

Guideline

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

**Under the *Mineral Resources Act 1989* and Mineral Resources
Regulation 2013**

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1 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 estimate the volume of associated water taken, and to report the volume of associated water taken to the chief executive. The requirements for measuring, estimating 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.

Section 3 of this guideline provides information on several methods for measuring and estimating water volumes entering a mine. Where associated water is taken from a metered borefield, direct measurement will be the most appropriate method and satisfies section 31A(2)(a) of the Regulation. Three methods: the water balance method, analytical methods and numerical modelling will satisfy section 31A(2)(b) of the Regulation when calculating the volume of associated water taken.

If the outlined methods are unsuitable for the environment at a mining operation, the mining tenement holder can seek prior approval to utilise an alternate methodology, in accordance with the requirements in section 31A(3) of the Regulation.

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

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

2 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.

The following examples of associated water take 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; or
- taking underground water as a result of evaporation from an open mine pit.

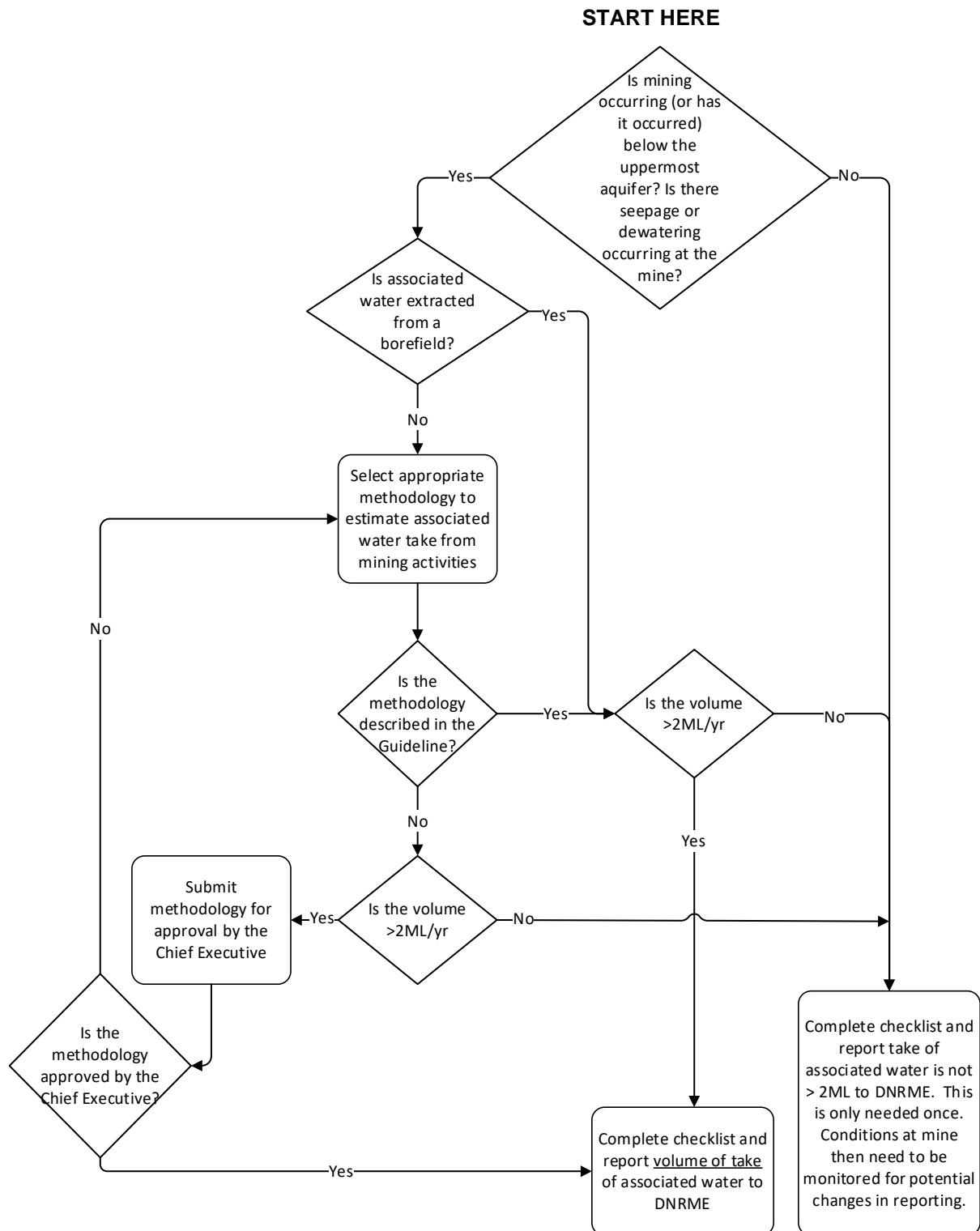
Other examples of associated water take include:

