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BLACK ROCK MINE OPERATIONS

NCHWANING AND GLORIA SLIMES STORAGE FACILITIES

DAM BREAK ANALYSIS

Report prepared for

ASSMANG MANGANESE
BLACK ROCK MINE OPERATIONS

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Rev 0: Original document

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1. INTRODUCTION

Geo Tail SA (Pty) Ltd (Geo Tail) was appointed by Black Rock Mining Operations (BRMO) to calculate the impacted zones in the event of a dam break (also referred to as a tailings dam breach) on the Gloria and Nchwaning slimes storage facilities (SSFs). The Gloria and Nchwaning operations are located approximately 6 km and 12 km north west of Hotazel respectively.

FIGURE 1: LOCATIONS OF OPERATIONS

2. SLIMES STORAGE FACILITY DESCRIPTIONS

2.1 Local Setting

The Gloria slimes storage facility is BRMO's only tailings storage facility complex serving the Gloria plant operations. The Nchwaning slimes storage facility is BRMO's only tailings storage facility complex serving the Nchwaning plant operations.

The Gloria slimes storage facility complex comprises an active deposition compartment, a dormant lined compartment, a standby compartment and a return water dam (shown in Figure 2). The Nchwaning slimes storage facility comprises an old and new SSF, with their respective return water dams (shown in Figure 3).

