# Water Monitoring Guidelines for Underground Mining Activities in the Special Areas

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# 1. Background

## 1.1 WaterNSW role, Special Areas and Mining Principles

WaterNSW is a State-Owned Corporation established under the *Water NSW Act 2014*. WaterNSW has an important statutory role "to protect and enhance the quality and quantity of water in declared catchment areas".

The Special Areas within the Sydney drinking water catchment (SDWC) provide natural buffers that protect critical water storages and infrastructure. These buffer zones are an essential component of the 'multi-barrier' approach to protecting water quality and quantity. Access to the Special Areas is restricted by law.

WaterNSW has no legislated powers to control or stop mining in the declared catchments, but as the partial owner and joint manager of the Special Areas we seek to influence planning decisions and hold the subsequent mining operations to account for all impacts which significantly harm our values (principally water quantity, water quality and ecological integrity).

WaterNSW has established a set of four principles that underpin its approach to managing the impacts of mining in SWDC. A copy of the principles can be found at: https://www.waternsw.com.au/water-quality/catchment/mining/principles.

The Mining Principles are summarised as follows:

1. ***Water supply infrastructure*** – mining must not result in the integrity of water supply infrastructure being compromised.

2. ***Water quantity*** – leakage from reservoirs because of mining activities must be avoided, and regional depressurisation and diversion of surface water flows must be avoided and minimised by adopting a precautionary approach to mine design.

3. ***Water quality*** – all mining activities must have a neutral or beneficial effect on water quality.

4. ***Ecological integrity*** – of the Special Areas must be maintained and protected.

## 1.2 Purpose

WaterNSW has an established surface water and groundwater monitoring guideline (SCA, 2009) for assessing impacts of underground longwall coal mining in the Special Areas. There have been significant advances in recent years to improve our understanding of the subsidence impacts and environmental consequences of longwall mining on surface and groundwater resources. In 2019, the Independent Expert Panel on Mining in the Catchments (IEPMC) published two reports and made several recommendations for improvements in surface and groundwater monitoring and upland swamp hydrological monitoring.

This document replaces the previous SCA (2009) monitoring guidelines, incorporates the relevant IEPMC (2019) recommendations and reflects current best practice science and recent advances in understanding and monitoring of subsidence impacts in the Special Areas.

The proposed updated monitoring guidelines will assist mining proponents to consider WaterNSW's Mining Principles and prepare robust surface water and groundwater monitoring programs to meet development consent and extraction plan requirements and allow regulators to assess the performance of the mine.

While these guidelines are specific to the Special Areas due to their unique environment and important role, there is no reason why they cannot be applied more broadly to other mining operations in the SDWC.

# 1. General Considerations

## 1.1 What to monitor

The design of a monitoring program to assess the impact of underground mining in the Special Areas should be comprehensive, appropriate and rigorous, and include monitoring of the natural baseline conditions, changes due to mining and recovery of the hydrological/hydrogeological systems following mining.

The surface water and groundwater environments/aspects required for monitoring and assessment of potential impacts of mining include:

- streams, pools, and lakes,
- shallow groundwater:
  - in swamps (swamp sediments and bedrock),
  - regional water table aquifer, and
- deep groundwater (in stratigraphic formations), and
- surface water and groundwater quality.

The objectives of surface water and groundwater monitoring programs, reasons why it is important to do, and potential methodologies for assessing these objectives in mining impacted catchments are outlined in Table 2.

WaterNSW acknowledges the need to consider historical context and existing evidence when designing any new monitoring program, to avoid potentially costly and environmental damaging replication of monitoring where sufficient evidence already exists. When assessing any monitoring program WaterNSW considers the practicality and potential impacts associated with implementing the monitoring techniques. It is recognised that these may sometimes outweigh any benefits gained from the information collected in particular contexts.

## 1.2 Where to monitor

Monitoring should focus on areas of concern where the impact of mining could cause environmental damage. Table 1 outlines areas of focus for monitoring and the reasons why monitoring should occur here.

