Appendix 8

TSF Liner and Seepage Monitoring

prepared by

ATC Williams Pty Ltd

(Total No. of pages including blank pages = 24)

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ORGANISATION:	EPA / NRAR	DATE:	21 March 2019
COPY:	Bowdens Silver	REFERENCE:	429

NO. OF PAGES (including attachments): 21

SUBJECT: Bowdens Silver Project TSF Liner and Seepage Monitoring

☐ ***Confidential*** ☐ ***Please Reply*** ■ ***For Follow-up*** ☐ ***Urgent*** ☐ ***For your information***

MESSAGE:

Greetings Darryl and Tim

Further to our discussions regarding the above, I have attached for your information, a copy of a letter report prepared by ATC Williams, the consultant engaged by Bowdens Silver Pty Ltd to prepare the design of the Tailings Storage Facility (TSF) for the Bowdens Silver Project.

We have requested that this letter report is prepared to document the manner in which the TSF liner has been designed and would be constructed to satisfy the 'Tailings Dam Liner Policy' issued by the EPA.

We would greatly appreciate if you and other officers within your Agencies could review this letter report and confirm that the manner in which the TSF would be constructed and the subsequent seepage monitoring will satisfy the 'Tailings Dam Liner Policy" and meet any other requirements relevant to the facility.

As discussed, we look forward to hosting a site inspection with you both on 8 April 2019 to enable you to gain an appreciation of the location of the TSF and all other Mine related components.

Should you have any questions about the attached letter report prior to the site inspection, please don't hesitate to contact me.

Regards

Rob Corkery
Principal/Managing Director

Attached: Letter Report re Bowdens Silver Project TSF Liner and Seepage Monitoring

Our Ref: 116217.07L001 Rev 0.docx

18 March 2019

Bowdens Silver Pty Limited
68 Maloneys Road,
Lue,
NSW 2850

ATTENTION: Anthony McClure, Neville Bergin and Rob Corkery

Dear Tony,

RE: BOWDENS SILVER PROJECT TSF LINER AND SEEPAGE MONITORING

1 INTRODUCTION

This letter is in response to the EPA Central West Region letter of 20 December 2018 to the client's representative, Mr Rob Corkery of R. W. Corkery & Co, requesting compliance with the "Tailings Dam Liner Policy". This policy was provided as a letter by Mr David Fowler, Director of Regulatory Reform, and Advice and addressed to Mr David Kitto, titled "Tailings Dam Liner Policy". Our letter provides the relevant information and analysis to show compliance for the Bowdens Silver Project with this policy.

A summary of the relevant fieldwork and laboratory test results currently contained in ATC Williams (ATCW) reports [**Ref. 1** and **Ref. 2**], together with additional field and laboratory work by other consultants [**Ref. 3** and **Ref. 4**] and the additional analysis is provided in this letter.

2 METHODOLOGY OF ASSESSMENT

The existing design for the tailings storage facility (TSF) at the Bowdens Silver Project is set out in the ATCW Feasibility Design report **[Ref. 5]**. The results of seepage analyses, and monitoring provisions for the Bowdens TSF have been re-presented here-in for completeness, and comparison with further results.

In order to assess compliance with the EPA policy, we have estimated 1D seepage through the proposed base liner configuration of the TSF and compared this with results derived for the stated EPA policy benchmark, i.e. with regards to protection from seepage via a prescribed clay liner of a minimum 1 m thickness and with a maximum permeability of 1×10^{-9} m/sec at the base of the storage.

3 SEEPAGE CONTROL AND MONITORING

3.1 General

The current Feasibility level design **[Ref 5]** provides for tailings to be retained by a cross-valley rock-fill embankment. The embankment will be constructed in a number of discrete stages. A low permeability composite geomembrane liner will be constructed on the upstream face as the principal water retaining element. Tailings will be discharged into the storage in a down valley direction, from three separate locations at the head of the storage. The decant and stormwater collection pond will form against the embankment, over the deposited tailings, where it will be recycled to the plant.

The philosophy for TSF seepage control as outlined in our Feasibility Study Report is to line the upstream slope of the TSF embankment with a bituminous liner and the operating pond floor with 0.45 m to 0.5 m of compacted clay recovered from within the operating pond floor itself. Furthermore, a grout curtain is proposed for the full length of the embankment foundation, tying into the bituminous liner. The aim of the grout curtain is to reduce the permeability of any higher permeable areas in the rock foundation. Some higher permeability rock was encountered during the preliminary geotechnical investigation, although much had a very low permeability **[Ref 1].**

A depth of 40 m of grouting has been proposed to control seepage through the more permeable zones in the bedrock. Further geotechnical investigation drilling will be required during the detailed design phase of the TSF to confirm the extent of the more permeable rock, to refine the design of the grout curtain. Such investigations are routine to ensure the grout curtain design would be effective.

Standard grouting methodology also requires the foundations to be continually evaluated by further specified testing during construction, with the extent of grouting adjusted according to the test outcomes.

Any seepage through the TSF embankment and foundation is expected to report primarily to the low points in the natural surface beneath the footprint of the embankment, then flow through the seepage collection drains and report to seepage collection ponds as shown in **Figure 1**.

3.2 Initial Seepage Modelling, Analysis, and Results

Seepage modelling and analysis has been carried out using the finite element computer software package SEEP/W to assess the quantity of seepage under the embankment and is reported in ATCW Feasibility Study Report [**Ref. 5**]. Results are reproduced here for completeness.

It is expected that the greatest long-term seepage will occur when the elevation of the decant pond is at its maximum, i.e., when the embankment is almost full of tailings (close to capacity) and decant is at the maximum operational pond level. For this assessment, this equates to a decant pond elevation of 615.3 m AHD. It is noted that this is a conservative scenario because following closure, deposition will cease, the pond area will diminish, and the rate of seepage will reduce.

The permeability values adopted for the seepage analysis are summarised in **Table 1**. The permeability adopted for the subsoil and rock foundations is based on in-situ permeability testing **[Ref 1]**. For the foundation clays, the permeability was based on a conservative assessment of remoulded sample test results. The permeability of the rockfill and sand filters are based on generally accepted permeabilities (and are not critical to the result). The permeability of the bituminous liner on the embankment has been based on the manufacturers' recommended value of 1×10^{-13} m/sec.

