Guideline

Quantifying the volume of associated water taken under a mining lease or mineral development licence

Under the *Mineral Resources Act 1989*

March 2018
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**Purpose**

Under section 334ZP of the *Mineral Resources Act 1989*, the holder of a mineral lease or mineral development licence is required to measure or (if the take is the result of evaporation) to estimate the volume of associated water taken, and to report the volume of associated water taken to the chief executive. The requirements for measuring and reporting the volume of associated water taken are set out in the *Mineral Resources Regulation 2013* (the Regulation).

This guideline has been prepared to assist mining tenure holders to measure, estimate and report the volume of associated water taken, and should be read in conjunction with the Regulation.

The guideline provides information on the water balance method for measuring and estimating associated water volumes entering a mine. This method provides a simple, consistent approach utilising data that is typically available at most mines. The advantages of this approach are that it is simple, transparent and provides consistency in how the volume of associated water is calculated.

It is recognised, however, that there is significant variability in hydrological settings, infrastructure and data availability in mining operations across Queensland. Hence, alternative methods, such as hydrogeological modelling for example, may be used to calculate the volume of associated water taken where appropriate. The mining tenement holder must seek prior approval of an alternative methodology for calculating the volume of associated water taken, in accordance with the requirements in the Regulation (section 31A).

This guideline applies to the take of associated water in surface mines and underground mines.

**Definition of take of associated water**

The *Mineral Resources Act 1989* states that the holder of a mineral development licence or mining lease may take or interfere with underground water in the area of the licence or lease if the taking or interference happens during the course of, or results from, the carrying out of an authorised activity for the licence or lease. It goes on to say that underground water taken or interfered with in this way, is associated water.

In other words, taking associated water refers to taking underground water where the taking or interfering happens during the course of, or results from, the carrying out of an authorised activity for the lease or licence. The following examples are given in the *Mineral Resources Act 1989*:

- mine dewatering of underground water to the extent necessary to achieve safe operating conditions in the mine; and
- taking underground water as a result of evaporation from an open mine pit.

There are a number of different scenarios where mining operations result in take of associated water. For example, associated water includes underground water taken by a borefield established for the purpose of dewatering a mine. Associated water also includes groundwater ingress to underground mines and mine pits, surface mines, and rehabilitated surface mines.

Entrained water contained within the mined ore that was not added to the ore and does not drain from it, is not considered to be associated water. It does not need to be accounted for in determining the volume of associated water.
Seepage inflows derived from rainfall on in-pit overburden in open cut mines are not considered to be associated water.

Quantifying the take of associated water

Selection of method

Not all surface and underground mines intersect aquifers and intercept large volumes of associated water. Some operate in relatively low permeability geological regimes where associated water is not problematic for mining and is commonly evident only as damp evaporating seeps in mine faces. In contrast, mines that do intercept aquifers that are found in alluvial sediments, basalt flows or highly porous sandstones of the Great Artesian Basin, for example, can have large and continuous flows of associated water to be removed as part of the mining process. These site specific differences necessitate “fit for purpose” approaches to estimating the volumes of associated water removed during mining and after closure.

Direct measurement of the volume of associated water removed by a borefield used to lower the water table is generally straightforward, as the bores may be readily fitted with flow meters.

The volume of associated water pumped from dewatering bores for surface and underground mines must be directly measured through flow meters complying with Australian Standard AS 4747-2013 (Meters for non-urban water supply), unless:

- if a water meter that does not comply with AS4747-2013 was installed prior to 3 February 2017—the meter may be used until either the next major maintenance of the meter is required or until 5 years after its initial installation; or
- an alternative approach is approved by the chief executive in accordance with the Regulation.

The volume of associated water taken from groundwater ingress to surface and underground mines, either actively being mined, or closed, is much more difficult to directly measure because it is not collected at a single point, and is subject to range of processes including evaporation, mixing with surface runoff and adhering to mined materials. Because of this difficulty the most appropriate method for any site will depend on a broad range of factors including geology, hydrogeology, climate, mine configuration, the mining method and mine management practices.

There are three main methods which can be used to quantify associated water taken during mining operations, or after mine closure (as opposed to direct measurement of associated water take through a borefield). These are:

1. water balance models, calculated at the scale of an underground mine or mine pit
2. distributed parameter numerical groundwater flow models
3. analytical groundwater flow models.