**Table 1. Placement of monitoring locations**

| Location | Reasons |
|---|---|
| Up-gradient and down-gradient of the proposed mining (surface water) | • Assess the extent of water quantity and quality changes away from actual mining area<br>• Assess impacts on water supply<br>• Up-gradient monitoring locations can be useful as control sites for assessing natural variability and for comparison of impacts within the mining area |
| Over and near the longwalls (surface water and groundwater) | • Determine the vertical extent of mining influence/impacts<br>• Assist with groundwater model calibration<br>• Inform future mining |
| Near and between a reservoir or significant water body and the longwalls (surface water and groundwater) | • Understand the groundwater regime and determine the extent of mining impacts and potential loss from the reservoir or significant water body |

| | |
|---|---|
| Over/near features of significance such as swamps, waterfalls, river/creeks etc. (surface water) | • Asses the extent of change and/or impact<br>• Determine adaptive management strategies |
| Within and around an intrusion (groundwater) | • Determine if there is a connection between the reservoir or significant water body and the mine<br>• Determine if there is increased conductivity and mine water ingress into the mine |

**Table 2. Objectives of surface water and groundwater monitoring programs**

| Objective | Reasons | Methodologies |
|---|---|---|
| Assess baseline conditions and develop a conceptual model(s) | • Characterise pre-mining surface and groundwater systems<br>• Identify key processes and their interactions<br>• Assess factors driving changes in the system | • Examine current understanding of the natural system using existing data and scientific literature<br>• Conduct studies/monitoring to improve knowledge and acquire baseline data |
| Assess subsurface stream flow diversion | • Provide data for models<br>• Understand permanent stream flow losses and impacts on water supply<br>• Estimate catchment water balance<br>• Assess discharges from upland swamps and baseflow discharge to streams<br>• Understand subsurface flow diversion and re-emergence further downstream | • Stream flow monitoring<br>• Visual observations<br>• Water quality monitoring<br>• Shallow groundwater monitoring<br>• Modelling |
| Estimate/predict change in baseflow discharge to streams or permanent water losses | • Determine whether groundwater depressurisation might have impacted on shallow groundwater system<br>• Examine whether there is a permanent loss of head and water resource potential during and post mining<br>• Assess the risks of poorer quality baseflow discharge (particularly pH, conductivity and metal concentrations) to streams | • Monitoring of stream flow, shallow groundwater and climate<br>• Surface water and groundwater modelling<br>• Analysis/comparison with a control catchment/baseline data<br>• Visual observations |
| Assess/predict impacts on water supply | • Detect changes in regional groundwater levels, groundwater depressurisation<br>• Provide verification of the results of hydrological modelling<br>• Understand groundwater level recovery following cessation of mining (across all important regional aquifers) | • Groundwater and surface water models |
| Assess a change in groundwater level fluctuation and recession rates in swamps | • Detect impacts on groundwater levels and recession rates<br>• Characterise connectivity between perched groundwater and local/regional aquifer<br>• Understand the role of a swamp in sustaining baseflow in local watercourses<br>• Calculate swamp water balance | • Monitoring of climate, soil moisture and groundwater in swamps sediments and swamp bedrock |

