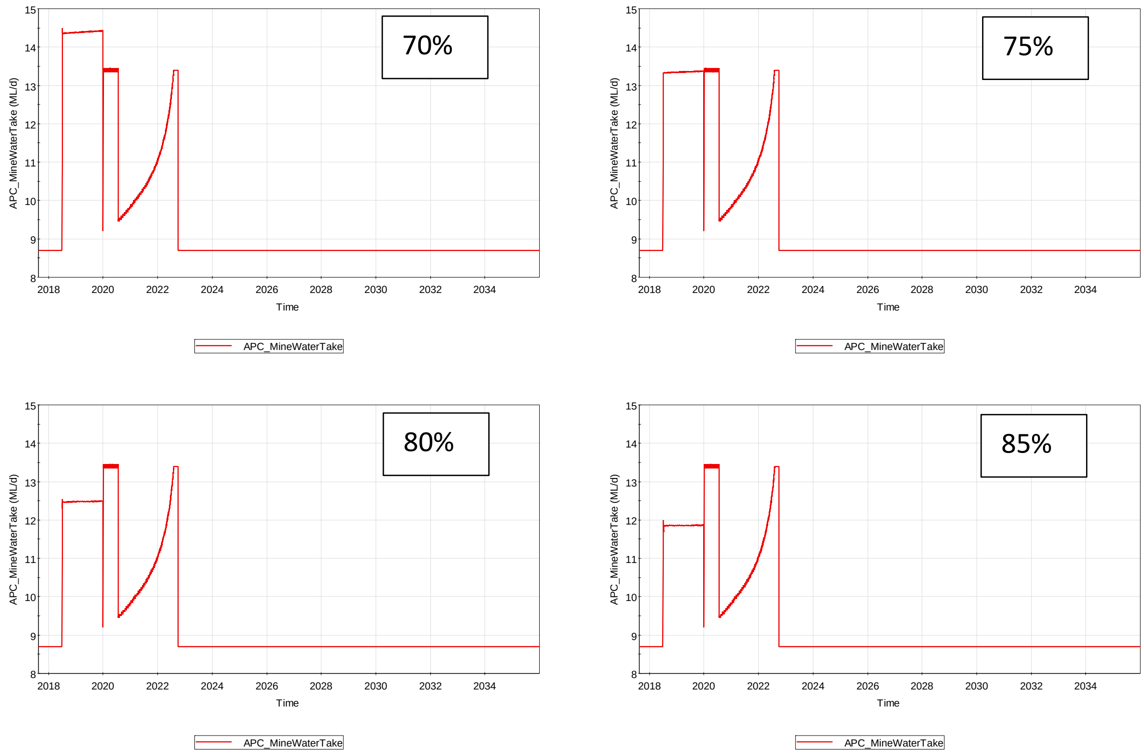


Figure 4.17: Combined Modelled Take from Angus Place Colliery (ML/d)

4.3 Water Quality Modelling of Stored Mine Water (Other Analytes)

4.3.1 Proposed Change

The proposed change to groundwater quality (other analytes) with the Project consists of:

- transfer of residuals into stored mine water within the 800 Panel Area

4.3.2 Results of Analysis

4.3.2.1 Model Approach

The United States Geological Survey (USGS) aqueous geochemical modelling platform, PHREEQCi was used in the assessment of the potential change in water quality due to temporary transfer of residuals into stored mine water in the existing workings of District 800.

Dynamic hydrogeochemical modelling was not undertaken, rather, outcomes from the SAPRRM presented in **Section 4.2**were used as the basis of two static models.

The current version of PHREEQCi is Version 3.4.0.12927 and Version 3.4.0.12927 was used in the assessment presented in this report.

4.3.2.2 Effect of Treatment on Raw Groundwater Quality

Model Setup

The Project will comprise water treatment to reduce salinity in the raw mine water, as EC, to 350µS/cm in treated water. The water treatment plant to be utilised for the reduction in salinity will be based on desalination (reverse osmosis) technology. The treatment will act to exclude dissolved salts from the raw mine water. Removal of totals suspended solids will occur during the pre-clarification process. Removal of dissolved metals will occur at the same time as the removal of salts

Detailed description of the proposed treatment method is presented in the main text of the Environmental Assessment, however, in principle, treatment will act to exclude dissolved salts. As noted in **Section 4.2.2.1**, the assumed efficiency of this process in the SAPRMM was 99% with respect to mass (salt) flux.

In order to assess the effect of water treatment on water quality in PHREEQCi, it was assumed that the efficiency of treatment was 100% with respect to mass (salt) flux (conservative).

From **Section 4.2.2.1**, the assumed ratio of volumetric bifurcation ranged between 63% permeate and 37% residual (treatment efficiency of 70%) to 80% permeate and 20% residual (treatment efficiency of 85%). It is expected that a 75% treatment efficiency design will be selected (69% Permeate and 31% Residual).

For simplicity in the PHREEQCi model, it was assumed that treatment would lead to 70% Permeate and 30% Residual.

From a geochemical modelling perspective, treatment represents removal of 70% of the water from a water quality sample, such as that noted from Bore 940 from December 2017 (refer **Table 3.5**).

The approach in PHREEQCi was therefore to use a concentration/evaporation type simulation.

Figure 4.18 presents the PHREEQCi input script used to calculate the effect of treatment.

Model Results

The model control file associated with this simulation was:

- R02RevA_PRD_01d.pqi

Table 4.1 presents the tabulated outcome of the PHREEQCi simulation. The data used in the model was the water quality sample for Bore 940 from December 2017 (refer **Table 3.5**).

```
TITLE Solution Definition
SOLUTION 1 Bore 940 7/12/2017 (Raw Mine Water)
units mg/L
pH 7.7
temp 22.1
Ca 8
Mg 6
Na 247
K 18
Cl 8
Alkalinity 644 as HCO3-
S(6) 11
Al 0.005 #half of DL
As  0.067 #not in database
Ba 0.069
B 0.07
Cd 0.00005 #half of DL
Cr 0.0005 #half of DL, not in database
Cu 0.0005 #half of DL
F 1.2 #estimated
Fe 0.23
Li 0.202
Mn 0.015
Ni 0.005 #not in database
Pb 0.0005 #half of DL
Si 4.15
Sr 0.048
Zn 0.0025 #half of DL
END

USE solution 1
REACTION 1
H2O  -1.0
38.88 moles
SAVE solution 2
END

TITLE Scale back to 1L (Residual Water Quality)
MIX 1
2 3.333
SAVE solution 3
END
```

Figure 4.18: PHREEQCi Input Script – Effect of Treatment of Raw Mine Water to Generate Residuals

Table 4.1: PHREEQCi Model Output – Effect of Treatment of Raw Mine Water to Generate Residuals

Analyte	95th% Prot. (ANZECC, 2000)	ADWG Health (NHRMC, 2016)	ADWG Aesthetic (NHRMC, 2016)	Raw Mine Water		Residual Water Quality	
				mg/L	mol/L	mg/L	mol/L
Physical Parameters							
Volume (L)					1.00252		1.00148
pH	6.5 – 8.0				7.70		7.65
EC(µS/cm)	350			766mg/L[2]	1,143µS/cm	2,380mg/L[2]	3,552µS/cm[1]
SC(µS/cm)[1]	-				964µS/cm		2,996µS/cm
Major Ions							
Na	-	f	180	247	1.08E-02	824	3.58E-02
K	-			18	4.61E-04	60	1.54E-03
Ca	-	-	-	8	2.00E-04	27	6.66E-04
Mg	-	-	-	6	2.47E-04	20	8.23E-04
Cl	-	c	250	8	2.26E-04	27	7.53E-04
SO4-	-	500	250	11	1.15E-04	32	3.33E-04
Alkalinity as $HCO3^-$	-	-	-	644	1.06E-02	2084	3.42E-02
Trace Ions							
Al	0.055 for pH>6.5	c	0.2	0.0050	1.86E-07	0.0167	6.18E-07
B	0.37	4	-	0.0701	6.48E-06	0.2335	2.16E-05
Ba	-	-	-	0.0691	5.03E-07	0.2302	1.68E-06
Cd	0.0002	0.002	-	0.0001	4.45E-10	0.0002	1.48E-09
Cu	0.0014 -	2	1	0.0005	7.88E-09	0.0017	2.63E-08
F	-	1.5	-	1.2012	6.32E-05	4.0033	2.11E-04
Fe	ID	c	0.3	0.2302	4.12E-06	0.7674	1.37E-05
Li	-	-	-	0.2022	2.91E-05	0.6740	9.71E-05
Mn	1.9	0.5	0.1	0.0150	2.73E-07	0.0500	9.11E-07
Pb	0.034	0.01	-	0.0005	2.42E-09	0.0017	8.05E-09
Si	-	37.4[4]	-	1.9421	6.91E-05	6.4719	2.30E-04
Sr	-	-	-	0.0480	5.48E-07	0.1602	1.83E-06
Zn	0.008	c	3	0.0025	3.83E-08	0.0083	1.28E-07
Error Checking							
CBE (%)[1,3]	n/a	n/a	n/a		4.62		4.69

Notes 1. Specific conductance (SC) is calculated in PHREEQCi and is approximately the same as EC. A linear conversion from EC to SC was assumed, namely (1,143µS/cm/964µS/cm = 1.186); 2. Conversion factor of 0.67; 3. Charge Balance Error; 4: Limit is 80mg/L as Silica; ID. Insufficient data to derive a reliable trigger value; c. Insufficient data to set guideline value based on health considerations; f. No health-based value considered necessary.

From **Table 4.1**, treatment of the raw water leads to a minor change in pH from 7.70 to 7.65 in the residuals and an increase in EC (PHREEQCi uses specific conductance, however, has been converted to EC) from 1,143µS/cm to 3,552µS/cm, which is a factor of increase of approximately 3.1.

It is noted that the EC of the December 2017 sample is less than that assumed (conservative) for the Water and Salt Balance Modelling presented in **Section 4.2**.

From **Table 4.1**, the increase in the concentration of Major Ions and Trace Ions in the residuals formed by reverse osmosis is, approximately, a factor of 3.2-3.3 increase.

The residuals are a Na-HCO_3 type water, of near neutral pH and are brackish, however, not saline.

It is noted that analytes that were below the detection limit, were assigned a value of half of the detection limit in the initial solution.

4.3.2.3 Predicted Quality of Stored Mine Water (Other Analytes)

Model Setup

The output from the PHREEQCi simulation presented in **Section 4.3.2.2**, would, theoretically, be then mixed with the 2,000ML of groundwater stored in District 800 and the calculation then repeated.

As noted in **Section 4.2**, however, due to the currently 'full' status of the existing workings in District 800 at Angus Place Colliery, both on-going groundwater inflow to District 800, at 1.3ML/d, as well as the rate of residual transfer to District 800, needs to be removed each day, to avoid overtopping and flooding of future workings (first workings of Angus Place Mine Extension Project, if approved).

As such, mass balance tracking becomes too complicated for PHREEQCi and instead output from the SAPRMM was used to formulate the PHREEQCi simulation.

The approach adopted was to examine the modelled change in salinity in District 800, as presented in **Figure 4.14**. From **Figure 4.14**, the salinity in District 800 increases from 804mg/L on 1 July 2018 to 2,541mg/L on 2 January 2020. This represents a concentration factor of approximately 3.1.

Using the same approach as presented in **Section 4.3.2.2**, however, with a concentration factor of 3.133, this equates to a reduction in effective volume to 1/3.133 = 0.319L. Accordingly, the associated amount of H2O to be removed is 37.77 moles.

Figure 4.19 presents the PHREEQCi input script for the simulation.

```
TITLE Solution Definition
SOLUTION 1 Bore 940 7/12/2017 (Raw Mine Water)
units mg/L
pH 7.7
temp 22.1
Ca 8
Mg 6
Na 247
K 18
Cl 8
Alkalinity 644 as HCO3-
S(6) 11
Si 4.15
Ba 0.069
Li 0.202
Mn 0.015
Sr 0.048
Fe 0.23
F 1.2 #estimated
END

USE solution 1
REACTION 1
H2O  -1.0
37.77 moles
SAVE solution 2
END

TITLE Scale back to 1L (Water Quality in District 800)
MIX 1
2 3.13
SAVE solution 3
END
```

Figure 4.19: PHREEQCi Input Script – Final Water Quality in District 800

Model Results

The model control file associated with the simulation is:

- R02RevA_PRD_02a.pqi

Table 4.2 presents the tabulated outcome of the PHREEQCi simulation.

Table 4.2: PHREEQCi Model Output – Predicted Quality of Stored Mine Water (Other Analytes) in District 800

Analyte	95th% Prot. (ANZECC, 2000)	ADWG Health (NHRMC, 2016)	ADWG Aesthetic (NHRMC, 2016)	Raw Mine Water		Water Quality in District 800	
				mg/L	mol/L	mg/L	mol/L
Physical Parameters							
Volume (L)					1.00252		1.00322
pH	6.5 – 8.0				7.70		7.65
EC(µS/cm)	350			766mg/L[2]	1,143µS/cm	2,242mg/L[2]	3,347µS/cm[1]
SC(µS/cm)[1]	-				964µS/cm		2,823µS/cm
Major Ions							
Na	-	f	180	247	1.08E-02	774	3.37E-02
K	-			18	4.61E-04	56	1.44E-03
Ca	-	-	-	8	2.00E-04	25	6.25E-04
Mg	-	-	-	6	2.47E-04	19	7.73E-04
Cl	-	c	250	8	2.26E-04	25	7.07E-04
SO4-	-	500	250	11	1.15E-04	30	3.14E-04
Alkalinity as $HCO3^-$	-	-	-	644	1.06E-02	1956	3.21E-02
Trace Ions							
Al	0.055 for pH>6.5	c	0.2	0.0050	1.86E-07	0.0157	5.81E-07
B	0.37	4	-	0.0701	6.48E-06	0.2193	2.03E-05
Ba	-	-	-	0.0691	5.03E-07	0.2162	1.57E-06
Cd	0.0002	0.002	-	0.0001	4.45E-10	0.0002	1.39E-09
Cu	0.0014 -	2	1	0.0005	7.88E-09	0.0016	2.47E-08
F	-	1.5	-	1.2012	6.32E-05	3.7601	1.98E-04
Fe	ID	c	0.3	0.2302	4.12E-06	0.7205	1.29E-05
Li	-	-	-	0.2022	2.91E-05	0.6329	9.12E-05
Mn	1.9	0.5	0.1	0.0150	2.73E-07	0.0470	8.55E-07
Pb	0.034	0.01	-	0.0005	2.42E-09	0.0016	7.56E-09
Si	-	37.4[4]	-	1.9421	6.91E-05	6.0787	2.16E-04
Sr	-	-	-	0.0480	5.48E-07	0.1504	1.72E-06
Zn	0.008	c	3	0.0025	3.83E-08	0.0078	1.20E-07
Error Checking							
CBE (%)[1,3]	n/a	n/a	n/a		4.62		4.68

Notes 1. Specific conductance (SC) is calculated in PHREEQCi and is approximately the same as EC. A linear conversion from EC to SC was assumed, namely (1,143µS/cm/964µS/cm = 1.186); 2. Conversion factor of 0.67; 3. Charge Balance Error; 4: Limit is 80mg/L as Silica; ID. Insufficient data to derive a reliable trigger value; c. Insufficient data to set guideline value based on health considerations; f. No health-based value considered necessary.

From **Table 4.2**, the EC (PHREEQCi uses specific conductance, however, has been converted to EC) from 1,143µS/cm to 3,347µS/cm, which is a factor of increase of 2.9, and the pH decreases slightly from 7.70 to 7.65 during the 18 months of continuous transfer of residuals to the 800 District.

From **Table 4.2**, the concentration of Major Ions and Trace Ions, generally speaking, increases by a factor of approximately 3.133, which was expected, since this was the assumed scaling factor obtained from the Water and Salt Balance Model.

The predicted water quality in the 800 District at the end of operation of the Project is a $Na\text{-}HCO_3$ type water, with near neutral pH, that is brackish but not saline.

From **Table 4.2**, there are no exceedances of the default trigger levels of the 95th% protection level for slightly to moderately disturbed aquatic ecosystems, aside from electrical conductivity, which is significantly exceeded.

4.4 Surface Water/Groundwater Interaction

4.4.1 Proposed Change

The proposed change to surface water/groundwater interaction with the Project consists of:

- transfer of residuals into stored mine water within the 800 Panel Area leading to change in surface water quality through surface water/groundwater interaction
- seepage of stored mine water within the 800 Panel Area toward the Wolgan Valley

4.4.2 Results of Analysis

As presented in **Section 3.2.6**, there is no direction connection between Lambs Creek, Kangaroo Creek and the Wolgan River (on the Newnes Plateau) and stored mine water within District 800.

Wolgan River (in the Wolgan Valley)

From **Section 3.2.6**, the Wolgan River, where is occurs within the Wolgan Valley, lies below the Lithgow Seam and, as such, there can be connection (via seepage face) between the Wolgan River (within the Wolgan Valley) and stored mine water within District 800.

To assess the potential for surface water/groundwater, the following aspects were considered:

<u>Average Groundwater Velocity</u>

Figure 3.2 presents the elevation of the floor of the Lithgow Seam (mAHD).

From **Figure 3.2**, the elevation of the Lithgow Seam at outcrop into the southern side of the Wolgan Valley is about 782mAHD. As noted in **Figure 3.4**, District 800 is currently maintained at a groundwater elevation of 805mAHD.

The average velocity of groundwater is calculated as follows:

$$V_x = -\frac{K}{n_e}\frac{dh}{dl}$$

where

K is hydraulic conductivity (m/d)

n_e is effective porosity and

dh/dl is the hydraulic gradient (m/m).

For Longwall 11 to 13 (District 700), which are the closest longwalls to the Wolgan Valley, the hydraulic gradient is (805m – 782m) over a distance of 750m = 0.0307 m/m.

If the hydraulic conductivity of the unmined Lithgow Seam is 0.0432m/d (equivalent to 5E-07m/s) and the effective porosity is 5%, then:

Vx = 0.0265m/d (2.65cm/d), which is equivalent to 9.7m/year or 48m in 5 years

The above calculation (conservative) implies that groundwater, stored mine water within District 800, may seep 48m toward the Wolgan Valley during the 5 year storage period. The five year storage period was derived from the outcome of the SAPRMM presented in **Section 4.2.2**, namely, that extraction of stored mine water in District 800 will be completed by August 2023.

<u>Modelled Hydrogeologic Divide</u>

The numerical groundwater model at Angus Place Colliery is in the process of being revised, however, the latest published version of the groundwater model is referred to as CSIRO 2016 (CSIRO, 2016). CSIRO 2016 reflects a minor update to the CSIRO 2015 version. The CSIRO 2015 version was also a minor update, to, the CSIRO 2013 version (CSIRO, 2013).

The CSIRO 2013 version of the model included extensive model calibration and sensitivity analysis and its prediction simulations assumed concurrent implementation of both the Springvale Mine Extension Project and the Angus Place Mine Extension Project. i.e. that mining would occur in the Springvale Mine Extension Project and Angus Place Mine Extension Project at the same time.

With Angus Place Colliery changing status to Care and Maintenance, the Angus Place Mine Extension Project has been delayed and the CSIRO 2015 version of the model presents updated prediction simulations, assuming sequential implementation of Springvale Mine Extension Project and then Angus Place Mine Extension Project. i.e. that mining would occur in the Springvale Mine Extension Project first and then Angus Place Mine Extension Project, should it be approved, afterwards.

Figure 3.3 presents predicted groundwater elevations in the Lithgow Seam in 2015.

From **Figure 3.3**, there is a hydrogeologic divide, at ~830mAHD, modelled between Longwall 11 to Longwall 13 (District 700) and the Wolgan Valley. A hydrogeologic divide at ~830mAHD, compared to the current groundwater elevation in District 700/800 of 805mAHD, would imply the groundwater flow direction is toward District 700/800 rather than toward the Wolgan Valley.

<u>Change in Groundwater Quality</u>

The groundwater quality within 48m of the existing workings would be, at worst, the same as that proposed to occur within District 800 itself, and would represent a large change (conservative).

4.5 Extraction of Stored Mine Water

4.5.1 Proposed Change

The proposed change to groundwater extraction with the Project consists of:

- extraction of stored mine water within the 800 Panel Area (post treatment phase)
- seepage of stored mine water within the 800 Panel Area toward the Wolgan Valley

4.5.2 Results of Analysis

Figure 3.2 presents the elevation of the floor of the Lithgow Seam, together with the mine layout.

To dewater District 800, it will be necessary for the groundwater elevation in the Lithgow Seam/Goaf to be drawdown down to the 'low point' with respect to each longwall.

Dewatering is necessary to facilitate recovery of stored mine water within District 800.

Upon commencement of dewatering of District 800, at the north-easterly end (see **Figure 3.2**), the hydraulic gradient between District 800 and the point of outcrop in the Wolgan Valley will be nullified.

From **Figure 3.2**, the target dewatering elevations to achieve recovery of stored mine water in District 800 are as follows:

- 784mAHD for Longwall 13
- 778mAHD for Longwall 26N or 26
- 770mAHD for Longwall 24.

It is noted that the above targets are indicative and the final dewatering design, expected to consist of both existing infrastructure (such as Bore 940) and new boreholes, if required, will be determined by Site.

5. Summary of Environmental Consequences

This chapter presents a summary of the environmental consequences of the Project, including cumulative impacts, with respect to the groundwater environment, neutral or beneficial effect to the drinking water catchment, groundwater dependent ecosystems, licensed water users and surface water/groundwater interaction.

5.1 Cumulative Impacts

Significant projects in the vicinity of Angus Place Colliery include:

- Springvale Mine
  - located to the immediate south of Angus Place Colliery
- Springvale Water Treatment Project
  - located at Mt Piper Station
- Angus Place Mine Extension Project (if approved)
  - located to the north east of Angus Place Colliery

With respect to Springvale Mine, Springvale is located hydrogeologically up-gradient of Angus Place Colliery. Accordingly, transfer of residuals from the Project into stored mine water in District 800 will have no impact on groundwater quality in Springvale Mine because District 800 is down-gradient of Springvale Mine.

With respect to the Springvale Water Treatment Project, modelling undertaken in the SAPRRM indicates that the Project will not exceed the volumetric and water quality (salinity) contractual limitations of the Springvale Water Treatment Project.

With respect to the Angus Place Mine Extension Project, the Project will completed (dissipation of stored residuals by August 2023) prior to the expected commencement of the Angus Place Mine Extension Project, if approved.

5.2 Groundwater Environment

Water and Salt Balance Modelling of Stored Mine Water

The outcome of modelling with the residual management model (SAPRMM) indicates that temporary transfer of residuals will result in an increase in salinity of stored mine water (District 800) from 804mg/L (1,200µS/cm) currently, which was the assumed salinity (conservative) in the model, to 2,541mg/L (3,790µS/cm) on 2 January 2020.

Analysis indicates that dewatering of stored mine water will be achieved (return to background salinity, 99%) by August 2023 (812mg/L (1,212µS/cm) on 30 July 2023).

The Project will lead to a reduction in groundwater elevation (deep groundwater system) in District 900 from 800mAHD to, approximately, 770mAHD (Longwall 24), which was the fully depressurised level prior to restriction in volumetric discharge limit from Angus Place Colliery through LDP001.

Dewatering of District 800, following completion of the Project, will reduce the groundwater elevation (deep groundwater system) from 805mAHD to 784mAHD. It is noted that the fully depressurised level in District 800 was 784mAHD prior to being allowed to flood.

Outcomes from the SAPRMM, presented in **Section 4.2.2.2**, indicate that the assigned maximum rate of groundwater extraction from Angus Place Colliery during the Project of 13.4ML/d can be achieved. The 13.4ML/d limit is based on the predicted inflow to existing working at Angus Place Colliery presented in the Surface and Groundwater Assessment for Modification 4 (RPS, 2014).

Following completion of the Project, transfer to the Springvale Water Treatment Project from Angus Place Colliery occurs at up to 13.4ML/d until District 800 is dewatered. As indicated in **Section 4.2.2.2**, transfer to the Springvale Water Treatment Project decreases to 8.7ML/d once District 800 and District 900 are dewatered.

Water Quality Modelling of Stored Mine Water (Other Analytes)

The potential change in groundwater quality to other analytes was assessed using the hydrogeochemical model PHREEQCi. The outcome of that modelling is presented in **Section 4.3**.

Analysis indicates that the concentration of Major and Trace Ions in the mine water stored in the 800 District increases by a factor of 3.13 due to the Project. The water quality of stored mine water is Na-HCO_3 type water, with near neutral pH that is brackish but not saline, with no exceedances of ANZECC (2000) default guideline values, with the exception of salinity, which is significantly exceeded. The impact of the Project to groundwater quality is significant, however, is manageable, as presented below.

5.3 Neutral or Beneficial Effect to the Drinking Water Catchment

As presented in **Section 4.4**, there is no predicted change to Lambs Creek and Kangaroo Creek, associated with the Project, since their thalwegs are well above the elevation of floor of the Lithgow Seam at respective locations.

Because there is no change to Lambs Creek or Kangaroo Creek due to the Project, there is no change to water quality within the Sydney Drinking Water Catchment.

The increase in mine water discharge through Angus Place LDP001, to up to 10ML/d (treated to 350µS/cm), will be undertaken as a Section 75W modification, Modification 5, and is not assessed in this assessment report.

5.4 Groundwater Dependent Ecosystems

Groundwater dependent ecosystems reside on the Newnes Plateau (THPSS communities).

The Newnes Plateau is located well above elevation of the Lithgow Seam, and therefore there is no impact to those ecosystems due to the Project.

5.5 Licensed Water Users

Groundwater Users

As established in **Section 3.2.5**, there are no groundwater users in the immediate vicinity of Angus Place Colliery and therefore there are no impacts to groundwater users due to the Project.

Surface Water Users

From **Table 3.2** in **Section 3.2.5**, there are multiple surface water users within the Hawkesbury and Lower Nepean River Water Source, located downstream of Angus Place Colliery within the Wolgan Valley and below.

There is potential for impact to these users from seepage from stored mine water within 800 Panel Area into the Wolgan River (within the Wolgan Valley), however, this impact can be managed through dewatering of the 800 Panel Area following completion of the treatment phase of the Project.

Further detail is presented in **Section 5.6** below.

5.6 Surface Water / Groundwater Interaction

There is no environmental consequence to Lambs Creek, Kangaroo Creek or the Wolgan River (on the Newnes Plateau) due to the Project.

Wolgan River (within the Wolgan Valley)

The potential for seepage from the Lithgow Seam into the Wolgan River, within Wolgan Valley, is assessed in **Section 4.4.2**. It was found that the seepage velocity is very low, at 9.7m/year, however, groundwater quality may be impacted at up to 48m from the existing workings, toward the Wolgan Valley, over the 5 year storage period. As stated in **Section 4.4.2**, groundwater quality within 48m of the existing workings would be, at worst, the same as that proposed to occur within District 800 itself, and would represent a large change (conservative).

The potential change to groundwater quality outside of District 800 would be a significant impact.

Analysis presented in **Section 4.5**, indicates, however, that the impact can be managed through nullifying the hydraulic gradient between District 800 and the Wolgan Valley, thereby facilitating recapture of potentially impacted groundwater.

Furthermore, as noted in **Section 4.4.2**, a hydrogeologic divide may exist between the Longwalls 11 to 13 (District 700) and the Wolgan Valley, which would prevent flow from District 700/800 into the Wolgan River.

6. Impact Assessment

This chapter presents an assessment of the impact of the Project against compliance with relevant governing legislation, regulations, environmental planning instruments, guidance documents and policies.

6.1 Commonwealth Legislation

6.1.1 Environment Protection and Biodiversity Conservation Act 1999 (Cth)

As summarised in **Section 5.4**, there are no proposed changes to impacts to the THPSS ecosystems that reside on the Newnes Plateau due to the Project.

Accordingly, there is no impact to THPSS due to the Project.

An assessment of the Project with respect to MNES (Water Resources) is presented in **Section 6.2.1**.

6.2 Commonwealth Guidelines and Policy

6.2.1 Significant Impact Guidelines for Coal Seam Gas and Large Coal Mines 2013

An assessment of the Project, with respect to management of groundwater, against the Significant Impact Guidelines for Coal Seam Gas and Large Coal Mines – Water Resources (DoE, 2013) is presented in **Table 6.1**. An assessment of the Project with respect to management of surface water is presented in the Surface Water Assessment for the Project (JBS&S, 2018).

Table 6.1 : Impact Assessment against Significant Impact Guidelines – Water Resources (DoE, 2013)

Impact Guideline	Compliant	Comment
Hydrological Characteristics		
A significant impact on the hydrological characteristics of a water resource may occur where there are, as a result of the action: a) changes in the water quantity, including the timing of variations in water quantity	Yes	As described in **Section 4.1** and modelled in **Section 4.2**, the Project comprises dewatering of existing flooded mine workings (District 900 and then District 800, once the Springvale Water Treatment Project is commissioned). Both of these workings have already been depressurised and dewatering of the workings will not lead to a change in water quantity with respect to the THPSS (Kangaroo Creek Swamp, West Wolgan Swamp, Narrow Swamp South and Narrow Swamp North that overlie District 900; and three unnamed swamps lie above or adjacent to District 800), or a significant change to surface water/groundwater interaction (quantity), with respect to riparian vegetation.
b) changes in the integrity of hydrological or hydrogeological connections, including substantial structural damage (e.g. large scale subsidence)	N/A	The Project does not include additional mining and, as such, will not lead to changes to subsidence at Angus Place Colliery. Accordingly, there is no impact from the Project on connection between hydrogeological units or surface water/groundwater interaction.
c) changes in the area or extent of a water resource	N/A	N/A
Water Quality		
A significant impact on a water resource may occur where, as a result of the action:	Yes	Model outcomes presented in **Section 4.2.2.2** indicates that temporary transfer of residuals into stored mine

Impact Guideline	Compliant	Comment
a) there is a risk that the ability to achieve relevant local or regional water quality objectives would be materially compromised, and as a result the action: i. creates risks to human or animal health or to the condition of the natural environment as a result of the change in water quality		water (District 800) will lead to an increase in salinity from 804mg/L on 1 July 2018 to 2,541mg/L on 2 January 2020. Modelling indicates that dewatering of stored mine water (District 800) will achieve (background water quality, 99%) by August 2023. Analysis presented in **Section 4.4** indicates that the magnitude of groundwater seepage toward the Wolgan Valley over a 5 year period would be 48m. Dewatering of District 800 will nullify the hydraulic gradient between District 800 and the Wolgan Valley, facilitating recapture of potentially impacted groundwater.
ii. substantially reduces the amount of water available for human consumptive uses or for other uses, including environmental uses, which are dependent on water of the appropriate quality	Yes	Assessment of the impact of the change in water quality of mine water discharge and the impact of cessation of mine water discharge after 31 December 2019 is presented in the Surface Water Assessment. With respect to the impact of transfer of residuals into District 800, and dewatering of District 800 and 900, there are no groundwater users in the vicinity of Angus Place Colliery that will be impacted by the Project. As above, modelling indicates that the temporary increase in salinity in District 800 will be dissipated by August 2023, whilst simultaneously facilitating recapture of potentially impacted groundwater.
iii. causes persistent organic chemicals, heavy metals, salt or other potentially harmful substances to accumulate in the environment	Yes	Whilst transfer of by-products from water treatment into stored mine water within District 800 will lead to an accumulation of salt in the environment, that stored mine water will be extracted following completion of the treatment phase of the Project via the, soon to be commissioned, Springvale Water Treatment Project.
iv. seriously affects the habitat or lifecycle of a native species dependent on a water resource, or	Yes	As presented in **Section 4.4**, there is no expected change to surface water/groundwater interaction with respect to Kangaroo Creek, Lambs Creek, the Coxs River and the Wolgan River on the Newnes Plateau due to the Project, since the Lithgow Seam lies well below the thalweg of these watercourses. Analysis presented in **Section 4.4** indicates there is potential for change to surface water/groundwater interaction in the Wolgan River within the Wolgan Valley, due to seepage from District 800 toward the Wolgan Valley. Review indicates that the hydraulic gradient between District 800 and the

Impact Guideline	Compliant	Comment
		Wolgan Valley is low and the expected groundwater velocity is 9.7m/year. Nullifying the hydraulic gradient between District 800 and the Wolgan Valley, following completion of the Project, will facilitate recapture of potentially impacted groundwater that may have seeped up to 48m from District 800 toward the Wolgan Valley.
v. causes the establishment of an invasive species (or the spread of an existing invasive species) that is harmful to the ecosystem function of the water resource, or	N/A	N/A
b) there is a significant worsening of local water quality (where current local water quality is superior to local or regional water quality objectives), or	Yes	As above, modelling indicates that the temporary increase in salinity in District 800 will be dissipated by August 2023 by dewatering to the Springvale Water Treatment Project, as capacity permits. As above, recapture of potentially impacted groundwater that may seep from District 800 toward the Wolgan Valley, through the unmined Lithgow Seam, will be facilitated through nullifying the hydraulic gradient between District 800 and the Wolgan Valley.
c) high quality water is released into an ecosystem which is adapted to a lower quality of water.	N/A	N/A

6.2.2 Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000

Assessment of the impact of the modification against ANZECC (2000) is presented in **Section 6.4.1** in regard to the NSW Groundwater Quality Protection Policy (DLWC, 1998).

