# Snowy 2.0 Main Works
# Subsidence Management Plan

Version: Rev J

Date: 5 December 2023

| | Name | Title |
|---|---|---|
| **Prepared By:** | B.Chapman<br>D.Frontini | Lead Tunnel Engineer - Snowy 2.0<br>Geotechnical Lead - Snowy 2.0 |
| **Reviewed By:** | D. Miller | Engineering Manager - Snowy 2.0 |
| **Approved By:** | D. Evans | Project Director - Snowy 2.0 |

## Department of Planning and Environment

Our ref: Snowy 2.0 - Main Works (SSI-9687)

Mr Chris Buscall
Environment Manager
SNOWY HYDRO LIMITED
Monaro Highway
COOMA New South Wales 2630
06/12/2023

**Subject:** Snowy 2.0 - Main Works – Subsidence Management Plan

Dear Mr Buscall,

I refer to your submission requesting review and approval of the Subsidence Management Plan required by condition 64 of Schedule 3 of the infrastructure approval (SSI – 9687). I also acknowledge your response to the Department's review comments and request for additional information.

I note the Subsidence Management Plan has been prepared in consultation with National Parks and Wildlife Service.

The Department has carefully reviewed the document with advice from a technical geotechnical expert and is satisfied that it meets the requirements of the relevant conditions of approval.

Accordingly, as nominee of the Planning Secretary, I approve the Subsidence Management Plan (Rev J2, dated 5 December 2023).

Please ensure you make the document publicly available on the project website at the earliest convenience.

If you wish to discuss the matter further, please contact Lauren Clear on (02) 8229 2974.

Yours sincerely

Nicole Brewer
Director
Energy Assessments
As a nominee of the Planning Secretary

# Contents

# 1. Introduction

## 1.1. Purpose and objectives

This Subsidence Management Plan has been developed in response to the Snowy 2.0 Main Works Modification Application (SSI-9687-Mod 2).

The purpose of this Management Plan is to provide a structure and process for managing the risk of subsidence through the nomination of the following:

- Trigger Action Response Plan,
- Survey and Monitoring Plan, and
- Management and Reporting commitment.

## 1.2. Scope

This Management Plan details the proposed monitoring and controls for the area of the Headrace Tunnel and Headrace Adit that are less than 100 m depth below surface (cover). This scope of Management Plan is specifically focused on the areas of less than 100m cover as this is considered the area at risk of potential subsidence as described in the Modification Application.

This plan identifies how ground movement, both surface and sub-surface will be identified and measured until the tunnel obtains sufficient surface cover and is outside of the known fault area whereby at that stage no surface settlement will be expected to occur. Both surface and in-tunnel monitoring activities are covered.

While surface monitoring techniques as described in Section 2 will cease once the Headrace Tunnel and Headrace Adit are beyond 100 m cover, in-tunnel monitoring techniques will continue for the complete length of the tunnelling in accordance with the design requirements.

## 1.3. Relationships with other documents / plans

This Subsidence Management Plan has been developed to be complementary and consistent with the following approval and modification documents;

- MOD2 to Snowy 2.0 Main Works (CSSI-9687), Modification Report, August 2023
- MOD2 to Snowy 2.0 Main Works (CSSI), Appendix A Tantangara Modification Geotechnical Report (S2-FGJV-GEO-GEN-REP-0001 Rev D) July 2023
- Snowy 2.0 Main Works - Modification 2 , Appendix B Water Assessment , August 2023
- MOD2 to Snowy 2.0 Main Works (CSSI-9687) , Submissions Report, October 2023
- S2-FGJV-ENV-DPE-LET-0032_A_HRT Subsidence Update September 2023
- S2 Main Works , Water Management Plan, Groundwater Management Plan (S2-FGJV-ENV-PLN-0012).

In addition to the above, this Plan is intended to function in conjunction with the following existing project documentation:

- Design Drawings, Reports and Specifications

- Project Geotechnical Instrumentation and Monitoring Plan
- Construction Method Statements
- Inspection and Test Plans.

## 1.4 Roles and Responsibilities

The team outlined in Table 1 below will work together to provide a consistent and cohesive approach to the implementation of this plan. These key personnel are responsible for the following:

- overall coordination of site operation procedures for TBM Florence;
- recording and verification of all monitoring instrument readings;
- collection, management and reporting of the monitoring results;
- review and action, as necessary, contingency plans and recommendations.

Area construction teams, survey team and the geotechnical team are responsible for installation of the monitoring instruments.

**Table 1 - Roles and responsibilities for the operation of TBM Florence**

<table>
<tr><th colspan="2">Role</th><th>Responsibility</th></tr>
<tr><td rowspan="3">Construction Team</td><td>Project Director</td><td><ul><li>Manage the delivery of the Snowy 2.0 Project including overseeing Instrumentation and Monitoring (I&M) planning and management.</li><li>Immediately notify SHL of the enactment of the Emergency Response Plan.</li><li>Formal communication with external authorities, where necessary.</li><li>Direct communication from the media to SHL except where FGJV has an obligation to meet legal requirements.</li></ul></td></tr>
<tr><td>TBM Construction Manager</td><td>Ensure that the design aspects of the I&M system are being correctly interpreted and implemented on site through the following;<ul><li>Provide review and input into the design for the I&M Plan</li><li>Provide review and input into Construction Method Statements</li><li>Allocate resources and personnel suitably qualified & experienced in underground construction, namely the Project Manager, Engineers and Supervision.</li><li>Conduct regular reviews of the instrumentation and monitoring data together with the TBM Senior Project Engineer and Senior Project Manager.</li><li>Attend Excavation Performance Review (EPR) meetings</li><li>Monitor the implementation of the Emergency Response Plan and provide high level decisions and instruction regarding the implementation of this Plan.</li></ul></td></tr>
<tr><td>TBM Senior Project Engineer & TBM Engineer</td><td><ul><li>On the ground implementation of this Plan as directed by the roles listed above</li><li>Review and interpret I&M data</li><li>Chair Permit to Tunnel (PTT) Meetings</li><li>Chair Excavation Performance Review (EPR) meetings</li><li>Confirm I&M complies with the design drawings, or in cases</li></ul></td></tr>
</table>

| | | |
|---|---|---|
| | | of departure from the design, that technical validation has been achieved and documented. |
| | **TBM General Superintendent** | ● Ensure TBM operation in accordance with all design and construction documentation, including this Plan.<br>● Immediately notify the roles above where trigger values are approached or exceeded. |
| | **TBM Superintendent** | ● Ensure TBM operation in accordance with all design and construction documentation, including this Plan.<br>● Immediately notify the roles above where trigger values are approached or exceeded. |
| | **TBM Pilot** | ● Ensure TBM operation in accordance with all design and construction documentation, including this Plan.<br>● Immediately notify the roles above where trigger values are approached or exceeded. |
| | **Geotechnical Engineer and Geologist** | ● Undertake geological inspections and/or mapping of the excavation face or spoil material and produce associated records<br>● Review and interpret I&M data<br>● Advise the convening of the Excavation Performance Review meeting, where necessary<br>● Chair the Geotechnical Monitoring Meetings (GMM)<br>● Advise the Permit to Tunnel (PTT) meetings<br>● Attend Excavation Performance Review (EPR) meetings |
| | **Survey Manager** | ● Manage all survey resourcing and data collection for I&M activities.<br>● Oversee implementation of this plan and the I&M process with regards to manual instrument installation.<br>● Ensure consistent application of I&M across all areas of responsibility.<br>● Review and interpret I&M data.<br>● Provide survey data for Geotechnical Monitoring and Permit to Tunnel meetings. |
| **Design Team** | **Design Site Representative** | ● Review and interpret I&M data<br>● Review any trigger level breach and provide design input for any required remediation.<br>● Design validation (confirming the works and geology are performing in accordance with the design intent and limits).<br>● Attend Geotechnical Monitoring, Permit to Tunnel and Excavation Performance Review (EPR) meetings<br>● Attend geological inspections and/or mapping of the excavation face or spoil material |
| **Assurance Team** | **Senior Project Manager** | ● Oversight of the implementation of the I&M planning and management. |
| | **Site Tunnel Engineer** | ● Oversight that all controls are in place and all relevant documentation and checklists are completed prior to commencement of excavation works.<br>● Oversight of compliance with Construction Method Statements, Inspection and Test Plans, IFC Design Drawings, I&M Plan and other relevant documentation<br>● Undertake geological inspections and review of excavation |

| | | |
|---|---|---|
| | | face mapping and associated records, as necessary to satisfy the Owner's assurance and oversight responsibilities |
| | **Underground Surveillance Officer** | ● Oversight of TBM operation and monitoring activities in accordance with I&M Plan and other design and construction documentation, including this Plan. |

# 2. Subsidence Instrumentation and Monitoring

## 2.1. Subsidence monitoring approach

The general approach to subsidence instrumentation and monitoring comprises the following steps:

1. Prediction of ground subsidence due to the proposed tunnelling activities, followed by the planning and installation of instrumentation and monitoring systems;
2. Monitoring, review and interpretation during construction;
3. Response to suit the observed performance.