Water balance models, in (1) above, entail measuring or estimating the components of the water balance in a pit or underground mine, then using these in a water balance equation to calculate the associated water volume (which cannot be readily measured). In contrast to groundwater flow models, water balance models do not attempt to represent the flow of associated water through geological strata and use the water balance equation of the pit or mine to calculate the volume of...
associated water. It is an advantage that the required information for this approach is readily available at many mines. Section 3.2 of this guideline provides a methodology for utilising the water balance method for quantifying associated water.

The volume of associated water can alternatively be quantified through a numerical groundwater flow model, by simulating the flux of associated water through geological strata into the mining areas. Numerical groundwater models represent spatial variability in aquifer parameters and transient time scales. They can provide good estimates of associated water where information on the groundwater system and mining is available. However, because numerical models utilise specific aquifer properties at different points in space, data requirements are usually high, if simulations are to be accurate. Large numerical models can also be demanding computationally. In such cases, whilst setup costs often dominate total modelling costs, when repeated runs are required, significant additional ongoing costs can be incurred. Barnett et al (2012) provide guidelines for developing and using groundwater flow models, particularly numerical models.

Sometimes relatively simple analytical models can be used to overcome the data requirements and costs associated with a numerical groundwater model. Darcy’s law is the best known equation that is utilised to develop analytical models of groundwater flow in mines. Applying Darcy’s law requires information on hydraulic conductivity of groundwater systems around the mine and on groundwater levels that are required to calculate hydraulic gradients. More sophisticated, but still relatively simple analytical models specifically developed to estimate the fluxes of associated water to mines have also been developed. Those described by Marinelli and Niccoli (2000), Powers et al (2007) and Hazel (2009) are in common usage for estimating groundwater flow to mines.

Analytical groundwater models have many simplifying assumptions, commonly including steady state conditions and uniform aquifer properties.

The most suitable method for estimating the volume of associated water will depend on the site specific characteristics of each mine, and the available data. Some mines will have suitable existing methods that they are using to estimate groundwater flows to pits and underground mines. If operators of mines require assistance with determining the most suitable methodology, it is recommended that they seek assistance from a suitably qualified person. Some mines may utilise multiple methods to maximise the accuracy in their estimates of associated water. The volume of associated water taken by groundwater ingress into a mine must be quantified using the water balance method described in Section 3.2, unless an alternative method is approved by the chief executive in accordance with the Regulation.

The flow chart in Figure 1 below shows the decision path that mine operators should follow annually to determine and report the estimated volume of associated water taken by mining activities.
Figure 1: decision path for determining and reporting the estimated volume of associated water taken by mining activities

**Water balance method**

Associated water seeping into surface (open cut) mines and underground mines can be calculated using the water balance method. This method is based on conservation of mass, whereby the change in stored water in the mining pit (or underground mining area) over the reporting period equals the sum of water inflows, minus the sum of water outflows:

\[
\text{Change in pit water storage volume} = \text{sum of water inflows} - \text{sum of water outflows}
\]

The associated water volume is a component of the water inflow and, in the absence of a direct method of estimation, can be calculated from the above relationship by evaluating all other terms.
Where possible, the water balance calculation should be applied to the mining pits or underground workings only, rather than the entire mine site which is likely to include additional complex water processes (such as ore processing and water use for dust suppression).

Whilst the reporting period for take of associated water is one year (from 1 July to 30 June), this time scale may not be suitable for estimation of some components of the total mine water balance. A monthly time step is likely to be a suitable time scale for the evaluation of most terms in the water balance method. However, surface runoff is highly variable and is better estimated on a daily basis (typically using a daily rainfall-runoff model). The estimated volumes for the various water balance components can then be summed to obtain an annual value for the reporting period.

Key terms in the water balance which are applicable at most mines are illustrated in Figure 2 and summarised in Table 1, along with typical methods of quantifying each term. Water balance components that are pumped must be measured through a water meter complying with AS 4747-2013.

Water taken from stores of associated water and added to the ore should be accounted for. Water that drains from the ore into the mine pit is accounted for through the associated change in pit water storage volume.