- underground water taken by a borefield established for the purpose of dewatering a mine; or
- 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 inflow derived from rainfall on in-pit overburden in open cut mines is not considered to be associated water.

Figure 1: Decision path for determining and reporting the estimated volume of associated water taken by mining activities



3 Quantifying the take of associated water

Several methods are available for quantifying the take of associated water, including direct measurement through water meters, or if the installation of water meters is not possible, estimation techniques through water balance, or analytical and numerical modelling methods.

3.1 Direct Measurement

Direct measurement from a borefield used to lower the water table is the simplest way to quantify the volume of associated water take, as the bores may be readily fitted with flow meters. Direct measurement will satisfy section 31A(2)(a) of the Regulation.

The volume of associated water pumped from bores that dewater 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 the next major maintenance of the meter, but no later than February 2022; or
- an alternative approach is approved by the chief executive in accordance with the Regulation.

Any pump that dewater 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 1 November 2019, the meter may be used until the next major maintenance of the meter, but no later than November 2023; or
- an alternative approach is approved by DNRME Chief Executive in accordance with the Regulation.

An authorised installer is to be used to commission the water meter and certify compliance to AS 4747-2013. The water meter is to be maintained and calibrated at an appropriate interval, but at least every 12 months, by an appropriately qualified person.

If you are operating a bore or bore field the details of extraction bores should be provided on the template available on <https://www.business.qld.gov.au/industries/mining-energy-water/resources/minerals-coal/reports-notices/water-reporting>.

3.2 Estimation methods

Guidance for selecting the most appropriate method is outlined below.

3.2.1 Selection of method

Not all surface and underground mines intersect aquifers nor 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 can have large and continuous flows of associated water removed as part of the mining process. Data availability and site-specific conditions necessitate “fit for

purpose” approaches to estimating the volumes of associated water removed during mining and after closure.

The volume of associated water taken due to groundwater ingress to surface and underground mines, either actively being mined, or closed, can be difficult to measure. This is because associated water is not collected at a single point and is subject to a range of processes including evaporation, mixing with surface runoff and adhering to mined materials. The most appropriate method for any site will depend on a broad range of factors, including geology, hydrogeology, climate, and site specific characteristics such as mine configuration, the mining method, mine management practices and available data.

Other important aspects to consider include the cost to implement and the degree of uncertainty or error that will be associated with the chosen method. Some mines will have suitable methods that are already in use to estimate groundwater flows to pits and underground mines. If mine operators require assistance with determining the most suitable methodology, it is recommended they seek assistance from a suitably qualified hydrologist, hydrogeologist or groundwater flow modeller.

Before selecting an estimation method, it is important to characterise the physical environment of the mine site correctly. Clear descriptions of the associated hydrogeological and hydrological processes are required in order to establish the basis to decide on the most appropriate method to estimate the associated water take.

Important Information:

- DNRME officials who review associated water take reports may request supporting information for the estimates. In particular, the associated water take reports will more likely be scrutinised and supporting information requested in priority resource management areas e.g. metered entitlement areas (Queensland *Water Act 2000*, Schedule 11 of the *Water Regulation 2016*); or projects that required approval from the Australian Government *Environment Protection and Biodiversity Conservation Act 1999* (matters of national environmental significance – water trigger).
- Data provided for the estimation should be specific to the current reporting period. If data from earlier reporting periods is used, this must be for the purpose of calibration and to confirm the accuracy of a model/solution, rather than for estimating the volume of associated water taken during the current reporting period.
- All methods and models have limitations in representing unique hydrogeological conditions. All model limitations and exclusions are to be documented. Exclusions are to be well defined to help avoid inappropriate model use, and be documented in the final summary report in a specific section.
- Keeping good water management records is vital for accurate associated water take estimates. The DNRME officials who review associated water take reports may audit mine water management records and associated processes.
- The accuracy of the associated water take estimates based on the water balance method or a simple analytical model may not be satisfactory in certain high priority resource management areas. In such instances, the chief executive might direct the leaseholders to develop a numerical groundwater model for estimating associated water take.
- It is the tenure holder’s responsibility to ensure that the associated water take estimates are accurate and the related uncertainty is addressed during the estimation process.