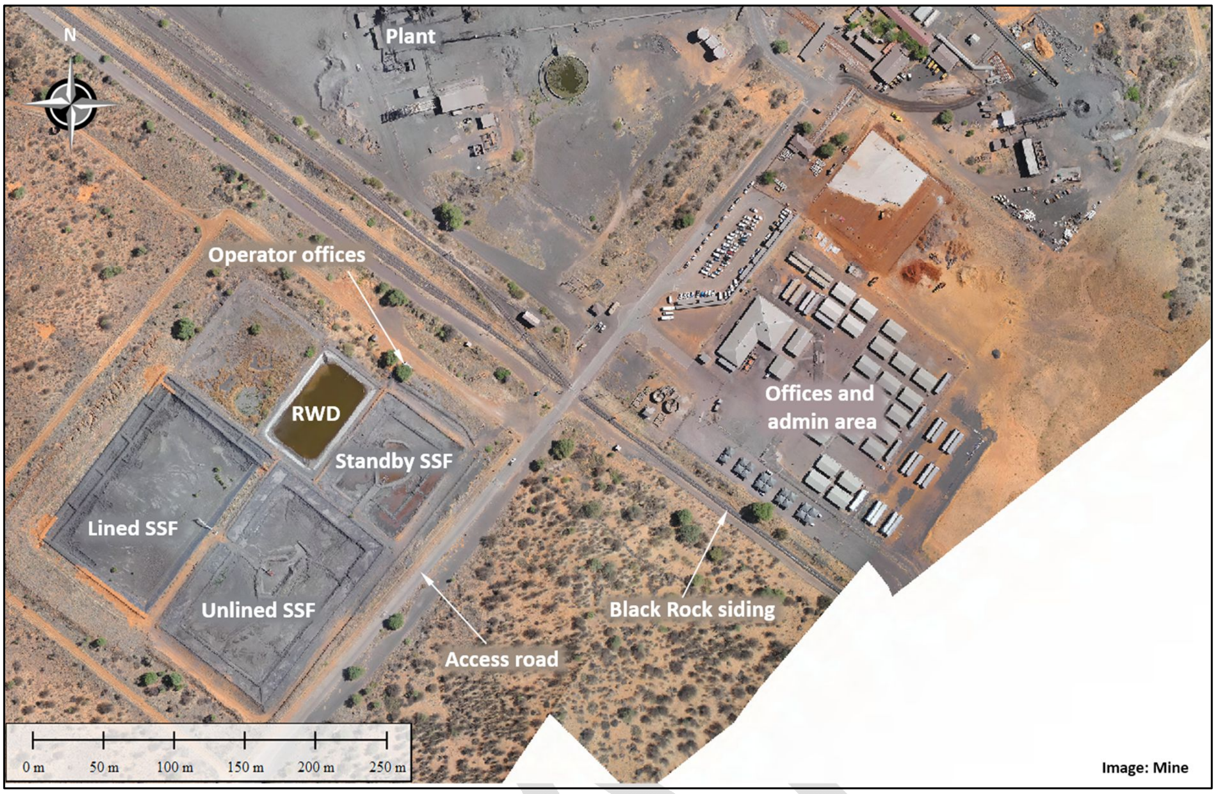


FIGURE 2: INFRASTRUCTURE LAYOUT – GLORIA

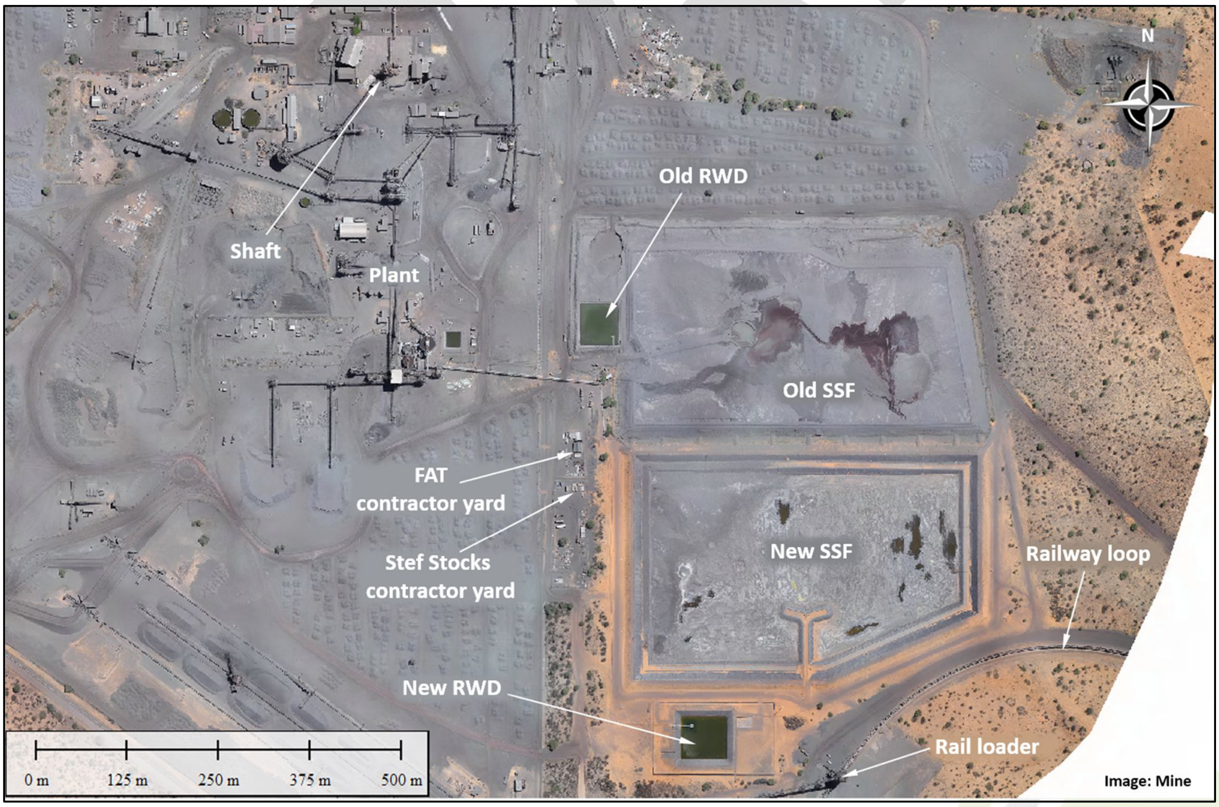


FIGURE 3: INFRASTRUCTURE LAYOUT – NCHWANING

2.2 Regional Setting

The Gloria slimes storage facility is located between the R380 national road and the Ga-Mogara River. The Black Rock siding runs between the slimes storage facility and the plant and offices. Access to the plant and the slimes storage facility is via an access road off the R380. A contractor's camp is located 600 m west of the slimes storage facility. Some of this infrastructure is shown in Figure 4. The Ga-Mogara River also flows from south to north, to the east of the SSF.