For the feasibility analysis, two different tailings samples were tested for basic parameters. For the purpose of seepage modelling, the permeability of the tailings (see **Table 1**) was based on a correlation of one selected tailings sample (the Bowdens CT sample) with the permeability of tailings from other operating mines, based on particle size distribution. It is envisaged that further testing will be carried out during detailed design, to confirm these results.

TABLE 1
PERMEABILITY COEFFICIENTS

Material Type (Zone)	Permeability (m/s)
Clay placed/compacted beneath Decant Pond (0.3 m thick)	1×10^{-9}
Sub-soil (adopt 0.15 m thick) Embankment Clay (Zone 1)*	1×10^{-8} 1×10^{-8}
Sand Filters (Zone 2A/2B)*	1×10^{-4}
Rockfill (Zone 3A/3B)*	1×10^{-5}
Tailings	2×10^{-8}
Rock Foundations (0 - 50m)	2×10^{-6}
Rock Foundations (50m – 100m)	4×10^{-7}
Bituminous Geomembrane	1×10^{-13}
Grout Curtain	5×10^{-7}

*Please note that the model results show that these zones experience very low flows because of the effect of the bituminous liner on the embankment but have been included for completeness.

The graphical output from SEEP/W is shown in **Figure 2**. This 2D analysis indicated a flux of 3.5×10^{-6} m^3/sec per m of embankment. Extending this for a 900 m long embankment gives an estimated seepage flow rate, across the Stage 3 embankment, of 3.2×10^{-3} m^3/sec or 3.2 L/sec.

Further, for comparison with later calculations, if the pond is taken to extend 400 m upstream from the embankment, this flow is equivalent to a unit vertical infiltration flux of 8.8×10^{-9} m^3/sec per m^2.

It is expected that most of the seepage beneath the TSF embankment would report to the seepage collection system underneath the embankment rockfill and be collected in lined ponds. This water would be pumped back to the TSF.

As this analysis was based upon preliminary testing, the following additional permeability assessments are proposed to be carried out to inform detailed design:

- Detailed tailings testing on a range of typical tailings.
- Detailed geotechnical site investigation to establish:
    - the depth of grouting required; and
    - impoundment clay borrow and seepage conditions.

As previously outlined, this assessment is a routine investigation and design procedure and will ensure the design of the TSF satisfies the EPA's policy.

3.3 Seepage Monitoring and Seepage Interception

It is proposed to monitor seepage under the embankment and through the grout curtain by measuring groundwater levels downstream of the embankment using standpipe piezometers, and vibrating wire piezometers as set out in **Figure 3 [Ref. 5]**. Appropriate reading intervals will be set, with a typical frequency being weekly.

Further monitoring bores are also to be installed beyond the TSF seepage collection ponds. This information would be used to assess both the safety of the TSF embankment and the potential for seepage beyond the seepage collection drains and ponds.

If contaminated seepage is observed in the monitoring piezometers, an additional seepage collection system would be designed and installed. Collected water would be pumped back to the TSF system. The most remote monitoring piezometers will be used as a final check on the effectiveness of this system.

4 CLAY AVAILABILITY

Based on the preliminary geotechnical investigation a high-level estimate of the clay available in the impoundment has been made.

Figure 4 shows the depth of soil in the TSF area (excluding the expected 0.25 m of topsoil which will be stripped) most of which is clay. Excess clay suitable for borrow and lining has been identified in a smaller area within the impoundment, comprising about 30 ha. The excess volume of clay in this borrow area has been estimated at 0.8 Mm^3, which is adequate to provide for the clay required in the modified lining arrangement, as discussed below.

5 EPA BENCHMARK LINER

5.1 General

It is understood from the EPA letter titled "Tailings Dam Liner Policy", that the benchmark position for the EPA with regards to protection from seepage is a prescribed clay liner of minimum 1 m thickness and with a maximum permeability of 1×10^{-9} m/sec, at the base of storage.

5.2 Liner Seepage

Based on this EPA benchmark, the seepage rate through the prescribed 1 m clay liner with a permeability of 1×10^{-9} m/sec was calculated. A one-dimensional steady-state analysis was undertaken with varying depths of water standing over the prescribed liner, and the seepage flux per square metre of the liner was calculated. It has been assumed that the material below the liner is relatively free draining and has zero head.

The calculated unit seepage rates for various heads of water are shown in **Table 2**.

TABLE 2
EXPECTED SEEPAGE RATES ($m^3/sec/m^2$)

Thickness of Clay (m)	Head of Water (m)		
	3	6	20
1.0	4.0×10^{-9}	7.0×10^{-9}	2.1×10^{-8}

The resulting seepage rate for a 20 m head of water has been considered as the maximum allowable seepage rate for any proposed alternative liner arrangement.

5.3 Seepage through the tailings and proposed liner

5.3.1 General

Seepage through the proposed liner (including a minor contribution from the placed tailings) has been calculated to enable a comparison with the EPA maximum limit of 2.1×10^{-8} $m^3/sec/m^2$ **(Table 2).**

The first stage of filling of the TSF is expected to take around 3 years, resulting with a maximum depth of tailings of about 20 m at the embankment. Taking a conservative approach, steady state seepage has been assumed after this time.

5.3.2 Tailings and Clay Liner Properties

For the purpose of this additional analysis, the parameters for both the proposed liner and the tailings have been considered in more detail.

The particle size distributions for the laboratory simulated tailings have been compared to our database of tailings from other sites. **Figure 5** shows the particle size distribution of a number of the Bowdens samples provided **[Ref 3]** and the original CT sample tested by ATCW **[Ref. 2],** as well as the distribution for two comparative tailings (one copper and one gold). The two database tailings samples provide reasonable upper and lower bounds to the Bowdens results. The Atterberg Limits for the samples show that the copper tailings are classified as CL-ML (low plasticity Clay/Silt) whilst the gold tailings and the Bowdens CT tailings are classified as a low plasticity Clay (CL). (Plasticity results on the other Bowdens samples are not available).