- All methods require analysis of uncertainty and associated water take reports should be accompanied by an evaluation of the potential error (error statement – see sections 0) associated with the estimates.

3.2.2 Approved methods for the Regulation

The three approved methods under section 31A(2)(b) of the Regulation that can be used to estimate and quantify associated water taken during mining operations or after mine closure are:

3.2.2.1 Water balance calculations;

3.2.2.2 Numerical groundwater models;

3.2.2.3 Analytical groundwater models.

These methods may be used by lease holders when estimating associated water take at a mine site, **without** obtaining prior approval from the chief executive. Some mines may utilise multiple methods to maximise the accuracy in their estimates of associated water take.

The volume of associated water taken due to groundwater ingress into a mine must be quantified using one of the above methods, i.e. water balance method or analytical or numerical groundwater models, unless an alternative method is approved by the chief executive in accordance with the Regulation.

This means if a tenure holder would like to use a method that is not described in 3.2.2 of this guideline then an alternative method must be developed and approval sought from the chief executive to use that method to estimate the associated water take.

3.2.2.1 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 the 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. The associated water is a component of water inflow.

Water balance methods involve 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). 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 November to 31 October), 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. The estimated volumes for the various water balance components can then be summed to obtain an annual value for the reporting period.

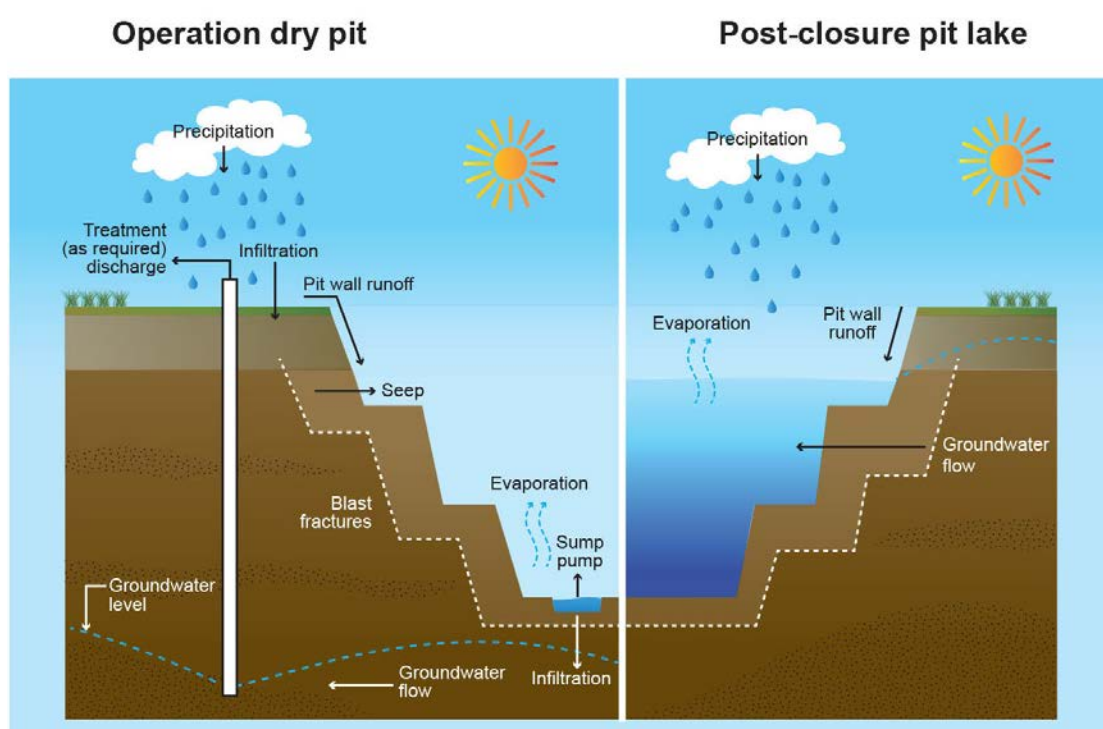
Key terms in the water balance which are applicable at most mines are illustrated in Figure 2 and summarised in Table 1, along with typical methods of quantifying each term. Water balance

components that are pumped must be measured through a water meter complying with AS 4747-2013.