An example of calculating the associated water for a surface mine pit is given in Attachment 1, and an example for an underground mine is given in Attachment 2. A water balance at the scale of the mine pit or underground mine that utilises different water balance components from those in the examples illustrated in attachments one and two, is not considered an “alternative methodology”, and therefore does not require prior approval by the chief executive in accordance with the Regulation.

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**Figure 2: Key terms used in the water balance method**
Data recording and reporting requirements

Requirements for reporting the total volume of associated water taken by mining tenement holders are set out in section 31B of the Mineral Resources Regulation 2013.

Section 31B indicates that reporting must be made using the Queensland Digital Exploration Reports System (QDEX).
Mining tenure holders do not have to report their take to the chief executive if their total volume of associated water take for all their mining operations is less than two mega litres (2ML) during the reporting period. This means that if a mining operation covers multiple tenures then the 2 ML exemption includes the combined take from those tenures.

Mining tenure holders who are required to report their take of associated water must provide all supporting information to the department as set out in section 31B (2) and (3) of the Mineral Resources Regulation 2013.
Table 1 – Typical water balance components and estimation methods

<table>
<thead>
<tr>
<th>Component</th>
<th>Method of estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in pit water storage volume</td>
<td>• Water storage volume at end of period minus water storage volume at beginning of period&lt;br&gt;• In purpose made storages, the change in volume may be estimated from recorded water levels&lt;br&gt;• A reduction in stored water volume would be recorded as a negative value&lt;br&gt;• During periods of no or low rainfall, storage changes can be used to more accurately calculate groundwater ingress</td>
</tr>
<tr>
<td>Inflows</td>
<td></td>
</tr>
<tr>
<td>Direct rainfall on water storage areas</td>
<td>• Recorded rainfall multiplied by water surface area&lt;br&gt;• Where the surface area varies significantly over the reporting period, the calculation should be broken down into shorter steps (for example, monthly)</td>
</tr>
<tr>
<td>Surface runoff</td>
<td>• Runoff is one of the most difficult components of the water balance to estimate and can vary widely with site and climatic conditions&lt;br&gt;Typically estimated from a numerical rainfall-runoff model of the catchment contributing to the pit. Note that the catchment area may change over the reporting period&lt;br&gt;• Greater accuracy will be obtained from a daily rainfall-runoff model calibrated to recorded data&lt;br&gt;• Estimates from a simple volumetric runoff coefficient are likely to have low accuracy</td>
</tr>
<tr>
<td>Groundwater ingress to pits or underground mines</td>
<td>• This parameter is typically an unknown in the water balance equation. Once all other terms in the equation are evaluated, the equation can be rearranged to give the groundwater inflow volume&lt;br&gt;• A negative calculated value for groundwater inflow may indicate inaccuracy in calculation of the other water balance terms and/or that the groundwater inflow volume is comparatively small.&lt;br&gt;• The contribution of seepage inflows from rainfall on in-pit overburden should be considered. These seepage inflows are not associated water</td>
</tr>
<tr>
<td>Pumped inflows</td>
<td>• Must be measured by flow meters complying with Australian standard AS 4747-2013 on pump lines</td>
</tr>
<tr>
<td>Outflows</td>
<td></td>
</tr>
<tr>
<td>Evaporation from water storage areas</td>
<td>• Estimated evaporation (typically as mm/month calculated from weather station or SILO data using Morton’s equation or similar) multiplied by water surface area</td>
</tr>
<tr>
<td>Pumped outflows</td>
<td>• Must be measured by flow meters complying with Australian standard AS 4747-2013 on pump lines</td>
</tr>
<tr>
<td>Other outflows</td>
<td>• Water collected in mining pits is sometimes used beneficially within the mining operation, for example being used for dust suppression. Use volumes, if unmetered, can be estimated from water cart volume and activity.&lt;br&gt;• Water vapour in ventilation airflows is a source of water loss in most underground mines</td>
</tr>
</tbody>
</table>
References


Glossary

**Associated water:** underground water that is taken or interfered with in the area of a mineral development licence or mining lease if the taking or interference happens during the course of, or results from, the carrying out of an authorised activity for the licence or lease.

**Borefield:** a single bore, or a group of bores, being used to dewater the whole, or a particular part, of a surface mine or underground mine.