Both the gold and copper tailings have similar permeabilities, but the values for the coarser copper tailings, being on the more conservative side, have been adopted for the analysis. The void ratio v. permeability relationship of the copper tailings as presented in **Figure 6** was used to determine the permeabilities for input into the seepage analysis.

The permeability adopted for the proposed clay liner was based on the results of permeability tests on compacted clay samples. These samples were taken from test pits excavated in the proposed TSF impoundment area [**Ref. 1**]. The results are reproduced in the laboratory sheet appended to this letter.

The hydraulic properties adopted for the seepage assessment are summarised in **Table 3.**

TABLE 3
HYDRAULIC PARAMETERS

Material	Average Saturated Hydraulic Conductivity, k (m/sec)	Source
Foundation Clay - Compacted	5×10^{-10}	Based on in-situ and laboratory testing as Appended
Tailings 0-3 m	1×10^{-7}	Consolidation test results for similar tailings (see **Figure 6)**
Tailings 3 -17 m	5×10^{-8}	
Tailings 17 – 20 m	3×10^{-8}	

5.3.3 Liner Seepage Analysis and Results

For the seepage analysis, it has been assumed, conservatively, that the water level in the tailings is at the top of the tailings. It has also been assumed, conservatively, that there is no water pressure under the liner, i.e. the pressure head on the underside of the liner is zero.

The estimated unit seepage for a range of thicknesses of foundation clay and depth of tailings are summarised below in **Table 4**.

TABLE 4
EXPECTED LINER SEEPAGE RATES (m^3/sec/m^2)

Thickness of Clay (m)	Depth of Tailings (m)		
	3	6	20
0.45	3.71×10^{-9}	6.52×10^{-9}	1.56×10^{-8}
0.70	2.59×10^{-9}	4.50×10^{-9}	1.14×10^{-8}

Figure 7 presents the estimated seepage rates for the TSF and shows a comparison with the allowable maximum derived from 1 m clay with a permeability of 1×10^{-9} m/sec (**Table 2**).

It is evident from **Figure 7** that the expected seepage rates from the TSF are lower than the maximum allowable seepage rates.

For comparison, the seepage analysis undertaken for the Feasibility Study Report, as outlined in **Section 3.2**, indicates that the seepage with the TSF full is equivalent to a unit flux of 8.8×10^{-9} m^3/sec per m^2.

The flux from the original Feasibility Study Report is less than both the allowable seepage rate for 20 m of head of water based on the EPA requirements (**Table 3**) and the calculated 1D liner seepage with 20 m of tailings and water (**Table 4**). The implication of this is that the overall site (including the effects of low permeability rock foundations) is actually less transmissive than the liner as a stand-alone (implicitly assuming a permeable underlying layer).

6 DESIGN MODIFICATIONS

As discussed above, in order to meet the EPA requirements (based on the liner seepage rates), a minimum of 0.45 m of well-compacted clay with a permeability of not less than 5×10^{-10} m/sec is required to form a liner beneath the TSF decant pond area.

The following modifications to the design are required. These comprise an increase in the required level of compaction and some degree of reworking of the foundations to achieve the minimum thickness of clay at all locations.

The areas of the impoundment below the spillway level are to be lined as follows:

- In areas where an adequate thickness of clay exists, a depth of 0.45 m of compacted clay liner will be provided as follows:
  - Remove topsoil and any clay required for borrow;
  - Remove the top 300 mm of exposed clay;
  - Rip to a depth of 0.15 m in the natural clay, moisture condition, and compact to 98% of Standard Compaction; and
  - Replace the 300mm of clay in two further layers (2 x 150mm). Moisture condition clay and compact as previously.
- In areas where clay is a total depth of less than 0.45 m, a total thickness of 0.45m of liner would be provided as follows:
-
  - Remove topsoil and any unsuitable material;
  - Rip to a depth of 0.15 m in the natural clay (if available), moisture condition, and compact to 98% of Standard Compaction; and
  - Place up to three layers (150 mm thick each) of moisture conditioned clay and compact to 98% of Standard Compaction.

Finally, place protective material over the clay to reduce shrinkage cracks from forming until covered by tailings.

This procedure may be carried out in stages ahead of the filling of the storage.

7 SUMMARY

Based on liner seepage analysis, a liner 0.45 m of well-compacted clay plus the effect of the overlying tailings is equivalent to the EPA's benchmark for the lining of the Bowden's TSF and this modification to the design is recommended. It is estimated that sufficient clay will be available within the impoundment.

The 2D seepage studies carried out as part of the Feasibility Study Report indicate that the combined effects of the base liner and low permeability rock foundations will result in a further lowering of the seepage rate compared to the 1D liner analysis.

Seepage monitoring will be implemented as outlined in the Feasibility Study Report with standpipe and vibrating wire piezometers, as a fundamental design requirement, with provision for additional interception and pump back of any identified contamination, should it occur.

Yours sincerely,

HEATHER WARDLAW
Senior Associate Engineer
ATC Williams Pty Ltd

Reviewer
Keith Seddon
Senior Principal Engineer
ATC Williams Pty Ltd

References

Ref. 1 ATCW (2017), Bowdens Silver Project, Lue, NSW, “Tailings Storage Facility Dam and Water Storage Dam, Preliminary Geotechnical Investigation”, 116217.05 R01, October 2017.