6.2.3 Australian Drinking Water Guidelines 2011

As presented in **Section 5.6**, the Project does not result in change to surface water/groundwater within the Sydney Drinking Water Catchment.

Accordingly, there is no impact due to the Project with respect to the Australian Drinking Water Guidelines. This is further discussed in **Section 6.3.1**.

6.3 NSW Legislation

6.3.1 Environmental Planning and Assessment Act 1979

6.3.1.1 State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011

As presented in **Section 5.6**, change to surface water/groundwater interaction due to the Project is limited to the Wolgan River within the Wolgan Valley.

Because there is no change to water quality in tributaries to the Drinking Water Catchment, the Project meets the Neutral or Beneficial Effect on Water Quality test.

The increase in mine water discharge through Angus Place LDP001, to up to 10ML/d (treated to 350µS/cm), will be undertaken as a Section 75W modification, Modification 5, and is not assessed in this assessment report.

6.3.2 Water Management Act 2000 (NSW)

There are no changes to groundwater licensing associated with the Project. Dewatering operations will be managed in accordance with the currently available licences listed in **Table 2.1**.

As noted in **Section 4.2.2.1**, the maximum rate of groundwater extraction from Angus Place Colliery in the SAPRMM was set at 13.4ML/d, which was the predicted mine inflow rate presented in the Surface and Groundwater Assessment for Modification 4 (RPS, 2014).

It was further noted in **Section 4.2.2.1**, that discharge of 'raw' mine water, at up to 6.9ML/d, which is the limit based on the current interpretation of the relevant Water Access Licence however may be revised in the future, to the SDWTS through the Bore 940 facility, if required.

6.3.3 Biodiversity Conservation Act 2016

The Project does not comprise any change to mining operation, either first or secondary workings, therefore there is no change due to Project with respect to subsidence. There is also no change to existing mine inflows due to the Project.

As such, there is no predicted change to THPSS communities due to the Project.

Accordingly, there is no impact on THPSS communities due to the Project.

6.4 NSW Guidelines and Policy

6.4.1 NSW Groundwater Protection Policy

An assessment of the Project against the NSW Groundwater Quality Protection Policy management principles is presented in **Table 6.2**.

In regard to potential impact to the Wolgan River within the Wolgan Valley, modelling indicates that the Project will lead to a temporary increase in salinity within District 800, however, that increase will be reverted to background water quality, through dewatering to the Springvale Water Treatment Project, once it becomes operational. Analysis indicates that the average groundwater velocity through the unmined Lithgow Seam is very low. Nullifying the hydraulic gradient between District 800 and the Wolgan Valley will facilitate recapture of potentially impacted groundwater

Table 6.2 : Groundwater Quality Protection Management Principles (DLWC, 1998)

Quality Protection Management Principle	Compliant	Assessment
All groundwater systems should be managed such that their most sensitive identified beneficial use (or environmental value) is maintained.	Yes	The most sensitive environmental value is the Protection of Aquatic Ecosystems through surface water/groundwater interaction. As presented in **Section 4.4**, there is no expected change to surface water/groundwater interaction with respect to Kangaroo Creek, Lambs Creek, the Coxs River and the Wolgan River on the Newnes Plateau due to the Project, since the Lithgow Seam lies well below the thalweg of these watercourses. Analysis presented in **Section 4.5** indicates there is potential for change to surface water/groundwater interaction in the Wolgan River within the Wolgan Valley, due to seepage from District 800 toward the Wolgan Valley. This change is outside of the proposed dewatering of District 800 following completion of the Project. Review indicates that the hydraulic gradient between District 800 and the Wolgan Valley is low and the expected groundwater velocity is 9.7m/year. Nullifying the hydraulic gradient between District 800 and the Wolgan Valley, following completion of the Project, will facilitate recapture of potentially impacted

Quality Protection Management Principle	Compliant	Assessment
		groundwater that may have seeped up to 48m from District 800 toward the Wolgan Valley.
Town water supplies should be afforded special protection against contamination.	Yes	There are no town water supplies in the vicinity of Angus Place Colliery, including the Project.
Groundwater pollution should be prevented so that future remediation is not required.	No	The Project proposes to temporarily transfer residuals from the water treatment process into stored mine water in existing workings (District 800). Following completion of the Project, stored mine water will be transferred to the Springvale Water Treatment Project for treatment and beneficial re-use. Analysis presented in **Section 4.5** indicates that potentially impacted groundwater may seep up to 48m from District 800 toward the Wolgan Valley through the unmined Lithgow Seam. As explained above, nullifying the hydraulic gradient between District 800 and the Wolgan Valley will facilitate recapture of stored residuals.
For new developments, the scale and scope of work required to demonstrate adequate groundwater protection shall be commensurate with the risk the development poses to a groundwater system and the value of the groundwater resource.	Yes	There has been significant study of the groundwater system at Angus Place Colliery and the adjacent operation at Springvale Mine. A groundwater model of Angus Place Colliery has been developed over many years (CSIRO, 2007, 2013 and 2016) and is the basis of predicted inflows to existing workings at Angus Place. As documented in this report, a water balance model for residual management has been developed and is presented in **Section 4.2**. In addition, a simple hydrogeochemical model for residual management was developed and is presented in **Section 4.3**. Accordingly, a significant amount of analysis has been undertaken to determine the expected changes in water quality in stored mine water in District 800 due to the Project.
A groundwater pumper shall bear the responsibility for environmental damage or degradation caused by using groundwaters that are incompatible with soil, vegetation or receiving waters.	Yes	The increase in mine water discharge through Angus Place LDP001, to up to 10ML/d (treated to 350µS/cm), will be undertaken as a Section 75W modification, Modification 5, and is not assessed in this assessment report.
Groundwater dependent ecosystems will be afforded protection.	Yes	As identified in **Section 5.4**, there is no proposed change to high priority groundwater dependent ecosystems on the Newnes Plateau because the Project does not include additional mining. Accordingly, there is no impact from the Project on those groundwater dependent ecosystems.
Groundwater quality protection should be integrated with the management of groundwater quantity.	Yes	Groundwater extraction at Angus Place Colliery occurs to allow safe operation of underground mining using the longwall method. Angus Place Colliery is currently in Care and Maintenance. The quality of mine water discharge is restricted through the Environmental

Quality Protection Management Principle	Compliant	Assessment
		Protection Licence (EPL) at Licensed Discharge Point (LDP) 001.
The cumulative impacts of developments on groundwater quality should be recognised by all those who manage, use, or impact on the resource.	Yes	As presented in **Section 5.1**, Springvale Mine is located up-gradient of the Project and therefore transfer of residuals into stored mine water in District 800 will not impact Springvale Mine. Modelling indicates that the Project will not lead to an exceedance of the volumetric and water quality (salinity) contractual limitations of the Springvale Water Treatment Project. With respect to the Angus Place Mine Extension Project, the Project will completed (dissipation of stored residuals by August 2023) prior to the expected commencement of the Angus Place Mine Extension Project, if approved.
Where possible and practical, environmentally degraded areas should be rehabilitated and their ecosystem support functions restored.	Yes	Residuals from the Project will be, temporarily, transferred underground. Following completion of the Project that stored mine water will be extracted and transferred to the Springvale Water Treatment Project for treatment and beneficial re-use.

6.4.2 NSW Aquifer Interference Policy

Table 6.3 presents an assessment of the Project against the Level 1 Minimum Harm Criteria for Less Productive and Highly Productive Porous Rock groundwater sources.

Table 6.3 : Level 1 Minimal Impact Consideration (NSW Office of Water, 2012)

Level 1 Minimal Impact Consideration	Compliant	Assessment
Water table: • Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 metres from any: ○ high priority groundwater dependent ecosystem or ○ high priority culturally significant site listed in the schedule of the relevant water sharing plan. OR • A maximum of a 2 metre water table decline cumulatively at any water supply work.	Yes	There is no proposed change to the water table (perched or shallow groundwater systems) associated with the Project, outside of that already assessed and approved with respect to Angus Place Colliery. Accordingly, there is therefore no expected change to any water supply work in the vicinity of Angus Place Colliery. It is noted that there are no water supply works between District 800 and the Wolgan Valley.
Water pressure: A cumulative pressure head decline of not more than a 2 metre decline, at any water supply work.	Yes	There is minimal change to water pressure (deep groundwater system) associated with the Project. Angus Place Colliery is already depressurised, however, the groundwater level has been allowed to recover to 805mAHD in District 800 and 800mAHD in District 900. Accordingly, there is therefore no expected change to any water supply work in the vicinity of Angus Place Colliery. It is noted that there are no water supply works between District 800 and the Wolgan Valley.
Water quality: Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.	Yes	Modelling indicates that the salinity of groundwater currently stored in District 800 will increase from 804mg/L (1,200µS/cm) on 1 July 2018 to 2,541mg/L (3,790µS/cm) on 2

Level 1 Minimal Impact Consideration	Compliant	Assessment
		January 2020, due to storage of residuals in District 800. Analysis indicates that the hydraulic gradient between District 700 and the Wolgan Valley (closest point of outcrop of the Lithgow Seam) is minor, and expected groundwater movement in the 5 years of proposed storage will be 48m only. Dewatering of District 800 will nullify the hydraulic gradient, thereby facilitating recapture of the stored residuals that may have seeped toward the Wolgan Valley. Accordingly, the beneficial use class of the groundwater source will not be lowered at 40m beyond the activity since stored residuals will be recaptured and groundwater quality will return to background levels by August 2023.

7. Licensing, Management, Mitigation and Monitoring

This chapter presents changes to licensing, management and monitoring due to the Project.

7.1 Licensing

There are no proposed changes to groundwater licensing associated with the Water Sharing Plans under the *Water Management Act* 2000 (NSW).

As identified above, 6.9ML/d is extracted from the Bore 940 facility currently. The 6.9ML/d rate is based on the current interpretation of the relevant Water Access Licence; however, this may be revised in the future.

7.2 Management

The Project will operate between 1 July 2018 and 31 December 2019, with residuals temporarily transferred into stored mine water within the 800 Panel Area.

From 1 January 2020, or earlier, as relevant, up to 13.4ML/d of mine water from the underground workings (800 and 900 Panel Areas) will be transferred to the Springvale Water Treatment Project for treatment and beneficial re-use within the Mt Piper Power Station cooling water system. This may occur via transfers to the SDWTS using the 940 Bore or through a new pipeline to be installed from the Angus Place pit top to the raw water pipeline in the Springvale Water Treatment Project and which will run along the existing Wallerawang Haul Road.

Nullifying the hydraulic gradient between District 800 and the Wolgan Valley, in accordance with the suggested target elevations presented in **Section 4.5**, will facilitate recapture of potentially impacted groundwater that may seep toward the Wolgan Valley due to the Project.

It is noted that the approach to dewatering of stored mine water within District 800 and District 900 is expected to consist of both existing infrastructure and new boreholes, if required, and will be determined by Site.

7.3 Mitigation

Drawdown of the water level in the 800 District is the main mitigation in the Project. It is expected that residuals temporarily transferred into stored mine water in District 800 will be able to be recovered when dewatering commences.

7.4 Monitoring

It is recommended that monitoring of the Wolgan River (monthly water quality) is undertaken. It is suggested that the following stations be considered (subject to satisfactory access):

- Wolgan River on the Newnes Plateau, up-gradient of the 800 Panel Area
- Wolgan River in Wolgan Valley, down-gradient of the 800 Panel Area.

8. References

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9. Limitations

This report has been prepared for use by the client who has commissioned the works in accordance with the project brief only, and has been based in part on information obtained from the client and other parties.

The advice herein relates only to this project and all results conclusions and recommendations made should be reviewed by a competent person with experience in environmental investigations, before being used for any other purpose.

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Appendix A PHREEQCi Model Output

Figure A.1: PHREEQCi Model Output - R02RevA_PRD_01d.pqi (Effect of Treatment)

```
   Input file: C:\Users\jbell\Jobs\54568\Phreeqci\Runs\R02RevA_PRD_01d.pqi
  Output file: C:\Users\jbell\Jobs\54568\Phreeqci\Runs\R02RevA_PRD_01d.pqo
Database file: C:\Program Files (x86)\USGS\Phreeqc Interactive 3.4.0-12927\database\phreeqc.dat

------------------
Reading data base.
------------------

        SOLUTION_MASTER_SPECIES
        SOLUTION_SPECIES
        PHASES
        EXCHANGE_MASTER_SPECIES
        EXCHANGE_SPECIES
        SURFACE_MASTER_SPECIES
        SURFACE_SPECIES
        RATES
        END
------------------------------------
Reading input data for simulation 1.
------------------------------------

        DATABASE C:\Program Files (x86)\USGS\Phreeqc Interactive 3.4.0-12927\database\phreeqc.dat
        TITLE Solution Definition
        SOLUTION 1 Bore 940 7/12/2017
        units mg/L
        pH      7.7
        temp 22.1
        Ca 8
        Mg 6
        Na 247
        K 18
        Cl 8
        Alkalinity       644 as HCO3-
        S(6) 11
        Al 0.005 #half of DL
        As  0.067 #not in database
        Ba 0.069
        B 0.07
        Cd 0.00005 #half of DL
        Cr 0.0005 #half of DL, not in database
        Cu 0.0005 #half of DL
        F 1.2 #estimated
        Fe 0.23
        Li 0.202
        Mn 0.015
        Ni 0.005 #not in database
        Pb 0.0005 #half of DL
        Si 4.15
        Sr 0.048
        Zn 0.0025 #half of DL
        END
-----
TITLE
-----

 Solution Definition

WARNING: Could not find element in database, As.
        Concentration is set to zero.
WARNING: Could not find element in database, Cr.
        Concentration is set to zero.
WARNING: Could not find element in database, Ni.
        Concentration is set to zero.
-------------------------------------------
Beginning of initial solution calculations.
-------------------------------------------

Initial solution 1.       Bore 940 7/12/2017

-----------------------------Solution composition------------------------------

        Elements           Molality       Moles

        Al                1.855e-07   1.855e-07
        Alkalinity        1.056e-02   1.056e-02
        B                 6.482e-06   6.482e-06
        Ba                5.029e-07   5.029e-07
        Ca                1.998e-04   1.998e-04
        Cd                4.453e-10   4.453e-10
        Cl                2.259e-04   2.259e-04
        Cu                7.876e-09   7.876e-09
        F                 6.322e-05   6.322e-05
        Fe                4.122e-06   4.122e-06
        K                 4.608e-04   4.608e-04
```

```
        Li                2.914e-05    2.914e-05
        Mg                2.470e-04    2.470e-04
        Mn                2.733e-07    2.733e-07
        Na                1.075e-02    1.075e-02
        Pb                2.416e-09    2.416e-09
        S(6)              1.146e-04    1.146e-04
        Si                6.914e-05    6.914e-05
        Sr                5.483e-07    5.483e-07
        Zn                3.828e-08    3.828e-08

----------------------------Description of solution----------------------------

                                       pH  =   7.700
                                       pe  =   4.000
      Specific Conductance (µS/cm,  22°C)  = 964
                          Density (g/cm³)  =   0.99845
                               Volume (L)  =   1.00252
                        Activity of water  =   1.000
                 Ionic strength (mol/kgw)  =   1.204e-02
                       Mass of water (kg)  =   1.000e+00
                    Total carbon (mol/kg)  =   1.095e-02
                       Total CO2 (mol/kg)  =   1.095e-02
                         Temperature (°C)  =  22.10
                  Electrical balance (eq)  =   1.063e-03
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =   4.62
                               Iterations  =  10
                                  Total H  = 1.110232e+02
                                  Total O  = 5.553940e+01

----------------------------Distribution of species----------------------------

                                               Log       Log       Log    mole V
   Species          Molality    Activity  Molality  Activity     Gamma   cm³/mol

   OH-             4.540e-07   4.052e-07    -6.343    -6.392    -0.049     -4.14
   H+              2.198e-08   1.995e-08    -7.658    -7.700    -0.042      0.00
   H2O             5.551e+01   9.996e-01     1.744    -0.000     0.000     18.06
Al            1.855e-07
   Al(OH)4-        1.833e-07   1.641e-07    -6.737    -6.785    -0.048     (0)
   Al(OH)3         1.799e-09   1.804e-09    -8.745    -8.744     0.001     (0)
   Al(OH)2+        3.382e-10   3.038e-10    -9.471    -9.517    -0.047     (0)
   AlF2+           4.064e-11   3.650e-11   -10.391   -10.438    -0.047     (0)
   AlF3            2.542e-11   2.549e-11   -10.595   -10.594     0.001     (0)
   AlF+2           2.042e-12   1.329e-12   -11.690   -11.876    -0.187     (0)
   AlOH+2          1.538e-12   1.001e-12   -11.813   -12.000    -0.187    -27.43
   AlF4-           6.299e-13   5.641e-13   -12.201   -12.249    -0.048     (0)
   Al+3            5.814e-15   2.431e-15   -14.236   -14.614    -0.379    -41.64
   AlSO4+          5.727e-16   5.129e-16   -15.242   -15.290    -0.048     (0)
   Al(SO4)2-       1.238e-18   1.109e-18   -17.907   -17.955    -0.048     (0)
   AlHSO4+2        1.382e-24   8.854e-25   -23.859   -24.053    -0.193     (0)
B             6.482e-06
   H3BO3           6.289e-06   6.306e-06    -5.201    -5.200     0.001     39.00
   H2BO3-          1.927e-07   1.724e-07    -6.715    -6.763    -0.048     (0)
   BF(OH)3-        1.514e-10   1.355e-10    -9.820    -9.868    -0.048     (0)
   BF2(OH)2-       1.808e-14   1.618e-14   -13.743   -13.791    -0.048     (0)
   BF3OH-          2.323e-20   2.078e-20   -19.634   -19.682    -0.048     (0)
   BF4-            1.055e-25   9.439e-26   -24.977   -25.025    -0.048     (0)
Ba            5.029e-07
   Ba+2            4.626e-07   2.967e-07    -6.335    -6.528    -0.193    -12.67
   BaHCO3+         2.708e-08   2.423e-08    -7.567    -7.616    -0.048     (0)
   BaSO4           1.027e-08   1.030e-08    -7.988    -7.987     0.001     (0)
   BaCO3           2.977e-09   2.985e-09    -8.526    -8.525     0.001    -10.73
   BaOH+           5.614e-13   5.036e-13   -12.251   -12.298    -0.047     (0)
C(4)          1.095e-02
   HCO3-           1.039e-02   9.333e-03    -1.983    -2.030    -0.047     24.56
   CO2             4.340e-04   4.352e-04    -3.363    -3.361     0.001     34.29
   NaHCO3          5.101e-05   5.115e-05    -4.292    -4.291     0.001      1.80
   CO3-2           3.172e-05   2.064e-05    -4.499    -4.685    -0.187     -5.23
   MgHCO3+         1.770e-05   1.582e-05    -4.752    -4.801    -0.049      5.45
   CaHCO3+         1.476e-05   1.329e-05    -4.831    -4.877    -0.046      9.62
   CaCO3           3.827e-06   3.838e-06    -5.417    -5.416     0.001    -14.61
   NaCO3-          3.553e-06   3.179e-06    -5.449    -5.498    -0.048     -1.19
   MgCO3           2.755e-06   2.763e-06    -5.560    -5.559     0.001    -17.09
   FeHCO3+         1.640e-07   1.468e-07    -6.785    -6.833    -0.048     (0)
   MnCO3           1.090e-07   1.093e-07    -6.963    -6.962     0.001     (0)
   FeCO3           7.766e-08   7.787e-08    -7.110    -7.109     0.001     (0)
   MnHCO3+         6.179e-08   5.543e-08    -7.209    -7.256    -0.047     (0)
   SrHCO3+         4.634e-08   4.162e-08    -7.334    -7.381    -0.047     (0)
   BaHCO3+         2.708e-08   2.423e-08    -7.567    -7.616    -0.048     (0)
   ZnCO3           1.588e-08   1.592e-08    -7.799    -7.798     0.001     (0)
   Zn(CO3)2-2      1.097e-08   7.029e-09    -7.960    -8.153    -0.193     (0)
   ZnHCO3+         5.077e-09   4.542e-09    -8.294    -8.343    -0.048     (0)
   CuCO3           4.983e-09   4.997e-09    -8.302    -8.301     0.001     (0)
   SrCO3           3.884e-09   3.895e-09    -8.411    -8.410     0.001    -14.14
   (CO2)2          3.145e-09   3.154e-09    -8.502    -8.501     0.001     68.58
   BaCO3           2.977e-09   2.985e-09    -8.526    -8.525     0.001    -10.73
   PbCO3           2.172e-09   2.178e-09    -8.663    -8.662     0.001     (0)
   CuHCO3+         2.357e-10   2.108e-10    -9.628    -9.676    -0.048     (0)
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Cu(CO3)2-2	2.027e-10	1.299e-10	-9.693	-9.886	-0.193	(0)
Pb(CO3)2-2	1.763e-10	1.130e-10	-9.754	-9.947	-0.193	(0)
CdHCO3+	7.514e-11	6.723e-11	-10.124	-10.172	-0.048	(0)
PbHCO3+	5.032e-11	4.502e-11	-10.298	-10.347	-0.048	(0)
CdCO3	3.725e-12	3.735e-12	-11.429	-11.428	0.001	(0)
Cd(CO3)2-2	3.807e-13	2.439e-13	-12.419	-12.613	-0.193	(0)
Ca	1.998e-04					
Ca+2	1.798e-04	1.169e-04	-3.745	-3.932	-0.187	-17.94
CaHCO3+	1.476e-05	1.329e-05	-4.831	-4.877	-0.046	9.62
CaCO3	3.827e-06	3.838e-06	-5.417	-5.416	0.001	-14.61
CaSO4	1.406e-06	1.410e-06	-5.852	-5.851	0.001	7.39
CaOH+	1.087e-09	9.723e-10	-8.964	-9.012	-0.048	(0)
CaHSO4+	1.984e-13	1.775e-13	-12.702	-12.751	-0.048	(0)
Cd	4.453e-10					
Cd+2	3.556e-10	2.278e-10	-9.449	-9.642	-0.193	-18.66
CdHCO3+	7.514e-11	6.723e-11	-10.124	-10.172	-0.048	(0)
CdCl+	4.858e-12	4.346e-12	-11.314	-11.362	-0.048	5.19
CdSO4	4.458e-12	4.471e-12	-11.351	-11.350	0.001	79.54
CdCO3	3.725e-12	3.735e-12	-11.429	-11.428	0.001	(0)
CdOH+	8.539e-13	7.639e-13	-12.069	-12.117	-0.048	(0)
Cd(CO3)2-2	3.807e-13	2.439e-13	-12.419	-12.613	-0.193	(0)
CdF+	1.783e-13	1.595e-13	-12.749	-12.797	-0.048	(0)
CdOHCl	8.425e-14	8.449e-14	-13.074	-13.073	0.001	(0)
Cd(SO4)2-2	5.398e-15	3.458e-15	-14.268	-14.461	-0.193	-107.39
CdCl2	3.606e-15	3.616e-15	-14.443	-14.442	0.001	23.14
Cd(OH)2	2.547e-15	2.554e-15	-14.594	-14.593	0.001	(0)
CdF2	2.223e-17	2.229e-17	-16.653	-16.652	0.001	(0)
CdCl3-	4.922e-19	4.404e-19	-18.308	-18.356	-0.048	71.55
Cd(OH)3-	1.605e-20	1.436e-20	-19.795	-19.843	-0.048	(0)
Cd2OH+3	2.407e-21	8.839e-22	-20.618	-21.054	-0.435	(0)
Cd(OH)4-2	1.001e-26	6.410e-27	-26.000	-26.193	-0.193	(0)
Cl	2.259e-04					
Cl-	2.259e-04	2.017e-04	-3.646	-3.695	-0.049	18.06
MnCl+	6.105e-11	5.476e-11	-10.214	-10.262	-0.047	-3.78
FeCl+	4.895e-11	4.379e-11	-10.310	-10.359	-0.048	(0)
CdCl+	4.858e-12	4.346e-12	-11.314	-11.362	-0.048	5.19
ZnCl+	2.064e-12	1.845e-12	-11.685	-11.734	-0.049	-16.85
ZnOHCl	1.290e-12	1.294e-12	-11.889	-11.888	0.001	(0)
CdOHCl	8.425e-14	8.449e-14	-13.074	-13.073	0.001	(0)
PbCl+	5.069e-14	4.535e-14	-13.295	-13.343	-0.048	7.90
CuCl2-	3.337e-14	2.983e-14	-13.477	-13.525	-0.049	(0)
CuCl+	2.372e-14	2.120e-14	-13.625	-13.674	-0.049	1.49
MnCl2	4.809e-15	4.823e-15	-14.318	-14.317	0.001	89.59
CdCl2	3.606e-15	3.616e-15	-14.443	-14.442	0.001	23.14
ZnCl2	3.841e-16	3.852e-16	-15.416	-15.414	0.001	107.93
PbCl2	1.527e-17	1.532e-17	-16.816	-16.815	0.001	34.73
CuCl3-2	1.457e-17	9.431e-18	-16.837	-17.025	-0.189	(0)
CuCl2	2.220e-18	2.226e-18	-17.654	-17.653	0.001	27.52
FeCl+2	1.097e-18	7.102e-19	-17.960	-18.149	-0.189	(0)
CdCl3-	4.922e-19	4.404e-19	-18.308	-18.356	-0.048	71.55
MnCl3-	2.987e-19	2.680e-19	-18.525	-18.572	-0.047	43.56
ZnCl3-	9.583e-20	8.567e-20	-19.018	-19.067	-0.049	16.68
PbCl3-	2.694e-21	2.410e-21	-20.570	-20.618	-0.048	65.66
FeCl2+	7.828e-22	7.022e-22	-21.106	-21.154	-0.047	(0)
ZnCl4-2	1.307e-23	8.463e-24	-22.884	-23.072	-0.189	145.08
CuCl3-	1.692e-24	1.513e-24	-23.772	-23.820	-0.049	(0)
PbCl4-2	3.552e-25	2.276e-25	-24.449	-24.643	-0.193	101.15
FeCl3	1.413e-26	1.417e-26	-25.850	-25.849	0.001	(0)
CuCl4-2	2.207e-30	1.429e-30	-29.656	-29.845	-0.189	(0)
Cu(1)	2.622e-12					
Cu+	2.589e-12	2.302e-12	-11.587	-11.638	-0.051	(0)
CuCl2-	3.337e-14	2.983e-14	-13.477	-13.525	-0.049	(0)
CuCl3-2	1.457e-17	9.431e-18	-16.837	-17.025	-0.189	(0)
Cu(2)	7.873e-09					
CuCO3	4.983e-09	4.997e-09	-8.302	-8.301	0.001	(0)
Cu(OH)2	2.357e-09	2.364e-09	-8.628	-8.626	0.001	(0)
CuHCO3+	2.357e-10	2.108e-10	-9.628	-9.676	-0.048	(0)
Cu(CO3)2-2	2.027e-10	1.299e-10	-9.693	-9.886	-0.193	(0)
Cu+2	6.872e-11	4.507e-11	-10.163	-10.346	-0.183	-26.36
CuOH+	2.526e-11	2.258e-11	-10.598	-10.646	-0.049	(0)
CuSO4	6.231e-13	6.248e-13	-12.205	-12.204	0.001	12.72
CuF+	4.965e-14	4.442e-14	-13.304	-13.352	-0.048	(0)
CuCl+	2.372e-14	2.120e-14	-13.625	-13.674	-0.049	1.49
Cu(OH)3-	7.975e-15	7.135e-15	-14.098	-14.147	-0.048	(0)
Cu2(OH)2+2	2.604e-16	1.668e-16	-15.584	-15.778	-0.193	(0)
CuCl2	2.220e-18	2.226e-18	-17.654	-17.653	0.001	27.52
Cu(OH)4-2	1.113e-19	7.132e-20	-18.953	-19.147	-0.193	(0)
CuCl3-	1.692e-24	1.513e-24	-23.772	-23.820	-0.049	(0)
CuCl4-2	2.207e-30	1.429e-30	-29.656	-29.845	-0.189	(0)
F	6.322e-05					
F-	6.234e-05	5.563e-05	-4.205	-4.255	-0.049	-1.28
MgF+	5.708e-07	5.112e-07	-6.244	-6.291	-0.048	-10.51
NaF	3.060e-07	3.069e-07	-6.514	-6.513	0.001	7.15
HF	1.576e-09	1.581e-09	-8.802	-8.801	0.001	12.36
BF(OH)3-	1.514e-10	1.355e-10	-9.820	-9.868	-0.048	(0)
FeF+	9.778e-11	8.748e-11	-10.010	-10.058	-0.048	(0)
AlF2+	4.064e-11	3.650e-11	-10.391	-10.438	-0.047	(0)
MnF+	2.859e-11	2.565e-11	-10.544	-10.591	-0.047	(0)

AlF3	2.542e-11	2.549e-11	-10.595	-10.594	0.001	(0)
ZnF+	3.273e-12	2.928e-12	-11.485	-11.533	-0.048	(0)
AlF+2	2.042e-12	1.329e-12	-11.690	-11.876	-0.187	(0)
AlF4-	6.299e-13	5.641e-13	-12.201	-12.249	-0.048	(0)
HF2-	3.684e-13	3.295e-13	-12.434	-12.482	-0.048	21.99
CdF+	1.783e-13	1.595e-13	-12.749	-12.797	-0.048	(0)
CuF+	4.965e-14	4.442e-14	-13.304	-13.352	-0.048	(0)
FeF2+	2.572e-14	2.307e-14	-13.590	-13.637	-0.047	(0)
BF2(OH)2-	1.808e-14	1.618e-14	-13.743	-13.791	-0.048	(0)
FeF+2	1.666e-14	1.078e-14	-13.778	-13.967	-0.189	(0)
PbF+	6.715e-15	6.007e-15	-14.173	-14.221	-0.048	(0)
FeF3	2.008e-15	2.014e-15	-14.697	-14.696	0.001	(0)
CdF2	2.223e-17	2.229e-17	-16.653	-16.652	0.001	(0)
PbF2	6.805e-18	6.823e-18	-17.167	-17.166	0.001	(0)
BF3OH-	2.323e-20	2.078e-20	-19.634	-19.682	-0.048	(0)
PbF3-	3.074e-21	2.750e-21	-20.512	-20.561	-0.048	(0)
PbF4-2	1.143e-25	7.323e-26	-24.942	-25.135	-0.193	(0)
BF4-	1.055e-25	9.439e-26	-24.977	-25.025	-0.048	(0)
SiF6-2	9.913e-31	6.418e-31	-30.004	-30.193	-0.189	42.67
Fe(2)	4.857e-07					
Fe+2	2.398e-07	1.572e-07	-6.620	-6.803	-0.183	-22.09
FeHCO3+	1.640e-07	1.468e-07	-6.785	-6.833	-0.048	(0)
FeCO3	7.766e-08	7.787e-08	-7.110	-7.109	0.001	(0)
FeOH+	2.231e-09	2.002e-09	-8.651	-8.699	-0.047	(0)
FeSO4	1.831e-09	1.836e-09	-8.737	-8.736	0.001	22.13
FeF+	9.778e-11	8.748e-11	-10.010	-10.058	-0.048	(0)
FeCl+	4.895e-11	4.379e-11	-10.310	-10.359	-0.048	(0)
Fe(OH)2	6.597e-13	6.616e-13	-12.181	-12.179	0.001	(0)
Fe(OH)3-	1.334e-15	1.196e-15	-14.875	-14.922	-0.047	(0)
FeHSO4+	2.668e-16	2.387e-16	-15.574	-15.622	-0.048	(0)
Fe(3)	3.637e-06					
Fe(OH)3	2.928e-06	2.936e-06	-5.533	-5.532	0.001	(0)
Fe(OH)2+	5.755e-07	5.169e-07	-6.240	-6.287	-0.047	(0)
Fe(OH)4-	1.328e-07	1.193e-07	-6.877	-6.923	-0.047	(0)
FeOH+2	5.378e-11	3.482e-11	-10.269	-10.458	-0.189	(0)
FeF2+	2.572e-14	2.307e-14	-13.590	-13.637	-0.047	(0)
FeF+2	1.666e-14	1.078e-14	-13.778	-13.967	-0.189	(0)
FeF3	2.008e-15	2.014e-15	-14.697	-14.696	0.001	(0)
Fe+3	3.058e-16	1.279e-16	-15.515	-15.893	-0.379	(0)
FeSO4+	1.015e-16	9.107e-17	-15.993	-16.041	-0.047	(0)
FeCl+2	1.097e-18	7.102e-19	-17.960	-18.149	-0.189	(0)
Fe2(OH)2+4	2.187e-19	3.683e-20	-18.660	-19.434	-0.774	(0)
Fe(SO4)2-	1.525e-19	1.365e-19	-18.817	-18.865	-0.048	(0)
FeCl2+	7.828e-22	7.022e-22	-21.106	-21.154	-0.047	(0)
Fe3(OH)4+5	8.429e-23	5.212e-24	-22.074	-23.283	-1.209	(0)
FeHSO4+2	7.613e-24	4.877e-24	-23.118	-23.312	-0.193	(0)
FeCl3	1.413e-26	1.417e-26	-25.850	-25.849	0.001	(0)
H(0)	5.787e-27					
H2	2.894e-27	2.902e-27	-26.539	-26.537	0.001	28.61
K	4.608e-04					
K+	4.606e-04	4.112e-04	-3.337	-3.386	-0.049	8.98
KSO4-	2.118e-07	1.902e-07	-6.674	-6.721	-0.047	34.10
Li	2.914e-05					
Li+	2.913e-05	2.621e-05	-4.536	-4.581	-0.046	-1.26
LiSO4-	8.839e-09	7.928e-09	-8.054	-8.101	-0.047	(0)
Mg	2.470e-04					
Mg+2	2.238e-04	1.466e-04	-3.650	-3.834	-0.184	-21.48
MgHCO3+	1.770e-05	1.582e-05	-4.752	-4.801	-0.049	5.45
MgCO3	2.755e-06	2.763e-06	-5.560	-5.559	0.001	-17.09
MgSO4	2.203e-06	2.209e-06	-5.657	-5.656	0.001	5.72
MgF+	5.708e-07	5.112e-07	-6.244	-6.291	-0.048	-10.51
MgOH+	2.272e-08	2.048e-08	-7.644	-7.689	-0.045	(0)
Mn(2)	2.733e-07					
MnCO3	1.090e-07	1.093e-07	-6.963	-6.962	0.001	(0)
Mn+2	1.016e-07	6.663e-08	-6.993	-7.176	-0.183	-19.79
MnHCO3+	6.179e-08	5.543e-08	-7.209	-7.256	-0.047	(0)
MnSO4	7.742e-10	7.764e-10	-9.111	-9.110	0.001	23.88
MnOH+	7.534e-11	6.758e-11	-10.123	-10.170	-0.047	(0)
MnCl+	6.105e-11	5.476e-11	-10.214	-10.262	-0.047	-3.78
MnF+	2.859e-11	2.565e-11	-10.544	-10.591	-0.047	(0)
MnCl2	4.809e-15	4.823e-15	-14.318	-14.317	0.001	89.59
MnCl3-	2.987e-19	2.680e-19	-18.525	-18.572	-0.047	43.56
Mn(OH)3-	1.480e-19	1.328e-19	-18.830	-18.877	-0.047	(0)
Mn(3)	3.210e-29					
Mn+3	3.210e-29	1.343e-29	-28.493	-28.872	-0.379	(0)
Na	1.075e-02					
Na+	1.070e-02	9.586e-03	-1.971	-2.018	-0.048	-1.52
NaHCO3	5.101e-05	5.115e-05	-4.292	-4.291	0.001	1.80
NaSO4-	3.638e-06	3.268e-06	-5.439	-5.486	-0.047	14.49
NaCO3-	3.553e-06	3.179e-06	-5.449	-5.498	-0.048	-1.19
NaF	3.060e-07	3.069e-07	-6.514	-6.513	0.001	7.15
NaOH	3.873e-19	3.884e-19	-18.412	-18.411	0.001	(0)
O(0)	0.000e+00					
O2	0.000e+00	0.000e+00	-40.252	-40.251	0.001	30.17
Pb	2.416e-09					
PbCO3	2.172e-09	2.178e-09	-8.663	-8.662	0.001	(0)
Pb(CO3)2-2	1.763e-10	1.130e-10	-9.754	-9.947	-0.193	(0)
PbHCO3+	5.032e-11	4.502e-11	-10.298	-10.347	-0.048	(0)