The Nchwaning slimes storage facility is located adjacent to the Nchwaning plant. A railway line and a loading loop are located to the south of the slimes storage facility. Some of this infrastructure is shown in Figure 5.

FIGURE 4: REGIONAL SETTING – GLORIA

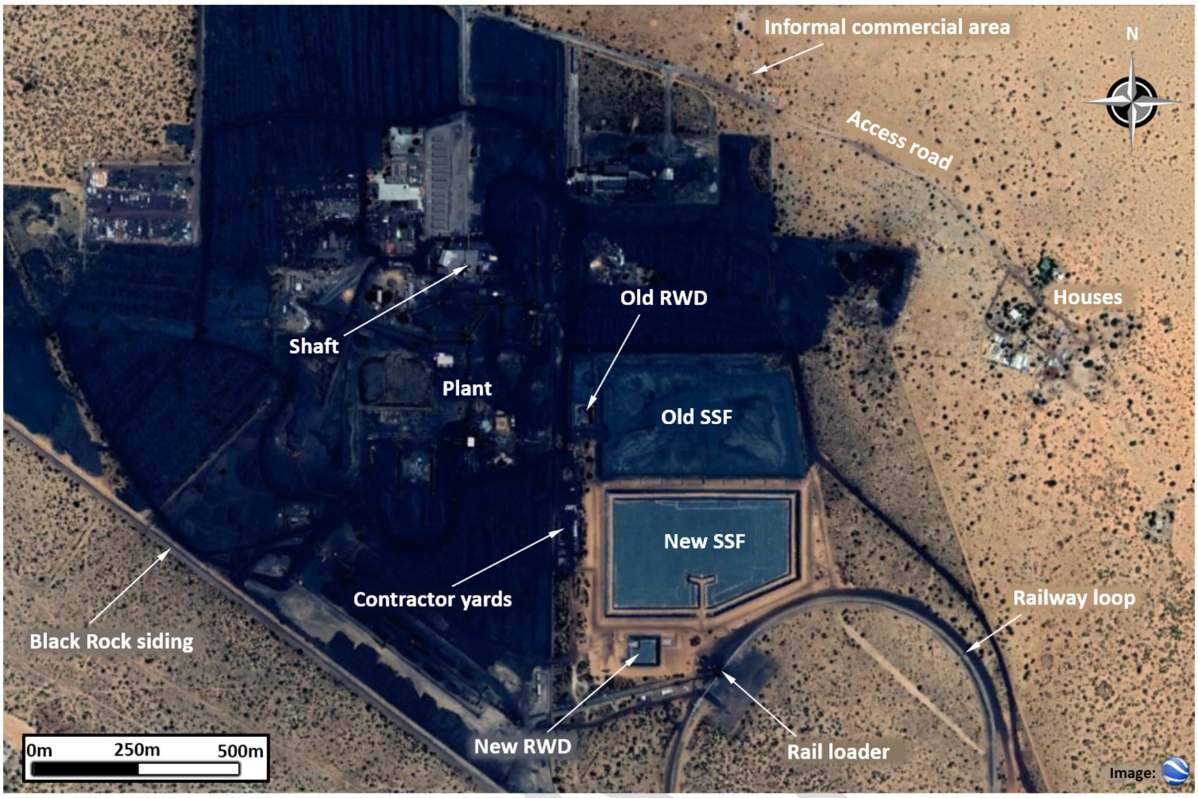


FIGURE 5: REGIONAL SETTING – NCHWANING

2.3 High Hazard Areas near the Slimes Storage Facilities

2.3.1 Gloria Slimes Storage Facility

There are no known private households close to the slimes storage facility. Two transportation routes are located close to the slimes storage facility – the Black Rock siding and the access road to the Gloria plant. Many of the Gloria plant and related infrastructures is located close to the slimes storage facility, as well as a contractor's camp and offices and admin buildings. Many workers work within this infrastructure. The operator offices are permanently manned and is located adjacent to the slimes storage facility. The Ga-Mogara River is an environmentally sensitive area. These areas are shown in Figure 6.