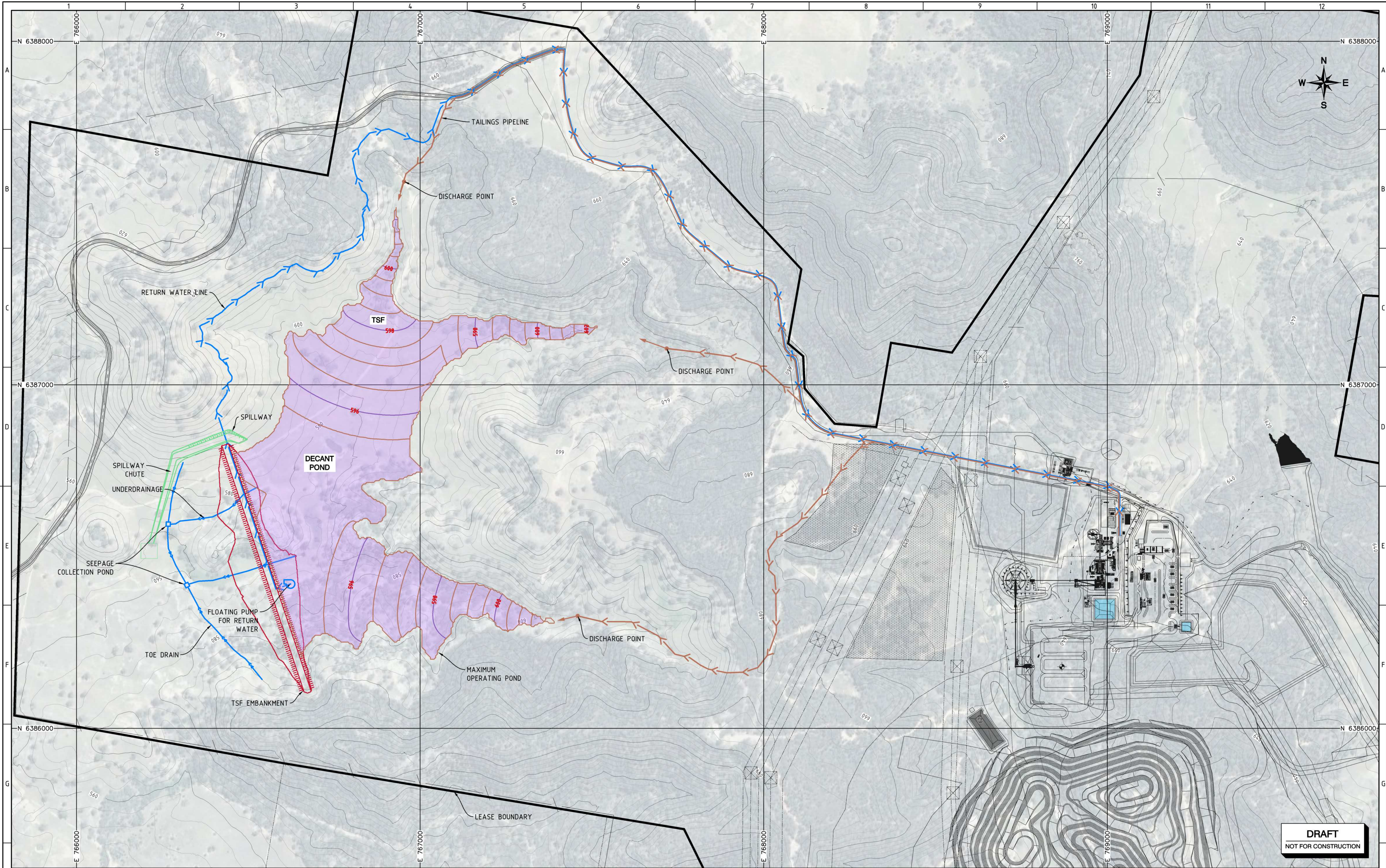
Ref. 2 ATCW (2017), “Laboratory Testing Report”, 116217.04 R02, April 2017

Ref. 3 Rheological Consulting Services, Department of Chemical and Biomolecular Engineering, The University of Melbourne, Vic (2017), “Bowdens Silver Project DFS Rheology Testwork”, 28th September 2017.

Ref. 4 “BSAL Assessment” provided by R W Corkery & Co, 4 May 2017

Ref. 5 ATCW (2018), Bowdens Silver Project, Lue, NSW, “Tailings Storage Facility, Feasibility Study Report”, 116217.01R02 Rev1, October 2018.

FIGURES



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BOWDENS SILVER PTY LIMITED
BOWDENS SILVER PROJECT

TSF FEASIBILITY STUDY
LAYOUT PLAN SEEPAGE COLLECTION

DWG. No. **FIGURE 1**

SHEET SIZE A3 Rev. A

SHEET 1 OF 1

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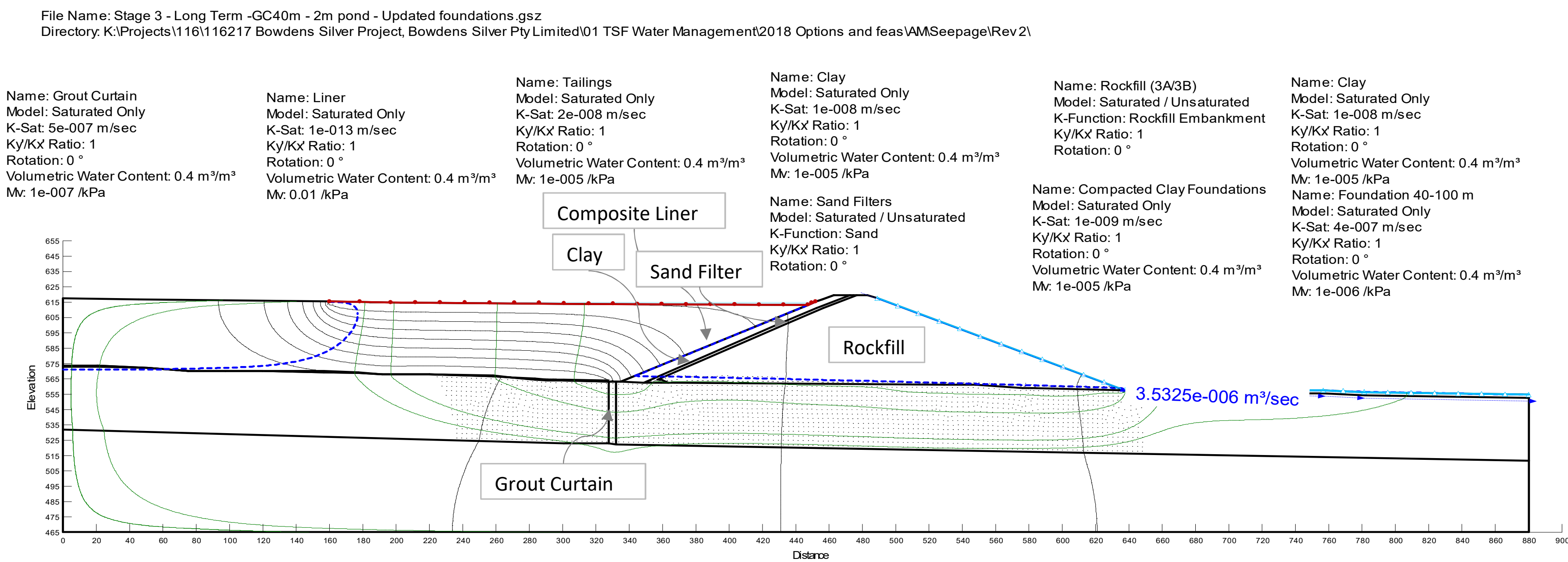