```
   Pb+2             9.478e-12   6.072e-12   -11.023   -11.217    -0.193    -15.28
   PbOH+            6.630e-12   5.931e-12   -11.178   -11.227    -0.048     (0)
   PbSO4            2.359e-13   2.366e-13   -12.627   -12.626     0.001     (0)
   Pb(OH)2          1.153e-13   1.156e-13   -12.938   -12.937     0.001     (0)
   PbCl+            5.069e-14   4.535e-14   -13.295   -13.343    -0.048      7.90
   PbF+             6.715e-15   6.007e-15   -14.173   -14.221    -0.048     (0)
   Pb(SO4)2-2       1.343e-16   8.602e-17   -15.872   -16.065    -0.193     (0)
   Pb(OH)3-         7.433e-17   6.650e-17   -16.129   -16.177    -0.048     (0)
   PbCl2            1.527e-17   1.532e-17   -16.816   -16.815     0.001     34.73
   PbF2             6.805e-18   6.823e-18   -17.167   -17.166     0.001     (0)
   Pb(OH)4-2        1.191e-20   7.632e-21   -19.924   -20.117    -0.193     (0)
   PbF3-            3.074e-21   2.750e-21   -20.512   -20.561    -0.048     (0)
   PbCl3-           2.694e-21   2.410e-21   -20.570   -20.618    -0.048     65.66
   Pb2OH+3          2.196e-21   8.063e-22   -20.658   -21.094    -0.435     (0)
   PbCl4-2          3.552e-25   2.276e-25   -24.449   -24.643    -0.193    101.15
   PbF4-2           1.143e-25   7.323e-26   -24.942   -25.135    -0.193     (0)
   Pb3(OH)4+2       1.870e-27   1.198e-27   -26.728   -26.921    -0.193     (0)
S(6)           1.146e-04
   SO4-2            1.071e-04   6.929e-05    -3.970    -4.159    -0.189     14.41
   NaSO4-           3.638e-06   3.268e-06    -5.439    -5.486    -0.047     14.49
   MgSO4            2.203e-06   2.209e-06    -5.657    -5.656     0.001      5.72
   CaSO4            1.406e-06   1.410e-06    -5.852    -5.851     0.001      7.39
   KSO4-            2.118e-07   1.902e-07    -6.674    -6.721    -0.047     34.10
   BaSO4            1.027e-08   1.030e-08    -7.988    -7.987     0.001     (0)
   LiSO4-           8.839e-09   7.928e-09    -8.054    -8.101    -0.047     (0)
   SrSO4            4.191e-09   4.202e-09    -8.378    -8.377     0.001     24.12
   FeSO4            1.831e-09   1.836e-09    -8.737    -8.736     0.001     22.13
   MnSO4            7.742e-10   7.764e-10    -9.111    -9.110     0.001     23.88
   HSO4-            1.411e-10   1.263e-10    -9.850    -9.899    -0.048     40.14
   ZnSO4            6.122e-11   6.139e-11   -10.213   -10.212     0.001     22.20
   CdSO4            4.458e-12   4.471e-12   -11.351   -11.350     0.001     79.54
   CuSO4            6.231e-13   6.248e-13   -12.205   -12.204     0.001     12.72
   PbSO4            2.359e-13   2.366e-13   -12.627   -12.626     0.001     (0)
   CaHSO4+          1.984e-13   1.775e-13   -12.702   -12.751    -0.048     (0)
   Zn(SO4)2-2       5.520e-14   3.536e-14   -13.258   -13.451    -0.193    -15.30
   Cd(SO4)2-2       5.398e-15   3.458e-15   -14.268   -14.461    -0.193   -107.39
   AlSO4+           5.727e-16   5.129e-16   -15.242   -15.290    -0.048     (0)
   FeHSO4+          2.668e-16   2.387e-16   -15.574   -15.622    -0.048     (0)
   Pb(SO4)2-2       1.343e-16   8.602e-17   -15.872   -16.065    -0.193     (0)
   FeSO4+           1.015e-16   9.107e-17   -15.993   -16.041    -0.047     (0)
   Al(SO4)2-        1.238e-18   1.109e-18   -17.907   -17.955    -0.048     (0)
   Fe(SO4)2-        1.525e-19   1.365e-19   -18.817   -18.865    -0.048     (0)
   FeHSO4+2         7.613e-24   4.877e-24   -23.118   -23.312    -0.193     (0)
   AlHSO4+2         1.382e-24   8.854e-25   -23.859   -24.053    -0.193     (0)
Si             6.914e-05
   H4SiO4           6.862e-05   6.881e-05    -4.164    -4.162     0.001     52.33
   H3SiO4-          5.133e-07   4.589e-07    -6.290    -6.338    -0.049     27.97
   H2SiO4-2         1.983e-12   1.291e-12   -11.703   -11.889    -0.187     (0)
   SiF6-2           9.913e-31   6.418e-31   -30.004   -30.193    -0.189     42.67
Sr             5.483e-07
   Sr+2             4.939e-07   3.220e-07    -6.306    -6.492    -0.186    -17.50
   SrHCO3+          4.634e-08   4.162e-08    -7.334    -7.381    -0.047     (0)
   SrSO4            4.191e-09   4.202e-09    -8.378    -8.377     0.001     24.12
   SrCO3            3.884e-09   3.895e-09    -8.411    -8.410     0.001    -14.14
   SrOH+            9.222e-13   8.273e-13   -12.035   -12.082    -0.047     (0)
Zn             3.828e-08
   ZnCO3            1.588e-08   1.592e-08    -7.799    -7.798     0.001     (0)
   Zn(CO3)2-2       1.097e-08   7.029e-09    -7.960    -8.153    -0.193     (0)
   Zn+2             5.971e-09   3.866e-09    -8.224    -8.413    -0.189    -24.93
   ZnHCO3+          5.077e-09   4.542e-09    -8.294    -8.343    -0.048     (0)
   ZnOH+            1.901e-10   1.701e-10    -9.721    -9.769    -0.048     (0)
   Zn(OH)2          1.218e-10   1.222e-10    -9.914    -9.913     0.001     (0)
   ZnSO4            6.122e-11   6.139e-11   -10.213   -10.212     0.001     22.20
   ZnF+             3.273e-12   2.928e-12   -11.485   -11.533    -0.048     (0)
   ZnCl+            2.064e-12   1.845e-12   -11.685   -11.734    -0.049    -16.85
   ZnOHCl           1.290e-12   1.294e-12   -11.889   -11.888     0.001     (0)
   Zn(SO4)2-2       5.520e-14   3.536e-14   -13.258   -13.451    -0.193    -15.30
   Zn(OH)3-         2.163e-14   1.935e-14   -13.665   -13.713    -0.048     (0)
   ZnCl2            3.841e-16   3.852e-16   -15.416   -15.414     0.001    107.93
   Zn(OH)4-2        2.399e-19   1.537e-19   -18.620   -18.813    -0.193     (0)
   ZnCl3-           9.583e-20   8.567e-20   -19.018   -19.067    -0.049     16.68
   ZnCl4-2          1.307e-23   8.463e-24   -22.884   -23.072    -0.189    145.08

------------------------------Saturation indices-------------------------------

  Phase               SI** log IAP   log K(295 K,   1 atm)

  Al(OH)3(a)        -2.51      8.49   10.99  Al(OH)3
  Albite            -3.10    -21.29  -18.19  NaAlSi3O8
  Alunite           -8.31     -9.35   -1.04  KAl3(SO4)2(OH)6
  Anglesite         -7.57    -15.38   -7.81  PbSO4
  Anhydrite         -3.85     -8.09   -4.25  CaSO4
  Anorthite         -6.03    -25.82  -19.80  CaAl2Si2O8
  Aragonite         -0.30     -8.62   -8.32  CaCO3
  Barite            -0.82    -10.69   -9.87  BaSO4
  Ca-Montmorillonite  -1.68    -47.13  -45.45  Ca0.165Al2.33Si3.67O10(OH)2
  Calcite           -0.15     -8.62   -8.46  CaCO3
  Cd(OH)2           -7.89      5.76   13.65  Cd(OH)2
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  CdSiO3           -7.58      1.60    9.18  CdSiO3
  CdSO4           -13.81    -13.80    0.01  CdSO4
  Celestite        -4.01    -10.65   -6.64  SrSO4
  Cerussite        -2.74    -15.90  -13.16  PbCO3
  Chalcedony       -0.58     -4.16   -3.59  SiO2
  Chlorite(14A)    -7.16     62.32   69.47  Mg5Al2Si3O10(OH)8
  Chrysotile       -6.19     26.37   32.56  Mg3Si2O5(OH)4
  CO2(g)           -1.93     -3.36   -1.43  CO2
  Dolomite         -0.11    -17.14  -17.02  CaMg(CO3)2
  Fe(OH)3(a)        2.32      7.21    4.89  Fe(OH)3
  Fluorite         -1.81    -12.44  -10.63  CaF2
  Gibbsite          0.21      8.49    8.27  Al(OH)3
  Goethite          8.10      7.21   -0.90  FeOOH
  Gypsum           -3.51     -8.09   -4.58  CaSO4:2H2O
  H2(g)           -23.44    -26.54   -3.09  H2
  H2O(g)           -1.58     -0.00    1.58  H2O
  Halite           -7.28     -5.71    1.57  NaCl
  Hausmannite     -13.68     48.07   61.75  Mn3O4
  Hematite         18.20     14.41   -3.79  Fe2O3
  Illite           -1.74    -42.40  -40.66  K0.6Mg0.25Al2.3Si3.5O10(OH)2
  Jarosite-K       -4.20    -13.19   -8.98  KFe3(SO4)2(OH)6
  K-feldspar       -1.86    -22.66  -20.79  KAlSi3O8
  K-mica            4.15     17.28   13.13  KAl3Si3O10(OH)2
  Kaolinite         0.96      8.65    7.69  Al2Si2O5(OH)4
  Manganite        -5.42     19.92   25.34  MnOOH
  Melanterite      -8.72    -10.96   -2.24  FeSO4:7H2O
  O2(g)           -37.38    -40.25   -2.87  O2
  Otavite          -2.23    -14.33  -12.10  CdCO3
  Pb(OH)2          -4.07      4.18    8.25  Pb(OH)2
  Pyrochroite      -6.98      8.22   15.20  Mn(OH)2
  Pyrolusite      -10.23     31.62   41.85  MnO2:H2O
  Quartz           -0.14     -4.16   -4.02  SiO2
  Rhodochrosite    -0.74    -11.86  -11.12  MnCO3
  Sepiolite        -5.19     10.65   15.84  Mg2Si3O7.5OH:3H2O
  Sepiolite(d)     -8.01     10.65   18.66  Mg2Si3O7.5OH:3H2O
  Siderite         -0.62    -11.49  -10.87  FeCO3
  SiO2(a)          -1.43     -4.16   -2.74  SiO2
  Smithsonite      -3.13    -13.10   -9.97  ZnCO3
  Strontianite     -1.91    -11.18   -9.27  SrCO3
  Sylvite          -7.97     -7.08    0.89  KCl
  Talc             -3.68     18.05   21.73  Mg3Si4O10(OH)2
  Willemite        -5.76      9.81   15.57  Zn2SiO4
  Witherite        -2.64    -11.21   -8.57  BaCO3
  Zn(OH)2(e)       -4.51      6.99   11.50  Zn(OH)2

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
  For ideal gases, phi = 1.

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End of simulation.
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Reading input data for simulation 2.
------------------------------------

        USE solution 1
        REACTION 1
        H2O  -1.0
        38.88 moles
        SAVE solution 2
        END
-----------------------------------------
Beginning of batch-reaction calculations.
-----------------------------------------

Reaction step 1.

Using solution 1.Bore 940 7/12/2017
Using reaction 1.

Reaction 1.

          3.888e+01 moles of the following reaction have been added:

                         Relative
        Reactant            moles

        H2O                -1.00000

                         Relative
        Element             moles
        H                  -2.00000
        O                  -1.00000