These steps define the framework of this Plan and in general, reflect the process adopted for the design and construction of the Snowy 2.0 Tunnels as defined in the specific project documentation. This Plan draws on the detailed information from this supporting documentation where necessary.

Given the Snowy 2.0 tunnels are predominantly located deep beneath the ground surface, a focus on in-tunnel instrumentation and monitoring has typically been adopted. This reflects the low risk of surface subsidence, but also the timeliness and effectiveness of in-tunnel systems with respect to monitoring and responding.

However, for areas of the Headrace Tunnel and Headrace Adit that are less then 100m in depth below surface level, where there is a potential risk of subsidence, ground surface instrumentation and monitoring subsystems have also been adopted. These subsystems supplement and complement the existing in-tunnel systems.

The following sections describe the main parts of the subsidence monitoring approach, in line with the above.

## 2.2. Subsidence prediction and impact assessment

As a key component of this Plan, assessments have been undertaken to predict the structural performance of the tunnel support system, and the corresponding tunnel and ground surface deformations which may occur during construction. Using these predictions, potential impacts on surrounding areas and the environment have then been assessed. The assessments rely on inputs from the following:

- The project Geotechnical Investigation Program, which was undertaken to gain an understanding of the ground conditions within which the tunnels will be constructed
- The tunnel design process, which aims to enable:
    - Safe construction
    - Safe and functional operation
    - Management of project risks and minimisation of environmental impacts

- Planning for an approach to construction, involving methodologies, sequences of works and risk mitigation and control measures which are compatible with the project and design requirements (and vice versa).

Applying the above, subsidence predictions have been undertaken based on a Gaussian distribution using the method proposed by Mair et al (1996), which is a standard industry accepted approach. In this method, the excavation of a tunnel provides an opening into which the surrounding ground can deform. The movement of the ground into the opening can be related to the concept of 'loss of ground', where the convergence of the ground surrounding the tunnel after excavation is related to the 'volume loss' at the surface.

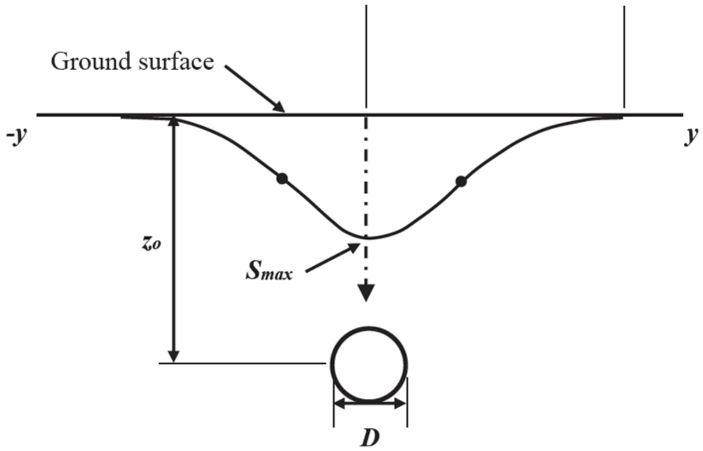


**Figure 1 - Cross Section of predicted subsidence during tunnelling.**

The volume loss parameter provides an assessment of the amount of tunnel convergence that may manifest as surface settlement. The volume loss parameter represents the change in excavated area due to convergence, compared with the original excavated volume of the tunnel, and is generally expressed as a percentage.

The volume loss is dependent on the geological conditions and the tunnel excavation methodology. Depending on the material that the tunnel passes through, the volume loss at the tunnel can be less than, equal to or greater than the volume of the settlement trough observed at the surface. Other factors controlling the magnitude of settlement include the size of the tunnel cross-section and the depth to the centreline of the tunnel.

The maximum settlement due to tunnelling is calculated using the following equation:

$$S_{\max} = \frac{0.31 V_L D^2}{K z_0}$$

Where:

*$S_{max}$ = maximum settlement at the tunnel centreline*

*$V_L$ = volume loss*

*D = equivalent diameter of a tunnel*

*K = trough width parameter*

$Z_o$ = *depth from ground surface to tunnel axis.*

Assessments have been conducted to identify the possible range of volume loss for the Headrace Adit and Headrace Tunnel. This was done by considering actual settlement data during tunnelling activities and back calculating the actual volume loss. Two sensitivity cases were used to evaluate the maximum potential settlement, the first assuming the material to be excavated is soil with no cohesion, the second assuming the material to be excavated is weak rock. These worked examples have been provided in Attachment 1.

Considering the geological model referenced in Section 1.3, the fault zone with mixed face conditions and the associated fault transition zone is expected to extend for 30 to 40 m in front of the current position of the TBM. Assuming this fault consists of a non-cohesive granular soil, a maximum settlement at surface of approximately 65 mm will be recorded in this area.

Once the TBM passes through the fault, the excavation will proceed into rock conditions. Assuming a conservative Volume Loss for weak rock, it is expected that a maximum of 2.5 mm settlement at surface may occur, with the TBM located at 30m depth. **Once the TBM is at 70 m depth, the expected settlement is predicted to be around 1 mm, which is negligible and falls outside the accuracy of survey systems.** As such it can be inferred that once the Headrace Tunnel has 70m or more of cover, negligible surface settlement is expected. This depth of cover will be reached in the near future, and from that point forward the tunnel cover does not reduce to less than 70m again.

## 2.3. Subsidence instrumentation and monitoring

To observe and control surface settlement (subsidence), it will be necessary to monitor the actual ground response to tunnelling. In this manner, the prediction assumptions (i.e. VL and K) will be confirmed or adjusted (this is also called "calibration of the model"). In parallel, the survey records will be used as part of a Trigger, Action and Response Plan (TARP), designed to manage and control the risk of impacts on the ground surface and surrounds.

As such, the monitoring of potential subsidence will be identified through two methods;

1) monitoring of tunnelling operations and equipment
2) monitoring of the surface using ground based and Unmanned Aerial Vehicles (UAV) or drone technology.

The "as built gaussian curve" recorded on site will be used to confirm/amend the assumption reported in chapter 2.2. The results will also be used to confirm/amend the required monitoring extension that, from the empirical analysis, is not predicted to be required once the tunnel will be at depth of 70m.

As highlighted, the approach to monitoring will focus on in-tunnel methods, with surface methods supplementing in certain areas. Both the surface and in-tunnel instrumentation and monitoring systems are described as follows.

### 2.3.1. In Tunnel Monitoring for Subsidence

As mentioned above, the volume loss is dependent on both the geological conditions and the tunnelling methodology. To control the volume loss due to excavation, monitoring inside the tunnel will also be required.

During tunnelling, the amount of sub-surface excavated material tends to lead to localised ground movement inward towards the tunnel. The first phase is volume loss due to stress relief ahead of the tunnel shield whereby the second phase occurs due to radial ground movement around the tunnel.