| Objective | Reasons | Methodologies |
|---|---|---|
| Assess loss of pools holding capacity and/or a change in pools drainage behaviour | • Monitor post-mining continuity of surface flow<br>• Determine post-mining changes in pools drainage behaviour and water level recession rates<br>• Assess rehabilitation options to limit the loss of water through fractured rock-bars<br>• Determine the effectiveness of stream remediation and restoration of ecological values | • Monitoring pool levels<br>• Visual inspection |
| Estimate leakage from reservoirs | • Understand hydraulic gradients and water quality attributes<br>• Determine any groundwater flow from stored water<br>• Identify, assess and respond to abnormal water inflows into the mine | • Groundwater pressure/levels and hydraulic gradients in the barrier zone<br>• Groundwater modelling<br>• Strata permeability assessment<br>• Groundwater fingerprinting<br>• Mine inflow monitoring |
| Assess spatial and temporal changes in water quality | • Understand the spatial and temporal extent of water quality impacts (iron staining, decrease/change in pH, increases in salinity)<br>• Confirm any mobilisation of metals associated with subsurface flow diversion<br>• Assess potential impacts on reservoir water quality<br>• Calculate any contaminant loads (metals) discharged from undermined catchments into reservoirs | • Iron staining/water quality monitoring<br>• Visual observations |
| Assess impacts on reservoir water quality | • Delineate sources of mine water inflows. | • Water quality monitoring |
| Assess surface to mine connectivity | • Examine pre-mining groundwater systems<br>• Understand any surface to mine connectivity and tracing surface sourced inflows into a mine<br>• Determine the post-mining connectivity between hydrostratigraphic units (vertical flow) | • Model predictions<br>• Monitoring of mine inflows<br>• Fingerprinting of source waters<br>• Mine inflow analysis<br>• Postmining investigations (height of depressurisation)<br>• Monitoring of groundwater pressures<br>• Tracer testing |
| Assess the extent of subsurface fracturing | • Understanding post-mining change in hydraulic gradients and groundwater flow | • Investigations of postmining height of depressurisation<br>• Ground movement monitoring |

| Objective | Reasons | Methodologies |
|---|---|---|
| | • Assessment of decline in groundwater levels during mining and post-mining recovery<br>• Determination of the height of depressurisation, the extent of the surface fracture zone and potential for surface to seam connectivity* | • Post mining fracture characterisation<br>• Strata permeability assessment |
| Assess effectiveness of stream remediation | • Restore surface flow and connectivity in impacted stream sections | • Develop Stream Remediation Management Plan and success criteria |
| Assess compliance with approval conditions and management strategies | • Demonstrate compliance with approval conditions | • Develop Trigger Action Response Plan<br>• Assessment against trigger levels<br>• Required reports |
| **WaterNSW acknowledges the distinction between fracturing associated with the mine goaf, and surface cracking induced by vertical and horizontal ground movements* | | |

WaterNSW notes that the design of the monitoring program may be influenced by a range of factors including:

- the mine footprint, depth of cover, longwall geometry and predicted subsidence effects,
- catchment characteristics in terms of size, topography, local geology including geological structures, vegetation cover and accessibility,
- catchment hydrology such as drainage pattern, significance of streams (stream order), location and significance of swamps,
- proximity to WaterNSW reservoirs,
- groundwater in the area and resource potential of aquifers,
- climatic conditions (seasonal variation, drought, dry and wet periods), and
- potential impacts on water resources.

## 1.3 How long and how often to monitor

Sufficient monitoring frequency is required to ensure that the monitoring data is adequate for characterising the hydrological and hydrogeological systems during varying climatic conditions (i.e. baseline data of at least two years). It must then continue during mining and post-mining. Monitoring frequency will depend on the type of monitoring program and if measurements are manual or automatic.

The post-mining monitoring period should continue long enough to provide sufficient data to:

- assess the recovery of the hydrological/hydrogeological system,
- allow for validation of predictions, and
- determine whether mining impacts have stabilised and/or the mine is considered by the relevant regulatory authorities to have been rehabilitated.

# 2. Surface Water Monitoring

The surface water monitoring program should include measurements of the volume in stream flow, water levels in pools and surface water quality. The monitoring of precipitation from rainfall stations representative of the catchment area is also required.

Values of surface waterways that should be considered include, importance to catchment yield, significance to water supply, scale of the watercourse, permanence of flow, water quality, ecological importance, environmental quality (pristine, modified, severely modified,), visual amenity (e.g. waterfalls, cascades runs, pools etc.), community value (value the community attributes to protection) and regional significance.