-----------------------------Solution composition------------------------------

        Elements           Molality       Moles
```

Al	6.192e-07	1.855e-07
B	2.164e-05	6.482e-06
Ba	1.679e-06	5.029e-07
C	3.656e-02	1.095e-02
Ca	6.670e-04	1.998e-04
Cd	1.486e-09	4.453e-10
Cl	7.540e-04	2.259e-04
Cu	2.629e-08	7.876e-09
F	2.111e-04	6.322e-05
Fe	1.376e-05	4.122e-06
K	1.538e-03	4.608e-04
Li	9.728e-05	2.914e-05
Mg	8.247e-04	2.470e-04
Mn	9.124e-07	2.733e-07
Na	3.590e-02	1.075e-02
Pb	8.064e-09	2.416e-09
S	3.826e-04	1.146e-04
Si	2.308e-04	6.914e-05
Sr	1.831e-06	5.483e-07
Zn	1.278e-07	3.828e-08

----------------------------Description of solution----------------------------

pH	=	7.650	Charge balance
pe	=	4.483	Adjusted to redox equilibrium
Specific Conductance (µS/cm, 22°C)	=	2996	
Density (g/cm³)	=	1.00010	
Volume (L)	=	0.30048	
Activity of water	=	0.999	
Ionic strength (mol/kgw)	=	3.947e-02	
Mass of water (kg)	=	2.995e-01	
Total alkalinity (eq/kg)	=	3.527e-02	
Total CO2 (mol/kg)	=	3.656e-02	
Temperature (°C)	=	22.10	
Electrical balance (eq)	=	1.063e-03	
Percent error, 100*(Cat-|An|)/(Cat+|An|)	=	4.69	
Iterations	=	12	
Total H	=	3.326322e+01	
Total O	=	1.665940e+01	

----------------------------Distribution of species----------------------------

Species		Molality	Activity	Log Molality	Log Activity	Log Gamma	mole V cm³/mol
OH-		4.355e-07	3.605e-07	-6.361	-6.443	-0.082	-4.03
H+		2.594e-08	2.240e-08	-7.586	-7.650	-0.064	0.00
H2O		5.551e+01	9.987e-01	1.744	-0.001	0.000	18.06
Al	6.192e-07						
Al(OH)4-		6.059e-07	5.063e-07	-6.218	-6.296	-0.078	(0)
Al(OH)3		6.198e-09	6.254e-09	-8.208	-8.204	0.004	(0)
AlF3		3.472e-09	3.504e-09	-8.459	-8.455	0.004	(0)
AlF2+		1.964e-09	1.654e-09	-8.707	-8.782	-0.075	(0)
Al(OH)2+		1.405e-09	1.184e-09	-8.852	-8.927	-0.075	(0)
AlF4-		2.816e-10	2.353e-10	-9.550	-9.628	-0.078	(0)
AlF+2		3.945e-11	1.985e-11	-10.404	-10.702	-0.298	(0)
AlOH+2		8.712e-12	4.383e-12	-11.060	-11.358	-0.298	-27.22
Al+3		4.467e-14	1.197e-14	-13.350	-13.922	-0.572	-41.28
AlSO4+		7.177e-15	5.997e-15	-14.144	-14.222	-0.078	(0)
Al(SO4)2-		3.685e-17	3.080e-17	-16.434	-16.511	-0.078	(0)
AlHSO4+2		2.387e-23	1.163e-23	-22.622	-22.935	-0.312	(0)
B	2.164e-05						
H3BO3		2.102e-05	2.121e-05	-4.677	-4.673	0.004	39.00
H2BO3-		6.182e-07	5.164e-07	-6.209	-6.287	-0.078	(0)
BF(OH)3-		1.655e-09	1.382e-09	-8.781	-8.859	-0.078	(0)
BF2(OH)2-		6.740e-13	5.630e-13	-12.171	-12.249	-0.078	(0)
BF3OH-		2.952e-18	2.466e-18	-17.530	-17.608	-0.078	(0)
BF4-		4.572e-23	3.819e-23	-22.340	-22.418	-0.078	(0)
Ba	1.679e-06						
Ba+2		1.400e-06	6.796e-07	-5.854	-6.168	-0.314	-12.44
BaHCO3+		2.047e-07	1.710e-07	-6.689	-6.767	-0.078	(0)
BaSO4		5.556e-08	5.606e-08	-7.255	-7.251	0.004	(0)
BaCO3		1.860e-08	1.877e-08	-7.731	-7.727	0.004	-10.73
BaOH+		1.223e-12	1.026e-12	-11.913	-11.989	-0.076	(0)
C(-4)	0.000e+00						
CH4		0.000e+00	0.000e+00	-75.102	-75.098	0.004	35.20
C(4)	3.656e-02						
HCO3-		3.415e-02	2.876e-02	-1.467	-1.541	-0.075	24.70
CO2		1.494e-03	1.507e-03	-2.826	-2.822	0.004	34.29
NaHCO3		4.832e-04	4.876e-04	-3.316	-3.312	0.004	1.80
MgHCO3+		1.348e-04	1.122e-04	-3.870	-3.950	-0.080	5.51
CO3-2		1.126e-04	5.665e-05	-3.948	-4.247	-0.298	-4.88
CaHCO3+		1.097e-04	9.281e-05	-3.960	-4.032	-0.072	9.67
NaCO3-		3.230e-05	2.699e-05	-4.491	-4.569	-0.078	-0.98
CaCO3		2.366e-05	2.388e-05	-4.626	-4.622	0.004	-14.61
MgCO3		1.729e-05	1.744e-05	-4.762	-4.758	0.004	-17.09
FeHCO3+		8.229e-07	6.875e-07	-6.085	-6.163	-0.078	(0)

MnCO3	4.285e-07	4.324e-07	-6.368	-6.364	0.004	(0)
SrHCO3+	3.447e-07	2.903e-07	-6.463	-6.537	-0.075	(0)
FeCO3	3.219e-07	3.249e-07	-6.492	-6.488	0.004	(0)
MnHCO3+	2.934e-07	2.463e-07	-6.533	-6.609	-0.076	(0)
BaHCO3+	2.047e-07	1.710e-07	-6.689	-6.767	-0.078	(0)
Zn(CO3)2-2	7.848e-08	3.822e-08	-7.105	-7.418	-0.312	(0)
(CO2)2	3.749e-08	3.783e-08	-7.426	-7.422	0.004	68.58
ZnCO3	3.127e-08	3.156e-08	-7.505	-7.501	0.004	(0)
SrCO3	2.398e-08	2.420e-08	-7.620	-7.616	0.004	-14.14
CuCO3	1.948e-08	1.966e-08	-7.710	-7.707	0.004	(0)
BaCO3	1.860e-08	1.877e-08	-7.731	-7.727	0.004	-10.73
ZnHCO3+	1.210e-08	1.011e-08	-7.917	-7.995	-0.078	(0)
PbCO3	6.081e-09	6.136e-09	-8.216	-8.212	0.004	(0)
Cu(CO3)2-2	2.878e-09	1.402e-09	-8.541	-8.853	-0.312	(0)
Pb(CO3)2-2	1.793e-09	8.732e-10	-8.746	-9.059	-0.312	(0)
CuHCO3+	1.115e-09	9.312e-10	-8.953	-9.031	-0.078	(0)
CdHCO3+	4.863e-10	4.063e-10	-9.313	-9.391	-0.078	(0)
PbHCO3+	1.704e-10	1.424e-10	-9.768	-9.847	-0.078	(0)
CdCO3	1.992e-11	2.010e-11	-10.701	-10.697	0.004	(0)
Cd(CO3)2-2	7.395e-12	3.602e-12	-11.131	-11.443	-0.312	(0)
Ca	6.670e-04					
Ca+2	5.261e-04	2.651e-04	-3.279	-3.577	-0.298	-17.72
CaHCO3+	1.097e-04	9.281e-05	-3.960	-4.032	-0.072	9.67
CaCO3	2.366e-05	2.388e-05	-4.626	-4.622	0.004	-14.61
CaSO4	7.523e-06	7.591e-06	-5.124	-5.120	0.004	7.39
CaOH+	2.348e-09	1.961e-09	-8.629	-8.707	-0.078	(0)
CaHSO4+	1.285e-12	1.074e-12	-11.891	-11.969	-0.078	(0)
Cd	1.486e-09					
Cd+2	9.172e-10	4.467e-10	-9.038	-9.350	-0.312	-18.45
CdHCO3+	4.863e-10	4.063e-10	-9.313	-9.391	-0.078	(0)
CdCl+	3.165e-11	2.644e-11	-10.500	-10.578	-0.078	5.45
CdSO4	2.064e-11	2.083e-11	-10.685	-10.681	0.004	79.54
CdCO3	1.992e-11	2.010e-11	-10.701	-10.697	0.004	(0)
Cd(CO3)2-2	7.395e-12	3.602e-12	-11.131	-11.443	-0.312	(0)
CdOH+	1.596e-12	1.333e-12	-11.797	-11.875	-0.078	(0)
CdF+	1.136e-12	9.493e-13	-11.944	-12.023	-0.078	(0)
CdOHCl	4.533e-13	4.574e-13	-12.344	-12.340	0.004	(0)
Cd(SO4)2-2	7.859e-14	3.827e-14	-13.105	-13.417	-0.312	-107.21
CdCl2	6.764e-14	6.826e-14	-13.170	-13.166	0.004	23.14
Cd(OH)2	3.929e-15	3.965e-15	-14.406	-14.402	0.004	(0)
CdF2	3.988e-16	4.025e-16	-15.399	-15.395	0.004	(0)
CdCl3-	3.088e-17	2.579e-17	-16.510	-16.588	-0.078	71.63
Cd(OH)3-	2.374e-20	1.983e-20	-19.625	-19.703	-0.078	(0)
Cd2OH+3	1.526e-20	3.025e-21	-19.816	-20.519	-0.703	(0)
Cd(OH)4-2	1.618e-26	7.878e-27	-25.791	-26.104	-0.312	(0)
CdHS+	0.000e+00	0.000e+00	-73.514	-73.592	-0.078	(0)
Cd(HS)2	0.000e+00	0.000e+00	-141.648	-141.644	0.004	(0)
Cd(HS)3-	0.000e+00	0.000e+00	-213.798	-213.876	-0.078	(0)
Cd(HS)4-2	0.000e+00	0.000e+00	-285.786	-286.098	-0.312	(0)
Cl	7.540e-04					
Cl-	7.540e-04	6.259e-04	-3.123	-3.203	-0.081	18.14
MnCl+	2.919e-10	2.450e-10	-9.535	-9.611	-0.076	-3.73
FeCl+	2.472e-10	2.065e-10	-9.607	-9.685	-0.078	(0)
CdCl+	3.165e-11	2.644e-11	-10.500	-10.578	-0.078	5.45
ZnCl+	4.969e-12	4.133e-12	-11.304	-11.384	-0.080	-16.89
ZnOHCl	2.556e-12	2.579e-12	-11.592	-11.589	0.004	(0)
CdOHCl	4.533e-13	4.574e-13	-12.344	-12.340	0.004	(0)
PbCl+	1.729e-13	1.444e-13	-12.762	-12.840	-0.078	7.94
CuCl2-	1.626e-13	1.352e-13	-12.789	-12.869	-0.080	(0)
CuCl+	1.134e-13	9.430e-14	-12.946	-13.026	-0.080	1.58
CdCl2	6.764e-14	6.826e-14	-13.170	-13.166	0.004	23.14
MnCl2	6.634e-14	6.694e-14	-13.178	-13.174	0.004	89.59
ZnCl2	2.653e-15	2.677e-15	-14.576	-14.572	0.004	107.93
CuCl3-2	2.673e-16	1.327e-16	-15.573	-15.877	-0.304	(0)
PbCl2	1.500e-16	1.513e-16	-15.824	-15.820	0.004	34.73
CdCl3-	3.088e-17	2.579e-17	-16.510	-16.588	-0.078	71.63
CuCl2	3.043e-17	3.071e-17	-16.517	-16.513	0.004	27.52
FeCl+2	2.054e-17	1.019e-17	-16.687	-16.992	-0.304	(0)
MnCl3-	1.375e-17	1.154e-17	-16.862	-16.938	-0.076	43.70
ZnCl3-	2.221e-18	1.848e-18	-17.653	-17.733	-0.080	16.55
PbCl3-	8.846e-20	7.390e-20	-19.053	-19.131	-0.078	65.74
FeCl2+	3.726e-20	3.127e-20	-19.429	-19.505	-0.076	(0)
ZnCl4-2	1.141e-21	5.663e-22	-20.943	-21.247	-0.304	145.49
CuCl3-	7.785e-23	6.475e-23	-22.109	-22.189	-0.080	(0)
PbCl4-2	4.444e-23	2.164e-23	-22.352	-22.665	-0.312	101.48
FeCl3	1.940e-24	1.957e-24	-23.712	-23.708	0.004	(0)
CuCl4-2	3.824e-28	1.898e-28	-27.417	-27.722	-0.304	(0)
Cu(1)	1.486e-12					
Cu+	1.324e-12	1.084e-12	-11.878	-11.965	-0.087	(0)
CuCl2-	1.626e-13	1.352e-13	-12.789	-12.869	-0.080	(0)
CuCl3-2	2.673e-16	1.327e-16	-15.573	-15.877	-0.304	(0)
Cu(2)	2.629e-08					
CuCO3	1.948e-08	1.966e-08	-7.710	-7.707	0.004	(0)
Cu(CO3)2-2	2.878e-09	1.402e-09	-8.541	-8.853	-0.312	(0)
Cu(OH)2	2.658e-09	2.682e-09	-8.576	-8.572	0.004	(0)
CuHCO3+	1.115e-09	9.312e-10	-8.953	-9.031	-0.078	(0)
Cu+2	1.259e-10	6.460e-11	-9.900	-10.190	-0.290	-26.15
CuOH+	3.462e-11	2.880e-11	-10.461	-10.541	-0.080	(0)

CuSO4	2.108e-12	2.128e-12	-11.676	-11.672	0.004	12.72
CuF+	2.312e-13	1.932e-13	-12.636	-12.714	-0.078	(0)
CuCl+	1.134e-13	9.430e-14	-12.946	-13.026	-0.080	1.58
Cu(OH)3-	8.623e-15	7.204e-15	-14.064	-14.142	-0.078	(0)
Cu2(OH)2+2	5.571e-16	2.713e-16	-15.254	-15.567	-0.312	(0)
CuCl2	3.043e-17	3.071e-17	-16.517	-16.513	0.004	27.52
Cu(OH)4-2	1.315e-19	6.407e-20	-18.881	-19.193	-0.312	(0)
CuCl3-	7.785e-23	6.475e-23	-22.109	-22.189	-0.080	(0)
CuCl4-2	3.824e-28	1.898e-28	-27.417	-27.722	-0.304	(0)
Cu(HS)3-	0.000e+00	0.000e+00	-207.448	-207.526	-0.078	(0)
F	2.111e-04					
F-	2.039e-04	1.688e-04	-3.691	-3.773	-0.082	-1.20
MgF+	4.269e-06	3.568e-06	-5.370	-5.448	-0.078	-10.45
NaF	2.854e-06	2.880e-06	-5.545	-5.541	0.004	7.15
HF	5.336e-09	5.385e-09	-8.273	-8.269	0.004	12.36
AlF3	3.472e-09	3.504e-09	-8.459	-8.455	0.004	(0)
AlF2+	1.964e-09	1.654e-09	-8.707	-8.782	-0.075	(0)
BF(OH)3-	1.655e-09	1.382e-09	-8.781	-8.859	-0.078	(0)
FeF+	4.830e-10	4.035e-10	-9.316	-9.394	-0.078	(0)
AlF4-	2.816e-10	2.353e-10	-9.550	-9.628	-0.078	(0)
MnF+	1.337e-10	1.122e-10	-9.874	-9.950	-0.076	(0)
AlF+2	3.945e-11	1.985e-11	-10.404	-10.702	-0.298	(0)
ZnF+	7.680e-12	6.416e-12	-11.115	-11.193	-0.078	(0)
HF2-	4.078e-12	3.406e-12	-11.390	-11.468	-0.078	22.08
FeF2+	1.170e-12	9.824e-13	-11.932	-12.008	-0.076	(0)
CdF+	1.136e-12	9.493e-13	-11.944	-12.023	-0.078	(0)
BF2(OH)2-	6.740e-13	5.630e-13	-12.171	-12.249	-0.078	(0)
FeF+2	3.049e-13	1.514e-13	-12.516	-12.820	-0.304	(0)
FeF3	2.578e-13	2.602e-13	-12.589	-12.585	0.004	(0)
CuF+	2.312e-13	1.932e-13	-12.636	-12.714	-0.078	(0)
PbF+	2.239e-14	1.871e-14	-13.650	-13.728	-0.078	(0)
CdF2	3.988e-16	4.025e-16	-15.399	-15.395	0.004	(0)
PbF2	6.389e-17	6.447e-17	-16.195	-16.191	0.004	(0)
BF3OH-	2.952e-18	2.466e-18	-17.530	-17.608	-0.078	(0)
PbF3-	9.437e-20	7.884e-20	-19.025	-19.103	-0.078	(0)
BF4-	4.572e-23	3.819e-23	-22.340	-22.418	-0.078	(0)
PbF4-2	1.308e-23	6.369e-24	-22.883	-23.196	-0.312	(0)
SiF6-2	5.409e-27	2.685e-27	-26.267	-26.571	-0.304	43.00
Fe(2)	1.621e-06					
FeHCO3+	8.229e-07	6.875e-07	-6.085	-6.163	-0.078	(0)
Fe+2	4.660e-07	2.390e-07	-6.332	-6.622	-0.290	-21.88
FeCO3	3.219e-07	3.249e-07	-6.492	-6.488	0.004	(0)
FeSO4	6.572e-09	6.632e-09	-8.182	-8.178	0.004	22.13
FeOH+	3.225e-09	2.707e-09	-8.491	-8.567	-0.076	(0)
FeF+	4.830e-10	4.035e-10	-9.316	-9.394	-0.078	(0)
FeCl+	2.472e-10	2.065e-10	-9.607	-9.685	-0.078	(0)
Fe(OH)2	7.889e-13	7.961e-13	-12.103	-12.099	0.004	(0)
Fe(OH)3-	1.526e-15	1.281e-15	-14.816	-14.892	-0.076	(0)
FeHSO4+	1.159e-15	9.679e-16	-14.936	-15.014	-0.078	(0)
Fe(HS)2	0.000e+00	0.000e+00	-146.500	-146.496	0.004	(0)
Fe(HS)3-	0.000e+00	0.000e+00	-218.793	-218.871	-0.078	(0)
Fe(3)	1.214e-05					
Fe(OH)3	9.482e-06	9.569e-06	-5.023	-5.019	0.004	(0)
Fe(OH)2+	2.248e-06	1.893e-06	-5.648	-5.723	-0.075	(0)
Fe(OH)4-	4.106e-07	3.458e-07	-6.387	-6.461	-0.075	(0)
FeOH+2	2.888e-10	1.433e-10	-9.539	-9.844	-0.304	(0)
FeF2+	1.170e-12	9.824e-13	-11.932	-12.008	-0.076	(0)
FeF+2	3.049e-13	1.514e-13	-12.516	-12.820	-0.304	(0)
FeF3	2.578e-13	2.602e-13	-12.589	-12.585	0.004	(0)
Fe+3	2.208e-15	5.917e-16	-14.656	-15.228	-0.572	(0)
FeSO4+	1.192e-15	1.001e-15	-14.924	-15.000	-0.076	(0)
FeCl+2	2.054e-17	1.019e-17	-16.687	-16.992	-0.304	(0)
Fe2(OH)2+4	1.109e-17	6.240e-19	-16.955	-18.205	-1.250	(0)
Fe(SO4)2-	4.266e-18	3.563e-18	-17.370	-17.448	-0.078	(0)
FeCl2+	3.726e-20	3.127e-20	-19.429	-19.505	-0.076	(0)
Fe3(OH)4+5	2.900e-20	3.234e-22	-19.538	-21.490	-1.953	(0)
FeHSO4+2	1.236e-22	6.019e-23	-21.908	-22.221	-0.312	(0)
FeCl3	1.940e-24	1.957e-24	-23.712	-23.708	0.004	(0)
H(0)	7.829e-28					
H2	3.915e-28	3.950e-28	-27.407	-27.403	0.004	28.61
K	1.538e-03					
K+	1.537e-03	1.274e-03	-2.813	-2.895	-0.082	9.05
KSO4-	1.662e-06	1.400e-06	-5.779	-5.854	-0.075	34.18
Li	9.728e-05					
Li+	9.721e-05	8.226e-05	-4.012	-4.085	-0.072	-1.18
LiSO4-	7.042e-08	5.911e-08	-7.152	-7.228	-0.076	(0)
Mg	8.247e-04					
Mg+2	6.563e-04	3.373e-04	-3.183	-3.472	-0.289	-21.27
MgHCO3+	1.348e-04	1.122e-04	-3.870	-3.950	-0.080	5.51
MgCO3	1.729e-05	1.744e-05	-4.762	-4.758	0.004	-17.09
MgSO4	1.196e-05	1.207e-05	-4.922	-4.918	0.004	5.72
MgF+	4.269e-06	3.568e-06	-5.370	-5.448	-0.078	-10.45
MgOH+	4.934e-08	4.191e-08	-7.307	-7.378	-0.071	(0)
Mn(2)	9.124e-07					
MnCO3	4.285e-07	4.324e-07	-6.368	-6.364	0.004	(0)
MnHCO3+	2.934e-07	2.463e-07	-6.533	-6.609	-0.076	(0)
Mn+2	1.873e-07	9.608e-08	-6.727	-7.017	-0.290	-18.97
MnSO4	2.636e-09	2.660e-09	-8.579	-8.575	0.004	23.88

MnCl+	2.919e-10	2.450e-10	-9.535	-9.611	-0.076	-3.73
MnF+	1.337e-10	1.122e-10	-9.874	-9.950	-0.076	(0)
MnOH+	1.033e-10	8.671e-11	-9.986	-10.062	-0.076	(0)
MnCl2	6.634e-14	6.694e-14	-13.178	-13.174	0.004	89.59
MnCl3-	1.375e-17	1.154e-17	-16.862	-16.938	-0.076	43.70
Mn(OH)3-	1.607e-19	1.349e-19	-18.794	-18.870	-0.076	(0)
Mn(3)	2.199e-28					
Mn+3	2.199e-28	5.892e-29	-27.658	-28.230	-0.572	(0)
Na	3.590e-02					
Na+	3.536e-02	2.965e-02	-1.452	-1.528	-0.076	-1.40
NaHCO3	4.832e-04	4.876e-04	-3.316	-3.312	0.004	1.80
NaCO3-	3.230e-05	2.699e-05	-4.491	-4.569	-0.078	-0.98
NaSO4-	2.851e-05	2.401e-05	-4.545	-4.620	-0.075	15.28
NaF	2.854e-06	2.880e-06	-5.545	-5.541	0.004	7.15
NaOH	1.059e-18	1.069e-18	-17.975	-17.971	0.004	(0)
O(0)	5.992e-39					
O2	2.996e-39	3.023e-39	-38.523	-38.520	0.004	30.17
Pb	8.064e-09					
PbCO3	6.081e-09	6.136e-09	-8.216	-8.212	0.004	(0)
Pb(CO3)2-2	1.793e-09	8.732e-10	-8.746	-9.059	-0.312	(0)
PbHCO3+	1.704e-10	1.424e-10	-9.768	-9.847	-0.078	(0)
Pb+2	1.280e-11	6.232e-12	-10.893	-11.205	-0.312	-15.06
PbOH+	6.484e-12	5.417e-12	-11.188	-11.266	-0.078	(0)
PbSO4	5.717e-13	5.769e-13	-12.243	-12.239	0.004	(0)
PbCl+	1.729e-13	1.444e-13	-12.762	-12.840	-0.078	7.94
Pb(OH)2	9.309e-14	9.394e-14	-13.031	-13.027	0.004	(0)
PbF+	2.239e-14	1.871e-14	-13.650	-13.728	-0.078	(0)
Pb(SO4)2-2	1.023e-15	4.984e-16	-14.990	-15.302	-0.312	(0)
PbCl2	1.500e-16	1.513e-16	-15.824	-15.820	0.004	34.73
PbF2	6.389e-17	6.447e-17	-16.195	-16.191	0.004	(0)
Pb(OH)3-	5.755e-17	4.808e-17	-16.240	-16.318	-0.078	(0)
PbF3-	9.437e-20	7.884e-20	-19.025	-19.103	-0.078	(0)
PbCl3-	8.846e-20	7.390e-20	-19.053	-19.131	-0.078	65.74
Pb(OH)4-2	1.008e-20	4.910e-21	-19.997	-20.309	-0.312	(0)
Pb2OH+3	3.814e-21	7.558e-22	-20.419	-21.122	-0.703	(0)
PbCl4-2	4.444e-23	2.164e-23	-22.352	-22.665	-0.312	101.48
PbF4-2	1.308e-23	6.369e-24	-22.883	-23.196	-0.312	(0)
Pb3(OH)4+2	1.667e-27	8.121e-28	-26.778	-27.090	-0.312	(0)
Pb(HS)2	0.000e+00	0.000e+00	-144.763	-144.759	0.004	(0)
Pb(HS)3-	0.000e+00	0.000e+00	-217.793	-217.871	-0.078	(0)
S(-2)	0.000e+00					
CdHS+	0.000e+00	0.000e+00	-73.514	-73.592	-0.078	(0)
HS-	0.000e+00	0.000e+00	-74.330	-74.412	-0.082	20.62
H2S	0.000e+00	0.000e+00	-75.085	-75.081	0.004	37.15
S-2	0.000e+00	0.000e+00	-79.463	-79.767	-0.304	(0)
Cd(HS)2	0.000e+00	0.000e+00	-141.648	-141.644	0.004	(0)
Zn(HS)2	0.000e+00	0.000e+00	-142.442	-142.438	0.004	(0)
Pb(HS)2	0.000e+00	0.000e+00	-144.763	-144.759	0.004	(0)
Fe(HS)2	0.000e+00	0.000e+00	-146.500	-146.496	0.004	(0)
Cu(HS)3-	0.000e+00	0.000e+00	-207.448	-207.526	-0.078	(0)
Cd(HS)3-	0.000e+00	0.000e+00	-213.798	-213.876	-0.078	(0)
Zn(HS)3-	0.000e+00	0.000e+00	-215.612	-215.690	-0.078	(0)
Pb(HS)3-	0.000e+00	0.000e+00	-217.793	-217.871	-0.078	(0)
Fe(HS)3-	0.000e+00	0.000e+00	-218.793	-218.871	-0.078	(0)
Cd(HS)4-2	0.000e+00	0.000e+00	-285.786	-286.098	-0.312	(0)
S(6)	3.826e-04					
SO4-2	3.328e-04	1.646e-04	-3.478	-3.784	-0.306	14.73
NaSO4-	2.851e-05	2.401e-05	-4.545	-4.620	-0.075	15.28
MgSO4	1.196e-05	1.207e-05	-4.922	-4.918	0.004	5.72
CaSO4	7.523e-06	7.591e-06	-5.124	-5.120	0.004	7.39
KSO4-	1.662e-06	1.400e-06	-5.779	-5.854	-0.075	34.18
LiSO4-	7.042e-08	5.911e-08	-7.152	-7.228	-0.076	(0)
BaSO4	5.556e-08	5.606e-08	-7.255	-7.251	0.004	(0)
SrSO4	2.239e-08	2.260e-08	-7.650	-7.646	0.004	24.12
FeSO4	6.572e-09	6.632e-09	-8.182	-8.178	0.004	22.13
MnSO4	2.636e-09	2.660e-09	-8.579	-8.575	0.004	23.88
HSO4-	4.032e-10	3.368e-10	-9.394	-9.473	-0.078	40.22
ZnSO4	1.044e-10	1.053e-10	-9.981	-9.977	0.004	22.20
CdSO4	2.064e-11	2.083e-11	-10.685	-10.681	0.004	79.54
CuSO4	2.108e-12	2.128e-12	-11.676	-11.672	0.004	12.72
CaHSO4+	1.285e-12	1.074e-12	-11.891	-11.969	-0.078	(0)
PbSO4	5.717e-13	5.769e-13	-12.243	-12.239	0.004	(0)
Zn(SO4)2-2	2.959e-13	1.441e-13	-12.529	-12.841	-0.312	-14.75
Cd(SO4)2-2	7.859e-14	3.827e-14	-13.105	-13.417	-0.312	-107.21
AlSO4+	7.177e-15	5.997e-15	-14.144	-14.222	-0.078	(0)
FeSO4+	1.192e-15	1.001e-15	-14.924	-15.000	-0.076	(0)
FeHSO4+	1.159e-15	9.679e-16	-14.936	-15.014	-0.078	(0)
Pb(SO4)2-2	1.023e-15	4.984e-16	-14.990	-15.302	-0.312	(0)
Al(SO4)2-	3.685e-17	3.080e-17	-16.434	-16.511	-0.078	(0)
Fe(SO4)2-	4.266e-18	3.563e-18	-17.370	-17.448	-0.078	(0)
FeHSO4+2	1.236e-22	6.019e-23	-21.908	-22.221	-0.312	(0)
AlHSO4+2	2.387e-23	1.163e-23	-22.622	-22.935	-0.312	(0)
Si	2.308e-04					
H4SiO4	2.292e-04	2.312e-04	-3.640	-3.636	0.004	52.33
H3SiO4-	1.651e-06	1.373e-06	-5.782	-5.862	-0.080	28.05
H2SiO4-2	6.838e-12	3.441e-12	-11.165	-11.463	-0.298	(0)
SiF6-2	5.409e-27	2.685e-27	-26.267	-26.571	-0.304	43.00
Sr	1.831e-06					

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     Sr+2            1.440e-06   7.288e-07    -5.842     -6.137     -0.296    -17.29
     SrHCO3+         3.447e-07   2.903e-07    -6.463     -6.537     -0.075     (0)
     SrCO3           2.398e-08   2.420e-08    -7.620     -7.616      0.004    -14.14
     SrSO4           2.239e-08   2.260e-08    -7.650     -7.646      0.004     24.12
     SrOH+           1.985e-12   1.666e-12   -11.702    -11.778     -0.076     (0)
Zn            1.278e-07
     Zn(CO3)2-2      7.848e-08   3.822e-08    -7.105     -7.418     -0.312     (0)
     ZnCO3           3.127e-08   3.156e-08    -7.505     -7.501      0.004     (0)
     ZnHCO3+         1.210e-08   1.011e-08    -7.917     -7.995     -0.078     (0)
     Zn+2            5.624e-09   2.792e-09    -8.250     -8.554     -0.304    -24.72
     ZnOH+           1.308e-10   1.093e-10    -9.883     -9.962     -0.078     (0)
     ZnSO4           1.044e-10   1.053e-10    -9.981     -9.977      0.004     22.20
     Zn(OH)2         6.920e-11   6.983e-11   -10.160    -10.156      0.004     (0)
     ZnF+            7.680e-12   6.416e-12   -11.115    -11.193     -0.078     (0)
     ZnCl+           4.969e-12   4.133e-12   -11.304    -11.384     -0.080    -16.89
     ZnOHCl          2.556e-12   2.579e-12   -11.592    -11.589      0.004     (0)
     Zn(SO4)2-2      2.959e-13   1.441e-13   -12.529    -12.841     -0.312    -14.75
     Zn(OH)3-        1.178e-14   9.844e-15   -13.929    -14.007     -0.078     (0)
     ZnCl2           2.653e-15   2.677e-15   -14.576    -14.572      0.004    107.93
     ZnCl3-          2.221e-18   1.848e-18   -17.653    -17.733     -0.080     16.55
     Zn(OH)4-2       1.428e-19   6.954e-20   -18.845    -19.158     -0.312     (0)
     ZnCl4-2         1.141e-21   5.663e-22   -20.943    -21.247     -0.304    145.49
     Zn(HS)2         0.000e+00   0.000e+00  -142.442   -142.438      0.004     (0)
     Zn(HS)3-        0.000e+00   0.000e+00  -215.612   -215.690     -0.078     (0)

------------------------------Saturation indices-------------------------------

  Phase               SI** log IAP   log K(295 K,   1 atm)

  Al(OH)3(a)        -1.97      9.03   10.99  Al(OH)3
  Albite            -0.54    -18.73  -18.19  NaAlSi3O8
  Alunite           -5.30     -6.33   -1.04  KAl3(SO4)2(OH)6
  Anglesite         -7.18    -14.99   -7.81  PbSO4
  Anhydrite         -3.11     -7.36   -4.25  CaSO4
  Anorthite         -3.64    -23.44  -19.80  CaAl2Si2O8
  Aragonite          0.49     -7.82   -8.32  CaCO3
  Barite            -0.08     -9.95   -9.87  BaSO4
  Ca-Montmorillonite   1.55    -43.90  -45.45  Ca0.165Al2.33Si3.67O10(OH)2
  Calcite            0.64     -7.82   -8.46  CaCO3
  Cd(OH)2           -7.70      5.95   13.65  Cd(OH)2
  CdSiO3            -6.87      2.31    9.18  CdSiO3
  CdSO4            -13.14    -13.13    0.01  CdSO4
  Celestite         -3.28     -9.92   -6.64  SrSO4
  Cerussite         -2.29    -15.45  -13.16  PbCO3
  CH4(g)           -72.32    -75.10   -2.77  CH4
  Chalcedony        -0.05     -3.63   -3.59  SiO2
  Chlorite(14A)     -3.19     66.28   69.47  Mg5Al2Si3O10(OH)8
  Chrysotile        -4.35     28.21   32.56  Mg3Si2O5(OH)4
  CO2(g)            -1.39     -2.82   -1.43  CO2
  Dolomite           1.48    -15.54  -17.02  CaMg(CO3)2
  Fe(OH)3(a)         2.83      7.72    4.89  Fe(OH)3
  FeS(ppt)         -69.47    -73.38   -3.92  FeS
  Fluorite          -0.49    -11.12  -10.63  CaF2
  Gibbsite           0.75      9.03    8.27  Al(OH)3
  Goethite           8.62      7.72   -0.90  FeOOH
  Gypsum            -2.78     -7.36   -4.58  CaSO4:2H2O
  H2(g)            -24.31    -27.40   -3.09  H2
  H2O(g)            -1.58     -0.00    1.58  H2O
  H2S(g)           -74.06    -82.06   -8.00  H2S
  Halite            -6.30     -4.73    1.57  NaCl
  Hausmannite      -12.64     49.11   61.75  Mn3O4
  Hematite          19.23     15.44   -3.79  Fe2O3
  Illite             1.68    -38.98  -40.66  K0.6Mg0.25Al2.3Si3.5O10(OH)2
  Jarosite-K        -1.27    -10.25   -8.98  KFe3(SO4)2(OH)6
  K-feldspar         0.70    -20.09  -20.79  KAlSi3O8
  K-mica             7.80     20.93   13.13  KAl3Si3O10(OH)2
  Kaolinite          3.09     10.78    7.69  Al2Si2O5(OH)4
  Mackinawite      -68.74    -73.38   -4.65  FeS
  Manganite         -4.93     20.41   25.34  MnOOH
  Melanterite       -8.16    -10.41   -2.24  FeSO4:7H2O
  O2(g)            -35.65    -38.52   -2.87  O2
  Otavite           -1.50    -13.60  -12.10  CdCO3
  Pb(OH)2           -4.16      4.09    8.25  Pb(OH)2
  Pyrite          -112.62   -131.18  -18.56  FeS2
  Pyrochroite       -6.92      8.28   15.20  Mn(OH)2
  Pyrolusite        -9.30     32.55   41.85  MnO2:H2O
  Quartz             0.39     -3.63   -4.02  SiO2
  Rhodochrosite     -0.14    -11.26  -11.12  MnCO3
  Sepiolite         -3.09     12.75   15.84  Mg2Si3O7.5OH:3H2O
  Sepiolite(d)      -5.91     12.75   18.66  Mg2Si3O7.5OH:3H2O
  Siderite           0.00    -10.87  -10.87  FeCO3
  SiO2(a)           -0.90     -3.63   -2.74  SiO2
  Smithsonite       -2.83    -12.80   -9.97  ZnCO3
  Sphalerite       -63.64    -75.32  -11.68  ZnS
  Strontianite      -1.12    -10.38   -9.27  SrCO3
  Sulfur           -55.77    -50.82    4.95  S
  Sylvite           -6.98     -6.10    0.89  KCl
  Talc              -0.79     20.94   21.73  Mg3Si4O10(OH)2
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  Willemite        -5.72      9.85   15.57  Zn2SiO4
  Witherite        -1.85    -10.41   -8.57  BaCO3
  Zn(OH)2(e)       -4.76      6.74   11.50  Zn(OH)2

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
  For ideal gases, phi = 1.

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End of simulation.
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Reading input data for simulation 3.
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        TITLE Scale back to 1L
        MIX 1
        2 3.333
        SAVE solution 3
        END
-----
TITLE
-----

 Scale back to 1L

-----------------------------------------
Beginning of batch-reaction calculations.
-----------------------------------------

Reaction step 1.

Using mix 1.

Mixture 1.

          3.333e+00 Solution 2    Solution after simulation 2.

-----------------------------Solution composition------------------------------

        Elements           Molality       Moles

        Al                6.192e-07   6.182e-07
        B                 2.164e-05   2.160e-05
        Ba                1.679e-06   1.676e-06
        C                 3.656e-02   3.650e-02
        Ca                6.670e-04   6.659e-04
        Cd                1.486e-09   1.484e-09
        Cl                7.540e-04   7.528e-04
        Cu                2.629e-08   2.625e-08
        F                 2.111e-04   2.107e-04
        Fe                1.376e-05   1.374e-05
        K                 1.538e-03   1.536e-03
        Li                9.728e-05   9.712e-05
        Mg                8.247e-04   8.233e-04
        Mn                9.124e-07   9.109e-07
        Na                3.590e-02   3.584e-02
        Pb                8.064e-09   8.051e-09
        S                 3.826e-04   3.820e-04
        Si                2.308e-04   2.304e-04
        Sr                1.831e-06   1.828e-06
        Zn                1.278e-07   1.276e-07

----------------------------Description of solution----------------------------

                                       pH  =   7.650      Charge balance
                                       pe  =   4.483      Adjusted to redox equilibrium
      Specific Conductance (µS/cm,  22°C)  = 2996
                          Density (g/cm³)  =   1.00010
                               Volume (L)  =   1.00148
                        Activity of water  =   0.999
                 Ionic strength (mol/kgw)  =   3.947e-02
                       Mass of water (kg)  =   9.984e-01
                 Total alkalinity (eq/kg)  =   3.527e-02
                       Total CO2 (mol/kg)  =   3.656e-02
                         Temperature (°C)  =  22.10
                  Electrical balance (eq)  =   3.543e-03
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =   4.69
                               Iterations  =   0
                                  Total H  = 1.108663e+02
                                  Total O  = 5.552579e+01

----------------------------Distribution of species----------------------------

                                               Log       Log       Log    mole V
   Species          Molality    Activity  Molality  Activity     Gamma   cm³/mol

   OH-             4.355e-07   3.605e-07    -6.361    -6.443    -0.082     -4.03
```

	H+	2.594e-08	2.240e-08	-7.586	-7.650	-0.064	0.00
	H2O	5.551e+01	9.987e-01	1.744	-0.001	0.000	18.06
Al		6.192e-07					
	Al(OH)4-	6.059e-07	5.063e-07	-6.218	-6.296	-0.078	(0)
	Al(OH)3	6.198e-09	6.254e-09	-8.208	-8.204	0.004	(0)
	AlF3	3.472e-09	3.504e-09	-8.459	-8.455	0.004	(0)
	AlF2+	1.964e-09	1.654e-09	-8.707	-8.782	-0.075	(0)
	Al(OH)2+	1.405e-09	1.184e-09	-8.852	-8.927	-0.075	(0)
	AlF4-	2.816e-10	2.353e-10	-9.550	-9.628	-0.078	(0)
	AlF+2	3.945e-11	1.985e-11	-10.404	-10.702	-0.298	(0)
	AlOH+2	8.712e-12	4.383e-12	-11.060	-11.358	-0.298	-27.22
	Al+3	4.467e-14	1.197e-14	-13.350	-13.922	-0.572	-41.28
	AlSO4+	7.177e-15	5.997e-15	-14.144	-14.222	-0.078	(0)
	Al(SO4)2-	3.685e-17	3.080e-17	-16.434	-16.511	-0.078	(0)
	AlHSO4+2	2.387e-23	1.163e-23	-22.622	-22.935	-0.312	(0)
B		2.164e-05					
	H3BO3	2.102e-05	2.121e-05	-4.677	-4.673	0.004	39.00
	H2BO3-	6.182e-07	5.164e-07	-6.209	-6.287	-0.078	(0)
	BF(OH)3-	1.655e-09	1.382e-09	-8.781	-8.859	-0.078	(0)
	BF2(OH)2-	6.740e-13	5.630e-13	-12.171	-12.249	-0.078	(0)
	BF3OH-	2.952e-18	2.466e-18	-17.530	-17.608	-0.078	(0)
	BF4-	4.572e-23	3.819e-23	-22.340	-22.418	-0.078	(0)
Ba		1.679e-06					
	Ba+2	1.400e-06	6.796e-07	-5.854	-6.168	-0.314	-12.44
	BaHCO3+	2.047e-07	1.710e-07	-6.689	-6.767	-0.078	(0)
	BaSO4	5.556e-08	5.606e-08	-7.255	-7.251	0.004	(0)
	BaCO3	1.860e-08	1.877e-08	-7.731	-7.727	0.004	-10.73
	BaOH+	1.223e-12	1.026e-12	-11.913	-11.989	-0.076	(0)
C(-4)		0.000e+00					
	CH4	0.000e+00	0.000e+00	-75.102	-75.098	0.004	35.20
C(4)		3.656e-02					
	HCO3-	3.415e-02	2.876e-02	-1.467	-1.541	-0.075	24.70
	CO2	1.494e-03	1.507e-03	-2.826	-2.822	0.004	34.29
	NaHCO3	4.832e-04	4.876e-04	-3.316	-3.312	0.004	1.80
	MgHCO3+	1.348e-04	1.122e-04	-3.870	-3.950	-0.080	5.51
	CO3-2	1.126e-04	5.665e-05	-3.948	-4.247	-0.298	-4.88
	CaHCO3+	1.097e-04	9.281e-05	-3.960	-4.032	-0.072	9.67
	NaCO3-	3.230e-05	2.699e-05	-4.491	-4.569	-0.078	-0.98
	CaCO3	2.366e-05	2.388e-05	-4.626	-4.622	0.004	-14.61
	MgCO3	1.729e-05	1.744e-05	-4.762	-4.758	0.004	-17.09
	FeHCO3+	8.229e-07	6.875e-07	-6.085	-6.163	-0.078	(0)
	MnCO3	4.285e-07	4.324e-07	-6.368	-6.364	0.004	(0)
	SrHCO3+	3.447e-07	2.903e-07	-6.463	-6.537	-0.075	(0)
	FeCO3	3.219e-07	3.249e-07	-6.492	-6.488	0.004	(0)
	MnHCO3+	2.934e-07	2.463e-07	-6.533	-6.609	-0.076	(0)
	BaHCO3+	2.047e-07	1.710e-07	-6.689	-6.767	-0.078	(0)
	Zn(CO3)2-2	7.848e-08	3.822e-08	-7.105	-7.418	-0.312	(0)
	(CO2)2	3.749e-08	3.783e-08	-7.426	-7.422	0.004	68.58
	ZnCO3	3.127e-08	3.156e-08	-7.505	-7.501	0.004	(0)
	SrCO3	2.398e-08	2.420e-08	-7.620	-7.616	0.004	-14.14
	CuCO3	1.948e-08	1.966e-08	-7.710	-7.707	0.004	(0)
	BaCO3	1.860e-08	1.877e-08	-7.731	-7.727	0.004	-10.73
	ZnHCO3+	1.210e-08	1.011e-08	-7.917	-7.995	-0.078	(0)
	PbCO3	6.081e-09	6.136e-09	-8.216	-8.212	0.004	(0)
	Cu(CO3)2-2	2.878e-09	1.402e-09	-8.541	-8.853	-0.312	(0)
	Pb(CO3)2-2	1.793e-09	8.732e-10	-8.746	-9.059	-0.312	(0)
	CuHCO3+	1.115e-09	9.312e-10	-8.953	-9.031	-0.078	(0)
	CdHCO3+	4.863e-10	4.063e-10	-9.313	-9.391	-0.078	(0)
	PbHCO3+	1.704e-10	1.424e-10	-9.768	-9.847	-0.078	(0)
	CdCO3	1.992e-11	2.010e-11	-10.701	-10.697	0.004	(0)
	Cd(CO3)2-2	7.395e-12	3.602e-12	-11.131	-11.443	-0.312	(0)
Ca		6.670e-04					
	Ca+2	5.261e-04	2.651e-04	-3.279	-3.577	-0.298	-17.72
	CaHCO3+	1.097e-04	9.281e-05	-3.960	-4.032	-0.072	9.67
	CaCO3	2.366e-05	2.388e-05	-4.626	-4.622	0.004	-14.61
	CaSO4	7.523e-06	7.591e-06	-5.124	-5.120	0.004	7.39
	CaOH+	2.348e-09	1.961e-09	-8.629	-8.707	-0.078	(0)
	CaHSO4+	1.285e-12	1.074e-12	-11.891	-11.969	-0.078	(0)
Cd		1.486e-09					
	Cd+2	9.172e-10	4.467e-10	-9.038	-9.350	-0.312	-18.45
	CdHCO3+	4.863e-10	4.063e-10	-9.313	-9.391	-0.078	(0)
	CdCl+	3.165e-11	2.644e-11	-10.500	-10.578	-0.078	5.45
	CdSO4	2.064e-11	2.083e-11	-10.685	-10.681	0.004	79.54
	CdCO3	1.992e-11	2.010e-11	-10.701	-10.697	0.004	(0)
	Cd(CO3)2-2	7.395e-12	3.602e-12	-11.131	-11.443	-0.312	(0)
	CdOH+	1.596e-12	1.333e-12	-11.797	-11.875	-0.078	(0)
	CdF+	1.136e-12	9.493e-13	-11.944	-12.023	-0.078	(0)
	CdOHCl	4.533e-13	4.574e-13	-12.344	-12.340	0.004	(0)
	Cd(SO4)2-2	7.859e-14	3.827e-14	-13.105	-13.417	-0.312	-107.21
	CdCl2	6.764e-14	6.826e-14	-13.170	-13.166	0.004	23.14
	Cd(OH)2	3.929e-15	3.965e-15	-14.406	-14.402	0.004	(0)
	CdF2	3.988e-16	4.025e-16	-15.399	-15.395	0.004	(0)
	CdCl3-	3.088e-17	2.579e-17	-16.510	-16.588	-0.078	71.63
	Cd(OH)3-	2.374e-20	1.983e-20	-19.625	-19.703	-0.078	(0)
	Cd2OH+3	1.526e-20	3.025e-21	-19.816	-20.519	-0.703	(0)
	Cd(OH)4-2	1.618e-26	7.878e-27	-25.791	-26.104	-0.312	(0)
	CdHS+	0.000e+00	0.000e+00	-73.514	-73.592	-0.078	(0)
	Cd(HS)2	0.000e+00	0.000e+00	-141.648	-141.644	0.004	(0)

Cd(HS)3-	0.000e+00	0.000e+00	-213.798	-213.876	-0.078	(0)
Cd(HS)4-2	0.000e+00	0.000e+00	-285.786	-286.098	-0.312	(0)
Cl	7.540e-04					
Cl-	7.540e-04	6.259e-04	-3.123	-3.203	-0.081	18.14
MnCl+	2.919e-10	2.450e-10	-9.535	-9.611	-0.076	-3.73
FeCl+	2.472e-10	2.065e-10	-9.607	-9.685	-0.078	(0)
CdCl+	3.165e-11	2.644e-11	-10.500	-10.578	-0.078	5.45
ZnCl+	4.969e-12	4.133e-12	-11.304	-11.384	-0.080	-16.89
ZnOHCl	2.556e-12	2.579e-12	-11.592	-11.589	0.004	(0)
CdOHCl	4.533e-13	4.574e-13	-12.344	-12.340	0.004	(0)
PbCl+	1.729e-13	1.444e-13	-12.762	-12.840	-0.078	7.94
CuCl2-	1.626e-13	1.352e-13	-12.789	-12.869	-0.080	(0)
CuCl+	1.134e-13	9.430e-14	-12.946	-13.026	-0.080	1.58
CdCl2	6.764e-14	6.826e-14	-13.170	-13.166	0.004	23.14
MnCl2	6.634e-14	6.694e-14	-13.178	-13.174	0.004	89.59
ZnCl2	2.653e-15	2.677e-15	-14.576	-14.572	0.004	107.93
CuCl3-2	2.673e-16	1.327e-16	-15.573	-15.877	-0.304	(0)
PbCl2	1.500e-16	1.513e-16	-15.824	-15.820	0.004	34.73
CdCl3-	3.088e-17	2.579e-17	-16.510	-16.588	-0.078	71.63
CuCl2	3.043e-17	3.071e-17	-16.517	-16.513	0.004	27.52
FeCl+2	2.054e-17	1.019e-17	-16.687	-16.992	-0.304	(0)
MnCl3-	1.375e-17	1.154e-17	-16.862	-16.938	-0.076	43.70
ZnCl3-	2.221e-18	1.848e-18	-17.653	-17.733	-0.080	16.55
PbCl3-	8.846e-20	7.390e-20	-19.053	-19.131	-0.078	65.74
FeCl2+	3.726e-20	3.127e-20	-19.429	-19.505	-0.076	(0)
ZnCl4-2	1.141e-21	5.663e-22	-20.943	-21.247	-0.304	145.49
CuCl3-	7.785e-23	6.475e-23	-22.109	-22.189	-0.080	(0)
PbCl4-2	4.444e-23	2.164e-23	-22.352	-22.665	-0.312	101.48
FeCl3	1.940e-24	1.957e-24	-23.712	-23.708	0.004	(0)
CuCl4-2	3.824e-28	1.898e-28	-27.417	-27.722	-0.304	(0)
Cu(1)	1.486e-12					
Cu+	1.324e-12	1.084e-12	-11.878	-11.965	-0.087	(0)
CuCl2-	1.626e-13	1.352e-13	-12.789	-12.869	-0.080	(0)
CuCl3-2	2.673e-16	1.327e-16	-15.573	-15.877	-0.304	(0)
Cu(2)	2.629e-08					
CuCO3	1.948e-08	1.966e-08	-7.710	-7.707	0.004	(0)
Cu(CO3)2-2	2.878e-09	1.402e-09	-8.541	-8.853	-0.312	(0)
Cu(OH)2	2.658e-09	2.682e-09	-8.576	-8.572	0.004	(0)
CuHCO3+	1.115e-09	9.312e-10	-8.953	-9.031	-0.078	(0)
Cu+2	1.259e-10	6.460e-11	-9.900	-10.190	-0.290	-26.15
CuOH+	3.462e-11	2.880e-11	-10.461	-10.541	-0.080	(0)
CuSO4	2.108e-12	2.128e-12	-11.676	-11.672	0.004	12.72
CuF+	2.312e-13	1.932e-13	-12.636	-12.714	-0.078	(0)
CuCl+	1.134e-13	9.430e-14	-12.946	-13.026	-0.080	1.58
Cu(OH)3-	8.623e-15	7.204e-15	-14.064	-14.142	-0.078	(0)
Cu2(OH)2+2	5.571e-16	2.713e-16	-15.254	-15.567	-0.312	(0)
CuCl2	3.043e-17	3.071e-17	-16.517	-16.513	0.004	27.52
Cu(OH)4-2	1.315e-19	6.407e-20	-18.881	-19.193	-0.312	(0)
CuCl3-	7.785e-23	6.475e-23	-22.109	-22.189	-0.080	(0)
CuCl4-2	3.824e-28	1.898e-28	-27.417	-27.722	-0.304	(0)
Cu(HS)3-	0.000e+00	0.000e+00	-207.448	-207.526	-0.078	(0)
F	2.111e-04					
F-	2.039e-04	1.688e-04	-3.691	-3.773	-0.082	-1.20
MgF+	4.269e-06	3.568e-06	-5.370	-5.448	-0.078	-10.45
NaF	2.854e-06	2.880e-06	-5.545	-5.541	0.004	7.15
HF	5.336e-09	5.385e-09	-8.273	-8.269	0.004	12.36
AlF3	3.472e-09	3.504e-09	-8.459	-8.455	0.004	(0)
AlF2+	1.964e-09	1.654e-09	-8.707	-8.782	-0.075	(0)
BF(OH)3-	1.655e-09	1.382e-09	-8.781	-8.859	-0.078	(0)
FeF+	4.830e-10	4.035e-10	-9.316	-9.394	-0.078	(0)
AlF4-	2.816e-10	2.353e-10	-9.550	-9.628	-0.078	(0)
MnF+	1.337e-10	1.122e-10	-9.874	-9.950	-0.076	(0)
AlF+2	3.945e-11	1.985e-11	-10.404	-10.702	-0.298	(0)
ZnF+	7.680e-12	6.416e-12	-11.115	-11.193	-0.078	(0)
HF2-	4.078e-12	3.406e-12	-11.390	-11.468	-0.078	22.08
FeF2+	1.170e-12	9.824e-13	-11.932	-12.008	-0.076	(0)
CdF+	1.136e-12	9.493e-13	-11.944	-12.023	-0.078	(0)
BF2(OH)2-	6.740e-13	5.630e-13	-12.171	-12.249	-0.078	(0)
FeF+2	3.049e-13	1.514e-13	-12.516	-12.820	-0.304	(0)
FeF3	2.578e-13	2.602e-13	-12.589	-12.585	0.004	(0)
CuF+	2.312e-13	1.932e-13	-12.636	-12.714	-0.078	(0)
PbF+	2.239e-14	1.871e-14	-13.650	-13.728	-0.078	(0)
CdF2	3.988e-16	4.025e-16	-15.399	-15.395	0.004	(0)
PbF2	6.389e-17	6.447e-17	-16.195	-16.191	0.004	(0)
BF3OH-	2.952e-18	2.466e-18	-17.530	-17.608	-0.078	(0)
PbF3-	9.437e-20	7.884e-20	-19.025	-19.103	-0.078	(0)
BF4-	4.572e-23	3.819e-23	-22.340	-22.418	-0.078	(0)
PbF4-2	1.308e-23	6.369e-24	-22.883	-23.196	-0.312	(0)
SiF6-2	5.409e-27	2.685e-27	-26.267	-26.571	-0.304	43.00
Fe(2)	1.621e-06					
FeHCO3+	8.229e-07	6.875e-07	-6.085	-6.163	-0.078	(0)
Fe+2	4.660e-07	2.390e-07	-6.332	-6.622	-0.290	-21.88
FeCO3	3.219e-07	3.249e-07	-6.492	-6.488	0.004	(0)
FeSO4	6.572e-09	6.632e-09	-8.182	-8.178	0.004	22.13
FeOH+	3.225e-09	2.707e-09	-8.491	-8.567	-0.076	(0)
FeF+	4.830e-10	4.035e-10	-9.316	-9.394	-0.078	(0)
FeCl+	2.472e-10	2.065e-10	-9.607	-9.685	-0.078	(0)
Fe(OH)2	7.889e-13	7.961e-13	-12.103	-12.099	0.004	(0)