Along the fault area, the ground material is assumed to be granular and without cohesion for the calculation of the maximum settlement (Smax), with the TBM assumed to be operating in 'closed' or 'slurry' mode. In principle, closed face tunnelling involves continuous face support, in order to reduce ground deformation. As for latest geological information, the transition between the fault zone and competent rock is expected to be ~ 30-50 metres in front of the actual position of the TBM. We will be proceeding the excavation in 'closed mode' up to this point. Before switching the TBM in open mode, a geological check of the condition ahead of the TBM will be performed (by face inspection, geological mapping, probe holes etc).

In 'closed mode' the control of the radial movement around the TBM shield will be guaranteed by the slurry in the shield gap, and by the TBM backfill grout between the excavated profile and the installed support. Refer to Attachment 2 for detailed information around 'closed' or 'slurry mode' provided in MOD2 to Snowy 2.0 Main Works (CSSI), Appendix A Tantangara Modification Geotechnical Report (S2-FGJV-GEO-GEN-REP-0001 Rev D) July 2023

In stable ground, where the TBM will be operated in 'open mode' the ground deformation is expected to be minimal in the TBM advance time frame.

The structural monitoring of the installed support is also a key parameter with regard to ground movement, and therefore tunnel convergence (closure) and lining stresses will also be monitored. In-tunnel convergence monitoring will involve survey targets installed on the tunnel segments after installation, while lining stresses will be monitored using strain gauges cast into the tunnel segments.

Over-excavations will affect, in an unfavourable way, the Volume Loss and as a consequence the settlement at surface. The control of the extracted volume from the TBM is the key parameter to avoid over-excavation leading to surface subsidence.

The volume of material being produced during TBM operations is measured through equipment which has a material extracted weight system for the 'open mode' and with a density system for the 'closed mode' whereby during excavation the TBM is recording continuously the weight, or the density depending on the operation mode, of the extracted material. This value is monitored and controlled by the TBM operator with a guidance sheet showing the muck tonnage/density required for a given length of mining. Any breach in the muck tonnage by +/- 10% at every 400mm will activate the TARP.

Convergence monitoring will be undertaken daily during excavation until excavation is greater than 30m from targets, between 30 to 60 m reading twice weekly. Greater than 60m from targets will be monitored weekly until stabilization, then continuing monthly. If no excavation works are ongoing, monitoring will continue twice weekly.

Strain gauges readings are undertaken with an automated logging system every 6 hours until stabilization.

### 2.3.2. Surface Subsidence Monitoring within EIS boundary

Ground surface subsidence monitoring within the EIS boundary will be undertaken using a combination of both surface survey points and aerial imagery, captured by a UAV.

Settlement sections will be installed inside the EIS boundary to calibrate the predicted gaussian curve and to trigger any breach of threshold activating the TARP. Considering the actual TBM location in the fault zone, the maximum expected settlement at ground surface is approximately 65 mm. A conservative trigger of 30 mm will be used to activate the TARP (half of forecast settlement). A tentative settlement dome design and location is reported below. Fine tuning will be done on site reflecting existing conditions. The point will be recorded by traditional survey methods using a precise levelling or a 3D survey target fixed on the top of the dome.

Settlement frequency monitoring will be undertaken twice a day during excavation. Monitoring will commence 30 m ahead of the face, then be undertaken until the excavation face is greater than 30 m from points, subsequently between 30 to 60 m reading twice weekly. Greater than 60 m from targets, survey monitoring will be undertaken weekly until stabilization. If no excavation works are ongoing, monitoring will continue twice weekly.

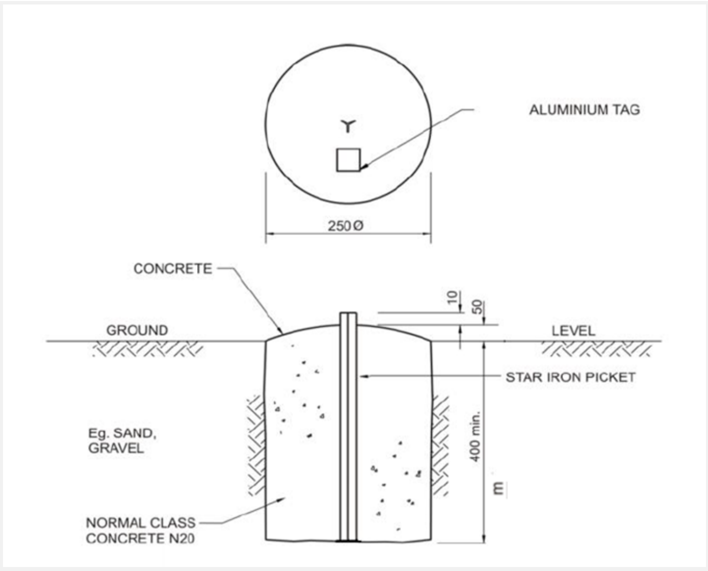


**Figure 2 - Equipment arrangement of survey markers to be used**

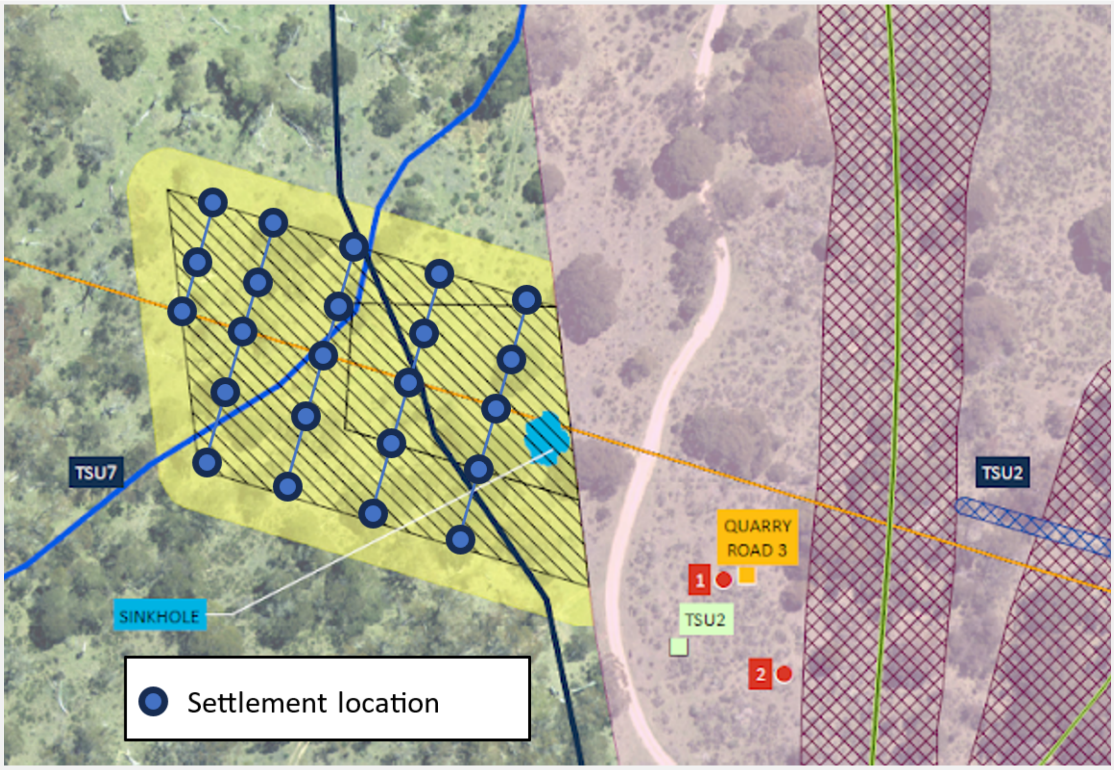


**Figure 3 - Location of survey markers inside the EIS boundary**

#### 2.3.3. Surface Subsidence Monitoring <u>outside</u> EIS boundary

The area outside of the EIS boundary will be monitored using aerial imagery, captured by a UAV. The flight path will be designed to capture images with a vertical accuracy of no more than 50mm.

The extent of the area to be flown will be a minimum of 350m from the current TBM location to a width of at least 100m (50m either side of the TBM alignment).