BOWDENS SILVER PTY LTD

BOWDENS SILVER PROJECT

Stage 3 Embankment Crest at Elevation 620 m AHD

Case 1 Steady State Seepage Analysis - 2m Operating Pond - Compacted Clay Foundations

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Date: 18/03/2019 **Job No:** 116217.07

FIGURE 2

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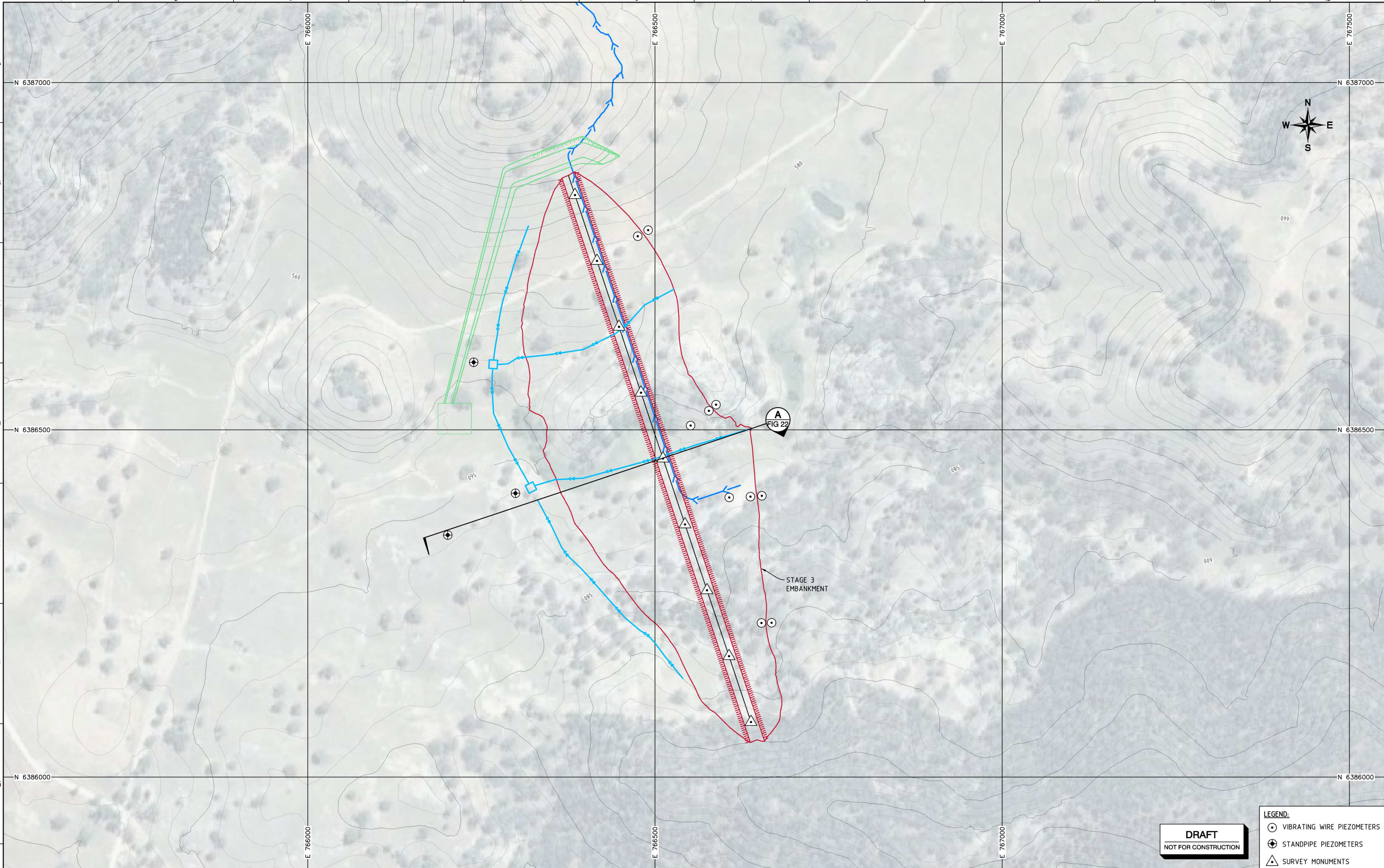