2.3.2 Nchwaning Slimes Storage Facility

Third party infrastructure close to the Nchwaning slimes storage facility includes a grouping of houses and some informal commercial operations, located to the north east and north respectively. A rail loader and its associated buildings is located south of the slimes storage facility. These are less than 1 km from the slimes storage facility. Much of the plant, the shaft, contractor yards, rail sidings and internal mine access roads are located close to the slimes storage facility. These areas are shown in Figure 7.

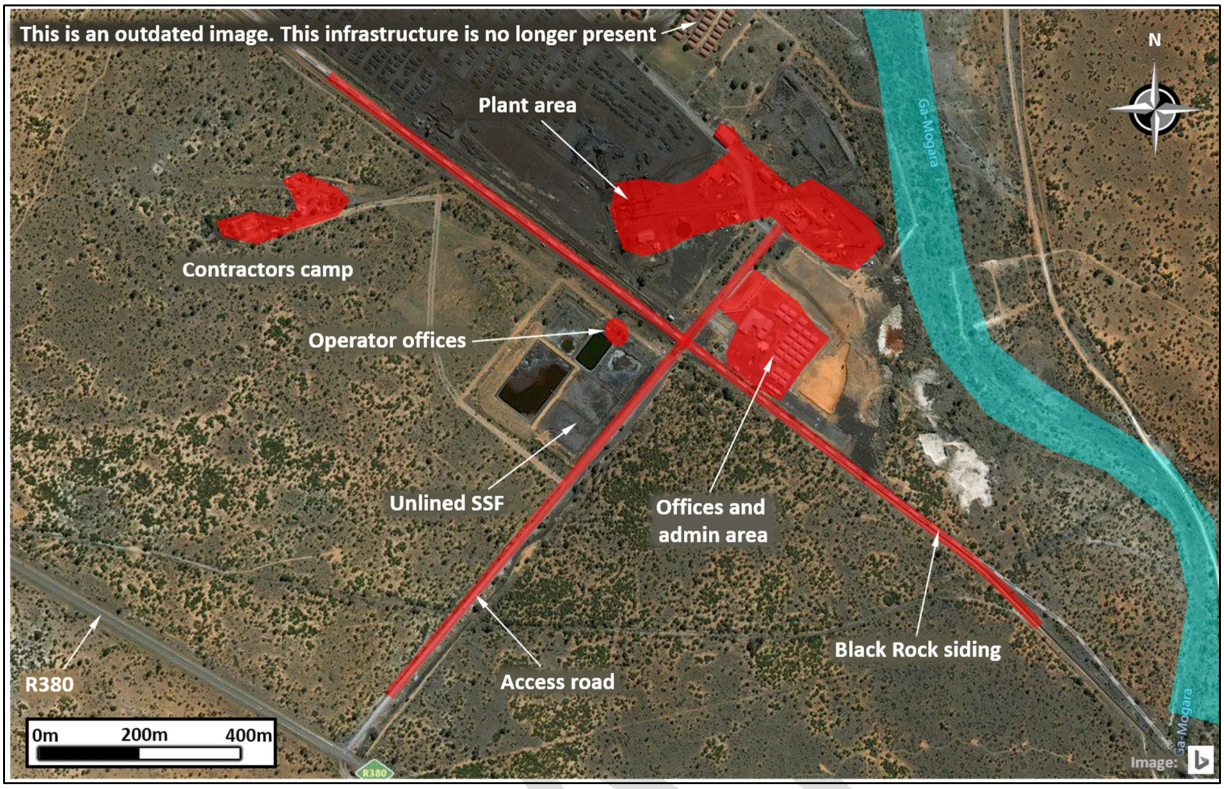


FIGURE 6: HIGH HAZARD AREAS CLOSE TO THE GLORIA SSF

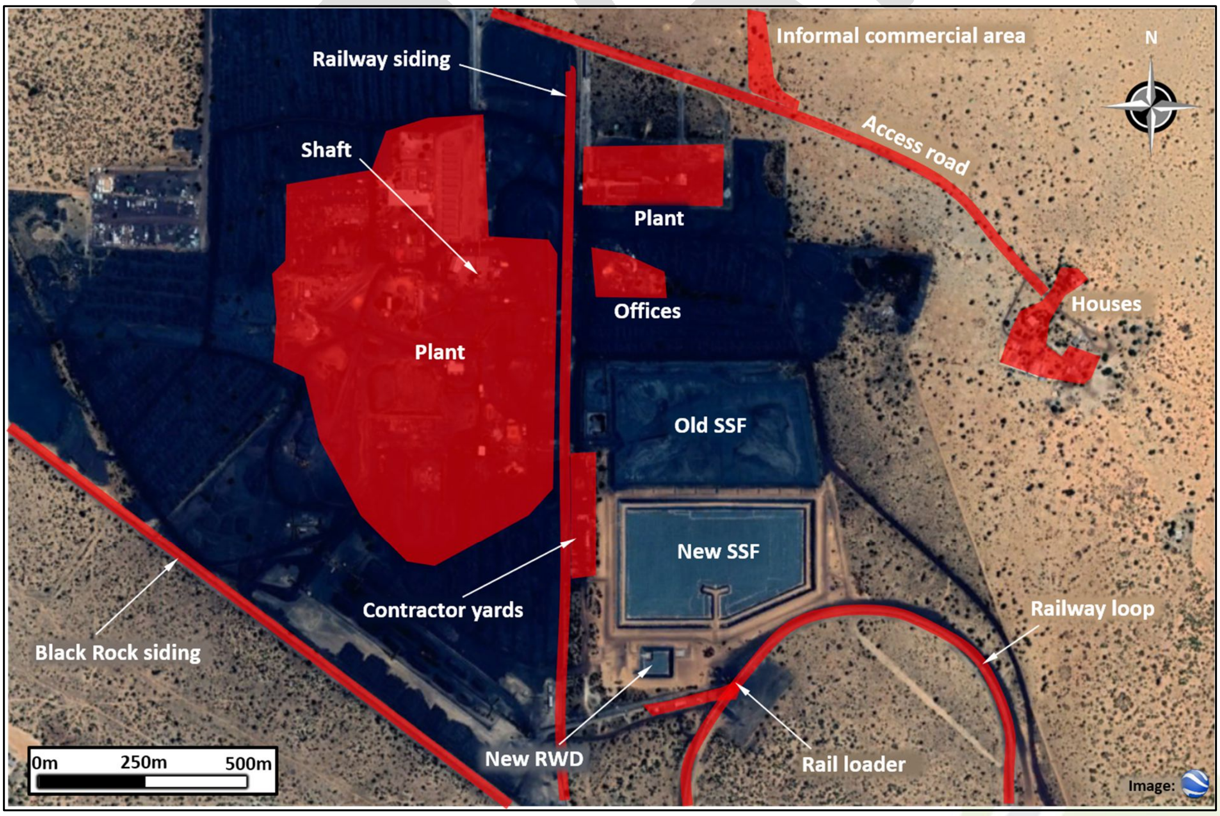


FIGURE 7: HIGH HAZARD AREAS CLOSE TO THE NCHWANING SSF

2.4 Slimes Storage Facilities

2.4.1 Slimes storage facilities construction

The construction material used to form the outer embankments are shown in Figure 8 and Figure 9.