The imagery will be controlled using Ground Control Points (GCPs), placed within the MOD2 boundary and Global Positioning System.

The imagery will be processed to conform with the GCPs and reclassified (i.e. correcting for the presence of trees) to provide the best representation of ground surface. A Digital Elevation Model (DEM) will then be created. The initial DEM will form the baseline for subsequent DEMs to overlay, and thus determine any variations.

Due to the nature of the ground cover it can be expected that variations of least 200mm will occur due to environmental / weather conditions. Where alarm levels are triggered, consultation with DPE and NPWS will be required. Monitoring by drone will be utilised to detect an area of movement relative to the surrounding area, which is expected to be within the accuracy of the drone.

Where Action or Alarm level is reached from the in tunnel TARP criteria, DPE and NPWS will be notified and the requirement and need for physical access for land based survey outside the EIS boundary will be discussed and determined. This includes Muck Tonnage exceeding plus 10%.

Monitoring will be undertaken daily during excavation. Once the TBM has reached 100m depth of cover, monitoring will continue in the excavated sections less than 100m cover on a monthly frequency until stabilization of settlement.

Attachment 4 includes the Survey Monitoring Plan and Headrace Tunnel Long Section detailing the extent of monitoring.

# 3. Ground Subsidence Review

## 3.1. Trigger Action Response Plan

As highlighted, survey data will be used as part of a Trigger, Action and Response Plan (TARP), designed to manage and control the risk of impacts on the ground surface and surrounds. This TARP will operate within the framework of the existing Daily Geotechnical Monitoring and Permit to Tunnel meetings, during which data will be reviewed by the project team within 24 hours of collection. Data review will involve the following:

- Confirmation of baseline readings
- Comparison of actual results to predicted results and trigger levels
- Assessment of current monitoring frequencies and need for change based on results
- Relationship to construction process
- Review of action plans
- Completion of monitoring.

The following three trigger levels shall apply during tunneling:

- Alert Level - Set to the anticipated design case
- Action Level - Set to approximately 50% of acceptance criteria
- Alarm Level - Set to nominally 100% of acceptance criteria

In the event that monitoring results equal or exceed trigger levels, an Excavation Performance Review (EPR) meeting will be convened to review the situation and define the requirements for revised support arrangements that will prevent ongoing deformation.

Where necessary, contingency measures will be implemented as defined within the Design and Construction Method Statements, in relation to:

- Additional instrumentation and monitoring
- Additional structural ground support measures, and
- Changes to the excavation methodology.

A full list of relevant contingency measures for consideration are provided in the TARP for the respective trigger levels.

Please refer to Attachment 3 for the Trigger Action Response Plan (TARP) that will be implemented during the tunnelling re-commencement works.

## 3.2. Trigger levels

The full list of trigger levels are provided in Attachment 3. Key trigger levels are summarised as follows:

**Surface Settlement**

| Measured Parameter | Alert Level | Action Level | Alarm Level |
|---|---|---|---|
| Settlement at Surface | 20 mm | 30 mm | 40 mm |

**In-tunnel Convergence and Stress**

| Measured Parameter | Alert Level | Action Level | Alarm Level |
|---|---|---|---|
| Tunnel Convergence | 5 mm | 10 mm | 20 mm |
| Segmental Lining Strain Guages Stresses | 320 Mpa | 400 Mpa | 500 Mpa |

**Excavated Volume**

Guidance sheet showing the muck tonnage required for the given length of the mining. Any breach in the muck tonnage by +10% at every 400mm will activate the given TARP.

Details of trigger levels are covered in detail in the Trigger Action Response Plan (TARP), refer Attachment 3.

# 4. Ground Subsidence Reporting

Snowy Hydro will report on the following monitoring aspects related to the Headrace Tunnel operations within the scope of this Subsidence Management Plan described in Section 1.2:

1. During construction, groundwater monitoring data will be collected, tabulated and assessed against thresholds. Reporting will occur in accordance with Section 6.8 of the GMP
2. A subsidence monitoring report will be submitted to the NSW Department of Planning & Environment on a fortnightly basis, and
3. Notification will be provided to the NSW Department of Planning & Environment in the event that any Action (yellow) or Alarm (red) trigger levels are reached, along with a description of the actions being undertaken in response. Refer to Attachment 5 for an example notification form.

# ATTACHMENT 1

Case A – Material to be excavated supposed granular and non-cohesive:

VL=1.5%

K=0.3

Tunnel diameter D = 11.07m

Tunnel depth Z0 = Varies

| Smax (mm) | VL | D (m) | K | Z0 (m) |
|---|---|---|---|---|
| 63.3 | 0.015 | 11.07 | 0.3 | 30 |
| 47.5 | 0.015 | 11.07 | 0.3 | 40 |
| 38.0 | 0.015 | 11.07 | 0.3 | 50 |
| 31.7 | 0.015 | 11.07 | 0.3 | 60 |
| 27.1 | 0.015 | 11.07 | 0.3 | 70 |
| 23.7 | 0.015 | 11.07 | 0.3 | 80 |
| 21.1 | 0.015 | 11.07 | 0.3 | 90 |
| 19.0 | 0.015 | 11.07 | 0.3 | 100 |
| 15.8 | 0.015 | 11.07 | 0.3 | 120 |

Case B – Material to be excavated supposedly Weak rock.

VL=0.1%

K=0.5

Tunnel diameter D = 11.07m

Tunnel depth Z0 = Varies

| Smax (mm) | VL | D (m) | K | Z0 (m) |
|---|---|---|---|---|
| 2.5 | 0.001 | 11.07 | 0.5 | 30 |
| 1.9 | 0.001 | 11.07 | 0.5 | 40 |
| 1.5 | 0.001 | 11.07 | 0.5 | 50 |
| 1.3 | 0.001 | 11.07 | 0.5 | 60 |
| 1.1 | 0.001 | 11.07 | 0.5 | 70 |
| 0.9 | 0.001 | 11.07 | 0.5 | 80 |
| 0.8 | 0.001 | 11.07 | 0.5 | 90 |
| 0.8 | 0.001 | 11.07 | 0.5 | 100 |
| 0.6 | 0.001 | 11.07 | 0.5 | 120 |

# ATTACHMENT 2

Subset of information provided in MOD2 to Snowy 2.0 Main Works (CSSI), Appendix A Tantangara Modification Geotechnical Report (S2-FGJV-GEO-GEN-REP-0001 Rev D) July 2023

### 7.5 TBM CLOSED MODE

The TBM3 S-1221 (also known as TBM Florence) is a 'multi-Mode machine' which can be converted between 'open' and 'closed' mode, providing the possibility to continue the excavation through a pressurized chamber and utilizing a slurry circuit as the primary mucking system. The 'closed' mode configuration is useful for unstable face conditions in coarse grained material with soil like behavior. During 'closed mode', the face-support pressure is supplied in part by the slurry, which creates a hydrostatic pressure as a function of its density, and in part by applying air pressure on the slurry.

The slurry circuit includes a treatment and a separation plant where the fluid is separated from the excavated material and reintroduced in the pressurized excavation chamber. A summary is presented at Table 7-2.

Table 7-2 Summary framework of TBM open and closed mode

| ITEM | UNDERGROUND CHARACTERISTICS (MOST SUITABLE CONDITION) | MUCKING SYSTEM | LINING TYPE | COUNTERMEASURES FOR FACE INSTABILITY |
|---|---|---|---|---|
| OPEN MODE | Medium to hard rock mass<br>(Rock Behaviour) | The rock fragments are extracted by an open conveyor belt | The precast concrete lining is assembled inside, and installed behind the TBM shield | The rock mass consolidation can be provided by perforation through the cutterhead and the shield |
| CLOSED MODE<br>(SLURRY SYSTEM) | Medium strength rock mass to well graded coarse-grained soil<br>(Soil behaviour) | The soil or the mechanically crushed rock mass fragments are extracted via slurry circuit. | The precast concrete lining is assembled inside, and installed behind the TBM shield | A pressure is applied to the excavation face through the slurry fluid |

This section provides additional information about the TBM Florence and its slurry system.