It is an advantage that the required data for this approach is readily available at many mines. If not, data from alternate sources can be used, provided justifications are documented.

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 calculation at the scale of the mine pit or underground mine that utilises different water balance components from those in the examples illustrated, is not considered an “alternative methodology”, and does not require prior approval by the chief executive in accordance with the Regulation.

Figure 2: Key terms used in the water balance method



3.2.2.2 Numerical groundwater models

Numerical groundwater models can be used to represent complex groundwater systems. Temporal and spatial variability in parameters allows numerical models to provide good estimates of associated water take, provided information on the groundwater systems and mining methods are available.

It should be noted that, if the simulations are to be accurate, the data requirements for numerical models are usually high. This is because numerical groundwater models utilise specific aquifer properties at different points in space. Large numerical models can also be demanding computationally. In such cases, whilst setup costs often dominate total modelling costs, the consequent running of the model will likely be at a lower cost. However, keeping the model current and adding alterations could add significant additional ongoing costs. Despite this, numerical groundwater models should be considered in priority areas where accurate associated water take estimates are required for resource management (Section 3.2.1).

Analytic Element Models are a method that embodies aspects of both numerical and analytical modelling. With regard to estimation methods outlined in this guideline, analytical element models should be considered a form of numerical model with the same considerations and requirements in their use and application.

The *Australian groundwater modelling guidelines* (AGWM Guidelines) document by Barnett et al (2012) provides guidelines for developing and using groundwater flow models, particularly numerical models. The approach outlined in the AGWM Guidelines is to be followed when developing numerical groundwater models.

3.2.2.3 Analytical groundwater models

Using an analytical groundwater model is most suited to simple mine situations to overcome the data requirements and costs associated with numerical groundwater models. The analytical solutions, specifically developed to estimate the fluxes of associated water to mines, described by Marinelli and Niccoli (2000), Powers et al (2007) and Hazel (2009) are in common usage for estimating groundwater flow to mines. Leaseholders may use other solutions if their applicability to the specific mine conditions can be justified and must be obtained from a published and peer reviewed reference publication. (A reference to the chosen method is to be kept with the supporting documentation for the submission, see Section 7.)

These analytical groundwater solutions have many simplifying assumptions, commonly including steady state conditions and uniform aquifer properties. It is noted that natural hydrogeological systems include complexities that may violate the simplifying assumptions of analytical models. For that reason, care is needed when choosing to use an analytical method because they can potentially provide relatively low accuracy estimates.

When analytical models are used all underlying assumptions should be listed with comments on their applicability and limitations.

3.2.4 Uncertainty and limitations

3.2.4.1 Water balance method

There will be a level of uncertainty associated with the parameters used in the water balance calculations. These uncertainties and the associated limitations should be documented and presented.

3.2.4.2 Analytical and numerical groundwater models

When developing a groundwater model, uncertainty is inherently associated with the conceptualisation of the real system. Uncertainties associated with aquifer property values, boundary conditions, climate regime, measurement of abstractions, estimation of recharge, representation of natural processes within algorithms of standard software packages, etc should all be addressed during the modelling process and presented with the outcomes of the model. The associated water take report should outline the methods used for handling the various relevant aspects of modelling uncertainty and their effect on the estimates.

The AGWM Guidelines provide guidance for assessing the uncertainty of a groundwater model.

4 Specific Mine Situations

4.1 Air Emissions in Underground Mines

A potentially significant source of associated water from an underground mine is due to moisture loss arising from air emissions. The moisture content in the air, associated with underground air emissions, is a required parameter when estimating moisture loss arising from air emissions

The role of a Ventilation Officer in an underground coal mine is a statutory position under the *Coal Mining Safety and Health Act 1999* (Qld). The Ventilation Officer is the appropriate person to estimate water losses from air emissions in underground mines.

If a mine does not employ a Ventilation Officer (due to being out of scope of legislative requirements), then moisture in air or humidity may need to be calculated. Further information including a calculation method is provided in Attachment 3.

5 Mine Care and Maintenance

If a mine stops being active and enters care and maintenance, the reporting obligations for associated water do not cease. If groundwater is still entering a mine excavation, then associated water will still require estimating.