Baseline characterisation of all watercourses within the project area (usually the mining area plus whichever is the greater between the 35° Angle of Draw for the maximum depth of cover or the 20 mm predicted limit of vertical subsidence) should include assessment of pool dimensions (i.e. width, length and depth), characteristics and dimensions of the retaining rock bar, characteristics of the water flow (channels, etc.), mapping of steep slopes, presence of small waterfalls and sediment accumulation and erosion.

## 2.1 Stream flow

The objectives for stream flow monitoring can be found in Table 2. When establishing stream flow monitoring sites, a range of factors should be considered such as:

- significance of streams (streams order and number, water supply),
- proximity to mining, including previously impacted mining sites,
- topography, catchment shape and area.

If mining occurs upstream of a WaterNSW reservoir or major/significant stream, monitoring should include downstream sites, to determine whether there is any reduction or loss of flow. For assessment of permanent stream flow losses within a mine footprint flow gauges should be located as close to a proposed set of workings as possible without being compromised by subsidence movements. The estimates of this distance will depend on the catchment response and the precision/reliability of stream observations (Tammetta, 2018).

The gauge types previously installed in Special Areas used natural flow control features such as rockbars. However, to achieve accurate flow measurements, the IEPMC (2019b) recommended installation of a weir and flume/halfpipe and highlighted the need for uncertainty estimates in the observational data (e.g. water levels in streams) and any resulting variables such as discharge from a rating curve and water level.

Guidelines for the establishment and operation of hydrometric monitoring sites is available in BOM (2019). A procedure to estimate uncertainty in discharge estimates within the gauged range can be found in McMahon and Peel (2019). The summary of the methods commonly used for undertaking surface water investigations are summarised in McMahon (2017).

The IEPMC (2018 and 2019b) recommended that surface water monitoring requirements in proposed future mining areas should include a distinction between primary and secondary watercourse monitoring sites (Table 3).

**Table 3. The IEPMC recommendations for stream flow monitoring in future mining areas**

| Site | Definition |
|---|---|
| Primary watercourse monitoring site | Are the sites at which performance measures are specified. The identification and the installation of flow monitoring at these sites is required at least four years in advance of mining activities |
| Secondary watercourse monitoring site | Provide additional information identified as necessary as the mine plan evolves. The identification and the installation of flow monitoring at these sites should be completed at least two years in advance of mining activities or a shorter time if approved as part of the mine plan approval |

Additional flow gauges and improvements to existing flow gauges should continue to be undertaken selectively by mining companies in consultation with WaterNSW, or by WaterNSW (with potential financing from the companies).

Surface flow monitoring associated with mining should be required to be continued until the consequences of mining (including any rehabilitation) have stabilised and/or the mine is considered by the relevant regulatory authorities to have been rehabilitated. This requires clear metrics of stabilisation.

## 2.2 Water levels

The objectives for water level monitoring can be found in Table 2. Monitoring of pool water levels should include pools directly overlying longwall panels as well as pools outside of the longwall extent. Pool water level monitoring may involve manual or automatic water level logging, depending on the significance of watercourse, predicted subsidence consequences and the project specific approval conditions.

Water levels should be measured relative to benchmarks installed on rocks or other stable features on the edge of the pools. When monthly manual monitoring is implemented, frequency should increase to weekly during active mining or in response to any identified impacts.

Assessment should involve comparison with reference/control sites.

Visual observations of pool behavior during regular site inspections should also be recorded.

## 2.3 Water quality

The objectives for water quality monitoring can be found in Table 2. Water quality impacts are site-specific related to the nature of the groundwater and surface water interaction and stream conditions (such as geomorphology, topography and flow) that may result in release of chemicals and gases into the water column.

The IEPMC (2018 and 2019b) recommended that contaminant concentrations be integrated with flow monitoring at operational mines to support calculation of contaminant loads at the main inputs to reservoirs and other key locations and to improve understanding of future contaminant loading risks. Relevant contaminants should be agreed between primary stakeholders.

Selection of monitoring sites, sampling frequency and sampling techniques will depend on the occurrence and nature of variability in measured contaminants and on the statistical techniques used for analysis (CoA, 2015).