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BOWDENS SILVER PROJECT

TSF FEASIBILITY STUDY
TYPICAL MONITORING PLAN

DWG. No.
FIGURE 3

SHEET SIZE	A3	Rev.	A

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SHEET 1 OF 1

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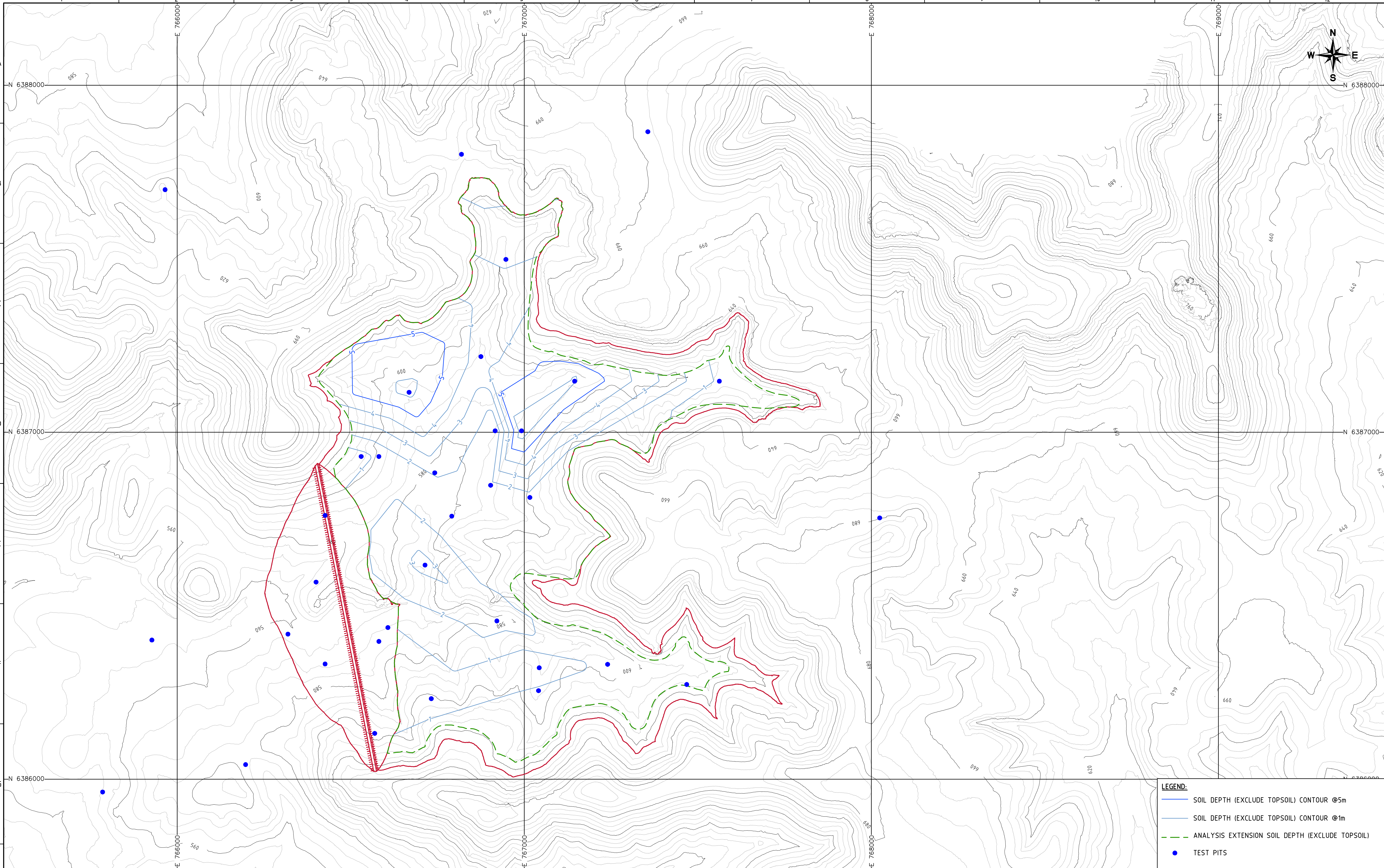

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BOWDENS SILVER PTY LTD
BOWDENS SILVER PROJECT

PRELIMINARY GEOTECHNICAL INVESTIGATION
TSF ESTIMATED SOIL DEPTH (EXCLUIDING TOP SOIL)
CONTOURS 5.0-1.0m

DWG. No.

FIGURE 4

SHEET SIZE	A3	Rev.	A

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SHEET 1 OF 1

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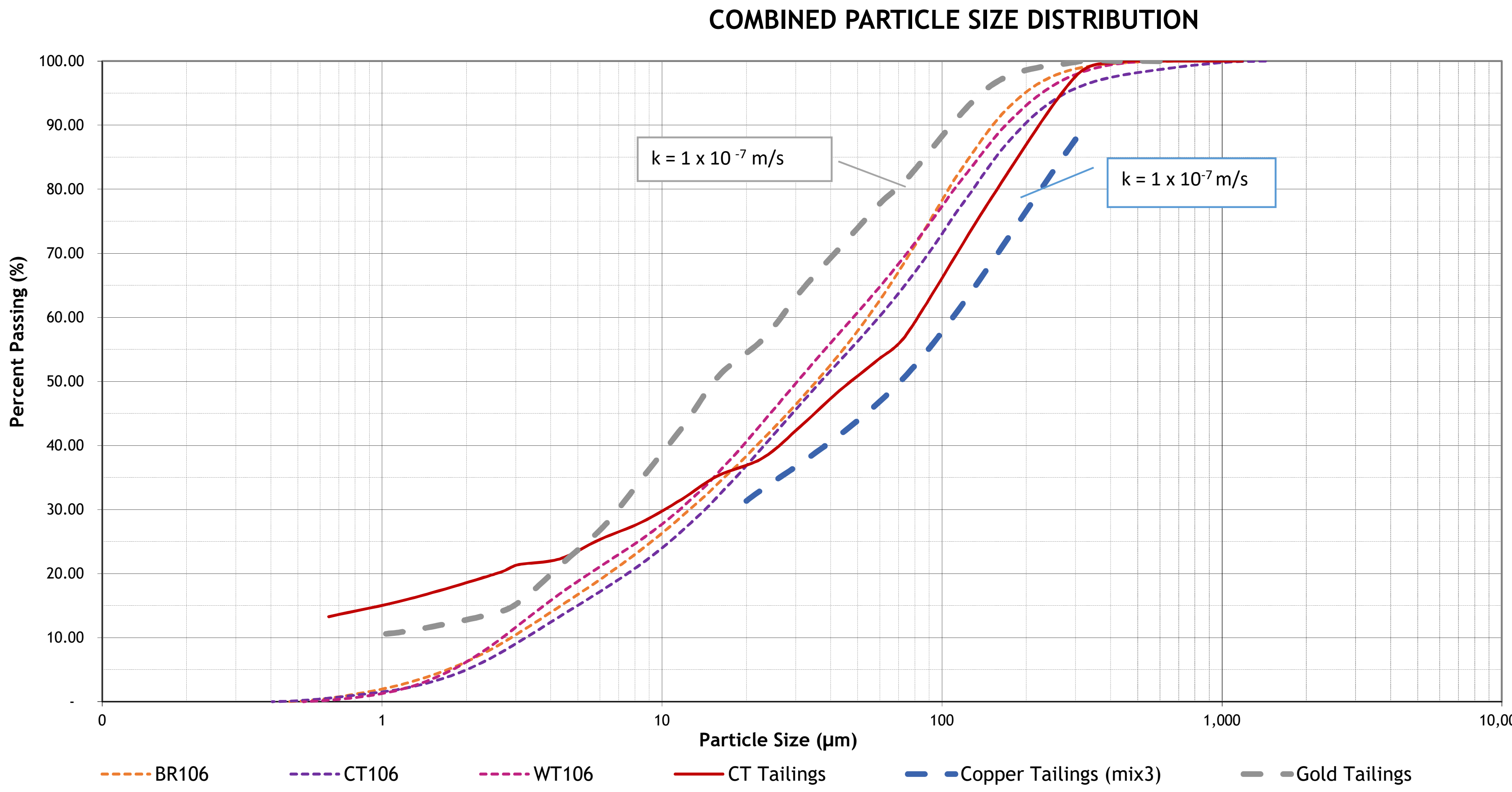