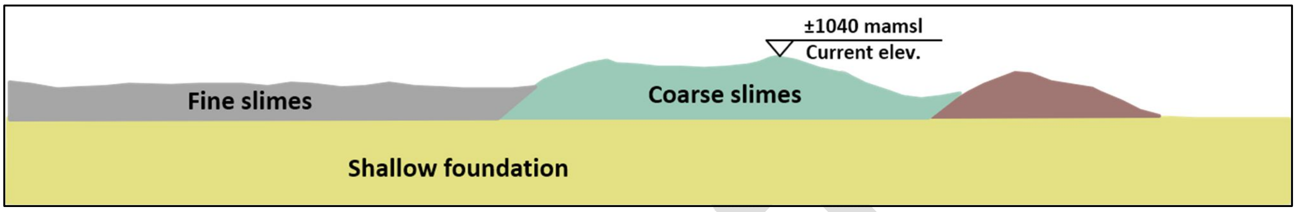


FIGURE 8: GLORIA SSF CONSTRUCTION MATERIALS

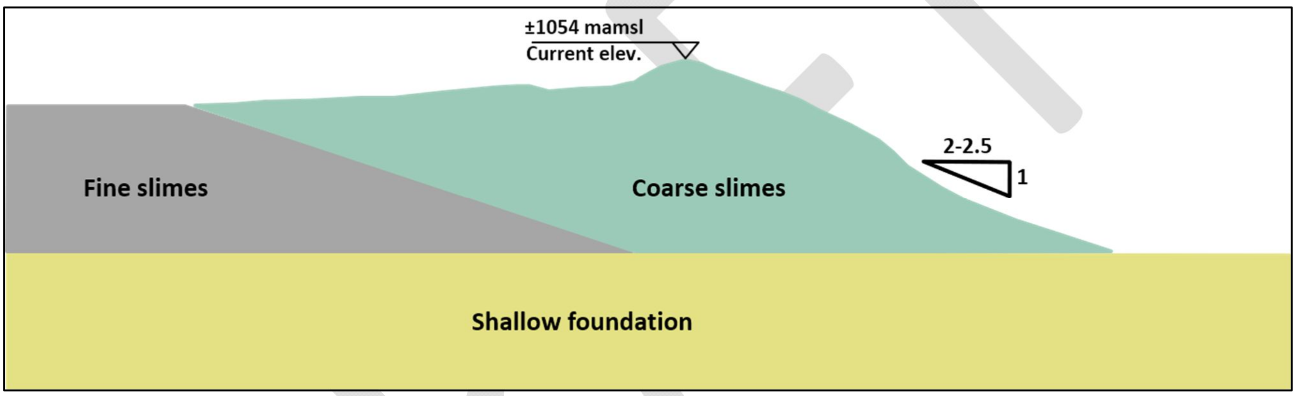


FIGURE 9: NCHWANING SSF CONSTRUCTION MATERIALS

2.4.2 Current slimes storage facility stability

<u>Geotechnical laboratory testing</u>

A representative disturbed paste sample was submitted to BM du Plessis Civil Engineering for geotechnical testing.

The following laboratory tests were undertaken (results summarised in Table 1):

- Particle Size Distribution
- Specific Gravity
- Settling – Top and Bottom Drained
- Air Drying
- Falling Head Permeability
- Tri-axial (Consolidated Undrained)

The laboratory test results completed to date can be summarised as follows:

TABLE 1: SUMMARY - LABORATORY TEST RESULTS

Item	Geotechnical Property	Unit	Nchwaning					Gloria
			Seam 1	Seam 1/2 70%/30%	Seam 1/2 50%/50%	Seam 1/2 30%/70%	Seam 2	
1	**Particle Size Distribution**							
1.1	< 2-micron	%	5	7	8	8	6	4
1.2	> 75-micron	%	59	43	39	22	6	69
2	**Specific Gravity**	ratio	4.21	4.28	4.32	4.34	4.33	3.67
3	**Settling Density @ Moisture Content**							
3.1	Undrained	t/m^3	1.90	1.91	1.80	1.73	1.92	1.62
3.2	Top drained	t/m^3	2.20	2.12	2.13	2.05	2.30	1.65
3.3	Bottom drained	t/m^3	2.20	2.12	2.13	2.12	2.01	1.88
3.4	Drying	t/m^3	2.31	2.12	2.13	2.13	2.16	2.32
3.5	Top drained	%	23	26	26	27	27	36
3.6	Bottom drained	%	24	25	25	28	25	26
3.7	Drying	%	10	11	7	13	13	10
5	**Maximum Dry Density and Optimum Moisture Content**							
5.1	MOD AASHTO	t/m^3	2.680	2.680	2.980	2.860	2.510	-
5.2	Moisture content	%	12.0	11.0	7.3	9.4	8.3	-
6	**Shear Strength**							
	Test		Shear Box					Consolidate Undrained Tri-Axial
6.1	Friction Angle	degree	39	38	38	38	38	38
6.2	Cohesion	kPa	0	0	0	0	0	0
7	**Permeability**	m/s	3.5E-7 (Falling head)	-	-	-	2.3E-8 (Constant head)	1.1E-6 (Constant head)