Most water quality guidelines prescribe a minimum of monthly sampling undertaken for benchmarking purposes (ANZECC & ARMCANZ 2000). Standard methods for water quality sampling and analysis are well established and described in DES (2018).

# 3. Groundwater Monitoring

The groundwater systems underlying the Metropolitan and Woronora Special Areas form a small but important component of the overall water balance for catchments across the Special Areas. Mining impacts to surficial and regional groundwater systems may result in consequences to baseflows, water quality, associated ecosystems and catchment yield (Advisian, 2016).

## 3.1 Shallow groundwater

The objectives for shallow groundwater monitoring can be found in Table 2. Piezometric/water level data are used to assess mining induced impacts and the connectivity of different groundwater systems. The first indications of impacts to a groundwater system are always pressure/water level related. Geochemical, selected isotope data and tracer techniques have been used more recently as secondary proof to assist in describing the attributes and connectivity of the different systems (Advisian, 2016). There are three broad characteristics of groundwater which are important to monitor (CoA, 2015):

- groundwater levels (or pressures),
- groundwater quality and
- hydrogeological properties (e.g., hydraulic conductivity, porosity, and storage).

Monitoring groundwater involves drilling and installing (standpipe) piezometers screened in the aquifers of interest. Piezometer screens need to be hydraulically isolated from overlying and underlying formations and should be constructed according to the minimum construction requirements for water bores in Australia (NUDLC, 2020). Additional advice on automatic water pressure/level measurements and accuracy of the manual checks are discussed in BOM (2019).

An alternative to a conventional screened piezometer is a vibrating wire piezometer (VWP) used for monitoring of deep groundwater. VWPs are grouted in using a bentonite-cement grout allowing multiple piezometers to be installed at different levels in the same borehole (CoA, 2015). The multi-level VWPs often cease to operate when horizontal shearing occurs during longwall mining.

Groundwater quality samples are collected from a set of dedicated bores with installed pumps. More information on standard groundwater quality sampling protocols can be found in Sundaram et.al. (2009) and DES (2021).

The IEPMC (2018) recommended that all future groundwater monitoring programs for longwall mining should include provision for:

- installation of multi-level piezometers on the centerline of panels to monitor pore pressure changes associated with subsidence. These should include at least five transducers per borehole with installation being completed at least two years in advance of being undermined,
- daily monitoring of local rainfall and of mine water ingress from overlying and surrounding strata
- separation of rainfall-correlated inflows for base flow volumetric analyses, and
- develop site-specific databases in relation to the height of complete drainage in lieu of relying on height of drainage equations.

WaterNSW notes that piezometers typically fail as the longwall passes. Depending on the mine and the longwall parameters involved it may be more valuable to install on a pillar as there is a lower risk of loss, or alternatively install a post-mining piezometer. It is accepted that not all panels would require a piezometer to confirm the height of depressurisation.

## 3.2 Upland swamps

The objectives for upland swamp monitoring can be found in Table 2. The ecological assessment guidelines by the Independent Expert Scientific Committee (IESC) (CoA, 2014b) contained recommendations for swamp baseline mapping (Table 4).

**Table 4. Swamps baseline mapping**

| Characteristic | Comments / Recommendations |
|---|---|
| Vegetation mapping | Survey plots and species counts undertaken two years prior to mining |
| Vegetation distribution | Survey plots and species count, remote-sensing analysis using classification techniques |
| Identification of flora and fauna species | All threatened or vulnerable species and identification of invasive species by survey plots and species count |
| Swamp extent | Using NDVI analysis of WorldView-2 or GeoEye field GPS readings of swamp edges. Also airborne laser scanning methods |
| Measurement of covariates/drivers of ecological response | Including hydrological regime |

The results from mining impacted swamps to date suggest that monitoring of groundwater levels give clear early evidence of hydrological change in response to mining as these precede any ecological response (IESC, 2015).