6 Licence Expiration and Surrendering

Once the mining lease expires or is surrendered, the holder must prepare a closure report outlining the long term impact on surrounding groundwater systems. This is a requirement of section 31B(3) of the Regulation.

The closure report is to outline the relationship and changes between the operational pit and the final void and/or landform for each licence or lease. Cross-sections showing the final void and final rehabilitated landform (including the lowest point of excavation across the site and the final elevation) are recommended to demonstrate the impact on groundwater. Inflows from aquifers intercepted during pit excavation are to be included on the cross-section.

The predicted long term annual, steady state entry of underground water into any rehabilitated mine pit (where it will pond for evaporation, or be diverted off-site) is to be quantified.

The method used to make the prediction is to be explained to demonstrate its validity. Robust scientific principles are to be used using actual data collected during ownership of the lease.

Please use the proforma "Closure report template" available on <https://www.business.qld.gov.au/industries/mining-energy-water/resources/minerals-coal/reports-notices/water-reporting> to prepare a closure report.

7 Data recording and reporting requirements

Supporting information that outlines how the associated water volume was estimated should be generated. The supporting information is to contain sufficient information to enable a competent person (i.e. someone with hydrogeological and groundwater modelling experience) to understand how the final associated water estimation was calculated. The supporting information may include (as appropriate):

- In the case of the water balance method:
 - o The excel document used to calculate the numbers;
 - o The assumptions used;
 - o Error estimation for parameters used.
- In the case of the analytical and numerical method:
 - o List of boundary conditions, limitations and assumptions;
 - o Excel document, formula used and/or the software package and version number;
 - o Summary outputs of model runs;
 - o Description of the scenario runs taken and the parameters that have been changed for those scenario runs;
 - o Summary of results and uncertainty quantification;
 - o Conclusions.

For comprehensive modelling, the AGWM Guidelines outline the structure of a model report (see Chapter 8 of the AGWM Guidelines). The reporting elements listed in the AGWM Guidelines should be followed.

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

Reports must be lodged using the System approved by the Chief Executive. The approved system is the GSQ Lodgement Portal which can be accessed through the department's website.

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 (2 ML) during the reporting period. This means that if a mining operation covers multiple tenures, then the 2 ML exemption includes the combined take from all of those tenures.

Mining tenure holders who are required to report their take of associated water, must provide all information to the department as set out in section 31B (2) and (3) of the Regulation. Tenure holders that have reported through GSQ Lodgement Portal, may be requested to supply details of the supporting information (as outlined above).

Reports are required to be lodged 1 calendar month after the end of the reporting period on 31 October each year, otherwise on the day the licence expires or is surrendered.

Table 1 – Typical data requirements for water balance calculation/water balance components and estimation methods

Components and notes		Common methods of estimation
Change in pit water storage volume: <ul style="list-style-type: none"> • A reduction in stored water volume would be recorded as a negative value • During periods of no or low rainfall, storage changes can be used to more accurately calculate groundwater ingress 		<ul style="list-style-type: none"> • Monitor pit water levels and dimensions and calculate the storage change between the beginning and end of the relevant period
Rainfall		<ul style="list-style-type: none"> • On site weather stations (preferred/ most suitable method) • Queensland Government SILO climate database
Evaporation		<ul style="list-style-type: none"> • On site weather stations (preferred/ most suitable method) • Queensland Government SILO climate database
Inflows	Direct rainfall on water storage areas	<ul style="list-style-type: none"> • Recorded rainfall multiplied by water surface area • Where the surface area varies significantly over the reporting period, the calculation should be broken down into appropriate shorter steps
	Surface runoff <ul style="list-style-type: none"> • Runoff is one of the most difficult components of the water balance to estimate and can vary widely with site and climatic conditions • Greater accuracy will be obtained from a daily rainfall-runoff model calibrated to recorded data • Estimates based on a simple runoff coefficient are likely to have low accuracy 	<ul style="list-style-type: none"> • Typically estimated from a rainfall-runoff model of the catchment contributing to the pit. Note that the catchment area may change over the reporting period
	Groundwater ingress to pits or underground mines <ul style="list-style-type: none"> • This component of the water balance represents the associated water take. • 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. • The contribution of seepage inflows from rainfall on in-pit overburden should be considered. These seepage inflows are not associated water 	<ul style="list-style-type: none"> • 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.
	Pumped inflows	<ul style="list-style-type: none"> • Must be measured by flow meters complying with Australian standard AS 4747-2013 on pump lines
Outflows	Evaporation from water storage areas	<ul style="list-style-type: none"> • Estimated evaporation (typically as mm/month) • calculated from weather station or SILO data using Morton's equation or similar (ie Linacre (1994)) multiplied by water surface area
	Pumped outflows	<ul style="list-style-type: none"> • Must be measured by flow meters complying with Australian standard AS 4747-2013 on pump lines
	Other outflows <ul style="list-style-type: none"> • Water collected in mining pits is sometimes used beneficially within the mining operation, for example being used for dust suppression. • Water vapour in ventilation airflows is a source of water loss in most underground mines 	<ul style="list-style-type: none"> • Use volumes, if unmetred, can be estimated from water cart volume and activity.