Fe(OH)3-	1.526e-15	1.281e-15	-14.816	-14.892	-0.076	(0)
FeHSO4+	1.159e-15	9.679e-16	-14.936	-15.014	-0.078	(0)
Fe(HS)2	0.000e+00	0.000e+00	-146.500	-146.496	0.004	(0)
Fe(HS)3-	0.000e+00	0.000e+00	-218.793	-218.871	-0.078	(0)
Fe(3)	1.214e-05					
Fe(OH)3	9.482e-06	9.569e-06	-5.023	-5.019	0.004	(0)
Fe(OH)2+	2.248e-06	1.893e-06	-5.648	-5.723	-0.075	(0)
Fe(OH)4-	4.106e-07	3.458e-07	-6.387	-6.461	-0.075	(0)
FeOH+2	2.888e-10	1.433e-10	-9.539	-9.844	-0.304	(0)
FeF2+	1.170e-12	9.824e-13	-11.932	-12.008	-0.076	(0)
FeF+2	3.049e-13	1.514e-13	-12.516	-12.820	-0.304	(0)
FeF3	2.578e-13	2.602e-13	-12.589	-12.585	0.004	(0)
Fe+3	2.208e-15	5.917e-16	-14.656	-15.228	-0.572	(0)
FeSO4+	1.192e-15	1.001e-15	-14.924	-15.000	-0.076	(0)
FeCl+2	2.054e-17	1.019e-17	-16.687	-16.992	-0.304	(0)
Fe2(OH)2+4	1.109e-17	6.240e-19	-16.955	-18.205	-1.250	(0)
Fe(SO4)2-	4.266e-18	3.563e-18	-17.370	-17.448	-0.078	(0)
FeCl2+	3.726e-20	3.127e-20	-19.429	-19.505	-0.076	(0)
Fe3(OH)4+5	2.900e-20	3.234e-22	-19.538	-21.490	-1.953	(0)
FeHSO4+2	1.236e-22	6.019e-23	-21.908	-22.221	-0.312	(0)
FeCl3	1.940e-24	1.957e-24	-23.712	-23.708	0.004	(0)
H(0)	7.829e-28					
H2	3.915e-28	3.950e-28	-27.407	-27.403	0.004	28.61
K	1.538e-03					
K+	1.537e-03	1.274e-03	-2.813	-2.895	-0.082	9.05
KSO4-	1.662e-06	1.400e-06	-5.779	-5.854	-0.075	34.18
Li	9.728e-05					
Li+	9.721e-05	8.226e-05	-4.012	-4.085	-0.072	-1.18
LiSO4-	7.042e-08	5.911e-08	-7.152	-7.228	-0.076	(0)
Mg	8.247e-04					
Mg+2	6.563e-04	3.373e-04	-3.183	-3.472	-0.289	-21.27
MgHCO3+	1.348e-04	1.122e-04	-3.870	-3.950	-0.080	5.51
MgCO3	1.729e-05	1.744e-05	-4.762	-4.758	0.004	-17.09
MgSO4	1.196e-05	1.207e-05	-4.922	-4.918	0.004	5.72
MgF+	4.269e-06	3.568e-06	-5.370	-5.448	-0.078	-10.45
MgOH+	4.934e-08	4.191e-08	-7.307	-7.378	-0.071	(0)
Mn(2)	9.124e-07					
MnCO3	4.285e-07	4.324e-07	-6.368	-6.364	0.004	(0)
MnHCO3+	2.934e-07	2.463e-07	-6.533	-6.609	-0.076	(0)
Mn+2	1.873e-07	9.608e-08	-6.727	-7.017	-0.290	-18.97
MnSO4	2.636e-09	2.660e-09	-8.579	-8.575	0.004	23.88
MnCl+	2.919e-10	2.450e-10	-9.535	-9.611	-0.076	-3.73
MnF+	1.337e-10	1.122e-10	-9.874	-9.950	-0.076	(0)
MnOH+	1.033e-10	8.671e-11	-9.986	-10.062	-0.076	(0)
MnCl2	6.634e-14	6.694e-14	-13.178	-13.174	0.004	89.59
MnCl3-	1.375e-17	1.154e-17	-16.862	-16.938	-0.076	43.70
Mn(OH)3-	1.607e-19	1.349e-19	-18.794	-18.870	-0.076	(0)
Mn(3)	2.199e-28					
Mn+3	2.199e-28	5.892e-29	-27.658	-28.230	-0.572	(0)
Na	3.590e-02					
Na+	3.536e-02	2.965e-02	-1.452	-1.528	-0.076	-1.40
NaHCO3	4.832e-04	4.876e-04	-3.316	-3.312	0.004	1.80
NaCO3-	3.230e-05	2.699e-05	-4.491	-4.569	-0.078	-0.98
NaSO4-	2.851e-05	2.401e-05	-4.545	-4.620	-0.075	15.29
NaF	2.854e-06	2.880e-06	-5.545	-5.541	0.004	7.15
NaOH	1.059e-18	1.069e-18	-17.975	-17.971	0.004	(0)
O(0)	5.992e-39					
O2	2.996e-39	3.023e-39	-38.523	-38.520	0.004	30.17
Pb	8.064e-09					
PbCO3	6.081e-09	6.136e-09	-8.216	-8.212	0.004	(0)
Pb(CO3)2-2	1.793e-09	8.732e-10	-8.746	-9.059	-0.312	(0)
PbHCO3+	1.704e-10	1.424e-10	-9.768	-9.847	-0.078	(0)
Pb+2	1.280e-11	6.232e-12	-10.893	-11.205	-0.312	-15.06
PbOH+	6.484e-12	5.417e-12	-11.188	-11.266	-0.078	(0)
PbSO4	5.717e-13	5.769e-13	-12.243	-12.239	0.004	(0)
PbCl+	1.729e-13	1.444e-13	-12.762	-12.840	-0.078	7.94
Pb(OH)2	9.309e-14	9.394e-14	-13.031	-13.027	0.004	(0)
PbF+	2.239e-14	1.871e-14	-13.650	-13.728	-0.078	(0)
Pb(SO4)2-2	1.023e-15	4.984e-16	-14.990	-15.302	-0.312	(0)
PbCl2	1.500e-16	1.513e-16	-15.824	-15.820	0.004	34.73
PbF2	6.389e-17	6.447e-17	-16.195	-16.191	0.004	(0)
Pb(OH)3-	5.755e-17	4.808e-17	-16.240	-16.318	-0.078	(0)
PbF3-	9.437e-20	7.884e-20	-19.025	-19.103	-0.078	(0)
PbCl3-	8.846e-20	7.390e-20	-19.053	-19.131	-0.078	65.74
Pb(OH)4-2	1.008e-20	4.910e-21	-19.997	-20.309	-0.312	(0)
Pb2OH+3	3.814e-21	7.558e-22	-20.419	-21.122	-0.703	(0)
PbCl4-2	4.444e-23	2.164e-23	-22.352	-22.665	-0.312	101.48
PbF4-2	1.308e-23	6.369e-24	-22.883	-23.196	-0.312	(0)
Pb3(OH)4+2	1.667e-27	8.121e-28	-26.778	-27.090	-0.312	(0)
Pb(HS)2	0.000e+00	0.000e+00	-144.763	-144.759	0.004	(0)
Pb(HS)3-	0.000e+00	0.000e+00	-217.793	-217.871	-0.078	(0)
S(-2)	0.000e+00					
CdHS+	0.000e+00	0.000e+00	-73.514	-73.592	-0.078	(0)
HS-	0.000e+00	0.000e+00	-74.330	-74.412	-0.082	20.62
H2S	0.000e+00	0.000e+00	-75.085	-75.081	0.004	37.15
S-2	0.000e+00	0.000e+00	-79.463	-79.767	-0.304	(0)
Cd(HS)2	0.000e+00	0.000e+00	-141.648	-141.644	0.004	(0)
Zn(HS)2	0.000e+00	0.000e+00	-142.442	-142.438	0.004	(0)

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     Pb(HS)2          0.000e+00   0.000e+00  -144.763  -144.759     0.004     (0)
     Fe(HS)2          0.000e+00   0.000e+00  -146.500  -146.496     0.004     (0)
     Cu(HS)3-         0.000e+00   0.000e+00  -207.448  -207.526    -0.078     (0)
     Cd(HS)3-         0.000e+00   0.000e+00  -213.798  -213.876    -0.078     (0)
     Zn(HS)3-         0.000e+00   0.000e+00  -215.612  -215.690    -0.078     (0)
     Pb(HS)3-         0.000e+00   0.000e+00  -217.793  -217.871    -0.078     (0)
     Fe(HS)3-         0.000e+00   0.000e+00  -218.793  -218.871    -0.078     (0)
     Cd(HS)4-2        0.000e+00   0.000e+00  -285.786  -286.098    -0.312     (0)
S(6)             3.826e-04
     SO4-2            3.328e-04   1.646e-04    -3.478    -3.784    -0.306     14.73
     NaSO4-           2.851e-05   2.401e-05    -4.545    -4.620    -0.075     15.29
     MgSO4            1.196e-05   1.207e-05    -4.922    -4.918     0.004      5.72
     CaSO4            7.523e-06   7.591e-06    -5.124    -5.120     0.004      7.39
     KSO4-            1.662e-06   1.400e-06    -5.779    -5.854    -0.075     34.18
     LiSO4-           7.042e-08   5.911e-08    -7.152    -7.228    -0.076     (0)
     BaSO4            5.556e-08   5.606e-08    -7.255    -7.251     0.004     (0)
     SrSO4            2.239e-08   2.260e-08    -7.650    -7.646     0.004     24.12
     FeSO4            6.572e-09   6.632e-09    -8.182    -8.178     0.004     22.13
     MnSO4            2.636e-09   2.660e-09    -8.579    -8.575     0.004     23.88
     HSO4-            4.032e-10   3.368e-10    -9.394    -9.473    -0.078     40.22
     ZnSO4            1.044e-10   1.053e-10    -9.981    -9.977     0.004     22.20
     CdSO4            2.064e-11   2.083e-11   -10.685   -10.681     0.004     79.54
     CuSO4            2.108e-12   2.128e-12   -11.676   -11.672     0.004     12.72
     CaHSO4+          1.285e-12   1.074e-12   -11.891   -11.969    -0.078     (0)
     PbSO4            5.717e-13   5.769e-13   -12.243   -12.239     0.004     (0)
     Zn(SO4)2-2       2.959e-13   1.441e-13   -12.529   -12.841    -0.312    -14.75
     Cd(SO4)2-2       7.859e-14   3.827e-14   -13.105   -13.417    -0.312   -107.21
     AlSO4+           7.177e-15   5.997e-15   -14.144   -14.222    -0.078     (0)
     FeSO4+           1.192e-15   1.001e-15   -14.924   -15.000    -0.076     (0)
     FeHSO4+          1.159e-15   9.679e-16   -14.936   -15.014    -0.078     (0)
     Pb(SO4)2-2       1.023e-15   4.984e-16   -14.990   -15.302    -0.312     (0)
     Al(SO4)2-        3.685e-17   3.080e-17   -16.434   -16.511    -0.078     (0)
     Fe(SO4)2-        4.266e-18   3.563e-18   -17.370   -17.448    -0.078     (0)
     FeHSO4+2         1.236e-22   6.019e-23   -21.908   -22.221    -0.312     (0)
     AlHSO4+2         2.387e-23   1.163e-23   -22.622   -22.935    -0.312     (0)
Si               2.308e-04
     H4SiO4           2.292e-04   2.312e-04    -3.640    -3.636     0.004     52.33
     H3SiO4-          1.651e-06   1.373e-06    -5.782    -5.862    -0.080     28.05
     H2SiO4-2         6.838e-12   3.441e-12   -11.165   -11.463    -0.298     (0)
     SiF6-2           5.409e-27   2.685e-27   -26.267   -26.571    -0.304     43.00
Sr               1.831e-06
     Sr+2             1.440e-06   7.288e-07    -5.842    -6.137    -0.296    -17.29
     SrHCO3+          3.447e-07   2.903e-07    -6.463    -6.537    -0.075     (0)
     SrCO3            2.398e-08   2.420e-08    -7.620    -7.616     0.004    -14.14
     SrSO4            2.239e-08   2.260e-08    -7.650    -7.646     0.004     24.12
     SrOH+            1.985e-12   1.666e-12   -11.702   -11.778    -0.076     (0)
Zn               1.278e-07
     Zn(CO3)2-2       7.848e-08   3.822e-08    -7.105    -7.418    -0.312     (0)
     ZnCO3            3.127e-08   3.156e-08    -7.505    -7.501     0.004     (0)
     ZnHCO3+          1.210e-08   1.011e-08    -7.917    -7.995    -0.078     (0)
     Zn+2             5.624e-09   2.792e-09    -8.250    -8.554    -0.304    -24.72
     ZnOH+            1.308e-10   1.093e-10    -9.883    -9.962    -0.078     (0)
     ZnSO4            1.044e-10   1.053e-10    -9.981    -9.977     0.004     22.20
     Zn(OH)2          6.920e-11   6.983e-11   -10.160   -10.156     0.004     (0)
     ZnF+             7.680e-12   6.416e-12   -11.115   -11.193    -0.078     (0)
     ZnCl+            4.969e-12   4.133e-12   -11.304   -11.384    -0.080    -16.89
     ZnOHCl           2.556e-12   2.579e-12   -11.592   -11.589     0.004     (0)
     Zn(SO4)2-2       2.959e-13   1.441e-13   -12.529   -12.841    -0.312    -14.75
     Zn(OH)3-         1.178e-14   9.844e-15   -13.929   -14.007    -0.078     (0)
     ZnCl2            2.653e-15   2.677e-15   -14.576   -14.572     0.004    107.93
     ZnCl3-           2.221e-18   1.848e-18   -17.653   -17.733    -0.080     16.55
     Zn(OH)4-2        1.428e-19   6.954e-20   -18.845   -19.158    -0.312     (0)
     ZnCl4-2          1.141e-21   5.663e-22   -20.943   -21.247    -0.304    145.49
     Zn(HS)2          0.000e+00   0.000e+00  -142.442  -142.438     0.004     (0)
     Zn(HS)3-         0.000e+00   0.000e+00  -215.612  -215.690    -0.078     (0)

------------------------------Saturation indices-------------------------------

  Phase               SI** log IAP   log K(295 K,   1 atm)

  Al(OH)3(a)        -1.97      9.03   10.99  Al(OH)3
  Albite            -0.54    -18.73  -18.19  NaAlSi3O8
  Alunite           -5.30     -6.33   -1.04  KAl3(SO4)2(OH)6
  Anglesite         -7.18    -14.99   -7.81  PbSO4
  Anhydrite         -3.11     -7.36   -4.25  CaSO4
  Anorthite         -3.64    -23.44  -19.80  CaAl2Si2O8
  Aragonite          0.49     -7.82   -8.32  CaCO3
  Barite            -0.08     -9.95   -9.87  BaSO4
  Ca-Montmorillonite  1.55    -43.90  -45.45  Ca0.165Al2.33Si3.67O10(OH)2
  Calcite            0.64     -7.82   -8.46  CaCO3
  Cd(OH)2           -7.70      5.95   13.65  Cd(OH)2
  CdSiO3            -6.87      2.31    9.18  CdSiO3
  CdSO4            -13.14    -13.13    0.01  CdSO4
  Celestite         -3.28     -9.92   -6.64  SrSO4
  Cerussite         -2.29    -15.45  -13.16  PbCO3
  CH4(g)           -72.32    -75.10   -2.77  CH4
  Chalcedony        -0.05     -3.63   -3.59  SiO2
  Chlorite(14A)     -3.19     66.28   69.47  Mg5Al2Si3O10(OH)8
```

```
  Chrysotile         -4.35     28.21   32.56  Mg3Si2O5(OH)4
  CO2(g)             -1.39     -2.82   -1.43  CO2
  Dolomite            1.48    -15.54  -17.02  CaMg(CO3)2
  Fe(OH)3(a)          2.83      7.72    4.89  Fe(OH)3
  FeS(ppt)          -69.47    -73.38   -3.92  FeS
  Fluorite           -0.49    -11.12  -10.63  CaF2
  Gibbsite            0.75      9.03    8.27  Al(OH)3
  Goethite            8.62      7.72   -0.90  FeOOH
  Gypsum             -2.78     -7.36   -4.58  CaSO4:2H2O
  H2(g)             -24.31    -27.40   -3.09  H2
  H2O(g)             -1.58     -0.00    1.58  H2O
  H2S(g)            -74.06    -82.06   -8.00  H2S
  Halite             -6.30     -4.73    1.57  NaCl
  Hausmannite       -12.64     49.11   61.75  Mn3O4
  Hematite           19.23     15.44   -3.79  Fe2O3
  Illite              1.68    -38.98  -40.66  K0.6Mg0.25Al2.3Si3.5O10(OH)2
  Jarosite-K         -1.27    -10.25   -8.98  KFe3(SO4)2(OH)6
  K-feldspar          0.70    -20.09  -20.79  KAlSi3O8
  K-mica              7.80     20.93   13.13  KAl3Si3O10(OH)2
  Kaolinite           3.09     10.78    7.69  Al2Si2O5(OH)4
  Mackinawite       -68.74    -73.38   -4.65  FeS
  Manganite          -4.93     20.41   25.34  MnOOH
  Melanterite        -8.16    -10.41   -2.24  FeSO4:7H2O
  O2(g)             -35.65    -38.52   -2.87  O2
  Otavite            -1.50    -13.60  -12.10  CdCO3
  Pb(OH)2            -4.16      4.09    8.25  Pb(OH)2
  Pyrite           -112.62   -131.18  -18.56  FeS2
  Pyrochroite        -6.92      8.28   15.20  Mn(OH)2
  Pyrolusite         -9.30     32.55   41.85  MnO2:H2O
  Quartz              0.39     -3.63   -4.02  SiO2
  Rhodochrosite      -0.14    -11.26  -11.12  MnCO3
  Sepiolite          -3.09     12.75   15.84  Mg2Si3O7.5OH:3H2O
  Sepiolite(d)       -5.91     12.75   18.66  Mg2Si3O7.5OH:3H2O
  Siderite            0.00    -10.87  -10.87  FeCO3
  SiO2(a)            -0.90     -3.63   -2.74  SiO2
  Smithsonite        -2.83    -12.80   -9.97  ZnCO3
  Sphalerite        -63.64    -75.32  -11.68  ZnS
  Strontianite       -1.12    -10.38   -9.27  SrCO3
  Sulfur            -55.77    -50.82    4.95  S
  Sylvite            -6.98     -6.10    0.89  KCl
  Talc               -0.79     20.94   21.73  Mg3Si4O10(OH)2
  Willemite          -5.72      9.85   15.57  Zn2SiO4
  Witherite          -1.85    -10.41   -8.57  BaCO3
  Zn(OH)2(e)         -4.76      6.74   11.50  Zn(OH)2

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
  For ideal gases, phi = 1.

------------------
End of simulation.
------------------

------------------------------------
Reading input data for simulation 4.
------------------------------------

-------------------------------
End of Run after 0.046 Seconds.
-------------------------------
```

Figure A.2: PHRREQCi Model Output - R02RevA_PRD_02a.pqi (Predicted Quality of Temporarily Stored Residuals)

```
   Input file: C:\Users\jbell\Jobs\54568\Phreeqci\Runs\R02RevA_PRD_02a.pqi
  Output file: C:\Users\jbell\Jobs\54568\Phreeqci\Runs\R02RevA_PRD_02a.pqo
Database file: C:\Program Files (x86)\USGS\Phreeqc Interactive 3.4.0-12927\database\phreeqc.dat

------------------
Reading data base.
------------------

        SOLUTION_MASTER_SPECIES
        SOLUTION_SPECIES
        PHASES
        EXCHANGE_MASTER_SPECIES
        EXCHANGE_SPECIES
        SURFACE_MASTER_SPECIES
        SURFACE_SPECIES
        RATES
        END
------------------------------------
Reading input data for simulation 1.
------------------------------------

        DATABASE C:\Program Files (x86)\USGS\Phreeqc Interactive 3.4.0-12927\database\phreeqc.dat
        TITLE Solution Definition
        SOLUTION 1 Bore 940 7/12/2017
        units mg/L
        pH      7.7
        temp 22.1
        Ca 8
        Mg 6
        Na 247
        K 18
        Cl 8
        Alkalinity       644 as HCO3-
        S(6) 11
        Al 0.005 #half of DL
        As  0.067 #not in database
        Ba 0.069
        B 0.07
        Cd 0.00005 #half of DL
        Cr 0.0005 #half of DL, not in database
        Cu 0.0005 #half of DL
        F 1.2 #estimated
        Fe 0.23
        Li 0.202
        Mn 0.015
        Ni 0.005 #not in database
        Pb 0.0005 #half of DL
        Si 4.15
        Sr 0.048
        Zn 0.0025 #half of DL
        END
-----
TITLE
-----

 Solution Definition

WARNING: Could not find element in database, As.
        Concentration is set to zero.
WARNING: Could not find element in database, Cr.
        Concentration is set to zero.
WARNING: Could not find element in database, Ni.
        Concentration is set to zero.
-------------------------------------------
Beginning of initial solution calculations.
-------------------------------------------