The IEPMC (2019b) recommended that future swamp monitoring and modelling programs should:

- provide a hydrological balance for representative swamps, sufficient to identify any mining-induced changes in soil moisture and in baseflow down the exit stream, and
- provide vertical leakage rates as inputs to groundwater models, in order to quantify how much of the leakage is diverted back into the catchment or elsewhere.

In addition to addressing the IEMPC recommendations, mining companies should also consider the OEH (2012) developed criteria for the assessment of a swamps significance and recommended that the key parameters for monitoring of subsidence consequences in swamps are water levels, evaporation and rainfall.

Monitoring is required before and after mining and at impacted sites and reference sites. This before-after and control-impact (BACI) monitoring approach is essential to diagnose the cause of observed changes, in particular to distinguish subsidence effects from site-related differences and temporal events such as variation in rainfall. Table 5 contains recommended inclusions for this approach.

**Table 5. Before-after control-impact monitoring design**

| Approach | Recommended inclusions |
|---|---|
| Before - after monitoring | • Pre-mining baseline monitoring for a period of no less than two years (earlier if possible)<br>• During and post-mining monitoring that continues if impacts could or do occur (or until such time a decision is made in regard to offsets)<br>• Where impacts occur and remediation is undertaken, the continuance of monitoring to determine its success or otherwise |
| Control - impact monitoring | • Include multiple reference swamps that are comparable to swamps to be undermined<br>• Within the region and be selected from areas which will not be undermined in the future<br>• Be used to distinguish between impacts of subsidence and confounding site-related or temporal factors |

More specifically, the IESC (2015) recommended that each swamp that is potentially subject to impact and each control swamp should install as a minimum:

- a transect of piezometers (at least three; more would be appropriate in large swamps) installed along a line from the highest area of the swamp to the swamp outflow point, and
- a second transect perpendicular to the first, located in the area where hydrological impact is most likely, such as directly above a longwall panel.

The selection of groundwater monitoring locations should also consider placement of a piezometer in the deepest point in the swamp's sediments and any other significant deep points to better understand potential mine-induced drainage and avoid locations overlying pillars between longwalls (IESC, 2015).

Soil moisture profiles are monitored at selected swamps, with sensor arrays typically positioned near shallow piezometers (where possible) and used to assess potential changes in ecosystem functionality.

CoA (2014a) has published preliminary guidelines on mine design for protection of peat swamps that are potentially affected by cracking of the underlying sandstone. Mining companies should demonstrate consideration of these guidelines and associated peer review.

WaterNSW will carefully consider and balance the value of the data to be obtained versus the level of impact associated with piezometer installation in swamps.

## 3.3 Regional groundwater (water table)

Monitoring of the regional groundwater system within the Hawkesbury Sandstone has been a relatively recent addition to the suite of groundwater data. The objectives for regional groundwater monitoring can be found in Table 2. Historical monitoring data of this key groundwater system within the Metropolitan and Woronora Special Areas has been somewhat limited (Advisian, 2016).

The site selection and bore design for groundwater monitoring is governed by the monitoring objectives. Bores for regional groundwater monitoring should be located, designed and constructed to be representative of groundwater level trends and/or quality across the wider groundwater system. To assess horizontal groundwater flow directions, a minimum of three bores completed within the same aquifer are required to determine flow gradients. The nested configuration of piezometers should be used to characterise vertical groundwater gradients and potential vertical groundwater flow.

It is particularly important to have shallow monitoring bores in the regional groundwater systems (Advisian, 2016):

- in close proximity to upland swamp monitoring to assess swamp dependence on regional (bedrock) groundwater discharge,
- in areas of permanent streams to assist in quantifying baseflow discharge volumes and determining where, when, and how the stream changes from connected-gaining to connected-losing (or disconnected-losing), and
- in the buffer zone near storages to assess gradients and groundwater flow from reservoir toward the depressurised areas above longwall panels.

Groundwater quality sampling and periodic monitoring (in addition to tritium monitoring) would be useful to characterise the vertical variability of groundwater within the regional groundwater systems. Automatic data logging for groundwater conductivity and temperature would be useful for determining the shallow groundwater system and surface water-groundwater interaction and is recommended at select piezometers.