Geotechnical founding conditions

SRK Consulting (South Africa) (Pty) Ltd (SRK) was appointed by Assmang (Pty) Ltd to conduct a geotechnical investigation for the new Gloria slimes dam. This slimes dam will be located adjacent to and to the west of the current SSF complex. Where appropriate, the results of these investigations are used as reference to the existing Gloria SSF. SRK undertook a site visit from 24 June to 4 July 2019, during which intrusive field investigations were conducted and samples retrieved for testing.

SRK was appointed by Assmang (Pty) Ltd to conduct a geotechnical investigation for the new Nchwaning SSF. Where appropriate, the results of these investigations are used as reference to the existing Old Nchwaning SSF.

Side slope stability analysis

Side slope stability analyses were undertaken for critical cross sections through the Gloria and Nchwaning slimes storage facilities. The results are summarised in Table 2.

TABLE 2: SUMMARY OF OVERALL FACTOR OF SAFETY

Slimes dam	Section	Factor of safety	Target factor of safety	Satisfactory
Gloria	Large unlined compartment (east flank – opposite pool)	2.832	1.5	Yes
Nchwaning	Compartment 1 (west flank)	1.679	1.5	Yes
	Compartment 1 (south flank)	1.380	1.5	No
	Compartment 2 (south flank)	1.589	1.5	Yes
	Compartment 2 (east flank)	1.772	1.5	Yes
	Compartment 2 (north flank)	1.294	1.5	No
	Compartment 3 (north flank)	1.796	1.5	Yes

Refer to Figure 10 to Figure 16.