TBM Florence will excavate Tantangara Adit and the Headrace Tunnel. Currently TBM Florence is operating in 'open mode'. This configuration can be subject to challenges when facing unconsolidated ground conditions. However, TBM Florence can be modified to slurry mode to change the excavation methodology, depending on the geological conditions.

Surface settlement will be controlled by the TBM operations balancing the pressure of the slurry against the soil pressure. The level pressure to be applied depends on the ground pressure and the hydrostatic pressure, if any. The face-support pressure is in part supplied by the slurry, which creates a hydrostatic pressure as a function of its density, and in part by applying air pressure on the slurry through the overlying "air cushion".

Working in slurry mode, the TBM machine is able to support the excavation face (ie soil condition) by a pressurized, bentonite slurry pumped into the excavation chamber. The slurry is substantially composed of a bentonite suspension in water, with a minor component of additives if necessary. Bentonite is a natural, non-hazardous clay product. The use of bentonite and any additives would be assessed and used in accordance with the Project approved environmental management plans.

The excavation chamber, called the "plenum", is a space between the excavation face and a steel bulkhead (separating the plenum from the remaining part of the TBM), where the excavated material is collected and mixed with the slurry. A pumping system performs the functions of feeding the fresh slurry to, and removing the muck from, the plenum through a pipeline. In the case of the TBM Florence, a supplementary bulkhead, installed further behind the primary bulkhead, creates a room or an auxiliary chamber, which is divided into two functional compartments.

The compressed air in the air cushion can push the slurry to the plenum in front, maintaining it under pressure. The air cushion pressure can be managed through an automatic regulation system. Consequently, it is possible to control the slurry pressure. The air bubble also acts as a compensative "shock absorber" to the unavoidable pressure fluctuations in the plenum.

The balance between inflow and outflow involved in this cycle allows the slurry to be maintained under pressure in the plenum. By the variation of the inflow and/or outflow of the slurry, it is possible to control the face-support pressure value which combats ground loss and the risk of sink hole formation. The TBM is equipped with pressure sensors. The pressure measurements are displayed to the operator on the screen in the cabin on-board the TBM to allow the operator to manage the face confinement pressure, specifically for stability control.

## Attachment 3 - TARP Monitoring triggers for TBM Excavation

## TARP Monitoring Triggers for TBM Excavation

Table 01

| Trigger Level | Condition | Action Plan |
|---|---|---|
| **Alert Level** | Movement is occurring, but system behaviour still within the range of target behaviour according to specifications of the design | • Performance of the ground support system to be more closely assessed<br>• Team undertaking monitoring, such as Survey Manager, or Geotechnical Engineer to immediately review the readings/assessments to ascertain the readings are reliable and not related to errors or other anomalies<br>• If the event is not caused by erroneous readings, the TBM Senior Project Engineer to be notified and is required to convene the Excavation Performance Review (EPR) meeting within 48 hours. Construction Team and Design Team to be notified by TBM Senior Project Engineer on becoming aware of the measurements<br>• Review the event and determine the cause and potential effects of the deformation<br>• Continue work as per normal operation |
| **Action Level** | System deviated from expected behaviour, and movement reaching design value | • Cease mining/excavation<br>• Monitoring team to immediately review the readings to ascertain the readings are reliable and not related to errors or other anomalies<br>• Team undertaking monitoring, such as Survey Manager, or Geotechnical Engineer to immediately review the readings/assessments to ascertain the readings are reliable and not related to errors or other anomalies<br>• If the event is not caused by erroneous readings, the TBM Senior Project Engineer to be notified and is required to convene the Excavation Performance Review (EPR) meeting within 24 hours. Construction Team and Design Team to be notified by TBM Senior Project Engineer on becoming aware of the measurements.<br>• Monitoring frequency will be increased<br>• The deformation will be reviewed by the designer to confirm that the tunnel is performing as anticipated<br>• Carry out structural survey for the tunnel to confirm structural stability<br>• Review available data and construction/excavation methodology, including;<br>    ○ Geotechnical, instrumentation and monitoring data<br>    ○ TBM operating parameters<br>    ○ Backfill (annulus) grout volume, injection pressure and gelling time targets<br>    ○ Slurry face pressure<br>    ○ Properties of the bentonite suspension<br>**Additional Contingency Measures:**<br>• Review ground support performance and install additional support or undertake additional measures where necessary, such as;<br>    ○ Installation of Support Class SC2-SG (strain gauge)<br>    ○ Additional proof drilling and secondary backfill (annulus) grouting<br>    ○ Installation of pre-support, including canopy tubes or spiling bars<br>    ○ Pre excavation grouting and/or face consolidation |

<table>
<tr><td></td><td></td><td><ul><li><ul><li>Installation of additional monitoring instrumentation</li><li>Post excavation grouting</li><li>Installation of steel ribs within installed segment lining</li><li>Application of limitations on TBM round length</li></ul></li><li>Determine necessary actions to be investigated, such as confirming necessary equipment and ground support elements are available for immediate installation if necessary and if surface monitoring is required.</li></ul></td></tr>
<tr><td>Alarm Level</td><td>Movement reaches acceptable tolerance level for the ground surface</td><td><ul><li>Immediately cease all construction work. No further excavation shall be allowed until deformation is controlled</li><li>The TBM Senior Project Engineer to be notified and is required to convene the Excavation Performance Review (EPR) meeting as soon as reasonably practicable, but within 24 hours. Construction Team and Design Team to be notified by TBM Senior Project Engineer immediately on becoming aware of the measurements.</li><li>Consider the enactment of the Emergency Response Plan</li><li>Review available data and construction/excavation methodology, including;<ul><li>Geotechnical, instrumentation and monitoring data</li><li>TBM operating parameters</li><li>Backfill (annulus) grout volume, injection pressure and gelling time targets</li><li>Slurry face pressure</li><li>Properties of the bentonite suspension</li></ul></li></ul>Additional Contingency Measures:<ul><li>Review ground support performance and install additional support or undertake additional measures where necessary, such as;<ul><li>Installation of Support Class SC2-SG (strain gauge)</li><li>Additional proof drilling and secondary backfill (annulus) grouting</li><li>Installation of pre-support, including canopy tubes or spiling bars</li><li>Pre excavation grouting and/or face consolidation</li><li>Installation of additional monitoring instrumentation</li><li>Post excavation grouting</li><li>Installation of steel ribs within installed segment lining</li><li>Application of limitations on TBM round length</li></ul></li><li>Carry out structural survey for the tunnel to confirm structural stability</li><li>Carry out remedial works where necessary<ul><li>Implementation of Exclusion Zones</li><li>Installation of steel rib support within installed segment lining</li><li>Backfilling of any voids or over excavations</li><li>Implement a recovery path, where TBM has deviated from the design alignment</li></ul></li><li>Monitoring frequency, extent of monitoring, Trigger Levels and if surface monitoring is required to be reviewed by the design and construction teams.</li><li>Work may only proceed if remedial measures and any other required actions are implemented</li></ul></td></tr>
</table>