Initial solution 1.       Bore 940 7/12/2017

-----------------------------Solution composition------------------------------

        Elements           Molality       Moles

        Al                1.855e-07   1.855e-07
        Alkalinity        1.056e-02   1.056e-02
        B                 6.482e-06   6.482e-06
        Ba                5.029e-07   5.029e-07
        Ca                1.998e-04   1.998e-04
        Cd                4.453e-10   4.453e-10
        Cl                2.259e-04   2.259e-04
        Cu                7.876e-09   7.876e-09
        F                 6.322e-05   6.322e-05
        Fe                4.122e-06   4.122e-06
```

K	4.608e-04	4.608e-04
Li	2.914e-05	2.914e-05
Mg	2.470e-04	2.470e-04
Mn	2.733e-07	2.733e-07
Na	1.075e-02	1.075e-02
Pb	2.416e-09	2.416e-09
S(6)	1.146e-04	1.146e-04
Si	6.914e-05	6.914e-05
Sr	5.483e-07	5.483e-07
Zn	3.828e-08	3.828e-08

----------------------------Description of solution----------------------------

pH	= 7.700
pe	= 4.000
Specific Conductance (µS/cm, 22°C)	= 964
Density (g/cm³)	= 0.99845
Volume (L)	= 1.00252
Activity of water	= 1.000
Ionic strength (mol/kgw)	= 1.204e-02
Mass of water (kg)	= 1.000e+00
Total carbon (mol/kg)	= 1.095e-02
Total CO2 (mol/kg)	= 1.095e-02
Temperature (°C)	= 22.10
Electrical balance (eq)	= 1.063e-03
Percent error, 100*(Cat-|An|)/(Cat+|An|)	= 4.62
Iterations	= 10
Total H	= 1.110232e+02
Total O	= 5.553940e+01

----------------------------Distribution of species----------------------------

Species	Molality	Activity	Log Molality	Log Activity	Log Gamma	mole V cm³/mol
OH-	4.540e-07	4.052e-07	-6.343	-6.392	-0.049	-4.14
H+	2.198e-08	1.995e-08	-7.658	-7.700	-0.042	0.00
H2O	5.551e+01	9.996e-01	1.744	-0.000	0.000	18.06
Al	1.855e-07					
Al(OH)4-	1.833e-07	1.641e-07	-6.737	-6.785	-0.048	(0)
Al(OH)3	1.799e-09	1.804e-09	-8.745	-8.744	0.001	(0)
Al(OH)2+	3.382e-10	3.038e-10	-9.471	-9.517	-0.047	(0)
AlF2+	4.064e-11	3.650e-11	-10.391	-10.438	-0.047	(0)
AlF3	2.542e-11	2.549e-11	-10.595	-10.594	0.001	(0)
AlF+2	2.042e-12	1.329e-12	-11.690	-11.876	-0.187	(0)
AlOH+2	1.538e-12	1.001e-12	-11.813	-12.000	-0.187	-27.43
AlF4-	6.299e-13	5.641e-13	-12.201	-12.249	-0.048	(0)
Al+3	5.814e-15	2.431e-15	-14.236	-14.614	-0.379	-41.64
AlSO4+	5.727e-16	5.129e-16	-15.242	-15.290	-0.048	(0)
Al(SO4)2-	1.238e-18	1.109e-18	-17.907	-17.955	-0.048	(0)
AlHSO4+2	1.382e-24	8.854e-25	-23.859	-24.053	-0.193	(0)
B	6.482e-06					
H3BO3	6.289e-06	6.306e-06	-5.201	-5.200	0.001	39.00
H2BO3-	1.927e-07	1.724e-07	-6.715	-6.763	-0.048	(0)
BF(OH)3-	1.514e-10	1.355e-10	-9.820	-9.868	-0.048	(0)
BF2(OH)2-	1.808e-14	1.618e-14	-13.743	-13.791	-0.048	(0)
BF3OH-	2.323e-20	2.078e-20	-19.634	-19.682	-0.048	(0)
BF4-	1.055e-25	9.439e-26	-24.977	-25.025	-0.048	(0)
Ba	5.029e-07					
Ba+2	4.626e-07	2.967e-07	-6.335	-6.528	-0.193	-12.67
BaHCO3+	2.708e-08	2.423e-08	-7.567	-7.616	-0.048	(0)
BaSO4	1.027e-08	1.030e-08	-7.988	-7.987	0.001	(0)
BaCO3	2.977e-09	2.985e-09	-8.526	-8.525	0.001	-10.73
BaOH+	5.614e-13	5.036e-13	-12.251	-12.298	-0.047	(0)
C(4)	1.095e-02					
HCO3-	1.039e-02	9.333e-03	-1.983	-2.030	-0.047	24.56
CO2	4.340e-04	4.352e-04	-3.363	-3.361	0.001	34.29
NaHCO3	5.101e-05	5.115e-05	-4.292	-4.291	0.001	1.80
CO3-2	3.172e-05	2.064e-05	-4.499	-4.685	-0.187	-5.23
MgHCO3+	1.770e-05	1.582e-05	-4.752	-4.801	-0.049	5.45
CaHCO3+	1.476e-05	1.329e-05	-4.831	-4.877	-0.046	9.62
CaCO3	3.827e-06	3.838e-06	-5.417	-5.416	0.001	-14.61
NaCO3-	3.553e-06	3.179e-06	-5.449	-5.498	-0.048	-1.19
MgCO3	2.755e-06	2.763e-06	-5.560	-5.559	0.001	-17.09
FeHCO3+	1.640e-07	1.468e-07	-6.785	-6.833	-0.048	(0)
MnCO3	1.090e-07	1.093e-07	-6.963	-6.962	0.001	(0)
FeCO3	7.766e-08	7.787e-08	-7.110	-7.109	0.001	(0)
MnHCO3+	6.179e-08	5.543e-08	-7.209	-7.256	-0.047	(0)
SrHCO3+	4.634e-08	4.162e-08	-7.334	-7.381	-0.047	(0)
BaHCO3+	2.708e-08	2.423e-08	-7.567	-7.616	-0.048	(0)
ZnCO3	1.588e-08	1.592e-08	-7.799	-7.798	0.001	(0)
Zn(CO3)2-2	1.097e-08	7.029e-09	-7.960	-8.153	-0.193	(0)
ZnHCO3+	5.077e-09	4.542e-09	-8.294	-8.343	-0.048	(0)
CuCO3	4.983e-09	4.997e-09	-8.302	-8.301	0.001	(0)
SrCO3	3.884e-09	3.895e-09	-8.411	-8.410	0.001	-14.14
(CO2)2	3.145e-09	3.154e-09	-8.502	-8.501	0.001	68.58
BaCO3	2.977e-09	2.985e-09	-8.526	-8.525	0.001	-10.73
PbCO3	2.172e-09	2.178e-09	-8.663	-8.662	0.001	(0)

CuHCO3+	2.357e-10	2.108e-10	-9.628	-9.676	-0.048	(0)
Cu(CO3)2-2	2.027e-10	1.299e-10	-9.693	-9.886	-0.193	(0)
Pb(CO3)2-2	1.763e-10	1.130e-10	-9.754	-9.947	-0.193	(0)
CdHCO3+	7.514e-11	6.723e-11	-10.124	-10.172	-0.048	(0)
PbHCO3+	5.032e-11	4.502e-11	-10.298	-10.347	-0.048	(0)
CdCO3	3.725e-12	3.735e-12	-11.429	-11.428	0.001	(0)
Cd(CO3)2-2	3.807e-13	2.439e-13	-12.419	-12.613	-0.193	(0)
Ca	1.998e-04					
Ca+2	1.798e-04	1.169e-04	-3.745	-3.932	-0.187	-17.94
CaHCO3+	1.476e-05	1.329e-05	-4.831	-4.877	-0.046	9.62
CaCO3	3.827e-06	3.838e-06	-5.417	-5.416	0.001	-14.61
CaSO4	1.406e-06	1.410e-06	-5.852	-5.851	0.001	7.39
CaOH+	1.087e-09	9.723e-10	-8.964	-9.012	-0.048	(0)
CaHSO4+	1.984e-13	1.775e-13	-12.702	-12.751	-0.048	(0)
Cd	4.453e-10					
Cd+2	3.556e-10	2.278e-10	-9.449	-9.642	-0.193	-18.66
CdHCO3+	7.514e-11	6.723e-11	-10.124	-10.172	-0.048	(0)
CdCl+	4.858e-12	4.346e-12	-11.314	-11.362	-0.048	5.19
CdSO4	4.458e-12	4.471e-12	-11.351	-11.350	0.001	79.54
CdCO3	3.725e-12	3.735e-12	-11.429	-11.428	0.001	(0)
CdOH+	8.539e-13	7.639e-13	-12.069	-12.117	-0.048	(0)
Cd(CO3)2-2	3.807e-13	2.439e-13	-12.419	-12.613	-0.193	(0)
CdF+	1.783e-13	1.595e-13	-12.749	-12.797	-0.048	(0)
CdOHCl	8.425e-14	8.449e-14	-13.074	-13.073	0.001	(0)
Cd(SO4)2-2	5.398e-15	3.458e-15	-14.268	-14.461	-0.193	-107.39
CdCl2	3.606e-15	3.616e-15	-14.443	-14.442	0.001	23.14
Cd(OH)2	2.547e-15	2.554e-15	-14.594	-14.593	0.001	(0)
CdF2	2.223e-17	2.229e-17	-16.653	-16.652	0.001	(0)
CdCl3-	4.922e-19	4.404e-19	-18.308	-18.356	-0.048	71.55
Cd(OH)3-	1.605e-20	1.436e-20	-19.795	-19.843	-0.048	(0)
Cd2OH+3	2.407e-21	8.839e-22	-20.618	-21.054	-0.435	(0)
Cd(OH)4-2	1.001e-26	6.410e-27	-26.000	-26.193	-0.193	(0)
Cl	2.259e-04					
Cl-	2.259e-04	2.017e-04	-3.646	-3.695	-0.049	18.06
MnCl+	6.105e-11	5.476e-11	-10.214	-10.262	-0.047	-3.78
FeCl+	4.895e-11	4.379e-11	-10.310	-10.359	-0.048	(0)
CdCl+	4.858e-12	4.346e-12	-11.314	-11.362	-0.048	5.19
ZnCl+	2.064e-12	1.845e-12	-11.685	-11.734	-0.049	-16.85
ZnOHCl	1.290e-12	1.294e-12	-11.889	-11.888	0.001	(0)
CdOHCl	8.425e-14	8.449e-14	-13.074	-13.073	0.001	(0)
PbCl+	5.069e-14	4.535e-14	-13.295	-13.343	-0.048	7.90
CuCl2-	3.337e-14	2.983e-14	-13.477	-13.525	-0.049	(0)
CuCl+	2.372e-14	2.120e-14	-13.625	-13.674	-0.049	1.49
MnCl2	4.809e-15	4.823e-15	-14.318	-14.317	0.001	89.59
CdCl2	3.606e-15	3.616e-15	-14.443	-14.442	0.001	23.14
ZnCl2	3.841e-16	3.852e-16	-15.416	-15.414	0.001	107.93
PbCl2	1.527e-17	1.532e-17	-16.816	-16.815	0.001	34.73
CuCl3-2	1.457e-17	9.431e-18	-16.837	-17.025	-0.189	(0)
CuCl2	2.220e-18	2.226e-18	-17.654	-17.653	0.001	27.52
FeCl+2	1.097e-18	7.102e-19	-17.960	-18.149	-0.189	(0)
CdCl3-	4.922e-19	4.404e-19	-18.308	-18.356	-0.048	71.55
MnCl3-	2.987e-19	2.680e-19	-18.525	-18.572	-0.047	43.56
ZnCl3-	9.583e-20	8.567e-20	-19.018	-19.067	-0.049	16.68
PbCl3-	2.694e-21	2.410e-21	-20.570	-20.618	-0.048	65.66
FeCl2+	7.828e-22	7.022e-22	-21.106	-21.154	-0.047	(0)
ZnCl4-2	1.307e-23	8.463e-24	-22.884	-23.072	-0.189	145.08
CuCl3-	1.692e-24	1.513e-24	-23.772	-23.820	-0.049	(0)
PbCl4-2	3.552e-25	2.276e-25	-24.449	-24.643	-0.193	101.15
FeCl3	1.413e-26	1.417e-26	-25.850	-25.849	0.001	(0)
CuCl4-2	2.207e-30	1.429e-30	-29.656	-29.845	-0.189	(0)
Cu(1)	2.622e-12					
Cu+	2.589e-12	2.302e-12	-11.587	-11.638	-0.051	(0)
CuCl2-	3.337e-14	2.983e-14	-13.477	-13.525	-0.049	(0)
CuCl3-2	1.457e-17	9.431e-18	-16.837	-17.025	-0.189	(0)
Cu(2)	7.873e-09					
CuCO3	4.983e-09	4.997e-09	-8.302	-8.301	0.001	(0)
Cu(OH)2	2.357e-09	2.364e-09	-8.628	-8.626	0.001	(0)
CuHCO3+	2.357e-10	2.108e-10	-9.628	-9.676	-0.048	(0)
Cu(CO3)2-2	2.027e-10	1.299e-10	-9.693	-9.886	-0.193	(0)
Cu+2	6.872e-11	4.507e-11	-10.163	-10.346	-0.183	-26.36
CuOH+	2.526e-11	2.258e-11	-10.598	-10.646	-0.049	(0)
CuSO4	6.231e-13	6.248e-13	-12.205	-12.204	0.001	12.72
CuF+	4.965e-14	4.442e-14	-13.304	-13.352	-0.048	(0)
CuCl+	2.372e-14	2.120e-14	-13.625	-13.674	-0.049	1.49
Cu(OH)3-	7.975e-15	7.135e-15	-14.098	-14.147	-0.048	(0)
Cu2(OH)2+2	2.604e-16	1.668e-16	-15.584	-15.778	-0.193	(0)
CuCl2	2.220e-18	2.226e-18	-17.654	-17.653	0.001	27.52
Cu(OH)4-2	1.113e-19	7.132e-20	-18.953	-19.147	-0.193	(0)
CuCl3-	1.692e-24	1.513e-24	-23.772	-23.820	-0.049	(0)
CuCl4-2	2.207e-30	1.429e-30	-29.656	-29.845	-0.189	(0)
F	6.322e-05					
F-	6.234e-05	5.563e-05	-4.205	-4.255	-0.049	-1.28
MgF+	5.708e-07	5.112e-07	-6.244	-6.291	-0.048	-10.51
NaF	3.060e-07	3.069e-07	-6.514	-6.513	0.001	7.15
HF	1.576e-09	1.581e-09	-8.802	-8.801	0.001	12.36
BF(OH)3-	1.514e-10	1.355e-10	-9.820	-9.868	-0.048	(0)
FeF+	9.778e-11	8.748e-11	-10.010	-10.058	-0.048	(0)
AlF2+	4.064e-11	3.650e-11	-10.391	-10.438	-0.047	(0)

MnF+	2.859e-11	2.565e-11	-10.544	-10.591	-0.047	(0)
AlF3	2.542e-11	2.549e-11	-10.595	-10.594	0.001	(0)
ZnF+	3.273e-12	2.928e-12	-11.485	-11.533	-0.048	(0)
AlF+2	2.042e-12	1.329e-12	-11.690	-11.876	-0.187	(0)
AlF4-	6.299e-13	5.641e-13	-12.201	-12.249	-0.048	(0)
HF2-	3.684e-13	3.295e-13	-12.434	-12.482	-0.048	21.99
CdF+	1.783e-13	1.595e-13	-12.749	-12.797	-0.048	(0)
CuF+	4.965e-14	4.442e-14	-13.304	-13.352	-0.048	(0)
FeF2+	2.572e-14	2.307e-14	-13.590	-13.637	-0.047	(0)
BF2(OH)2-	1.808e-14	1.618e-14	-13.743	-13.791	-0.048	(0)
FeF+2	1.666e-14	1.078e-14	-13.778	-13.967	-0.189	(0)
PbF+	6.715e-15	6.007e-15	-14.173	-14.221	-0.048	(0)
FeF3	2.008e-15	2.014e-15	-14.697	-14.696	0.001	(0)
CdF2	2.223e-17	2.229e-17	-16.653	-16.652	0.001	(0)
PbF2	6.805e-18	6.823e-18	-17.167	-17.166	0.001	(0)
BF3OH-	2.323e-20	2.078e-20	-19.634	-19.682	-0.048	(0)
PbF3-	3.074e-21	2.750e-21	-20.512	-20.561	-0.048	(0)
PbF4-2	1.143e-25	7.323e-26	-24.942	-25.135	-0.193	(0)
BF4-	1.055e-25	9.439e-26	-24.977	-25.025	-0.048	(0)
SiF6-2	9.913e-31	6.418e-31	-30.004	-30.193	-0.189	42.67
Fe(2)	4.857e-07					
Fe+2	2.398e-07	1.572e-07	-6.620	-6.803	-0.183	-22.09
FeHCO3+	1.640e-07	1.468e-07	-6.785	-6.833	-0.048	(0)
FeCO3	7.766e-08	7.787e-08	-7.110	-7.109	0.001	(0)
FeOH+	2.231e-09	2.002e-09	-8.651	-8.699	-0.047	(0)
FeSO4	1.831e-09	1.836e-09	-8.737	-8.736	0.001	22.13
FeF+	9.778e-11	8.748e-11	-10.010	-10.058	-0.048	(0)
FeCl+	4.895e-11	4.379e-11	-10.310	-10.359	-0.048	(0)
Fe(OH)2	6.597e-13	6.616e-13	-12.181	-12.179	0.001	(0)
Fe(OH)3-	1.334e-15	1.196e-15	-14.875	-14.922	-0.047	(0)
FeHSO4+	2.668e-16	2.387e-16	-15.574	-15.622	-0.048	(0)
Fe(3)	3.637e-06					
Fe(OH)3	2.928e-06	2.936e-06	-5.533	-5.532	0.001	(0)
Fe(OH)2+	5.755e-07	5.169e-07	-6.240	-6.287	-0.047	(0)
Fe(OH)4-	1.328e-07	1.193e-07	-6.877	-6.923	-0.047	(0)
FeOH+2	5.378e-11	3.482e-11	-10.269	-10.458	-0.189	(0)
FeF2+	2.572e-14	2.307e-14	-13.590	-13.637	-0.047	(0)
FeF+2	1.666e-14	1.078e-14	-13.778	-13.967	-0.189	(0)
FeF3	2.008e-15	2.014e-15	-14.697	-14.696	0.001	(0)
Fe+3	3.058e-16	1.279e-16	-15.515	-15.893	-0.379	(0)
FeSO4+	1.015e-16	9.107e-17	-15.993	-16.041	-0.047	(0)
FeCl+2	1.097e-18	7.102e-19	-17.960	-18.149	-0.189	(0)
Fe2(OH)2+4	2.187e-19	3.683e-20	-18.660	-19.434	-0.774	(0)
Fe(SO4)2-	1.525e-19	1.365e-19	-18.817	-18.865	-0.048	(0)
FeCl2+	7.828e-22	7.022e-22	-21.106	-21.154	-0.047	(0)
Fe3(OH)4+5	8.429e-23	5.212e-24	-22.074	-23.283	-1.209	(0)
FeHSO4+2	7.613e-24	4.877e-24	-23.118	-23.312	-0.193	(0)
FeCl3	1.413e-26	1.417e-26	-25.850	-25.849	0.001	(0)
H(0)	5.787e-27					
H2	2.894e-27	2.902e-27	-26.539	-26.537	0.001	28.61
K	4.608e-04					
K+	4.606e-04	4.112e-04	-3.337	-3.386	-0.049	8.98
KSO4-	2.118e-07	1.902e-07	-6.674	-6.721	-0.047	34.10
Li	2.914e-05					
Li+	2.913e-05	2.621e-05	-4.536	-4.581	-0.046	-1.26
LiSO4-	8.839e-09	7.928e-09	-8.054	-8.101	-0.047	(0)
Mg	2.470e-04					
Mg+2	2.238e-04	1.466e-04	-3.650	-3.834	-0.184	-21.48
MgHCO3+	1.770e-05	1.582e-05	-4.752	-4.801	-0.049	5.45
MgCO3	2.755e-06	2.763e-06	-5.560	-5.559	0.001	-17.09
MgSO4	2.203e-06	2.209e-06	-5.657	-5.656	0.001	5.72
MgF+	5.708e-07	5.112e-07	-6.244	-6.291	-0.048	-10.51
MgOH+	2.272e-08	2.048e-08	-7.644	-7.689	-0.045	(0)
Mn(2)	2.733e-07					
MnCO3	1.090e-07	1.093e-07	-6.963	-6.962	0.001	(0)
Mn+2	1.016e-07	6.663e-08	-6.993	-7.176	-0.183	-19.79
MnHCO3+	6.179e-08	5.543e-08	-7.209	-7.256	-0.047	(0)
MnSO4	7.742e-10	7.764e-10	-9.111	-9.110	0.001	23.88
MnOH+	7.534e-11	6.758e-11	-10.123	-10.170	-0.047	(0)
MnCl+	6.105e-11	5.476e-11	-10.214	-10.262	-0.047	-3.78
MnF+	2.859e-11	2.565e-11	-10.544	-10.591	-0.047	(0)
MnCl2	4.809e-15	4.823e-15	-14.318	-14.317	0.001	89.59
MnCl3-	2.987e-19	2.680e-19	-18.525	-18.572	-0.047	43.56
Mn(OH)3-	1.480e-19	1.328e-19	-18.830	-18.877	-0.047	(0)
Mn(3)	3.210e-29					
Mn+3	3.210e-29	1.343e-29	-28.493	-28.872	-0.379	(0)
Na	1.075e-02					
Na+	1.070e-02	9.586e-03	-1.971	-2.018	-0.048	-1.52
NaHCO3	5.101e-05	5.115e-05	-4.292	-4.291	0.001	1.80
NaSO4-	3.638e-06	3.268e-06	-5.439	-5.486	-0.047	14.49
NaCO3-	3.553e-06	3.179e-06	-5.449	-5.498	-0.048	-1.19
NaF	3.060e-07	3.069e-07	-6.514	-6.513	0.001	7.15
NaOH	3.873e-19	3.884e-19	-18.412	-18.411	0.001	(0)
O(0)	0.000e+00					
O2	0.000e+00	0.000e+00	-40.252	-40.251	0.001	30.17
Pb	2.416e-09					
PbCO3	2.172e-09	2.178e-09	-8.663	-8.662	0.001	(0)
Pb(CO3)2-2	1.763e-10	1.130e-10	-9.754	-9.947	-0.193	(0)

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    PbHCO3+          5.032e-11   4.502e-11   -10.298   -10.347    -0.048     (0)
    Pb+2             9.478e-12   6.072e-12   -11.023   -11.217    -0.193    -15.28
    PbOH+            6.630e-12   5.931e-12   -11.178   -11.227    -0.048     (0)
    PbSO4            2.359e-13   2.366e-13   -12.627   -12.626     0.001     (0)
    Pb(OH)2          1.153e-13   1.156e-13   -12.938   -12.937     0.001     (0)
    PbCl+            5.069e-14   4.535e-14   -13.295   -13.343    -0.048      7.90
    PbF+             6.715e-15   6.007e-15   -14.173   -14.221    -0.048     (0)
    Pb(SO4)2-2       1.343e-16   8.602e-17   -15.872   -16.065    -0.193     (0)
    Pb(OH)3-         7.433e-17   6.650e-17   -16.129   -16.177    -0.048     (0)
    PbCl2            1.527e-17   1.532e-17   -16.816   -16.815     0.001     34.73
    PbF2             6.805e-18   6.823e-18   -17.167   -17.166     0.001     (0)
    Pb(OH)4-2        1.191e-20   7.632e-21   -19.924   -20.117    -0.193     (0)
    PbF3-            3.074e-21   2.750e-21   -20.512   -20.561    -0.048     (0)
    PbCl3-           2.694e-21   2.410e-21   -20.570   -20.618    -0.048     65.66
    Pb2OH+3          2.196e-21   8.063e-22   -20.658   -21.094    -0.435     (0)
    PbCl4-2          3.552e-25   2.276e-25   -24.449   -24.643    -0.193    101.15
    PbF4-2           1.143e-25   7.323e-26   -24.942   -25.135    -0.193     (0)
    Pb3(OH)4+2       1.870e-27   1.198e-27   -26.728   -26.921    -0.193     (0)
S(6)            1.146e-04
    SO4-2            1.071e-04   6.929e-05    -3.970    -4.159    -0.189     14.41
    NaSO4-           3.638e-06   3.268e-06    -5.439    -5.486    -0.047     14.49
    MgSO4            2.203e-06   2.209e-06    -5.657    -5.656     0.001      5.72
    CaSO4            1.406e-06   1.410e-06    -5.852    -5.851     0.001      7.39
    KSO4-            2.118e-07   1.902e-07    -6.674    -6.721    -0.047     34.10
    BaSO4            1.027e-08   1.030e-08    -7.988    -7.987     0.001     (0)
    LiSO4-           8.839e-09   7.928e-09    -8.054    -8.101    -0.047     (0)
    SrSO4            4.191e-09   4.202e-09    -8.378    -8.377     0.001     24.12
    FeSO4            1.831e-09   1.836e-09    -8.737    -8.736     0.001     22.13
    MnSO4            7.742e-10   7.764e-10    -9.111    -9.110     0.001     23.88
    HSO4-            1.411e-10   1.263e-10    -9.850    -9.899    -0.048     40.14
    ZnSO4            6.122e-11   6.139e-11   -10.213   -10.212     0.001     22.20
    CdSO4            4.458e-12   4.471e-12   -11.351   -11.350     0.001     79.54
    CuSO4            6.231e-13   6.248e-13   -12.205   -12.204     0.001     12.72
    PbSO4            2.359e-13   2.366e-13   -12.627   -12.626     0.001     (0)
    CaHSO4+          1.984e-13   1.775e-13   -12.702   -12.751    -0.048     (0)
    Zn(SO4)2-2       5.520e-14   3.536e-14   -13.258   -13.451    -0.193    -15.30
    Cd(SO4)2-2       5.398e-15   3.458e-15   -14.268   -14.461    -0.193   -107.39
    AlSO4+           5.727e-16   5.129e-16   -15.242   -15.290    -0.048     (0)
    FeHSO4+          2.668e-16   2.387e-16   -15.574   -15.622    -0.048     (0)
    Pb(SO4)2-2       1.343e-16   8.602e-17   -15.872   -16.065    -0.193     (0)
    FeSO4+           1.015e-16   9.107e-17   -15.993   -16.041    -0.047     (0)
    Al(SO4)2-        1.238e-18   1.109e-18   -17.907   -17.955    -0.048     (0)
    Fe(SO4)2-        1.525e-19   1.365e-19   -18.817   -18.865    -0.048     (0)
    FeHSO4+2         7.613e-24   4.877e-24   -23.118   -23.312    -0.193     (0)
    AlHSO4+2         1.382e-24   8.854e-25   -23.859   -24.053    -0.193     (0)
Si              6.914e-05
    H4SiO4           6.862e-05   6.881e-05    -4.164    -4.162     0.001     52.33
    H3SiO4-          5.133e-07   4.589e-07    -6.290    -6.338    -0.049     27.97
    H2SiO4-2         1.983e-12   1.291e-12   -11.703   -11.889    -0.187     (0)
    SiF6-2           9.913e-31   6.418e-31   -30.004   -30.193    -0.189     42.67
Sr              5.483e-07
    Sr+2             4.939e-07   3.220e-07    -6.306    -6.492    -0.186    -17.50
    SrHCO3+          4.634e-08   4.162e-08    -7.334    -7.381    -0.047     (0)
    SrSO4            4.191e-09   4.202e-09    -8.378    -8.377     0.001     24.12
    SrCO3            3.884e-09   3.895e-09    -8.411    -8.410     0.001    -14.14
    SrOH+            9.222e-13   8.273e-13   -12.035   -12.082    -0.047     (0)
Zn              3.828e-08
    ZnCO3            1.588e-08   1.592e-08    -7.799    -7.798     0.001     (0)
    Zn(CO3)2-2       1.097e-08   7.029e-09    -7.960    -8.153    -0.193     (0)
    Zn+2             5.971e-09   3.866e-09    -8.224    -8.413    -0.189    -24.93
    ZnHCO3+          5.077e-09   4.542e-09    -8.294    -8.343    -0.048     (0)
    ZnOH+            1.901e-10   1.701e-10    -9.721    -9.769    -0.048     (0)
    Zn(OH)2          1.218e-10   1.222e-10    -9.914    -9.913     0.001     (0)
    ZnSO4            6.122e-11   6.139e-11   -10.213   -10.212     0.001     22.20
    ZnF+             3.273e-12   2.928e-12   -11.485   -11.533    -0.048     (0)
    ZnCl+            2.064e-12   1.845e-12   -11.685   -11.734    -0.049    -16.85
    ZnOHCl           1.290e-12   1.294e-12   -11.889   -11.888     0.001     (0)
    Zn(SO4)2-2       5.520e-14   3.536e-14   -13.258   -13.451    -0.193    -15.30
    Zn(OH)3-         2.163e-14   1.935e-14   -13.665   -13.713    -0.048     (0)
    ZnCl2            3.841e-16   3.852e-16   -15.416   -15.414     0.001    107.93
    Zn(OH)4-2        2.399e-19   1.537e-19   -18.620   -18.813    -0.193     (0)
    ZnCl3-           9.583e-20   8.567e-20   -19.018   -19.067    -0.049     16.68
    ZnCl4-2          1.307e-23   8.463e-24   -22.884   -23.072    -0.189    145.08

------------------------------Saturation indices-------------------------------

  Phase               SI** log IAP   log K(295 K,   1 atm)

  Al(OH)3(a)        -2.51      8.49   10.99  Al(OH)3
  Albite            -3.10    -21.29  -18.19  NaAlSi3O8
  Alunite           -8.31     -9.35   -1.04  KAl3(SO4)2(OH)6
  Anglesite         -7.57    -15.38   -7.81  PbSO4
  Anhydrite         -3.85     -8.09   -4.25  CaSO4
  Anorthite         -6.03    -25.82  -19.80  CaAl2Si2O8
  Aragonite         -0.30     -8.62   -8.32  CaCO3
  Barite            -0.82    -10.69   -9.87  BaSO4
  Ca-Montmorillonite  -1.68     -47.13  -45.45  Ca0.165Al2.33Si3.67O10(OH)2
  Calcite           -0.15     -8.62   -8.46  CaCO3
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  Cd(OH)2          -7.89      5.76   13.65  Cd(OH)2
  CdSiO3           -7.58      1.60    9.18  CdSiO3
  CdSO4           -13.81    -13.80    0.01  CdSO4
  Celestite        -4.01    -10.65   -6.64  SrSO4
  Cerussite        -2.74    -15.90  -13.16  PbCO3
  Chalcedony       -0.58     -4.16   -3.59  SiO2
  Chlorite(14A)    -7.16     62.32   69.47  Mg5Al2Si3O10(OH)8
  Chrysotile       -6.19     26.37   32.56  Mg3Si2O5(OH)4
  CO2(g)           -1.93     -3.36   -1.43  CO2
  Dolomite         -0.11    -17.14  -17.02  CaMg(CO3)2
  Fe(OH)3(a)        2.32      7.21    4.89  Fe(OH)3
  Fluorite         -1.81    -12.44  -10.63  CaF2
  Gibbsite          0.21      8.49    8.27  Al(OH)3
  Goethite          8.10      7.21   -0.90  FeOOH
  Gypsum           -3.51     -8.09   -4.58  CaSO4:2H2O
  H2(g)           -23.44    -26.54   -3.09  H2
  H2O(g)           -1.58     -0.00    1.58  H2O
  Halite           -7.28     -5.71    1.57  NaCl
  Hausmannite     -13.68     48.07   61.75  Mn3O4
  Hematite         18.20     14.41   -3.79  Fe2O3
  Illite           -1.74    -42.40  -40.66  K0.6Mg0.25Al2.3Si3.5O10(OH)2
  Jarosite-K       -4.20    -13.19   -8.98  KFe3(SO4)2(OH)6
  K-feldspar       -1.86    -22.66  -20.79  KAlSi3O8
  K-mica            4.15     17.28   13.13  KAl3Si3O10(OH)2
  Kaolinite         0.96      8.65    7.69  Al2Si2O5(OH)4
  Manganite        -5.42     19.92   25.34  MnOOH
  Melanterite      -8.72    -10.96   -2.24  FeSO4:7H2O
  O2(g)           -37.38    -40.25   -2.87  O2
  Otavite          -2.23    -14.33  -12.10  CdCO3
  Pb(OH)2          -4.07      4.18    8.25  Pb(OH)2
  Pyrochroite      -6.98      8.22   15.20  Mn(OH)2
  Pyrolusite      -10.23     31.62   41.85  MnO2:H2O
  Quartz           -0.14     -4.16   -4.02  SiO2
  Rhodochrosite    -0.74    -11.86  -11.12  MnCO3
  Sepiolite        -5.19     10.65   15.84  Mg2Si3O7.5OH:3H2O
  Sepiolite(d)     -8.01     10.65   18.66  Mg2Si3O7.5OH:3H2O
  Siderite         -0.62    -11.49  -10.87  FeCO3
  SiO2(a)          -1.43     -4.16   -2.74  SiO2
  Smithsonite      -3.13    -13.10   -9.97  ZnCO3
  Strontianite     -1.91    -11.18   -9.27  SrCO3
  Sylvite          -7.97     -7.08    0.89  KCl
  Talc             -3.68     18.05   21.73  Mg3Si4O10(OH)2
  Willemite        -5.76      9.81   15.57  Zn2SiO4
  Witherite        -2.64    -11.21   -8.57  BaCO3
  Zn(OH)2(e)       -4.51      6.99   11.50  Zn(OH)2

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
  For ideal gases, phi = 1.

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End of simulation.
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Reading input data for simulation 2.
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        USE solution 1
        REACTION 1
        H2O  -1.0
        37.77 moles
        SAVE solution 2
        END
-----------------------------------------
Beginning of batch-reaction calculations.
-----------------------------------------

Reaction step 1.

Using solution 1.Bore 940 7/12/2017
Using reaction 1.

Reaction 1.

          3.777e+01 moles of the following reaction have been added:

                         Relative
        Reactant            moles

        H2O                -1.00000

                         Relative
        Element             moles
        H                  -2.00000
        O                  -1.00000

-----------------------------Solution composition------------------------------
```

Elements	Molality	Moles
Al	5.805e-07	1.855e-07
B	2.028e-05	6.482e-06
Ba	1.574e-06	5.029e-07
C	3.427e-02	1.095e-02
Ca	6.253e-04	1.998e-04
Cd	1.393e-09	4.453e-10
Cl	7.069e-04	2.259e-04
Cu	2.465e-08	7.876e-09
F	1.979e-04	6.322e-05
Fe	1.290e-05	4.122e-06
K	1.442e-03	4.608e-04
Li	9.119e-05	2.914e-05
Mg	7.731e-04	2.470e-04
Mn	8.553e-07	2.733e-07
Na	3.366e-02	1.075e-02
Pb	7.560e-09	2.416e-09
S	3.587e-04	1.146e-04
Si	2.164e-04	6.914e-05
Sr	1.716e-06	5.483e-07
Zn	1.198e-07	3.828e-08

----------------------------Description of solution----------------------------

pH	=	7.653	Charge balance
pe	=	4.454	Adjusted to redox equilibrium
Specific Conductance (µS/cm, 22°C)	=	2823	
Density (g/cm³)	=	0.99996	
Volume (L)	=	0.32052	
Activity of water	=	0.999	
Ionic strength (mol/kgw)	=	3.705e-02	
Mass of water (kg)	=	3.195e-01	
Total alkalinity (eq/kg)	=	3.306e-02	
Total CO2 (mol/kg)	=	3.427e-02	
Temperature (°C)	=	22.10	
Electrical balance (eq)	=	1.063e-03	
Percent error, 100*(Cat-|An|)/(Cat+|An|)	=	4.68	
Iterations	=	11	
Total H	=	3.548322e+01	
Total O	=	1.776940e+01	

----------------------------Distribution of species----------------------------

Species	Molality	Activity	Log Molality	Log Activity	Log Gamma	mole V cm³/mol
OH-	4.368e-07	3.633e-07	-6.360	-6.440	-0.080	-4.04
H+	2.566e-08	2.223e-08	-7.591	-7.653	-0.062	0.00
H2O	5.551e+01	9.988e-01	1.744	-0.001	0.000	18.06
Al	5.805e-07					
Al(OH)4-	5.689e-07	4.775e-07	-6.245	-6.321	-0.076	(0)
Al(OH)3	5.803e-09	5.853e-09	-8.236	-8.233	0.004	(0)
AlF3	2.667e-09	2.690e-09	-8.574	-8.570	0.004	(0)
AlF2+	1.591e-09	1.346e-09	-8.798	-8.871	-0.073	(0)
Al(OH)2+	1.300e-09	1.099e-09	-8.886	-8.959	-0.073	(0)
AlF4-	2.030e-10	1.704e-10	-9.692	-9.769	-0.076	(0)
AlF+2	3.349e-11	1.712e-11	-10.475	-10.766	-0.291	(0)
AlOH+2	7.900e-12	4.038e-12	-11.102	-11.394	-0.291	-27.24
Al+3	3.979e-14	1.094e-14	-13.400	-13.961	-0.561	-41.30
AlSO4+	6.258e-15	5.253e-15	-14.204	-14.280	-0.076	(0)
Al(SO4)2-	3.078e-17	2.584e-17	-16.512	-16.588	-0.076	(0)
AlHSO4+2	2.040e-23	1.010e-23	-22.690	-22.996	-0.305	(0)
B	2.028e-05					
H3BO3	1.970e-05	1.987e-05	-4.705	-4.702	0.004	39.00
H2BO3-	5.811e-07	4.875e-07	-6.236	-6.312	-0.076	(0)
BF(OH)3-	1.456e-09	1.222e-09	-8.837	-8.913	-0.076	(0)
BF2(OH)2-	5.552e-13	4.658e-13	-12.256	-12.332	-0.076	(0)
BF3OH-	2.277e-18	1.910e-18	-17.643	-17.719	-0.076	(0)
BF4-	3.301e-23	2.769e-23	-22.481	-22.558	-0.076	(0)
Ba	1.574e-06					
Ba+2	1.321e-06	6.526e-07	-5.879	-6.185	-0.306	-12.46
BaHCO3+	1.845e-07	1.547e-07	-6.734	-6.810	-0.076	(0)
BaSO4	5.114e-08	5.157e-08	-7.291	-7.288	0.004	(0)
BaCO3	1.697e-08	1.711e-08	-7.770	-7.767	0.004	-10.73
BaOH+	1.179e-12	9.934e-13	-11.929	-12.003	-0.074	(0)
C(-4)	0.000e+00					
CH4	0.000e+00	0.000e+00	-74.920	-74.916	0.004	35.20
C(4)	3.427e-02					
HCO3-	3.205e-02	2.710e-02	-1.494	-1.567	-0.073	24.69
CO2	1.397e-03	1.409e-03	-2.855	-2.851	0.004	34.29
NaHCO3	4.291e-04	4.328e-04	-3.367	-3.364	0.004	1.80
MgHCO3+	1.215e-04	1.015e-04	-3.916	-3.994	-0.078	5.51
CO3-2	1.052e-04	5.380e-05	-3.978	-4.269	-0.291	-4.90
CaHCO3+	9.894e-05	8.404e-05	-4.005	-4.075	-0.071	9.66
NaCO3-	2.877e-05	2.414e-05	-4.541	-4.617	-0.076	-1.00
CaCO3	2.160e-05	2.179e-05	-4.665	-4.662	0.004	-14.61
MgCO3	1.577e-05	1.590e-05	-4.802	-4.799	0.004	-17.09