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BOWDENS SILVER PROJECT

EIS RESPONSE - SEEPAGE

Particle Size Distribution Curve of RCS 106 Samples & ATCW Sample

Date: 7/02/2019 **Job No:** 116217.07

FIGURE 5

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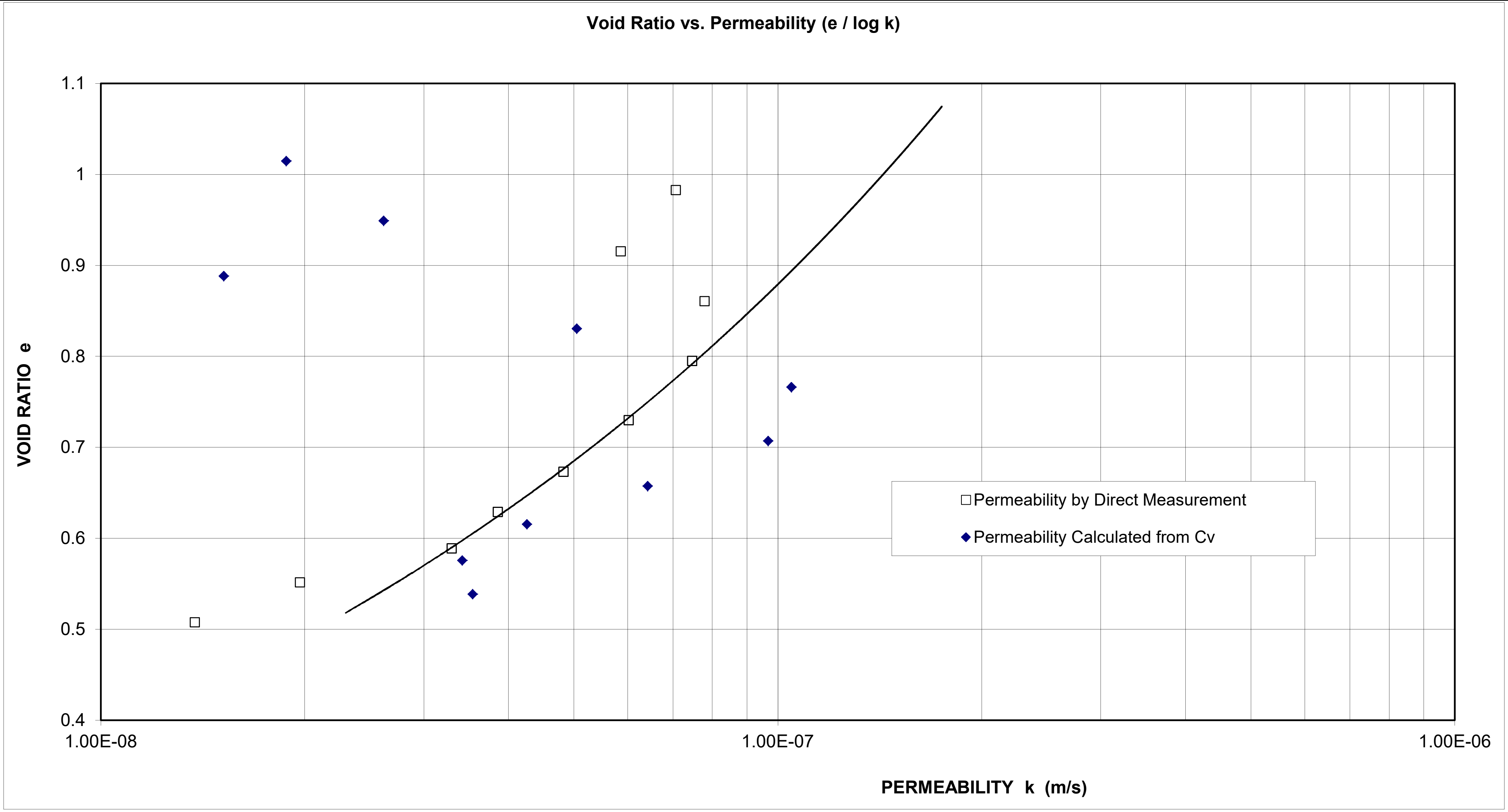