# 4. Subsidence

Subsidence monitoring of watercourses and watercourse features are an integral part of the water monitoring program to assess against performance measures and manage impacts. Valley closure, upsidence and horizontal and vertical strains are some key subsidence parameters that need to be monitored. This is undertaken during mining using a range of measurement techniques including ground surface surveys, and remote sensing using airborne and/or satellite-based techniques.

Ground survey techniques involve the development of a network of pegs or permanent survey marks and surveying techniques such as precise levelling, control traversing or using GNSS (Global Navigation Satellite System) to accurately measure position and change in position over time. Remote sensing methods such as airborne laser scanning (ALS) uses light to measure elevation (light detection and ranging or LiDAR) and estimate subsidence by calculating differences in terrain models. Satellite imaging methods for mapping of ground subsidence are based on Interferometric Synthetic Aperture Radar (InSAR) systems (CoA, 2015).

# 5. Geological Structures

A key recommendation for future mine design by the IEPMC (2019a) is consideration of "*the potential implications for water quantity of faulting, bedding plane shears and lineaments need to be very carefully considered and risk assessed at all mining operations in the Special Areas*".

The mapping of faults, igneous intrusion, bedding plane shears, lithological contact and lineaments, through surface geological mapping, seismic surveys and geophysical logging of boreholes, can be useful for identifying the:

- distribution and size of faults, bedding planes and lineaments,
- potential depths and location of geological features which may become enlarged and bedding planes which may separate,
- likely recharge and discharge areas along streams,
- likely baseflow discharge locations, and
- main groundwater flow paths.

Surface geological mapping in combination with seismic surveys before, during and after mining can be compared to assess the changes in the distribution and size of existing geological features, and whether hydraulic conductivity changes in faults or lineaments developed and bedding planes parted.

Geophysical logging is useful for determining the lithology and should be conducted on uncased boreholes, likely to be boreholes used during exploration and geotechnical characterisation. The geophysical techniques to be used may include natural gamma, caliper, spontaneous potential and resistivity methods.

Borehole inclinometers can detect both magnitude and direction of shear movements at multiple depths down a vertical borehole.

Time Domain Reflectometry (TDR) installed in a borehole detects the location of breaks in the transmission of pulsed signal (usually low voltage) along the length of a conductive cable. This can be due to faults or breaks in the cable which can be attributed to shear movement.

# 6. Dams and Reservoirs

Before November 2019, the requirements for mining near dams were covered by the *Mining Act 1992*. These now come under the *Dams Safety Act 2015 (Dam Safety NSW, 2019)*. Mining should not introduce unacceptable dam safety risks, based on the dam's design and construction and its consequence category.

Mining companies must consider the *Dams Safety NSW Monitoring Guidelines for all mining activities near declared dams and notification areas* when designing monitoring programs (DPIE, 2020).

# 7. Landscape and Built Features

Surface subsidence related vertical and horizontal movements can result in surface and subsurface cracking, uplifting, buckling, dilation and tilting. These impacts can affect watercourse hydrology and morphology, swamp hydrology and ecological function due to surface cracking.

Landscape monitoring programs should include visual inspections of the undermined catchment areas and surrounds to check for subsidence impacts such as:

- the location and approximate dimensions (width and length) and orientations of surface cracks along watercourses and watercourse features like rockbars, pools and waterfalls,
- rock falls at cliffs and overhangs,
- steep slopes stability
- any soil erosion and/or sedimentation impacts
- impacts to roads, fire trails and any WaterNSW infrastructure
- the nature and extent of iron staining and any gas releases in streams
- any changes in vegetation, and
- any observable loss of surface water or water diversion.

Landscape monitoring should be conducted monthly during active subsidence and until any necessary rehabilitation is complete. Airborne Laser Scanning (ALS/LiDAR) can be employed to assess landscape impacts in areas with restricted access due to steep terrain and/or vegetation cover.

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