**Groundwater ingress:** Groundwater inflow to a mine pit or underground mine.

**Mining tenement:** means a mineral development licence or mining lease. (Note that holders of other types of tenement are not subject to the requirement to measure, estimate and report the take of associated water under the *Mineral Resources Act 1989* s334ZP)


**Surface mine:** a mine other than an underground mine or the surface operations of an underground mine.

**Surface water run-in:** surface water than runs into a surface mine pit from the surrounding pit catchment area.

**Underground mine:** a mine where workers normally work beneath the surface of the earth, and includes structures, apparatus and equipment that extend continuously from the surface into an underground mine, but does not include the surface operations of the mine.

**Water balance** for an underground mine or surface mine pit is an accounting procedure for all major water inflows to, outflows from and water storage changes to the pit or underground mine.

**Water Year** is the accounting period prescribed under the regulation (1 July – 30 June).
Attachment 1 – Calculation of underground water ingress to a surface mine

Water balance for a surface mine

The diagram below describes a conceptual hydrological model for a bunded mine pit with water inputs from rainfall, groundwater ingress and rainfall run off. Water losses from the pit are from evaporation, and mine water use. The example below utilises a water balance approach, as described in section 3.2. The example below is a mined out pit that has not been backfilled, or a mine pit used for water storage.

The volume of associated groundwater can be calculated from the pit water balance. Conservation of mass of water in the pit dictates that any change in water storage is the result of the difference between water inflows (groundwater, run off and rainfall) and outflows (evaporation and mine water use), i.e.:

\[
\Delta L_V = G_i + \left( \frac{R \times A_E - E_L \times A_L}{100} \right) - WU + Ro
\]

Where:

- \( \Delta L_V \) is the change in pit water storage volume calculated from the change in pit water levels over the period and the ponded area (ML);
- \( G_i \) is the volume of associated groundwater inflow to the pit (ML);
- \( Ro \) is rainfall run off from the pit catchment area (ML);
• R is rainfall over the time period (mm);
• AE is the effective rainfall area over the pit (ha); this area is constrained by the pit walls or pit bunds;
• EL is evaporation from the pit lake (mm);
• AL is the area of the pit lake (ha); and
• WU is the net mine water use from the pit (ML). WU can be positive or negative depending on the volume of water pumped into the pit from other sources.

A number of assumptions are associated with this simple model, including:
• Any evaporation from the pit walls of groundwater seepage from stratigraphic sequences overlying the ore body or coal seam, is also assumed small and therefore ignored.
• The area over which rain falls over the pit (AE) is not substantially greater that the pit water surface area (AL), as can occur for pits in high watertable areas after mine closure. Where AE is substantially greater than AL, it is likely that runoff modelling will need to be incorporated into the water balance.
• Rainfall is assumed to fall over the entirety of the pit area at the surface (AE), and evaporative loss of rainfall interception storage in pit spoil, roadways or other in-pit interception storage assumed small and therefore ignored.

Rearranging Equation (1) in terms of groundwater ingress yields:

\[ G_i = \frac{(E_L \times A_L - R \times A_E)}{100} + WU + \Delta L_V - Ro \]  

An example of the use of Equation (2) can serve to illustrate the simplicity of this approach.

Pit groundwater ingress can be calculated over a month by using daily weather station data (or downloaded from DNRM’s SILO database) to calculate EL for the month using Morton’s equation.

Parameters to be used in this example are given in the table below, adapted from Table 1 in this guideline.

For a bunded mine pit with effective rainfall catchment area (AE) of 10 ha, pit runoff of 4 ML, a mean lake evaporative area of 9.5 ha over the month, mean daily evaporation rate from Morton’s equation of 8mm/d, total rainfall of 30 mm over a 30 day month, with metered net pit water inputs from the mine of 3 ML (i.e. WU=-3 ML), net pit storage volume increase of 6 ML over the month, then groundwater ingress from Equation 2 is:

\[ G_i = \frac{[(30 \times 8 \text{ mm/d} \times 9.5 \text{ ha}) - 30 \text{ mm} \times 10 \text{ ha})/100] \text{ ML} - 3 \text{ ML} - 4 \text{ ML} + 6 \text{ ML} \]

\[ G_i = 19.8 \text{ ML} - 3 \text{ ML} - 4 + 6 \text{ ML} \text{ for the month.} \]

\[ G_i = 18.8 \text{ ML for the month.} \]

Where the change in evaporative surface area of the storage is subject to significant changes over the month, Equation 2 can be calculated for a shorter time period and the results summed for each time period for the year. Rainfall runoff into the pit can be measured through an installed flume, or
calculated through an antecedent moisture dependent calibrated runoff coefficient, or other suitable site validated hydrologic procedure.