Table 02

| **Surface Monitoring During Excavation** | **Alert Level** | **Action Level** | **Alarm Level** |
|---|---|---|---|
| Settlement at surface, measured by survey of targets | 20mm | 30mm | 40mm |
| Settlement at surface, measured by LiDAR drone | 20mm average over 2m2 | 30mm average over 2m2 | 40mm average over 2m2 |
| Settlement at surface, visual observation from drone | - | - | Any visual settlement |
| **Geotechnical Monitoring of the Excavated Tunnel and Segmental Lining** | **Alert Level** | **Action Level** | **Alarm Level** |
| Tunnel Convergence measurements taken from Displacement Monitoring Points | 5mm | 10mm | 20mm |
| Segmental Lining Strain Gauge Stresses | 320 Mpa | 400 Mpa | 500 Mpa |
| **TBM Navigation** | **Alert Level** | **Action Level** | **Alarm Level** |
| TBM Vertical Deviation | - | 25mm | 50mm |
| TBM Horizontal Deviation | - | 25mm | 50mm |
| TBM Pitch | -10% | -13.5% | -15% |

| **TBM Operating Parameters**<br>**(Continuously adjusted to suit the conditions through Job Order)** | **Maximum Allowable Limit** |
|---|---|
| **Thrust Force** | 90,000 kN |
| **Contact Force** (Should there be a significant drop in contact force, excavation to be stopped immediately) | 25,000 kN |
| **Maximum Torque** | 12.5 MNm |
| **Cutterhead rpm** | 0.8 rpm |
| **Maximum Advance Speed** | 30 mm/minute |
| **Cutterhead maintained against the excavated face** | All times |
| **Backfill Grout Volume**<br>(Backfill Grout Pressure to be up to 2bar. If the amount of the grout exceeds 25% of the required volume during the advance, Inform TBM Supervisor and Engineer. Further assessment must be conducted) | Volume: 13.5 - 16 m3<br>Pressure: 1.5 - 2 bar |
| **Parameters that are Only Relevant to TBM Closed Mode Operation** | **Maximum Allowable Limit** |
| **Continuous Loss of Slurry or Groundwater Inflow** | Stable Level of Slurry in the Working Chamber Must be Maintained |
| **Required Minimum level of Slurry in the working Chamber** | 2.8 m Below the Centre Line |
| **Slurry Face Pressure**<br>(Face pressure will be adjusted to suit the conditions encountered) | 1.5 ± 0.5 bar |

| | |
|---|---|
| **Primary KPIs of the Bentonite Suspension**<br>(Fluid loss, Filter cake, Yield point and Density) | Parameters Must be Maintained Within the Limits, associated with a 10% variation in theoretical excavated volume, as per the relevant Mix Design |
| **Ground Water Ingress** | **Trigger Value Action** |
| **Probe Hole Triggers and Groundwater Inflow Performance Criteria**<br>(Headrace Tunnel Ch.375 to 2200 m falls under Inflow Performance Class 1) | **Class 1:**<br>Inflow < 2.0 l/s from Probe Holes<br>or<br>Inflow of 6 l/s/km |
| **Excavated Volume (based on TBM belt scale measurements when excavated in Open Mode)** | |
| During excavation, TBM operators will be provided with the guidance sheet showing the muck tonnage required for the given length of the mining. Any breach in the muck tonnage by +/- 10% at every 400mm will activate the given TARP.<br>**Note: Tonnage (Table 03) will be adjusted based on the density of the material encountered.** | |

Table 03

| Advance Length | Excavated Weight (t)<br>Calculated for Density of 2.8 t/m3 |
|---|---|
| 0-200 | 54 |
| 200-400 | 108 |
| 400-600 | 162 |
| 600-800 | 215 |
| 800-1000 | 270 |
| 1000-1200 | 323 |
| 1200-1400 | 377 |
| 1400-1600 | 430 |
| 1600-1800 | 485 |
| **1800-2000** | **540** |