8 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).

GSQ Lodgement Portal: available at <https://www.business.qld.gov.au/industries/mining-energy-water/resources/minerals-coal/online-services/gsq-lodgement-portal>.

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

Surface water run-in: surface water that 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: an accounting procedure for all major water inflows to, outflows from and water storage changes to a surface or underground mine.

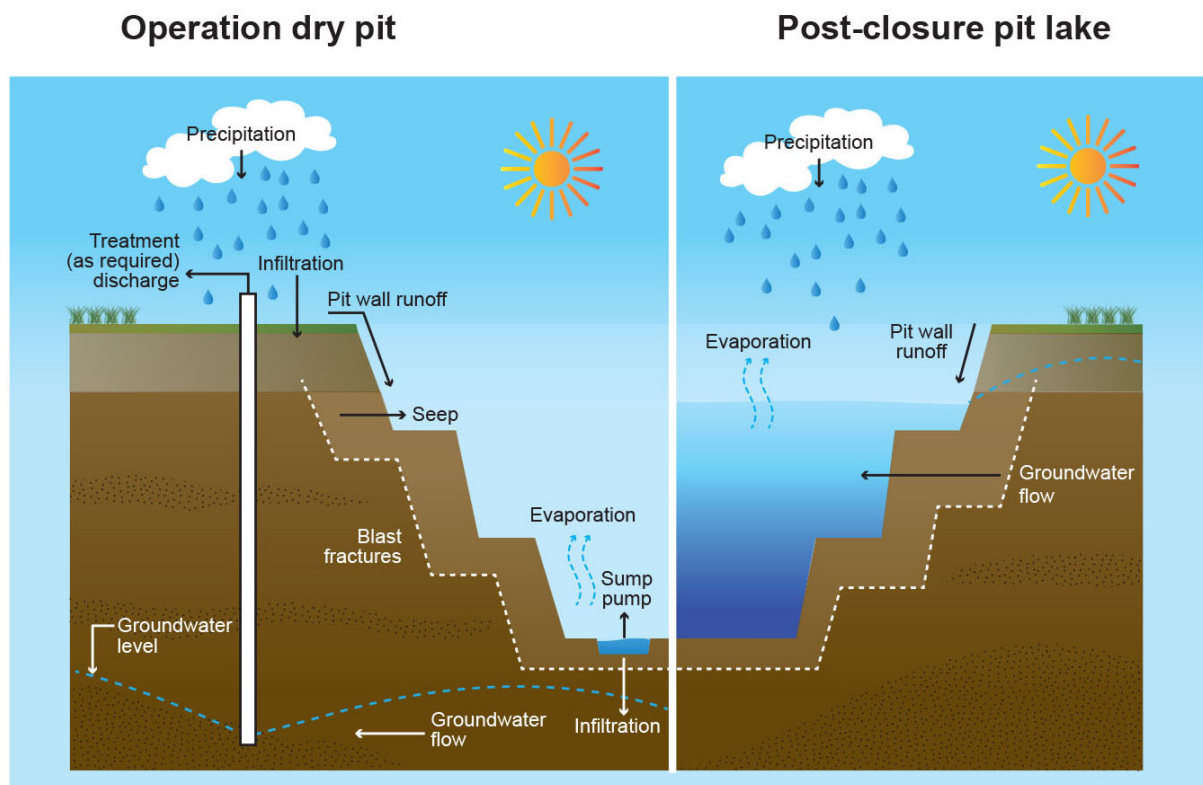
Water Year: is the accounting period prescribed under the Regulation (1 November – 31 October).