FeHCO3+	7.585e-07	6.363e-07	-6.120	-6.196	-0.076	(0)
MnCO3	4.002e-07	4.036e-07	-6.398	-6.394	0.004	(0)
SrHCO3+	3.110e-07	2.630e-07	-6.507	-6.580	-0.073	(0)
FeCO3	3.004e-07	3.030e-07	-6.522	-6.519	0.004	(0)
MnHCO3+	2.707e-07	2.282e-07	-6.568	-6.642	-0.074	(0)
BaHCO3+	1.845e-07	1.547e-07	-6.734	-6.810	-0.076	(0)
Zn(CO3)2-2	7.156e-08	3.544e-08	-7.145	-7.450	-0.305	(0)
(CO2)2	3.279e-08	3.307e-08	-7.484	-7.481	0.004	68.58
ZnCO3	3.055e-08	3.082e-08	-7.515	-7.511	0.004	(0)
SrCO3	2.190e-08	2.209e-08	-7.660	-7.656	0.004	-14.14
CuCO3	1.827e-08	1.843e-08	-7.738	-7.735	0.004	(0)
BaCO3	1.697e-08	1.711e-08	-7.770	-7.767	0.004	-10.73
ZnHCO3+	1.168e-08	9.795e-09	-7.933	-8.009	-0.076	(0)
PbCO3	5.787e-09	5.837e-09	-8.238	-8.234	0.004	(0)
Cu(CO3)2-2	2.519e-09	1.248e-09	-8.599	-8.904	-0.305	(0)
Pb(CO3)2-2	1.592e-09	7.887e-10	-8.798	-9.103	-0.305	(0)
CuHCO3+	1.033e-09	8.663e-10	-8.986	-9.062	-0.076	(0)
CdHCO3+	4.427e-10	3.714e-10	-9.354	-9.430	-0.076	(0)
PbHCO3+	1.602e-10	1.344e-10	-9.795	-9.872	-0.076	(0)
CdCO3	1.836e-11	1.852e-11	-10.736	-10.732	0.004	(0)
Cd(CO3)2-2	6.360e-12	3.150e-12	-11.197	-11.502	-0.305	(0)
Ca	6.253e-04					
Ca+2	4.978e-04	2.548e-04	-3.303	-3.594	-0.291	-17.73
CaHCO3+	9.894e-05	8.404e-05	-4.005	-4.075	-0.071	9.66
CaCO3	2.160e-05	2.179e-05	-4.665	-4.662	0.004	-14.61
CaSO4	6.929e-06	6.988e-06	-5.159	-5.156	0.004	7.39
CaOH+	2.264e-09	1.899e-09	-8.645	-8.721	-0.076	(0)
CaHSO4+	1.169e-12	9.807e-13	-11.932	-12.008	-0.076	(0)
Cd	1.393e-09					
Cd+2	8.749e-10	4.334e-10	-9.058	-9.363	-0.305	-18.46
CdHCO3+	4.427e-10	3.714e-10	-9.354	-9.430	-0.076	(0)
CdCl+	2.880e-11	2.416e-11	-10.541	-10.617	-0.076	5.43
CdSO4	1.919e-11	1.936e-11	-10.717	-10.713	0.004	79.54
CdCO3	1.836e-11	1.852e-11	-10.736	-10.732	0.004	(0)
Cd(CO3)2-2	6.360e-12	3.150e-12	-11.197	-11.502	-0.305	(0)
CdOH+	1.553e-12	1.303e-12	-11.809	-11.885	-0.076	(0)
CdF+	1.036e-12	8.688e-13	-11.985	-12.061	-0.076	(0)
CdOHCl	4.176e-13	4.211e-13	-12.379	-12.376	0.004	(0)
Cd(SO4)2-2	6.878e-14	3.407e-14	-13.163	-13.468	-0.305	-107.22
CdCl2	5.823e-14	5.873e-14	-13.235	-13.231	0.004	23.14
Cd(OH)2	3.873e-15	3.906e-15	-14.412	-14.408	0.004	(0)
CdF2	3.445e-16	3.475e-16	-15.463	-15.459	0.004	(0)
CdCl3-	2.492e-17	2.090e-17	-16.604	-16.680	-0.076	71.62
Cd(OH)3-	2.347e-20	1.969e-20	-19.629	-19.706	-0.076	(0)
Cd2OH+3	1.394e-20	2.869e-21	-19.856	-20.542	-0.687	(0)
Cd(OH)4-2	1.591e-26	7.883e-27	-25.798	-26.103	-0.305	(0)
CdHS+	0.000e+00	0.000e+00	-73.340	-73.416	-0.076	(0)
Cd(HS)2	0.000e+00	0.000e+00	-141.283	-141.279	0.004	(0)
Cd(HS)3-	0.000e+00	0.000e+00	-213.246	-213.323	-0.076	(0)
Cd(HS)4-2	0.000e+00	0.000e+00	-285.051	-285.356	-0.305	(0)
Cl	7.069e-04					
Cl-	7.069e-04	5.895e-04	-3.151	-3.230	-0.079	18.13
MnCl+	2.691e-10	2.268e-10	-9.570	-9.644	-0.074	-3.73
FeCl+	2.278e-10	1.911e-10	-9.643	-9.719	-0.076	(0)
CdCl+	2.880e-11	2.416e-11	-10.541	-10.617	-0.076	5.43
ZnCl+	4.791e-12	4.003e-12	-11.320	-11.398	-0.078	-16.88
ZnOHCl	2.496e-12	2.517e-12	-11.603	-11.599	0.004	(0)
CdOHCl	4.176e-13	4.211e-13	-12.379	-12.376	0.004	(0)
PbCl+	1.624e-13	1.363e-13	-12.789	-12.866	-0.076	7.94
CuCl2-	1.518e-13	1.268e-13	-12.819	-12.897	-0.078	(0)
CuCl+	1.049e-13	8.768e-14	-12.979	-13.057	-0.078	1.57
CdCl2	5.823e-14	5.873e-14	-13.235	-13.231	0.004	23.14
MnCl2	5.788e-14	5.837e-14	-13.237	-13.234	0.004	89.59
ZnCl2	2.422e-15	2.442e-15	-14.616	-14.612	0.004	107.93
CuCl3-2	2.321e-16	1.171e-16	-15.634	-15.931	-0.297	(0)
PbCl2	1.333e-16	1.345e-16	-15.875	-15.871	0.004	34.73
CuCl2	2.666e-17	2.689e-17	-16.574	-16.570	0.004	27.52
CdCl3-	2.492e-17	2.090e-17	-16.604	-16.680	-0.076	71.62
FeCl+2	1.745e-17	8.807e-18	-16.758	-17.055	-0.297	(0)
MnCl3-	1.124e-17	9.478e-18	-16.949	-17.023	-0.074	43.69
ZnCl3-	1.900e-18	1.587e-18	-17.721	-17.799	-0.078	16.56
PbCl3-	7.371e-20	6.184e-20	-19.132	-19.209	-0.076	65.73
FeCl2+	3.019e-20	2.545e-20	-19.520	-19.594	-0.074	(0)
ZnCl4-2	9.079e-22	4.582e-22	-21.042	-21.339	-0.297	145.46
CuCl3-	6.391e-23	5.340e-23	-22.194	-22.272	-0.078	(0)
PbCl4-2	3.444e-23	1.706e-23	-22.463	-22.768	-0.305	101.46
FeCl3	1.487e-24	1.500e-24	-23.828	-23.824	0.004	(0)
CuCl4-2	2.921e-28	1.474e-28	-27.534	-27.831	-0.297	(0)
Cu(1)	1.544e-12					
Cu+	1.392e-12	1.146e-12	-11.856	-11.941	-0.084	(0)
CuCl2-	1.518e-13	1.268e-13	-12.819	-12.897	-0.078	(0)
CuCl3-2	2.321e-16	1.171e-16	-15.634	-15.931	-0.297	(0)
Cu(2)	2.465e-08					
CuCO3	1.827e-08	1.843e-08	-7.738	-7.735	0.004	(0)
Cu(OH)2	2.666e-09	2.689e-09	-8.574	-8.570	0.004	(0)
Cu(CO3)2-2	2.519e-09	1.248e-09	-8.599	-8.904	-0.305	(0)
CuHCO3+	1.033e-09	8.663e-10	-8.986	-9.062	-0.076	(0)
Cu+2	1.225e-10	6.378e-11	-9.912	-10.195	-0.283	-26.17

CuOH+	3.429e-11	2.865e-11	-10.465	-10.543	-0.078	(0)
CuSO4	1.995e-12	2.012e-12	-11.700	-11.696	0.004	12.72
CuF+	2.145e-13	1.799e-13	-12.669	-12.745	-0.076	(0)
CuCl+	1.049e-13	8.768e-14	-12.979	-13.057	-0.078	1.57
Cu(OH)3-	8.676e-15	7.279e-15	-14.062	-14.138	-0.076	(0)
Cu2(OH)2+2	5.422e-16	2.686e-16	-15.266	-15.571	-0.305	(0)
CuCl2	2.666e-17	2.689e-17	-16.574	-16.570	0.004	27.52
Cu(OH)4-2	1.317e-19	6.524e-20	-18.880	-19.185	-0.305	(0)
CuCl3-	6.391e-23	5.340e-23	-22.194	-22.272	-0.078	(0)
CuCl4-2	2.921e-28	1.474e-28	-27.534	-27.831	-0.297	(0)
Cu(HS)3-	0.000e+00	0.000e+00	-206.889	-206.965	-0.076	(0)
F	1.979e-04					
F-	1.915e-04	1.592e-04	-3.718	-3.798	-0.080	-1.20
MgF+	3.851e-06	3.232e-06	-5.414	-5.491	-0.076	-10.46
NaF	2.538e-06	2.559e-06	-5.596	-5.592	0.004	7.15
HF	4.998e-09	5.041e-09	-8.301	-8.297	0.004	12.36
AlF3	2.667e-09	2.690e-09	-8.574	-8.570	0.004	(0)
AlF2+	1.591e-09	1.346e-09	-8.798	-8.871	-0.073	(0)
BF(OH)3-	1.456e-09	1.222e-09	-8.837	-8.913	-0.076	(0)
FeF+	4.457e-10	3.739e-10	-9.351	-9.427	-0.076	(0)
AlF4-	2.030e-10	1.704e-10	-9.692	-9.769	-0.076	(0)
MnF+	1.235e-10	1.041e-10	-9.908	-9.983	-0.074	(0)
AlF+2	3.349e-11	1.712e-11	-10.475	-10.766	-0.291	(0)
ZnF+	7.419e-12	6.224e-12	-11.130	-11.206	-0.076	(0)
HF2-	3.586e-12	3.009e-12	-11.445	-11.522	-0.076	22.07
CdF+	1.036e-12	8.688e-13	-11.985	-12.061	-0.076	(0)
FeF2+	9.516e-13	8.020e-13	-12.022	-12.096	-0.074	(0)
BF2(OH)2-	5.552e-13	4.658e-13	-12.256	-12.332	-0.076	(0)
FeF+2	2.596e-13	1.310e-13	-12.586	-12.883	-0.297	(0)
CuF+	2.145e-13	1.799e-13	-12.669	-12.745	-0.076	(0)
FeF3	1.987e-13	2.004e-13	-12.702	-12.698	0.004	(0)
PbF+	2.107e-14	1.768e-14	-13.676	-13.753	-0.076	(0)
CdF2	3.445e-16	3.475e-16	-15.463	-15.459	0.004	(0)
PbF2	5.699e-17	5.748e-17	-16.244	-16.240	0.004	(0)
BF3OH-	2.277e-18	1.910e-18	-17.643	-17.719	-0.076	(0)
PbF3-	7.904e-20	6.631e-20	-19.102	-19.178	-0.076	(0)
BF4-	3.301e-23	2.769e-23	-22.481	-22.558	-0.076	(0)
PbF4-2	1.020e-23	5.054e-24	-22.991	-23.296	-0.305	(0)
SiF6-2	3.406e-27	1.719e-27	-26.468	-26.765	-0.297	42.98
Fe(2)	1.520e-06					
FeHCO3+	7.585e-07	6.363e-07	-6.120	-6.196	-0.076	(0)
Fe+2	4.509e-07	2.348e-07	-6.346	-6.629	-0.283	-21.90
FeCO3	3.004e-07	3.030e-07	-6.522	-6.519	0.004	(0)
FeSO4	6.187e-09	6.240e-09	-8.209	-8.205	0.004	22.13
FeOH+	3.180e-09	2.680e-09	-8.498	-8.572	-0.074	(0)
FeF+	4.457e-10	3.739e-10	-9.351	-9.427	-0.076	(0)
FeCl+	2.278e-10	1.911e-10	-9.643	-9.719	-0.076	(0)
Fe(OH)2	7.875e-13	7.943e-13	-12.104	-12.100	0.004	(0)
Fe(OH)3-	1.528e-15	1.288e-15	-14.816	-14.890	-0.074	(0)
FeHSO4+	1.077e-15	9.038e-16	-14.968	-15.044	-0.076	(0)
Fe(HS)2	0.000e+00	0.000e+00	-146.129	-146.126	0.004	(0)
Fe(HS)3-	0.000e+00	0.000e+00	-218.236	-218.312	-0.076	(0)
Fe(3)	1.138e-05					
Fe(OH)3	8.908e-06	8.984e-06	-5.050	-5.047	0.004	(0)
Fe(OH)2+	2.086e-06	1.764e-06	-5.681	-5.754	-0.073	(0)
Fe(OH)4-	3.870e-07	3.272e-07	-6.412	-6.485	-0.073	(0)
FeOH+2	2.626e-10	1.325e-10	-9.581	-9.878	-0.297	(0)
FeF2+	9.516e-13	8.020e-13	-12.022	-12.096	-0.074	(0)
FeF+2	2.596e-13	1.310e-13	-12.586	-12.883	-0.297	(0)
FeF3	1.987e-13	2.004e-13	-12.702	-12.698	0.004	(0)
Fe+3	1.974e-15	5.428e-16	-14.705	-15.265	-0.561	(0)
FeSO4+	1.044e-15	8.795e-16	-14.982	-15.056	-0.074	(0)
FeCl+2	1.745e-17	8.807e-18	-16.758	-17.055	-0.297	(0)
Fe2(OH)2+4	8.861e-18	5.334e-19	-17.052	-18.273	-1.220	(0)
Fe(SO4)2-	3.575e-18	2.999e-18	-17.447	-17.523	-0.076	(0)
FeCl2+	3.019e-20	2.545e-20	-19.520	-19.594	-0.074	(0)
Fe3(OH)4+5	2.079e-20	2.575e-22	-19.682	-21.589	-1.907	(0)
FeHSO4+2	1.060e-22	5.248e-23	-21.975	-22.280	-0.305	(0)
FeCl3	1.487e-24	1.500e-24	-23.828	-23.824	0.004	(0)
H(0)	8.846e-28					
H2	4.423e-28	4.461e-28	-27.354	-27.351	0.004	28.61
K	1.442e-03					
K+	1.441e-03	1.200e-03	-2.841	-2.921	-0.079	9.04
KSO4-	1.494e-06	1.263e-06	-5.826	-5.899	-0.073	34.18
Li	9.119e-05					
Li+	9.113e-05	7.741e-05	-4.040	-4.111	-0.071	-1.18
LiSO4-	6.321e-08	5.328e-08	-7.199	-7.273	-0.074	(0)
Mg	7.731e-04					
Mg+2	6.210e-04	3.239e-04	-3.207	-3.490	-0.283	-21.29
MgHCO3+	1.215e-04	1.015e-04	-3.916	-3.994	-0.078	5.51
MgCO3	1.577e-05	1.590e-05	-4.802	-4.799	0.004	-17.09
MgSO4	1.101e-05	1.110e-05	-4.958	-4.955	0.004	5.72
MgF+	3.851e-06	3.232e-06	-5.414	-5.491	-0.076	-10.46
MgOH+	4.757e-08	4.055e-08	-7.323	-7.392	-0.069	(0)
Mn(2)	8.553e-07					
MnCO3	4.002e-07	4.036e-07	-6.398	-6.394	0.004	(0)
MnHCO3+	2.707e-07	2.282e-07	-6.568	-6.642	-0.074	(0)
Mn+2	1.814e-07	9.446e-08	-6.741	-7.025	-0.283	-19.01

MnSO4	2.483e-09	2.505e-09	-8.605	-8.601	0.004	23.88
MnCl+	2.691e-10	2.268e-10	-9.570	-9.644	-0.074	-3.73
MnF+	1.235e-10	1.041e-10	-9.908	-9.983	-0.074	(0)
MnOH+	1.019e-10	8.591e-11	-9.992	-10.066	-0.074	(0)
MnCl2	5.788e-14	5.837e-14	-13.237	-13.234	0.004	89.59
MnCl3-	1.124e-17	9.478e-18	-16.949	-17.023	-0.074	43.69
Mn(OH)3-	1.610e-19	1.357e-19	-18.793	-18.867	-0.074	(0)
Mn(3)	1.967e-28					
Mn+3	1.967e-28	5.409e-29	-27.706	-28.267	-0.561	(0)
Na	3.366e-02					
Na+	3.317e-02	2.793e-02	-1.479	-1.554	-0.075	-1.41
NaHCO3	4.291e-04	4.328e-04	-3.367	-3.364	0.004	1.80
NaCO3-	2.877e-05	2.414e-05	-4.541	-4.617	-0.076	-1.00
NaSO4-	2.562e-05	2.167e-05	-4.591	-4.664	-0.073	15.23
NaF	2.538e-06	2.559e-06	-5.596	-5.592	0.004	7.15
NaOH	1.006e-18	1.015e-18	-17.997	-17.994	0.004	(0)
O(0)	4.703e-39					
O2	2.351e-39	2.372e-39	-38.629	-38.625	0.004	30.17
Pb	7.560e-09					
PbCO3	5.787e-09	5.837e-09	-8.238	-8.234	0.004	(0)
Pb(CO3)2-2	1.592e-09	7.887e-10	-8.798	-9.103	-0.305	(0)
PbHCO3+	1.602e-10	1.344e-10	-9.795	-9.872	-0.076	(0)
Pb+2	1.260e-11	6.243e-12	-10.899	-11.205	-0.305	-15.07
PbOH+	6.519e-12	5.469e-12	-11.186	-11.262	-0.076	(0)
PbSO4	5.489e-13	5.536e-13	-12.261	-12.257	0.004	(0)
PbCl+	1.624e-13	1.363e-13	-12.789	-12.866	-0.076	7.94
Pb(OH)2	9.476e-14	9.557e-14	-13.023	-13.020	0.004	(0)
PbF+	2.107e-14	1.768e-14	-13.676	-13.753	-0.076	(0)
Pb(SO4)2-2	9.248e-16	4.581e-16	-15.034	-15.339	-0.305	(0)
PbCl2	1.333e-16	1.345e-16	-15.875	-15.871	0.004	34.73
Pb(OH)3-	5.876e-17	4.929e-17	-16.231	-16.307	-0.076	(0)
PbF2	5.699e-17	5.748e-17	-16.244	-16.240	0.004	(0)
PbF3-	7.904e-20	6.631e-20	-19.102	-19.178	-0.076	(0)
PbCl3-	7.371e-20	6.184e-20	-19.132	-19.209	-0.076	65.73
Pb(OH)4-2	1.024e-20	5.073e-21	-19.990	-20.295	-0.305	(0)
Pb2OH+3	3.714e-21	7.643e-22	-20.430	-21.117	-0.687	(0)
PbCl4-2	3.444e-23	1.706e-23	-22.463	-22.768	-0.305	101.46
PbF4-2	1.020e-23	5.054e-24	-22.991	-23.296	-0.305	(0)
Pb3(OH)4+2	1.700e-27	8.420e-28	-26.770	-27.075	-0.305	(0)
Pb(HS)2	0.000e+00	0.000e+00	-144.385	-144.381	0.004	(0)
Pb(HS)3-	0.000e+00	0.000e+00	-217.228	-217.304	-0.076	(0)
S(-2)	0.000e+00					
CdHS+	0.000e+00	0.000e+00	-73.340	-73.416	-0.076	(0)
HS-	0.000e+00	0.000e+00	-74.143	-74.223	-0.080	20.61
H2S	0.000e+00	0.000e+00	-74.899	-74.896	0.004	37.15
S-2	0.000e+00	0.000e+00	-79.278	-79.575	-0.297	(0)
Cd(HS)2	0.000e+00	0.000e+00	-141.283	-141.279	0.004	(0)
Zn(HS)2	0.000e+00	0.000e+00	-142.052	-142.048	0.004	(0)
Pb(HS)2	0.000e+00	0.000e+00	-144.385	-144.381	0.004	(0)
Fe(HS)2	0.000e+00	0.000e+00	-146.129	-146.126	0.004	(0)
Cu(HS)3-	0.000e+00	0.000e+00	-206.889	-206.965	-0.076	(0)
Cd(HS)3-	0.000e+00	0.000e+00	-213.246	-213.323	-0.076	(0)
Zn(HS)3-	0.000e+00	0.000e+00	-215.035	-215.111	-0.076	(0)
Pb(HS)3-	0.000e+00	0.000e+00	-217.228	-217.304	-0.076	(0)
Fe(HS)3-	0.000e+00	0.000e+00	-218.236	-218.312	-0.076	(0)
Cd(HS)4-2	0.000e+00	0.000e+00	-285.051	-285.356	-0.305	(0)
S(6)	3.587e-04					
SO4-2	3.135e-04	1.577e-04	-3.504	-3.802	-0.298	14.71
NaSO4-	2.562e-05	2.167e-05	-4.591	-4.664	-0.073	15.23
MgSO4	1.101e-05	1.110e-05	-4.958	-4.955	0.004	5.72
CaSO4	6.929e-06	6.988e-06	-5.159	-5.156	0.004	7.39
KSO4-	1.494e-06	1.263e-06	-5.826	-5.899	-0.073	34.18
LiSO4-	6.321e-08	5.328e-08	-7.199	-7.273	-0.074	(0)
BaSO4	5.114e-08	5.157e-08	-7.291	-7.288	0.004	(0)
SrSO4	2.063e-08	2.081e-08	-7.685	-7.682	0.004	24.12
FeSO4	6.187e-09	6.240e-09	-8.209	-8.205	0.004	22.13
MnSO4	2.483e-09	2.505e-09	-8.605	-8.601	0.004	23.88
HSO4-	3.817e-10	3.202e-10	-9.418	-9.495	-0.076	40.22
ZnSO4	1.029e-10	1.037e-10	-9.988	-9.984	0.004	22.20
CdSO4	1.919e-11	1.936e-11	-10.717	-10.713	0.004	79.54
CuSO4	1.995e-12	2.012e-12	-11.700	-11.696	0.004	12.72
CaHSO4+	1.169e-12	9.807e-13	-11.932	-12.008	-0.076	(0)
PbSO4	5.489e-13	5.536e-13	-12.261	-12.257	0.004	(0)
Zn(SO4)2-2	2.746e-13	1.360e-13	-12.561	-12.866	-0.305	-14.79
Cd(SO4)2-2	6.878e-14	3.407e-14	-13.163	-13.468	-0.305	-107.22
AlSO4+	6.258e-15	5.253e-15	-14.204	-14.280	-0.076	(0)
FeHSO4+	1.077e-15	9.038e-16	-14.968	-15.044	-0.076	(0)
FeSO4+	1.044e-15	8.795e-16	-14.982	-15.056	-0.074	(0)
Pb(SO4)2-2	9.248e-16	4.581e-16	-15.034	-15.339	-0.305	(0)
Al(SO4)2-	3.078e-17	2.584e-17	-16.512	-16.588	-0.076	(0)
Fe(SO4)2-	3.575e-18	2.999e-18	-17.447	-17.523	-0.076	(0)
FeHSO4+2	1.060e-22	5.248e-23	-21.975	-22.280	-0.305	(0)
AlHSO4+2	2.040e-23	1.010e-23	-22.690	-22.996	-0.305	(0)
Si	2.164e-04					
H4SiO4	2.148e-04	2.167e-04	-3.668	-3.664	0.004	52.33
H3SiO4-	1.551e-06	1.296e-06	-5.809	-5.887	-0.078	28.05
H2SiO4-2	6.403e-12	3.273e-12	-11.194	-11.485	-0.291	(0)
SiF6-2	3.406e-27	1.719e-27	-26.468	-26.765	-0.297	42.98

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Sr            1.716e-06
   Sr+2            1.362e-06   7.006e-07    -5.866    -6.155    -0.289    -17.30
   SrHCO3+         3.110e-07   2.630e-07    -6.507    -6.580    -0.073     (0)
   SrCO3           2.190e-08   2.209e-08    -7.660    -7.656     0.004    -14.14
   SrSO4           2.063e-08   2.081e-08    -7.685    -7.682     0.004     24.12
   SrOH+           1.915e-12   1.614e-12   -11.718   -11.792    -0.074     (0)
Zn            1.198e-07
   Zn(CO3)2-2      7.156e-08   3.544e-08    -7.145    -7.450    -0.305     (0)
   ZnCO3           3.055e-08   3.082e-08    -7.515    -7.511     0.004     (0)
   ZnHCO3+         1.168e-08   9.795e-09    -7.933    -8.009    -0.076     (0)
   Zn+2            5.689e-09   2.871e-09    -8.245    -8.542    -0.297    -24.73
   ZnOH+           1.350e-10   1.132e-10    -9.870    -9.946    -0.076     (0)
   ZnSO4           1.029e-10   1.037e-10    -9.988    -9.984     0.004     22.20
   Zn(OH)2         7.232e-11   7.294e-11   -10.141   -10.137     0.004     (0)
   ZnF+            7.419e-12   6.224e-12   -11.130   -11.206    -0.076     (0)
   ZnCl+           4.791e-12   4.003e-12   -11.320   -11.398    -0.078    -16.88
   ZnOHCl          2.496e-12   2.517e-12   -11.603   -11.599     0.004     (0)
   Zn(SO4)2-2      2.746e-13   1.360e-13   -12.561   -12.866    -0.305    -14.79
   Zn(OH)3-        1.235e-14   1.036e-14   -13.908   -13.985    -0.076     (0)
   ZnCl2           2.422e-15   2.442e-15   -14.616   -14.612     0.004    107.93
   ZnCl3-          1.900e-18   1.587e-18   -17.721   -17.799    -0.078     16.56
   Zn(OH)4-2       1.489e-19   7.377e-20   -18.827   -19.132    -0.305     (0)
   ZnCl4-2         9.079e-22   4.582e-22   -21.042   -21.339    -0.297    145.46
   Zn(HS)2         0.000e+00   0.000e+00  -142.052  -142.048     0.004     (0)
   Zn(HS)3-        0.000e+00   0.000e+00  -215.035  -215.111    -0.076     (0)

------------------------------Saturation indices-------------------------------

  Phase               SI** log IAP   log K(295 K,   1 atm)

  Al(OH)3(a)       -1.99      9.00   10.99  Al(OH)3
  Albite           -0.68    -18.86  -18.19  NaAlSi3O8
  Alunite          -5.46     -6.49   -1.04  KAl3(SO4)2(OH)6
  Anglesite        -7.20    -15.01   -7.81  PbSO4
  Anhydrite        -3.15     -7.40   -4.25  CaSO4
  Anorthite        -3.76    -23.56  -19.80  CaAl2Si2O8
  Aragonite         0.46     -7.86   -8.32  CaCO3
  Barite           -0.12     -9.99   -9.87  BaSO4
  Ca-Montmorillonite   1.38    -44.07  -45.45  Ca0.165Al2.33Si3.67O10(OH)2
  Calcite           0.60     -7.86   -8.46  CaCO3
  Cd(OH)2          -7.71      5.94   13.65  Cd(OH)2
  CdSiO3           -6.90      2.28    9.18  CdSiO3
  CdSO4           -13.17    -13.17    0.01  CdSO4
  Celestite        -3.31     -9.96   -6.64  SrSO4
  Cerussite        -2.31    -15.47  -13.16  PbCO3
  CH4(g)          -72.14    -74.92   -2.77  CH4
  Chalcedony       -0.08     -3.66   -3.59  SiO2
  Chlorite(14A)    -3.39     66.08   69.47  Mg5Al2Si3O10(OH)8
  Chrysotile       -4.44     28.12   32.56  Mg3Si2O5(OH)4
  CO2(g)           -1.42     -2.85   -1.43  CO2
  Dolomite          1.40    -15.62  -17.02  CaMg(CO3)2
  Fe(OH)3(a)        2.80      7.69    4.89  Fe(OH)3
  FeS(ppt)        -69.28    -73.20   -3.92  FeS
  Fluorite         -0.56    -11.19  -10.63  CaF2
  Gibbsite          0.72      9.00    8.27  Al(OH)3
  Goethite          8.59      7.69   -0.90  FeOOH
  Gypsum           -2.81     -7.40   -4.58  CaSO4:2H2O
  H2(g)           -24.26    -27.35   -3.09  H2
  H2O(g)           -1.58     -0.00    1.58  H2O
  H2S(g)          -73.88    -81.88   -8.00  H2S
  Halite           -6.35     -4.78    1.57  NaCl
  Hausmannite     -12.70     49.05   61.75  Mn3O4
  Hematite         19.17     15.39   -3.79  Fe2O3
  Illite            1.49    -39.17  -40.66  K0.6Mg0.25Al2.3Si3.5O10(OH)2
  Jarosite-K       -1.42    -10.41   -8.98  KFe3(SO4)2(OH)6
  K-feldspar        0.56    -20.23  -20.79  KAlSi3O8
  K-mica            7.60     20.73   13.13  KAl3Si3O10(OH)2
  Kaolinite         2.98     10.67    7.69  Al2Si2O5(OH)4
  Mackinawite     -68.55    -73.20   -4.65  FeS
  Manganite        -4.95     20.39   25.34  MnOOH
  Melanterite      -8.19    -10.44   -2.24  FeSO4:7H2O
  O2(g)           -35.75    -38.62   -2.87  O2
  Otavite          -1.53    -13.63  -12.10  CdCO3
  Pb(OH)2          -4.15      4.10    8.25  Pb(OH)2
  Pyrite         -112.30   -130.86  -18.56  FeS2
  Pyrochroite      -6.92      8.28   15.20  Mn(OH)2
  Pyrolusite       -9.36     32.49   41.85  MnO2:H2O
  Quartz            0.36     -3.66   -4.02  SiO2
  Rhodochrosite    -0.17    -11.29  -11.12  MnCO3
  Sepiolite        -3.20     12.64   15.84  Mg2Si3O7.5OH:3H2O
  Sepiolite(d)     -6.02     12.64   18.66  Mg2Si3O7.5OH:3H2O
  Siderite         -0.03    -10.90  -10.87  FeCO3
  SiO2(a)          -0.93     -3.66   -2.74  SiO2
  Smithsonite      -2.84    -12.81   -9.97  ZnCO3
  Sphalerite      -63.43    -75.11  -11.68  ZnS
  Strontianite     -1.15    -10.42   -9.27  SrCO3
  Sulfur          -55.63    -50.68    4.95  S
  Sylvite          -7.04     -6.15    0.89  KCl
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  Talc              -0.94     20.79   21.73  Mg3Si4O10(OH)2
  Willemite         -5.71      9.86   15.57  Zn2SiO4
  Witherite         -1.89    -10.45   -8.57  BaCO3
  Zn(OH)2(e)        -4.74      6.76   11.50  Zn(OH)2

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
  For ideal gases, phi = 1.

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End of simulation.
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Reading input data for simulation 3.
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        TITLE Scale back to 1L
        MIX 1
        2 3.13
        SAVE solution 3
        END
-----
TITLE
-----

 Scale back to 1L

-----------------------------------------
Beginning of batch-reaction calculations.
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Reaction step 1.

Using mix 1.

Mixture 1.

          3.130e+00 Solution 2    Solution after simulation 2.