<table>
<thead>
<tr>
<th>Component</th>
<th>Estimated water balance component for 1 month</th>
<th>Comments on uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in water storage volume</td>
<td>Increase in storage = 6 ML</td>
<td></td>
</tr>
<tr>
<td>Inflows</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct rainfall on water storage areas</td>
<td>30 mm × 10 ha = 3 ML</td>
<td>Accurate rainfall from on-site weather station. Errors &lt;5%</td>
</tr>
<tr>
<td>Surface runoff</td>
<td>4 ML</td>
<td>Small when measured. Could be &gt;10% for site calibrated model</td>
</tr>
<tr>
<td>Groundwater</td>
<td>Calculated from equation (2)</td>
<td></td>
</tr>
<tr>
<td>Pumped inflows</td>
<td>Net pumped inputs of 3 ML</td>
<td>AS meter, less than 5% error</td>
</tr>
<tr>
<td>Outflows</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaporation from water storage areas</td>
<td>240 mm × 9.5 ha = 22.8 ML</td>
<td>Errors &lt; 5%</td>
</tr>
<tr>
<td>Pumped outflows</td>
<td>Net pumped inputs of 3 ML</td>
<td>AS meter, less than 5% error</td>
</tr>
<tr>
<td>Other outflows</td>
<td>Zero</td>
<td></td>
</tr>
</tbody>
</table>
Attachment 2 – Example calculation of groundwater ingress to an underground mine

Example of water balance for an underground mine

A water balance schematic for an underground mine is given below. In this mine the volume of water storage is negligibly small and therefore ignored. The mine inputs (from groundwater ingress, $G_i$, the water treatment plant, $TP$ and mine ventilation inflow $Vi$) are therefore equal to the water volumes exported from the underground mine (to the mine affected water dam, $MAW$ and through the mine ventilation system $Vo$):

$$Gi + TP + Vi = MAW + Vo \quad (3)$$

or

$$Gi = MAW - TP + Vo - Vi \quad (4)$$

![Figure 3: Example of water balance components of an underground mine](image)

If $MAW = 450 \text{ ML/y}$, $TP=200 \text{ ML/y}$, $Vi=10 \text{ ML/y}$ and $Vo=30 \text{ ML/y}$, then groundwater ingress into the underground mine is $(450 - 200 + 30 - 10) \text{ ML/y} = 270 \text{ ML/y}$

The water balance components for the underground mine are given in the table below, adapted from Table 1 in this guideline.

<table>
<thead>
<tr>
<th>Component</th>
<th>Estimated or measured water balance component over 1 year</th>
<th>Uncertainty in parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater ingress, $G_i$</td>
<td>From treatment plant, $TP$</td>
<td>Inflow from ventilation system, $Vi$</td>
</tr>
</tbody>
</table>

Guideline for quantifying the volume of take of associated water under a mining lease or mineral development licence, Department of Natural Resources, Mines and Energy March 2018

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<table>
<thead>
<tr>
<th>Increase in water storage volume</th>
<th>Assumed zero for underground mine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inflows</strong></td>
<td></td>
</tr>
<tr>
<td>Direct rainfall on water storage areas</td>
<td>Zero for underground mine</td>
</tr>
<tr>
<td>Surface runoff</td>
<td>Zero for underground mine</td>
</tr>
<tr>
<td>Groundwater</td>
<td>Calculated from Equation (4)</td>
</tr>
<tr>
<td>Pumped inflows</td>
<td>From treatment plant = 200 ML/y AS meter, &lt; 5%</td>
</tr>
<tr>
<td><strong>Outflows</strong></td>
<td></td>
</tr>
<tr>
<td>Evaporation from water storage areas</td>
<td>Zero for underground mine</td>
</tr>
<tr>
<td>Pumped outflows</td>
<td>MAW = 450 ML/y AS meter, &lt; 5%</td>
</tr>
<tr>
<td>Other outflows</td>
<td>Net water loss through ventilation = 20 ML/y Metered &lt; 10%</td>
</tr>
</tbody>
</table>