9 References

- Barnett et al, 2012; Australian groundwater modelling guidelines, Waterlines report, National Water Commission, Canberra.
- Darcy, H, 1856; Les Fontaines Publiques de la Ville de Dijon, Dalmont, Paris.
- Hazel, C, 2009; Groundwater Hydraulics, Second Edition June 2009.
- Huntington JL & McEvoy D, 2011; Climatological estimates of open water evaporation from selected Truckee and Carson River Basin water bodies, California and Nevada. Pub No 41254, Div of Hydrol. Sci, Desert Res Inst, Reno, NV.
- Middlemis H and Peeters LJM, 2018; *Uncertainty Analysis – Guidance for groundwater modelling within a risk management framework*, A report prepared for the Independent Expert Scientific committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia 2018.
- Kahler, D.M. and Brutsaert, W, 2006; Complementary relationship between daily evaporation in the environment and pan evaporation. Water Resources Research, 42, W05413, doi:10.1029/2005WR00454.
- Linacre, 1994; Estimating U.S. Class-A pan evaporation from few climate data, Australian National University, Canberra.
- Marinelli and Niccoli, 2000; Simple analytical equations for estimating groundwater inflow to a mine pit. Vol 38, No. 2 – GROUNDWATER – March-April 2000 (pages 311-314).
- McMahon, TA, Peel, MC Lowe, L2, Srikanthan, R, and McVicar, TR, 2013; Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis.
- McPherson, 1993; https://www.mvsengineering.com/files/Subsurface-Book/MVS-SVE_Chapter14.pdf, downloaded 19/03/2019.
- Morton FI, 1979; Climatological estimates of lake evaporation, Water Resource Research, 15:64-76.
- Morton FI, 1983; Operational estimates of Lake evaporation, Journal of Hydrology, 66:77-100.
- Powers, Corwin, Schmall and Kaeck, 2007; Construction Dewatering and Groundwater Control, Wiley, Third edition.

Attachment 1 – Calculation of underground water ingress to a surface mine using the water balance method

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. This example utilises a water balance approach, as described in section 3.2 and can be used for a mined pit that has not been backfilled and 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 in the pits is a result of the difference between water inflows (groundwater, run off and rainfall) and outflows (evaporation and mine water use), i.e.:

$$\Delta L_V = G_i + \frac{(R \times A_E - E_L \times A_L)}{100} - WU + Ro \quad (1)$$

Where:

- ΔL_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);

- A_E is the effective rainfall area over the pit (ha); this area is constrained by the pit walls or pit bunds;
- E_L is evaporation from the pit lake (mm);
- A_L 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 of groundwater seepage from the pit walls, including stratigraphic sequences overlying the ore body or coal seam, is assumed small and therefore ignored.
- The area over which rain falls over the pit (A_E) is not substantially greater than the pit water surface area (A_L), as can occur for pits in high water table areas after mine closure. Where A_E is substantially greater than A_L , 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 (A_E). Evaporation from pit soil, roadways or other pit storage is considered insignificant and therefore ignored.

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

$$G_i = \frac{(E_L \times A_L - R \times A_E)}{100} + WU + \Delta L_V - Ro \quad (2)$$

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 DNRME's SILO database) to calculate E_L 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 bounded mine pit with effective rainfall catchment area (A_E) 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:

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

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

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

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.

Component		Estimated water balance component for 1 month	Comments on uncertainty
Increase in water storage volume		Increase in storage = 6 ML	
Inflows	Direct rainfall on water storage areas	30 mm × 10 ha = 3 ML	Accurate rainfall from on-site weather station. Errors < 5%
	Surface runoff	4 ML	Small when measured. Could be > 10% for site calibrated model
	Groundwater	Calculated from equation (2)	
	Pumped inflows	Net pumped inputs of 3 ML	Australian Standard meter. Error < 5%
Outflows	Evaporation from water storage areas	240 mm × 9.5 ha = 22.8 ML	Accurate evaporation from on-site weather station. Errors < 5%
	Pumped outflows	Net pumped output of 3 ML	Australian Standard meter. Error < 5%
	Other outflows	Zero	

Attachment 2 – Example calculation of groundwater ingress to an underground mine using the water balance method