**Below flow Chart is to be Followed if Excavation Tonnage Breaches the Parameters**

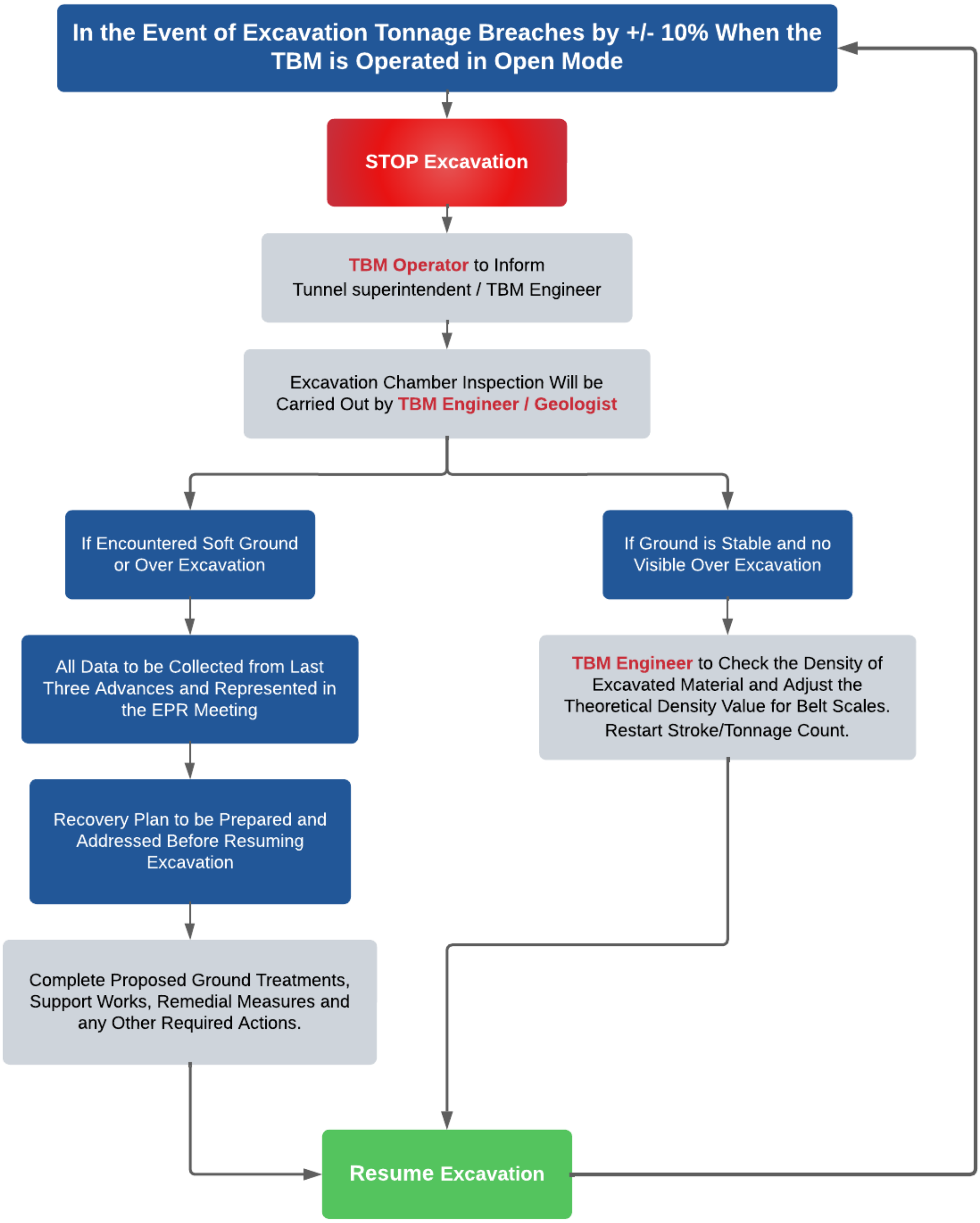


**Figure 01**

**Below Flow Chart is to be Followed in an Event of Continuous Loss of Slurry or Groundwater Inflow**

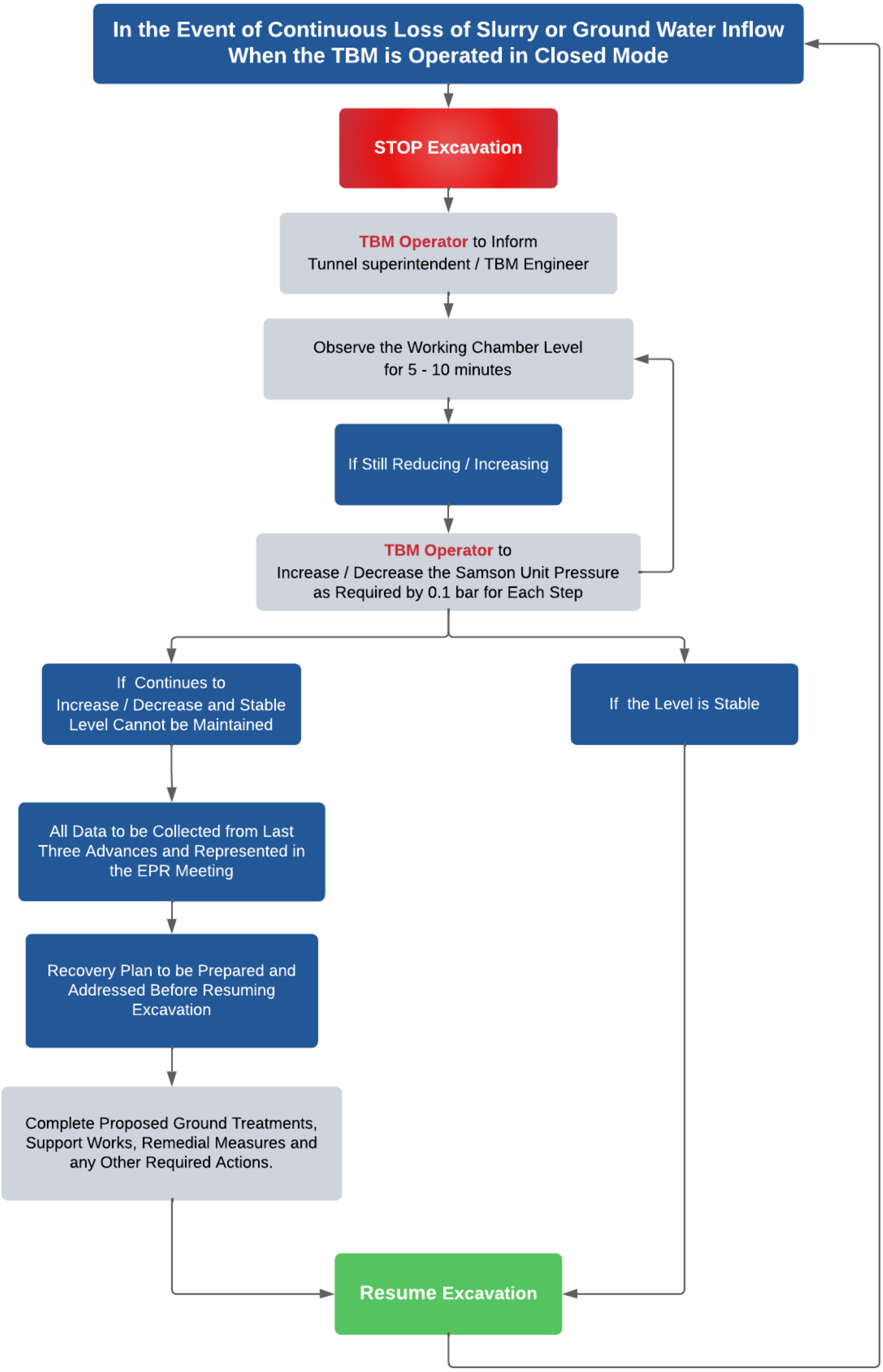


Figure 02

**Below Flow Chart is to be Followed if Settlement Alert (or greater) Triggered or Any Visual Observation of Ground Movement**

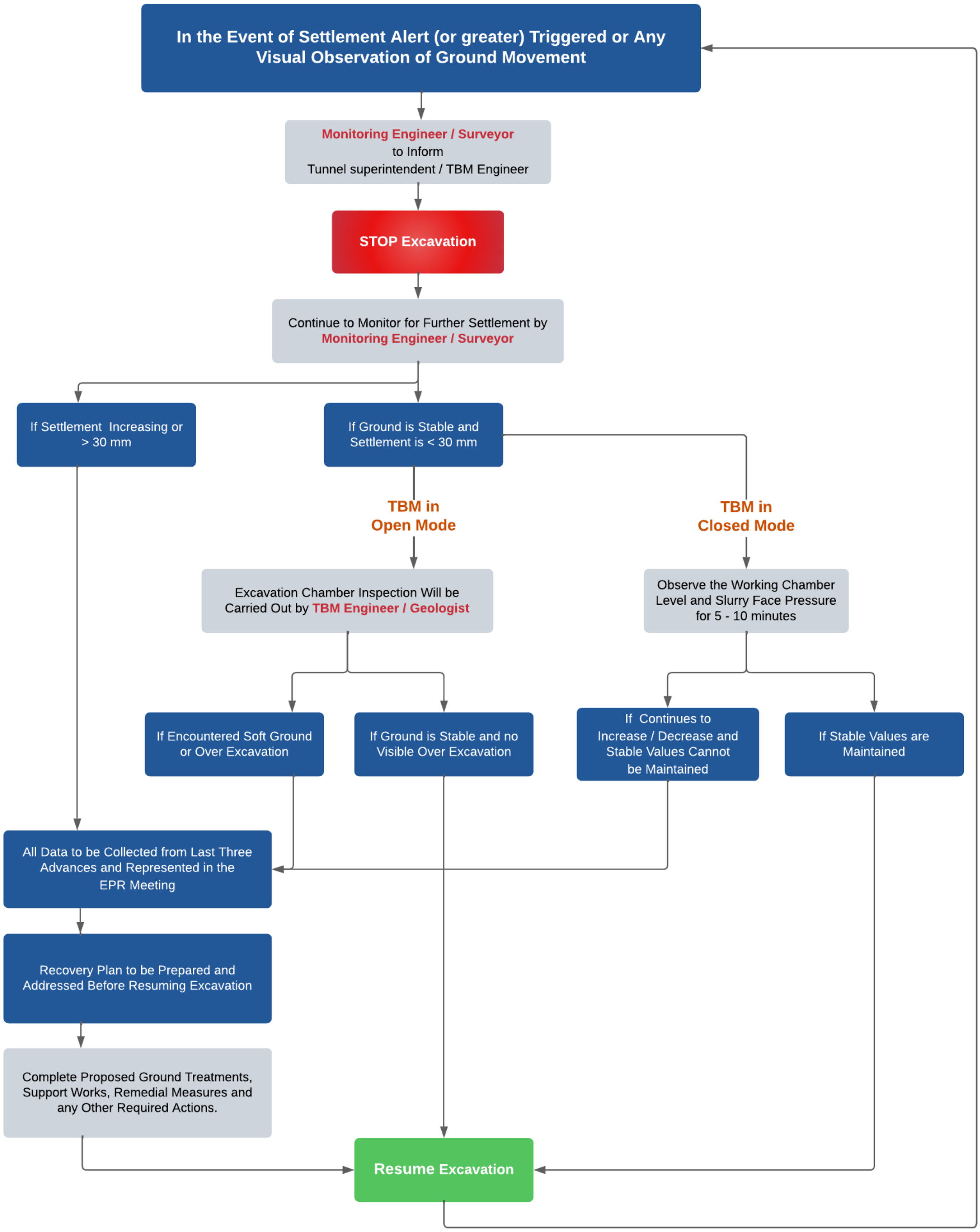


Figure 03

# Attachment 4

## Survey Monitoring Plan

## Headrace Tunnel Longsection



| Rev | Description | Initials | Date |
|---|---|---|---|
| 0 | Initial Issue | HM | 14/06/2023 |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

Thursday, November 09, 2023

**ISSUED FOR INFORMATION**

**SURVEY SKETCH**



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DRAWING TO BE READ IN CONJUNCTION WITH GENERAL NOTES

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## TANTANGARA - HRT02
## PROPOSED MONITORING & DRONE FLIGHT AREA
## SURVEY SKETCH