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COPPER MINE

ROWE CELL CONSOLIDATION

Mix No. 3

Date:	2/09/2011	**Job No:**	116217.07	**FIGURE 6**

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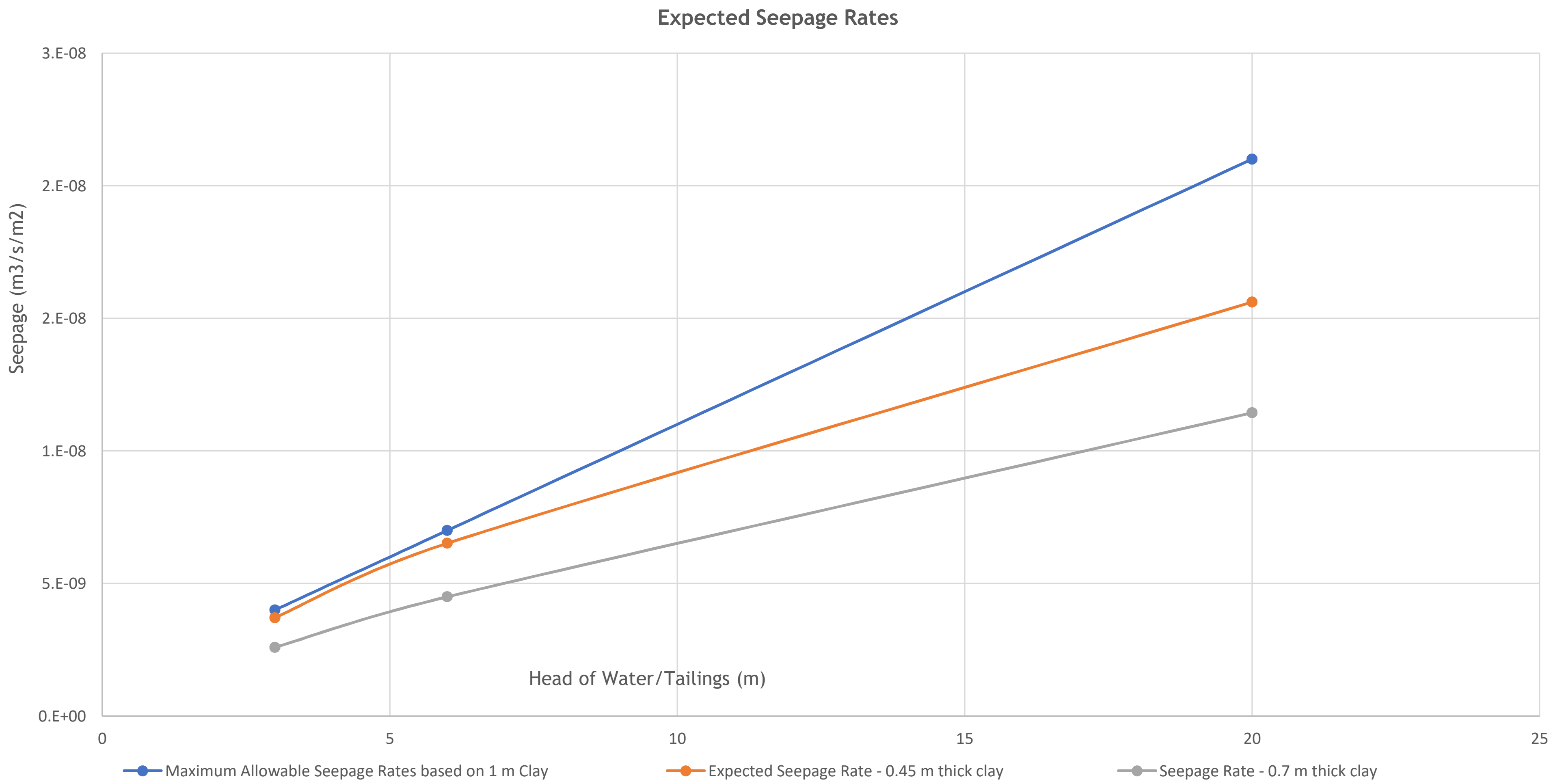

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BOWDENS SILVER PTY LTD

BOWDENS SILVER PROJECT

Tailings Storage Facility

Expected Seepage Rates

Date:	13/09/2017	**Job No:**	116217.01	**FIGURE 7**

K:\Projects\116\116217 Bowdens Silver Project, Bowdens Silver Pty Limited\07 EIS Response - Seepage\DWGs & Figs\Figs\Figure 7 Figure 1

ATTACHMENTS

ATTACHMENT 1

Permeability - Falling Head Method

TEST IN ACCORDANCE WITH IN-HOUSE PROCEDURE 7.3
SAMPLE PREPARATION IN ACCORDANCE WITH
☒ AS 1289.5.1.1 ☐ AS 1289.5.2.1

ATC Williams GROUNDED IN DESIGN

Client: Bowdens Silver Pty Ltd **NATA Report No.: R25717**

Address: 68 Maloneys Road, Lue, NSW 2850 **Job No.:** 116217.05

Project: Bowdens Silver Project **Location:** NSW

Sample Register No.	23117	23317	23617	
Test Pit Number	TSF TP 10	TSF TP 21	WSD TP 9	
Sample Depth (m)	2.0-2.2	0.6-0.8	1.0-1.2	

Sample as prepared

Initial Dry Density (t/m^3)	1.76	1.463	1.87	
Moisture Content (%)	14.0	24.0	11.0	
Oversize (>19mm) Discarded (%)	None	None	None	

Test Conditions

Surcharge (kPa)	30.4	36.5	24.5	
Sample Swell During Saturation (mm)	0	0	0	
Test Dry Density (t/m^3)	1.75	1.45	1.86	
Water Used	Melbourne Tap	Melbourne Tap	Melbourne Tap	
Conductivity of Water (μS/cm)	70	70	70	
Hydraulic Gradient	36.5	34.1	33.0	

Test Results

Permeability @ 20°C (m/s)	6.87×10^{-11}	2.77×10^{-11}	3.46×10^{-10}	
Final Moisture Content (%)	16.2	30.7	13.2	

Test Notes:

☒ Sampled by ATC Williams Pty Ltd in accordance with AS 1289.1.2.1, Clause 6.5.4 (Machine Excavated Test Pit)

The test results relate only to the items tested.

NATA ACCREDITED FOR TECHNICAL COMPETENCE

NATA ACCREDITED LABORATORY NUMBER: 3372

Accredited for compliance with ISO/IEC 17025

Approved Signatory .... Date 30/08/2017

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