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 (V_i)) 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 (V_o)):

$$G_i + TP + V_i = MAW + V_o \quad (3)$$

or

$$G_i = MAW - TP + V_o - V_i \quad (4)$$

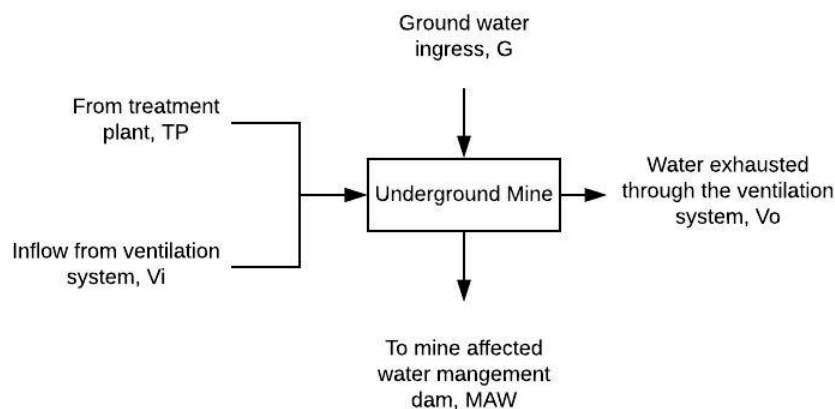


Figure 3: Example of water balance components of an underground mine

If MAW= 450 ML/y, TP=200 ML/y, V_i =10 ML/y and V_o =30 ML/y, then groundwater ingress into the underground mine is $(450 - 200 + 30 - 10)$ ML/y = 270 ML/y

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

Component		Estimated or measured water balance component over 1 year	Uncertainty in parameter
Increase in water storage volume		Assumed zero for underground mine	
Inflows	Direct rainfall on water storage areas	Zero for underground mine	
	Surface runoff	Zero for underground mine	
	Groundwater	Calculated from Equation (4)	
	Pumped inflows	From treatment plant = 200 ML/y	Australian Standard meter. Error < 5%
Outflows	Evaporation from water storage areas	Zero for underground mine	
	Pumped outflows	MAW = 450 ML/y	Australian Standard meter. Error < 5%
	Other outflows	Net water loss through ventilation = 20 ML/y	Metered < 10%

Attachment 3 – Information on Estimating Water Loss from Underground Mines

There are a number of methods to measure the moisture in air also called the humidity. This can include chemical methods, electrical methods such as humidity meters and hair hygrometers. Wet and dry bulb hygrometers/psychrometers are the most widely used type of hygrometers in underground mines. The better psychrometers can be read to the nearest 0.1°C. Variations considerably greater than 1°C may occur over the cross section of an airway, particularly near shaft stations. The approximate extremes of temperature should be known prior to conducting a psychrometric survey, and an appropriate instrument selected. The difference between the wet and dry bulb temperatures is more important than the absolute temperature.

Whirling or sling psychrometers need to be rotated manually about the handle approximately 200rpm and then the wet bulb temperature read immediately. Aspirated psychrometers are also valuable for more accurate measurements.

The wet and dry bulb temperatures, together with the barometric pressure, allow all other parameters to be calculated. See equations 5 and 6 below.

$$X_s \left(\frac{kg}{kg \text{ dry air}} \right) = 0.622 \left(\frac{e}{P-e} \right) \text{ - Equation 5}$$

Where:

X_s – wet bulb moisture content

e – partial pressure of the water vapour

P – absolute (barometric) pressure

$$X \left(\frac{kg}{kg \text{ dry air}} \right) = \frac{LX_s - C_{pa} \Delta t}{C_{pv} \Delta t + L} \text{ - Equation 6}$$

Where:

X – moisture content of the air

L – latent heat of evaporation ($L = 3154.2 - 2.386 T$) x 1000 J/kg where T is in °K

P – barometric pressure

C_{pa} – specific heat of dry air at constant pressure (1005J/kg K)

C_{pv} – specific heat at constant pressure for water vapour (1884 J/kg K)

t_w – wet bulb temperature

t_d – dry bulb temperature

Δt - temperature difference between dry bulb and wet bulb ¹

Using the air flow of the ventilation system, the total water emissions can be calculated using the moisture content (X) obtained above.

¹ McPherson (undated) https://www.mvsengineering.com/files/Subsurface-Book/MVS-SVE_Chapter14.pdf, downloaded 19/03/2019.