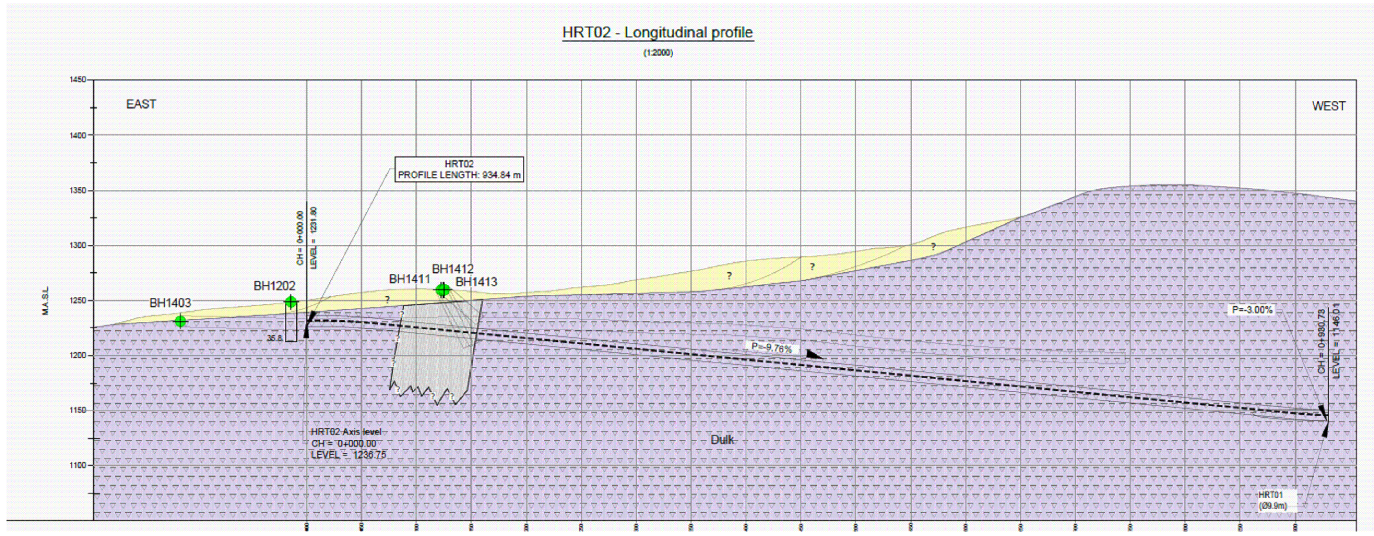
| | | | |
|---|---|---|---|
| **Surveyor:** H. McBRIDE | | | |
| **Approved:** H. McBRIDE | | **Sheet No:** | 1 of 1 |
| **Datum** | **Horiz:** SSGH | **Vert:** | AHD |
| **Survey Request No:** | | REV : | 0 |

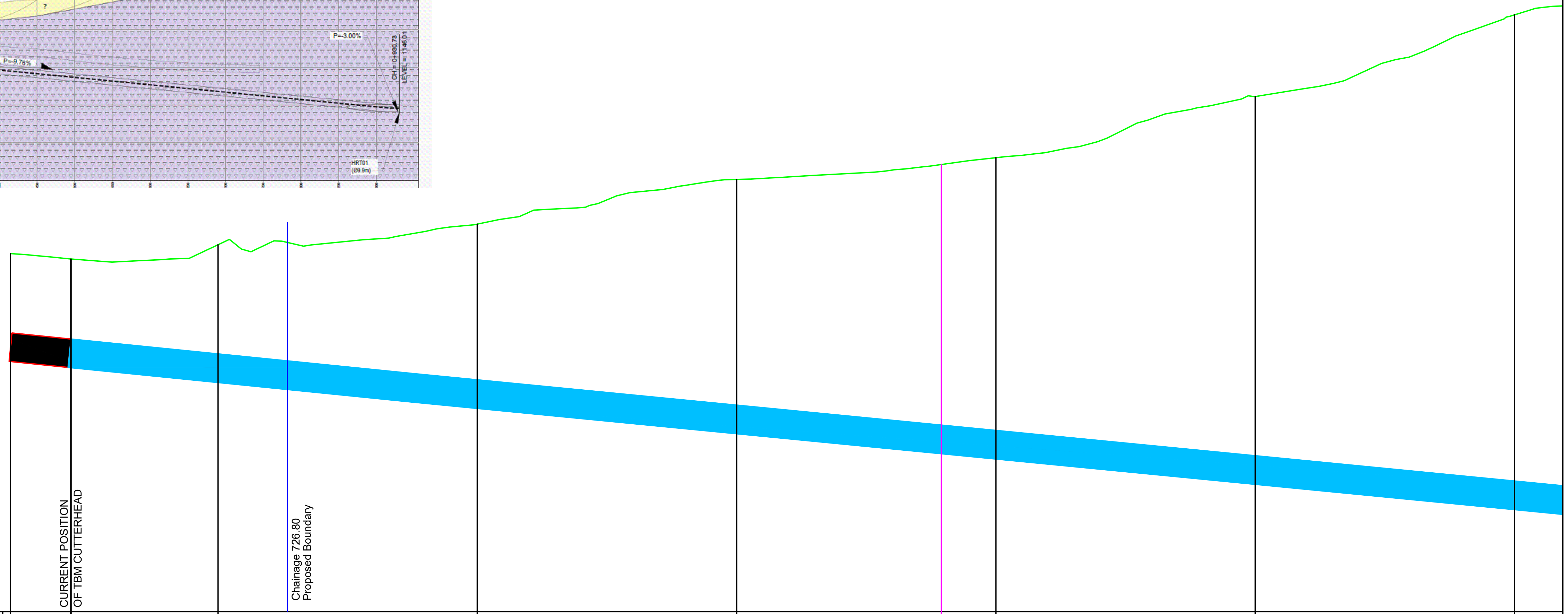
A3 STANDARD DRAWING 15/12/2022

**File Name:** D:\Survey\Data\data\FGJV-SYN-1\HRT Headrace Tunnel Tantangara_40\04 Digital Files Reports Out\HRT AB 0011 TBM Cutter Head Position 230614\HRT AB 0011 TBM Cutter Head Position 231107.dwg

1:1000 @ A3

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150




Datum 1126

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HRT01 - HRT02 Merged ver 2 | 1227.988 | 1227.988 | 1219.857 | 1209.898 | 1200.142 | 1197.96 | 1190.385 | 1180.629 | 1170.873 |
| tin HRT02 Surface Points TTSSG | 1264.095 | 1264.095 | 1267.499 | 1275.459 | 1292.690 | 1298.44 | 1301.074 | 1324.639 | 1356.149 |
| Depth | 36.107 | 36.107 | 47.642 | 65.561 | 92.548 | TOP OF CUTTERHEAD 100.00 | 110.688 | 144.010 | 185.276 |
| Chainages | 620.000 | 643.34 | 700.000 | 800.000 | 900.000 | 978.96 | 1000.000 | 1100.000 | 1200.000 |

| Rev | Description | Initials | Date |
|---|---|---|---|
| 0 | Initial Issue | HM | 07/11/23 |

**ISSUED FOR INFORMATION**

**SURVEY SKETCH**



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DRAWING TO BE READ IN CONJUNCTION WITH GENERAL NOTES

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**HT02D - HEADRACE TUNNEL LONGSECTION**

Surveyor: FGJV
Approved: H. McBRIDE Sheet No: 1 of 1
Datum Horiz: TTSSG Vert: AHD
Survey Request No: - REV : 0

Tuesday, November 07, 2023

A3 STANDARD DRAWING 15/12/2022

File Name: D:\Survey\Data\data\FGJV-SYN-1\HRT Headrace Tunnel Tantangara_40\04 Digital Files Reports Out\HRT CV 0002 Tunnel Longsection\HRT CV 0002 Tunnel Longsection.dwg

## Attachment 5 - Instrumentation & Monitoring Notification of Alert Form

| Document No: | Snowy 2.0<br>Instrumentation and<br>Monitoring Notification of Alert | snowy 2.0 |
|---|---|---|
| Issue: 01 | | |
| Date & Time: | | |

Trigger Level Exceedance - Action and Alarm

| The purpose of this form is to provide notification of trigger | |
|---|---|
| Drive: | Headrace Adit / Headrace Tunnel |
| Instrumentation Type: | |
| Instrument ID: | |
| Chainage: | |
| Current Value: | Trigger Value: |

Details of alert:

| Area of Work Affected: |
|---|
| Monitoring Details: |
| General Information: |

| Proposed Action: |
|---|

| Prepared: FGJV TBM Construction Manager | Reviewed: SHL Senior Project Manager |
|---|---|
| Signature: | Signature: |
| Name: | Name: |