-----------------------------Solution composition------------------------------

        Elements           Molality       Moles

        Al                5.805e-07   5.806e-07
        B                 2.028e-05   2.029e-05
        Ba                1.574e-06   1.574e-06
        C                 3.427e-02   3.428e-02
        Ca                6.253e-04   6.253e-04
        Cd                1.393e-09   1.394e-09
        Cl                7.069e-04   7.070e-04
        Cu                2.465e-08   2.465e-08
        F                 1.979e-04   1.979e-04
        Fe                1.290e-05   1.290e-05
        K                 1.442e-03   1.442e-03
        Li                9.119e-05   9.120e-05
        Mg                7.731e-04   7.732e-04
        Mn                8.553e-07   8.554e-07
        Na                3.366e-02   3.366e-02
        Pb                7.560e-09   7.561e-09
        S                 3.587e-04   3.587e-04
        Si                2.164e-04   2.164e-04
        Sr                1.716e-06   1.716e-06
        Zn                1.198e-07   1.198e-07

----------------------------Description of solution----------------------------

                                       pH  =   7.653      Charge balance
                                       pe  =   4.454      Adjusted to redox equilibrium
      Specific Conductance (µS/cm,  22°C)  = 2823
                          Density (g/cm³)  =   0.99996
                               Volume (L)  =   1.00322
                        Activity of water  =   0.999
                 Ionic strength (mol/kgw)  =   3.705e-02
                       Mass of water (kg)  =   1.000e+00
                 Total alkalinity (eq/kg)  =   3.306e-02
                       Total CO2 (mol/kg)  =   3.427e-02
                         Temperature (°C)  =  22.10
                  Electrical balance (eq)  =   3.328e-03
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =   4.68
                               Iterations  =   0
                                  Total H  = 1.110625e+02
                                  Total O  = 5.561823e+01

----------------------------Distribution of species----------------------------

                                               Log       Log       Log    mole V
   Species          Molality    Activity  Molality  Activity     Gamma   cm³/mol
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OH-	4.368e-07	3.633e-07	-6.360	-6.440	-0.080	-4.04
H+	2.566e-08	2.223e-08	-7.591	-7.653	-0.062	0.00
H2O	5.551e+01	9.988e-01	1.744	-0.001	0.000	18.06
Al	5.805e-07					
Al(OH)4-	5.689e-07	4.775e-07	-6.245	-6.321	-0.076	(0)
Al(OH)3	5.803e-09	5.853e-09	-8.236	-8.233	0.004	(0)
AlF3	2.667e-09	2.690e-09	-8.574	-8.570	0.004	(0)
AlF2+	1.591e-09	1.346e-09	-8.798	-8.871	-0.073	(0)
Al(OH)2+	1.300e-09	1.099e-09	-8.886	-8.959	-0.073	(0)
AlF4-	2.030e-10	1.704e-10	-9.692	-9.769	-0.076	(0)
AlF+2	3.349e-11	1.712e-11	-10.475	-10.766	-0.291	(0)
AlOH+2	7.900e-12	4.038e-12	-11.102	-11.394	-0.291	-27.24
Al+3	3.979e-14	1.094e-14	-13.400	-13.961	-0.561	-41.30
AlSO4+	6.258e-15	5.253e-15	-14.204	-14.280	-0.076	(0)
Al(SO4)2-	3.078e-17	2.584e-17	-16.512	-16.588	-0.076	(0)
AlHSO4+2	2.040e-23	1.010e-23	-22.690	-22.996	-0.305	(0)
B	2.028e-05					
H3BO3	1.970e-05	1.987e-05	-4.705	-4.702	0.004	39.00
H2BO3-	5.811e-07	4.875e-07	-6.236	-6.312	-0.076	(0)
BF(OH)3-	1.456e-09	1.222e-09	-8.837	-8.913	-0.076	(0)
BF2(OH)2-	5.552e-13	4.658e-13	-12.256	-12.332	-0.076	(0)
BF3OH-	2.277e-18	1.910e-18	-17.643	-17.719	-0.076	(0)
BF4-	3.301e-23	2.769e-23	-22.481	-22.558	-0.076	(0)
Ba	1.574e-06					
Ba+2	1.321e-06	6.526e-07	-5.879	-6.185	-0.306	-12.46
BaHCO3+	1.845e-07	1.547e-07	-6.734	-6.810	-0.076	(0)
BaSO4	5.114e-08	5.157e-08	-7.291	-7.288	0.004	(0)
BaCO3	1.697e-08	1.711e-08	-7.770	-7.767	0.004	-10.73
BaOH+	1.179e-12	9.934e-13	-11.929	-12.003	-0.074	(0)
C(-4)	0.000e+00					
CH4	0.000e+00	0.000e+00	-74.920	-74.916	0.004	35.20
C(4)	3.427e-02					
HCO3-	3.205e-02	2.710e-02	-1.494	-1.567	-0.073	24.69
CO2	1.397e-03	1.409e-03	-2.855	-2.851	0.004	34.29
NaHCO3	4.291e-04	4.328e-04	-3.367	-3.364	0.004	1.80
MgHCO3+	1.215e-04	1.015e-04	-3.916	-3.994	-0.078	5.51
CO3-2	1.052e-04	5.380e-05	-3.978	-4.269	-0.291	-4.90
CaHCO3+	9.894e-05	8.404e-05	-4.005	-4.075	-0.071	9.66
NaCO3-	2.877e-05	2.414e-05	-4.541	-4.617	-0.076	-1.00
CaCO3	2.160e-05	2.179e-05	-4.665	-4.662	0.004	-14.61
MgCO3	1.577e-05	1.590e-05	-4.802	-4.799	0.004	-17.09
FeHCO3+	7.585e-07	6.363e-07	-6.120	-6.196	-0.076	(0)
MnCO3	4.002e-07	4.036e-07	-6.398	-6.394	0.004	(0)
SrHCO3+	3.110e-07	2.630e-07	-6.507	-6.580	-0.073	(0)
FeCO3	3.004e-07	3.030e-07	-6.522	-6.519	0.004	(0)
MnHCO3+	2.707e-07	2.282e-07	-6.568	-6.642	-0.074	(0)
BaHCO3+	1.845e-07	1.547e-07	-6.734	-6.810	-0.076	(0)
Zn(CO3)2-2	7.156e-08	3.544e-08	-7.145	-7.450	-0.305	(0)
(CO2)2	3.279e-08	3.307e-08	-7.484	-7.481	0.004	68.58
ZnCO3	3.055e-08	3.082e-08	-7.515	-7.511	0.004	(0)
SrCO3	2.190e-08	2.209e-08	-7.660	-7.656	0.004	-14.14
CuCO3	1.827e-08	1.843e-08	-7.738	-7.735	0.004	(0)
BaCO3	1.697e-08	1.711e-08	-7.770	-7.767	0.004	-10.73
ZnHCO3+	1.168e-08	9.795e-09	-7.933	-8.009	-0.076	(0)
PbCO3	5.787e-09	5.837e-09	-8.238	-8.234	0.004	(0)
Cu(CO3)2-2	2.519e-09	1.248e-09	-8.599	-8.904	-0.305	(0)
Pb(CO3)2-2	1.592e-09	7.887e-10	-8.798	-9.103	-0.305	(0)
CuHCO3+	1.033e-09	8.663e-10	-8.986	-9.062	-0.076	(0)
CdHCO3+	4.427e-10	3.714e-10	-9.354	-9.430	-0.076	(0)
PbHCO3+	1.602e-10	1.344e-10	-9.795	-9.872	-0.076	(0)
CdCO3	1.836e-11	1.852e-11	-10.736	-10.732	0.004	(0)
Cd(CO3)2-2	6.360e-12	3.150e-12	-11.197	-11.502	-0.305	(0)
Ca	6.253e-04					
Ca+2	4.978e-04	2.548e-04	-3.303	-3.594	-0.291	-17.73
CaHCO3+	9.894e-05	8.404e-05	-4.005	-4.075	-0.071	9.66
CaCO3	2.160e-05	2.179e-05	-4.665	-4.662	0.004	-14.61
CaSO4	6.929e-06	6.988e-06	-5.159	-5.156	0.004	7.39
CaOH+	2.264e-09	1.899e-09	-8.645	-8.721	-0.076	(0)
CaHSO4+	1.169e-12	9.807e-13	-11.932	-12.008	-0.076	(0)
Cd	1.393e-09					
Cd+2	8.749e-10	4.334e-10	-9.058	-9.363	-0.305	-18.46
CdHCO3+	4.427e-10	3.714e-10	-9.354	-9.430	-0.076	(0)
CdCl+	2.880e-11	2.416e-11	-10.541	-10.617	-0.076	5.43
CdSO4	1.919e-11	1.936e-11	-10.717	-10.713	0.004	79.54
CdCO3	1.836e-11	1.852e-11	-10.736	-10.732	0.004	(0)
Cd(CO3)2-2	6.360e-12	3.150e-12	-11.197	-11.502	-0.305	(0)
CdOH+	1.553e-12	1.303e-12	-11.809	-11.885	-0.076	(0)
CdF+	1.036e-12	8.688e-13	-11.985	-12.061	-0.076	(0)
CdOHCl	4.176e-13	4.211e-13	-12.379	-12.376	0.004	(0)
Cd(SO4)2-2	6.878e-14	3.407e-14	-13.163	-13.468	-0.305	-107.22
CdCl2	5.823e-14	5.873e-14	-13.235	-13.231	0.004	23.14
Cd(OH)2	3.873e-15	3.906e-15	-14.412	-14.408	0.004	(0)
CdF2	3.445e-16	3.475e-16	-15.463	-15.459	0.004	(0)
CdCl3-	2.492e-17	2.090e-17	-16.604	-16.680	-0.076	71.62
Cd(OH)3-	2.347e-20	1.969e-20	-19.629	-19.706	-0.076	(0)
Cd2OH+3	1.394e-20	2.869e-21	-19.856	-20.542	-0.687	(0)
Cd(OH)4-2	1.591e-26	7.883e-27	-25.798	-26.103	-0.305	(0)
CdHS+	0.000e+00	0.000e+00	-73.340	-73.416	-0.076	(0)

Cd(HS)2	0.000e+00	0.000e+00	-141.283	-141.279	0.004	(0)
Cd(HS)3-	0.000e+00	0.000e+00	-213.246	-213.323	-0.076	(0)
Cd(HS)4-2	0.000e+00	0.000e+00	-285.051	-285.356	-0.305	(0)
Cl	7.069e-04					
Cl-	7.069e-04	5.895e-04	-3.151	-3.230	-0.079	18.13
MnCl+	2.691e-10	2.268e-10	-9.570	-9.644	-0.074	-3.73
FeCl+	2.278e-10	1.911e-10	-9.643	-9.719	-0.076	(0)
CdCl+	2.880e-11	2.416e-11	-10.541	-10.617	-0.076	5.43
ZnCl+	4.791e-12	4.003e-12	-11.320	-11.398	-0.078	-16.88
ZnOHCl	2.496e-12	2.517e-12	-11.603	-11.599	0.004	(0)
CdOHCl	4.176e-13	4.211e-13	-12.379	-12.376	0.004	(0)
PbCl+	1.624e-13	1.363e-13	-12.789	-12.866	-0.076	7.94
CuCl2-	1.518e-13	1.268e-13	-12.819	-12.897	-0.078	(0)
CuCl+	1.049e-13	8.768e-14	-12.979	-13.057	-0.078	1.57
CdCl2	5.823e-14	5.873e-14	-13.235	-13.231	0.004	23.14
MnCl2	5.788e-14	5.837e-14	-13.237	-13.234	0.004	89.59
ZnCl2	2.422e-15	2.442e-15	-14.616	-14.612	0.004	107.93
CuCl3-2	2.321e-16	1.171e-16	-15.634	-15.931	-0.297	(0)
PbCl2	1.333e-16	1.345e-16	-15.875	-15.871	0.004	34.73
CuCl2	2.666e-17	2.689e-17	-16.574	-16.570	0.004	27.52
CdCl3-	2.492e-17	2.090e-17	-16.604	-16.680	-0.076	71.62
FeCl+2	1.745e-17	8.807e-18	-16.758	-17.055	-0.297	(0)
MnCl3-	1.124e-17	9.478e-18	-16.949	-17.023	-0.074	43.69
ZnCl3-	1.900e-18	1.587e-18	-17.721	-17.799	-0.078	16.56
PbCl3-	7.371e-20	6.184e-20	-19.132	-19.209	-0.076	65.73
FeCl2+	3.019e-20	2.545e-20	-19.520	-19.594	-0.074	(0)
ZnCl4-2	9.079e-22	4.582e-22	-21.042	-21.339	-0.297	145.46
CuCl3-	6.391e-23	5.340e-23	-22.194	-22.272	-0.078	(0)
PbCl4-2	3.444e-23	1.706e-23	-22.463	-22.768	-0.305	101.46
FeCl3	1.487e-24	1.500e-24	-23.828	-23.824	0.004	(0)
CuCl4-2	2.921e-28	1.474e-28	-27.534	-27.831	-0.297	(0)
Cu(1)	1.544e-12					
Cu+	1.392e-12	1.146e-12	-11.856	-11.941	-0.084	(0)
CuCl2-	1.518e-13	1.268e-13	-12.819	-12.897	-0.078	(0)
CuCl3-2	2.321e-16	1.171e-16	-15.634	-15.931	-0.297	(0)
Cu(2)	2.465e-08					
CuCO3	1.827e-08	1.843e-08	-7.738	-7.735	0.004	(0)
Cu(OH)2	2.666e-09	2.689e-09	-8.574	-8.570	0.004	(0)
Cu(CO3)2-2	2.519e-09	1.248e-09	-8.599	-8.904	-0.305	(0)
CuHCO3+	1.033e-09	8.663e-10	-8.986	-9.062	-0.076	(0)
Cu+2	1.225e-10	6.378e-11	-9.912	-10.195	-0.283	-26.17
CuOH+	3.429e-11	2.865e-11	-10.465	-10.543	-0.078	(0)
CuSO4	1.995e-12	2.012e-12	-11.700	-11.696	0.004	12.72
CuF+	2.145e-13	1.799e-13	-12.669	-12.745	-0.076	(0)
CuCl+	1.049e-13	8.768e-14	-12.979	-13.057	-0.078	1.57
Cu(OH)3-	8.676e-15	7.279e-15	-14.062	-14.138	-0.076	(0)
Cu2(OH)2+2	5.422e-16	2.686e-16	-15.266	-15.571	-0.305	(0)
CuCl2	2.666e-17	2.689e-17	-16.574	-16.570	0.004	27.52
Cu(OH)4-2	1.317e-19	6.524e-20	-18.880	-19.185	-0.305	(0)
CuCl3-	6.391e-23	5.340e-23	-22.194	-22.272	-0.078	(0)
CuCl4-2	2.921e-28	1.474e-28	-27.534	-27.831	-0.297	(0)
Cu(HS)3-	0.000e+00	0.000e+00	-206.889	-206.965	-0.076	(0)
F	1.979e-04					
F-	1.915e-04	1.592e-04	-3.718	-3.798	-0.080	-1.20
MgF+	3.851e-06	3.232e-06	-5.414	-5.491	-0.076	-10.46
NaF	2.538e-06	2.559e-06	-5.596	-5.592	0.004	7.15
HF	4.998e-09	5.041e-09	-8.301	-8.297	0.004	12.36
AlF3	2.667e-09	2.690e-09	-8.574	-8.570	0.004	(0)
AlF2+	1.591e-09	1.346e-09	-8.798	-8.871	-0.073	(0)
BF(OH)3-	1.456e-09	1.222e-09	-8.837	-8.913	-0.076	(0)
FeF+	4.457e-10	3.739e-10	-9.351	-9.427	-0.076	(0)
AlF4-	2.030e-10	1.704e-10	-9.692	-9.769	-0.076	(0)
MnF+	1.235e-10	1.041e-10	-9.908	-9.983	-0.074	(0)
AlF+2	3.349e-11	1.712e-11	-10.475	-10.766	-0.291	(0)
ZnF+	7.419e-12	6.224e-12	-11.130	-11.206	-0.076	(0)
HF2-	3.586e-12	3.009e-12	-11.445	-11.522	-0.076	22.07
CdF+	1.036e-12	8.688e-13	-11.985	-12.061	-0.076	(0)
FeF2+	9.516e-13	8.020e-13	-12.022	-12.096	-0.074	(0)
BF2(OH)2-	5.552e-13	4.658e-13	-12.256	-12.332	-0.076	(0)
FeF+2	2.596e-13	1.310e-13	-12.586	-12.883	-0.297	(0)
CuF+	2.145e-13	1.799e-13	-12.669	-12.745	-0.076	(0)
FeF3	1.987e-13	2.004e-13	-12.702	-12.698	0.004	(0)
PbF+	2.107e-14	1.768e-14	-13.676	-13.753	-0.076	(0)
CdF2	3.445e-16	3.475e-16	-15.463	-15.459	0.004	(0)
PbF2	5.699e-17	5.748e-17	-16.244	-16.240	0.004	(0)
BF3OH-	2.277e-18	1.910e-18	-17.643	-17.719	-0.076	(0)
PbF3-	7.904e-20	6.631e-20	-19.102	-19.178	-0.076	(0)
BF4-	3.301e-23	2.769e-23	-22.481	-22.558	-0.076	(0)
PbF4-2	1.020e-23	5.054e-24	-22.991	-23.296	-0.305	(0)
SiF6-2	3.406e-27	1.719e-27	-26.468	-26.765	-0.297	42.98
Fe(2)	1.520e-06					
FeHCO3+	7.585e-07	6.363e-07	-6.120	-6.196	-0.076	(0)
Fe+2	4.509e-07	2.348e-07	-6.346	-6.629	-0.283	-21.90
FeCO3	3.004e-07	3.030e-07	-6.522	-6.519	0.004	(0)
FeSO4	6.187e-09	6.240e-09	-8.209	-8.205	0.004	22.13
FeOH+	3.180e-09	2.680e-09	-8.498	-8.572	-0.074	(0)
FeF+	4.457e-10	3.739e-10	-9.351	-9.427	-0.076	(0)
FeCl+	2.278e-10	1.911e-10	-9.643	-9.719	-0.076	(0)

Fe(OH)2	7.875e-13	7.943e-13	-12.104	-12.100	0.004	(0)
Fe(OH)3-	1.528e-15	1.288e-15	-14.816	-14.890	-0.074	(0)
FeHSO4+	1.077e-15	9.038e-16	-14.968	-15.044	-0.076	(0)
Fe(HS)2	0.000e+00	0.000e+00	-146.129	-146.126	0.004	(0)
Fe(HS)3-	0.000e+00	0.000e+00	-218.236	-218.312	-0.076	(0)
Fe(3)	1.138e-05					
Fe(OH)3	8.908e-06	8.984e-06	-5.050	-5.047	0.004	(0)
Fe(OH)2+	2.086e-06	1.764e-06	-5.681	-5.754	-0.073	(0)
Fe(OH)4-	3.870e-07	3.272e-07	-6.412	-6.485	-0.073	(0)
FeOH+2	2.626e-10	1.325e-10	-9.581	-9.878	-0.297	(0)
FeF2+	9.516e-13	8.020e-13	-12.022	-12.096	-0.074	(0)
FeF+2	2.596e-13	1.310e-13	-12.586	-12.883	-0.297	(0)
FeF3	1.987e-13	2.004e-13	-12.702	-12.698	0.004	(0)
Fe+3	1.974e-15	5.428e-16	-14.705	-15.265	-0.561	(0)
FeSO4+	1.044e-15	8.795e-16	-14.982	-15.056	-0.074	(0)
FeCl+2	1.745e-17	8.807e-18	-16.758	-17.055	-0.297	(0)
Fe2(OH)2+4	8.861e-18	5.334e-19	-17.052	-18.273	-1.220	(0)
Fe(SO4)2-	3.575e-18	2.999e-18	-17.447	-17.523	-0.076	(0)
FeCl2+	3.019e-20	2.545e-20	-19.520	-19.594	-0.074	(0)
Fe3(OH)4+5	2.079e-20	2.575e-22	-19.682	-21.589	-1.907	(0)
FeHSO4+2	1.060e-22	5.248e-23	-21.975	-22.280	-0.305	(0)
FeCl3	1.487e-24	1.500e-24	-23.828	-23.824	0.004	(0)
H(0)	8.846e-28					
H2	4.423e-28	4.461e-28	-27.354	-27.351	0.004	28.61
K	1.442e-03					
K+	1.441e-03	1.200e-03	-2.841	-2.921	-0.079	9.04
KSO4-	1.494e-06	1.263e-06	-5.826	-5.899	-0.073	34.18
Li	9.119e-05					
Li+	9.113e-05	7.741e-05	-4.040	-4.111	-0.071	-1.18
LiSO4-	6.321e-08	5.328e-08	-7.199	-7.273	-0.074	(0)
Mg	7.731e-04					
Mg+2	6.210e-04	3.239e-04	-3.207	-3.490	-0.283	-21.29
MgHCO3+	1.215e-04	1.015e-04	-3.916	-3.994	-0.078	5.51
MgCO3	1.577e-05	1.590e-05	-4.802	-4.799	0.004	-17.09
MgSO4	1.101e-05	1.110e-05	-4.958	-4.955	0.004	5.72
MgF+	3.851e-06	3.232e-06	-5.414	-5.491	-0.076	-10.46
MgOH+	4.757e-08	4.055e-08	-7.323	-7.392	-0.069	(0)
Mn(2)	8.553e-07					
MnCO3	4.002e-07	4.036e-07	-6.398	-6.394	0.004	(0)
MnHCO3+	2.707e-07	2.282e-07	-6.568	-6.642	-0.074	(0)
Mn+2	1.814e-07	9.446e-08	-6.741	-7.025	-0.283	-19.01
MnSO4	2.483e-09	2.505e-09	-8.605	-8.601	0.004	23.88
MnCl+	2.691e-10	2.268e-10	-9.570	-9.644	-0.074	-3.73
MnF+	1.235e-10	1.041e-10	-9.908	-9.983	-0.074	(0)
MnOH+	1.019e-10	8.591e-11	-9.992	-10.066	-0.074	(0)
MnCl2	5.788e-14	5.837e-14	-13.237	-13.234	0.004	89.59
MnCl3-	1.124e-17	9.478e-18	-16.949	-17.023	-0.074	43.69
Mn(OH)3-	1.610e-19	1.357e-19	-18.793	-18.867	-0.074	(0)
Mn(3)	1.967e-28					
Mn+3	1.967e-28	5.409e-29	-27.706	-28.267	-0.561	(0)
Na	3.366e-02					
Na+	3.317e-02	2.793e-02	-1.479	-1.554	-0.075	-1.41
NaHCO3	4.291e-04	4.328e-04	-3.367	-3.364	0.004	1.80
NaCO3-	2.877e-05	2.414e-05	-4.541	-4.617	-0.076	-1.00
NaSO4-	2.562e-05	2.167e-05	-4.591	-4.664	-0.073	15.23
NaF	2.538e-06	2.559e-06	-5.596	-5.592	0.004	7.15
NaOH	1.006e-18	1.015e-18	-17.997	-17.994	0.004	(0)
O(0)	4.703e-39					
O2	2.351e-39	2.372e-39	-38.629	-38.625	0.004	30.17
Pb	7.560e-09					
PbCO3	5.787e-09	5.837e-09	-8.238	-8.234	0.004	(0)
Pb(CO3)2-2	1.592e-09	7.887e-10	-8.798	-9.103	-0.305	(0)
PbHCO3+	1.602e-10	1.344e-10	-9.795	-9.872	-0.076	(0)
Pb+2	1.260e-11	6.243e-12	-10.899	-11.205	-0.305	-15.07
PbOH+	6.519e-12	5.469e-12	-11.186	-11.262	-0.076	(0)
PbSO4	5.489e-13	5.536e-13	-12.261	-12.257	0.004	(0)
PbCl+	1.624e-13	1.363e-13	-12.789	-12.866	-0.076	7.94
Pb(OH)2	9.476e-14	9.557e-14	-13.023	-13.020	0.004	(0)
PbF+	2.107e-14	1.768e-14	-13.676	-13.753	-0.076	(0)
Pb(SO4)2-2	9.248e-16	4.581e-16	-15.034	-15.339	-0.305	(0)
PbCl2	1.333e-16	1.345e-16	-15.875	-15.871	0.004	34.73
Pb(OH)3-	5.876e-17	4.929e-17	-16.231	-16.307	-0.076	(0)
PbF2	5.699e-17	5.748e-17	-16.244	-16.240	0.004	(0)
PbF3-	7.904e-20	6.631e-20	-19.102	-19.178	-0.076	(0)
PbCl3-	7.371e-20	6.184e-20	-19.132	-19.209	-0.076	65.73
Pb(OH)4-2	1.024e-20	5.073e-21	-19.990	-20.295	-0.305	(0)
Pb2OH+3	3.714e-21	7.643e-22	-20.430	-21.117	-0.687	(0)
PbCl4-2	3.444e-23	1.706e-23	-22.463	-22.768	-0.305	101.46
PbF4-2	1.020e-23	5.054e-24	-22.991	-23.296	-0.305	(0)
Pb3(OH)4+2	1.700e-27	8.420e-28	-26.770	-27.075	-0.305	(0)
Pb(HS)2	0.000e+00	0.000e+00	-144.385	-144.381	0.004	(0)
Pb(HS)3-	0.000e+00	0.000e+00	-217.228	-217.304	-0.076	(0)
S(-2)	0.000e+00					
CdHS+	0.000e+00	0.000e+00	-73.340	-73.416	-0.076	(0)
HS-	0.000e+00	0.000e+00	-74.143	-74.223	-0.080	20.61
H2S	0.000e+00	0.000e+00	-74.899	-74.896	0.004	37.15
S-2	0.000e+00	0.000e+00	-79.278	-79.575	-0.297	(0)
Cd(HS)2	0.000e+00	0.000e+00	-141.283	-141.279	0.004	(0)

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     Zn(HS)2          0.000e+00   0.000e+00  -142.052  -142.048     0.004     (0)
     Pb(HS)2          0.000e+00   0.000e+00  -144.385  -144.381     0.004     (0)
     Fe(HS)2          0.000e+00   0.000e+00  -146.129  -146.126     0.004     (0)
     Cu(HS)3-         0.000e+00   0.000e+00  -206.889  -206.965    -0.076     (0)
     Cd(HS)3-         0.000e+00   0.000e+00  -213.246  -213.323    -0.076     (0)
     Zn(HS)3-         0.000e+00   0.000e+00  -215.035  -215.111    -0.076     (0)
     Pb(HS)3-         0.000e+00   0.000e+00  -217.228  -217.304    -0.076     (0)
     Fe(HS)3-         0.000e+00   0.000e+00  -218.236  -218.312    -0.076     (0)
     Cd(HS)4-2        0.000e+00   0.000e+00  -285.051  -285.356    -0.305     (0)
S(6)             3.587e-04
     SO4-2            3.135e-04   1.577e-04    -3.504    -3.802    -0.298     14.71
     NaSO4-           2.562e-05   2.167e-05    -4.591    -4.664    -0.073     15.23
     MgSO4            1.101e-05   1.110e-05    -4.958    -4.955     0.004      5.72
     CaSO4            6.929e-06   6.988e-06    -5.159    -5.156     0.004      7.39
     KSO4-            1.494e-06   1.263e-06    -5.826    -5.899    -0.073     34.18
     LiSO4-           6.321e-08   5.328e-08    -7.199    -7.273    -0.074     (0)
     BaSO4            5.114e-08   5.157e-08    -7.291    -7.288     0.004     (0)
     SrSO4            2.063e-08   2.081e-08    -7.685    -7.682     0.004     24.12
     FeSO4            6.187e-09   6.240e-09    -8.209    -8.205     0.004     22.13
     MnSO4            2.483e-09   2.505e-09    -8.605    -8.601     0.004     23.88
     HSO4-            3.817e-10   3.202e-10    -9.418    -9.495    -0.076     40.22
     ZnSO4            1.029e-10   1.037e-10    -9.988    -9.984     0.004     22.20
     CdSO4            1.919e-11   1.936e-11   -10.717   -10.713     0.004     79.54
     CuSO4            1.995e-12   2.012e-12   -11.700   -11.696     0.004     12.72
     CaHSO4+          1.169e-12   9.807e-13   -11.932   -12.008    -0.076     (0)
     PbSO4            5.489e-13   5.536e-13   -12.261   -12.257     0.004     (0)
     Zn(SO4)2-2       2.746e-13   1.360e-13   -12.561   -12.866    -0.305    -14.79
     Cd(SO4)2-2       6.878e-14   3.407e-14   -13.163   -13.468    -0.305   -107.22
     AlSO4+           6.258e-15   5.253e-15   -14.204   -14.280    -0.076     (0)
     FeHSO4+          1.077e-15   9.038e-16   -14.968   -15.044    -0.076     (0)
     FeSO4+           1.044e-15   8.795e-16   -14.982   -15.056    -0.074     (0)
     Pb(SO4)2-2       9.248e-16   4.581e-16   -15.034   -15.339    -0.305     (0)
     Al(SO4)2-        3.078e-17   2.584e-17   -16.512   -16.588    -0.076     (0)
     Fe(SO4)2-        3.575e-18   2.999e-18   -17.447   -17.523    -0.076     (0)
     FeHSO4+2         1.060e-22   5.248e-23   -21.975   -22.280    -0.305     (0)
     AlHSO4+2         2.040e-23   1.010e-23   -22.690   -22.996    -0.305     (0)
Si               2.164e-04
     H4SiO4           2.148e-04   2.167e-04    -3.668    -3.664     0.004     52.33
     H3SiO4-          1.551e-06   1.296e-06    -5.809    -5.887    -0.078     28.05
     H2SiO4-2         6.403e-12   3.273e-12   -11.194   -11.485    -0.291     (0)
     SiF6-2           3.406e-27   1.719e-27   -26.468   -26.765    -0.297     42.98
Sr               1.716e-06
     Sr+2             1.362e-06   7.006e-07    -5.866    -6.155    -0.289    -17.30
     SrHCO3+          3.110e-07   2.630e-07    -6.507    -6.580    -0.073     (0)
     SrCO3            2.190e-08   2.209e-08    -7.660    -7.656     0.004    -14.14
     SrSO4            2.063e-08   2.081e-08    -7.685    -7.682     0.004     24.12
     SrOH+            1.915e-12   1.614e-12   -11.718   -11.792    -0.074     (0)
Zn               1.198e-07
     Zn(CO3)2-2       7.156e-08   3.544e-08    -7.145    -7.450    -0.305     (0)
     ZnCO3            3.055e-08   3.082e-08    -7.515    -7.511     0.004     (0)
     ZnHCO3+          1.168e-08   9.795e-09    -7.933    -8.009    -0.076     (0)
     Zn+2             5.689e-09   2.871e-09    -8.245    -8.542    -0.297    -24.73
     ZnOH+            1.350e-10   1.132e-10    -9.870    -9.946    -0.076     (0)
     ZnSO4            1.029e-10   1.037e-10    -9.988    -9.984     0.004     22.20
     Zn(OH)2          7.232e-11   7.294e-11   -10.141   -10.137     0.004     (0)
     ZnF+             7.419e-12   6.224e-12   -11.130   -11.206    -0.076     (0)
     ZnCl+            4.791e-12   4.003e-12   -11.320   -11.398    -0.078    -16.88
     ZnOHCl           2.496e-12   2.517e-12   -11.603   -11.599     0.004     (0)
     Zn(SO4)2-2       2.746e-13   1.360e-13   -12.561   -12.866    -0.305    -14.79
     Zn(OH)3-         1.235e-14   1.036e-14   -13.908   -13.985    -0.076     (0)
     ZnCl2            2.422e-15   2.442e-15   -14.616   -14.612     0.004    107.93
     ZnCl3-           1.900e-18   1.587e-18   -17.721   -17.799    -0.078     16.56
     Zn(OH)4-2        1.489e-19   7.377e-20   -18.827   -19.132    -0.305     (0)
     ZnCl4-2          9.079e-22   4.582e-22   -21.042   -21.339    -0.297    145.46
     Zn(HS)2          0.000e+00   0.000e+00  -142.052  -142.048     0.004     (0)
     Zn(HS)3-         0.000e+00   0.000e+00  -215.035  -215.111    -0.076     (0)

------------------------------Saturation indices-------------------------------

  Phase               SI** log IAP   log K(295 K,   1 atm)

  Al(OH)3(a)        -1.99      9.00   10.99  Al(OH)3
  Albite            -0.68    -18.86  -18.19  NaAlSi3O8
  Alunite           -5.46     -6.49   -1.04  KAl3(SO4)2(OH)6
  Anglesite         -7.20    -15.01   -7.81  PbSO4
  Anhydrite         -3.15     -7.40   -4.25  CaSO4
  Anorthite         -3.76    -23.56  -19.80  CaAl2Si2O8
  Aragonite          0.46     -7.86   -8.32  CaCO3
  Barite            -0.12     -9.99   -9.87  BaSO4
  Ca-Montmorillonite   1.38    -44.07  -45.45  Ca0.165Al2.33Si3.67O10(OH)2
  Calcite            0.60     -7.86   -8.46  CaCO3
  Cd(OH)2           -7.71      5.94   13.65  Cd(OH)2
  CdSiO3            -6.90      2.28    9.18  CdSiO3
  CdSO4            -13.17    -13.17    0.01  CdSO4
  Celestite         -3.31     -9.96   -6.64  SrSO4
  Cerussite         -2.31    -15.47  -13.16  PbCO3
  CH4(g)           -72.14    -74.92   -2.77  CH4
  Chalcedony        -0.08     -3.66   -3.59  SiO2
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  Chlorite(14A)     -3.39     66.08    69.47  Mg5Al2Si3O10(OH)8
  Chrysotile        -4.44     28.12    32.56  Mg3Si2O5(OH)4
  CO2(g)            -1.42     -2.85    -1.43  CO2
  Dolomite           1.40    -15.62   -17.02  CaMg(CO3)2
  Fe(OH)3(a)         2.80      7.69     4.89  Fe(OH)3
  FeS(ppt)         -69.28    -73.20    -3.92  FeS
  Fluorite          -0.56    -11.19   -10.63  CaF2
  Gibbsite           0.72      9.00     8.27  Al(OH)3
  Goethite           8.59      7.69    -0.90  FeOOH
  Gypsum            -2.81     -7.40    -4.58  CaSO4:2H2O
  H2(g)            -24.26    -27.35    -3.09  H2
  H2O(g)            -1.58     -0.00     1.58  H2O
  H2S(g)           -73.88    -81.88    -8.00  H2S
  Halite            -6.35     -4.78     1.57  NaCl
  Hausmannite      -12.70     49.05    61.75  Mn3O4
  Hematite          19.17     15.39    -3.79  Fe2O3
  Illite             1.49    -39.17   -40.66  K0.6Mg0.25Al2.3Si3.5O10(OH)2
  Jarosite-K        -1.42    -10.41    -8.98  KFe3(SO4)2(OH)6
  K-feldspar         0.56    -20.23   -20.79  KAlSi3O8
  K-mica             7.60     20.73    13.13  KAl3Si3O10(OH)2
  Kaolinite          2.98     10.67     7.69  Al2Si2O5(OH)4
  Mackinawite      -68.55    -73.20    -4.65  FeS
  Manganite         -4.95     20.39    25.34  MnOOH
  Melanterite       -8.19    -10.44    -2.24  FeSO4:7H2O
  O2(g)            -35.75    -38.62    -2.87  O2
  Otavite           -1.53    -13.63   -12.10  CdCO3
  Pb(OH)2           -4.15      4.10     8.25  Pb(OH)2
  Pyrite          -112.30   -130.86   -18.56  FeS2
  Pyrochroite       -6.92      8.28    15.20  Mn(OH)2
  Pyrolusite        -9.36     32.49    41.85  MnO2:H2O
  Quartz             0.36     -3.66    -4.02  SiO2
  Rhodochrosite     -0.17    -11.29   -11.12  MnCO3
  Sepiolite         -3.20     12.64    15.84  Mg2Si3O7.5OH:3H2O
  Sepiolite(d)      -6.02     12.64    18.66  Mg2Si3O7.5OH:3H2O
  Siderite          -0.03    -10.90   -10.87  FeCO3
  SiO2(a)           -0.93     -3.66    -2.74  SiO2
  Smithsonite       -2.84    -12.81    -9.97  ZnCO3
  Sphalerite       -63.43    -75.11   -11.68  ZnS
  Strontianite      -1.15    -10.42    -9.27  SrCO3
  Sulfur           -55.63    -50.68     4.95  S
  Sylvite           -7.04     -6.15     0.89  KCl
  Talc              -0.94     20.79    21.73  Mg3Si4O10(OH)2
  Willemite         -5.71      9.86    15.57  Zn2SiO4
  Witherite         -1.89    -10.45    -8.57  BaCO3
  Zn(OH)2(e)        -4.74      6.76    11.50  Zn(OH)2

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
  For ideal gases, phi = 1.

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End of simulation.
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Reading input data for simulation 4.
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End of Run after 0.05 Seconds.
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