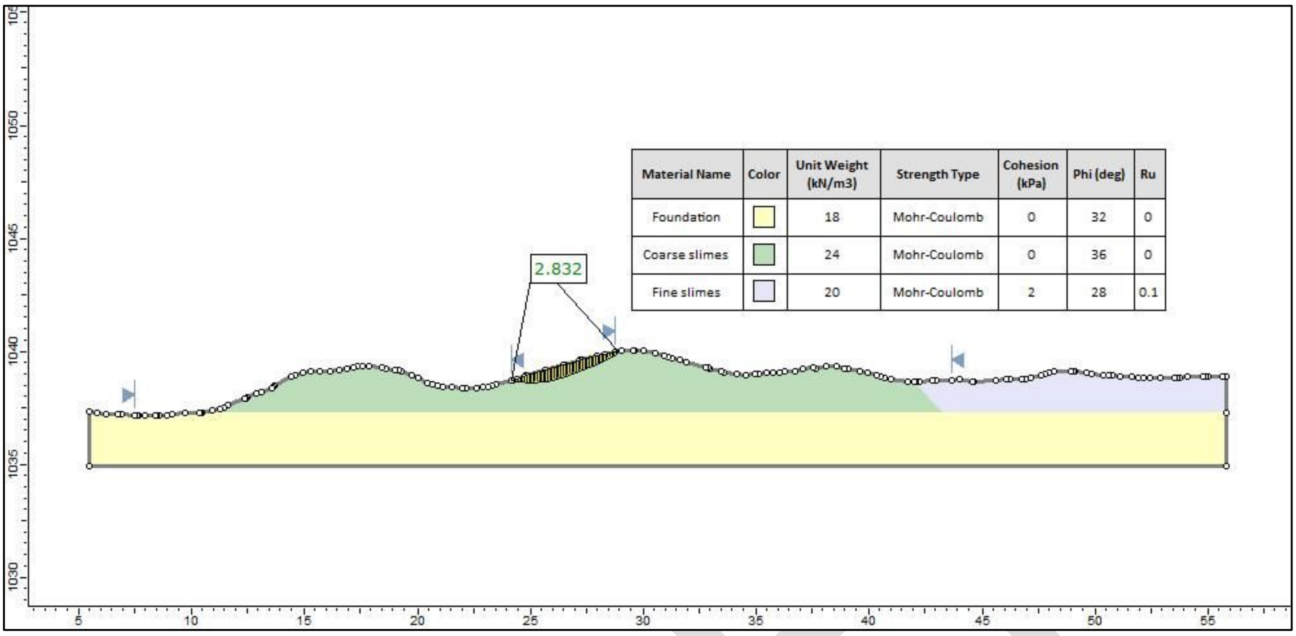


FIGURE 10: SIDE SLOPE STABILITY – GLORIA LARGE UNLINED COMPARTMENT (EAST FLANK – OPPOSITE POOL)

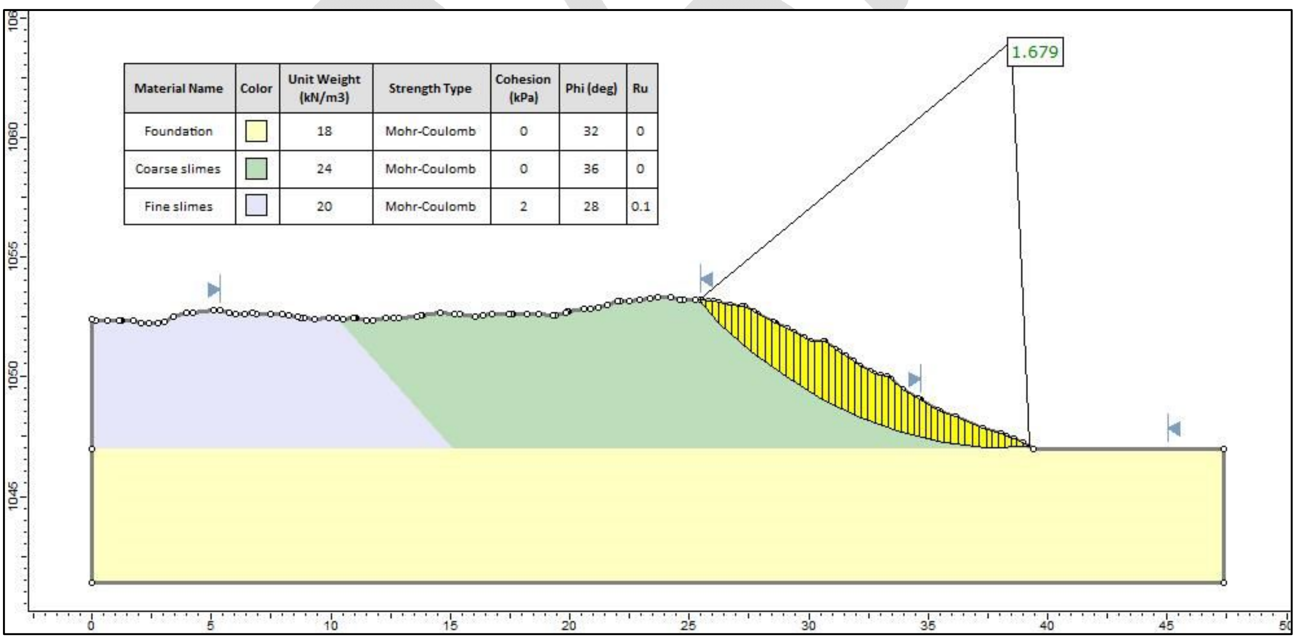


FIGURE 11: SIDE SLOPE STABILITY – NCHWANING COMPARTMENT 1 (WEST FLANK)

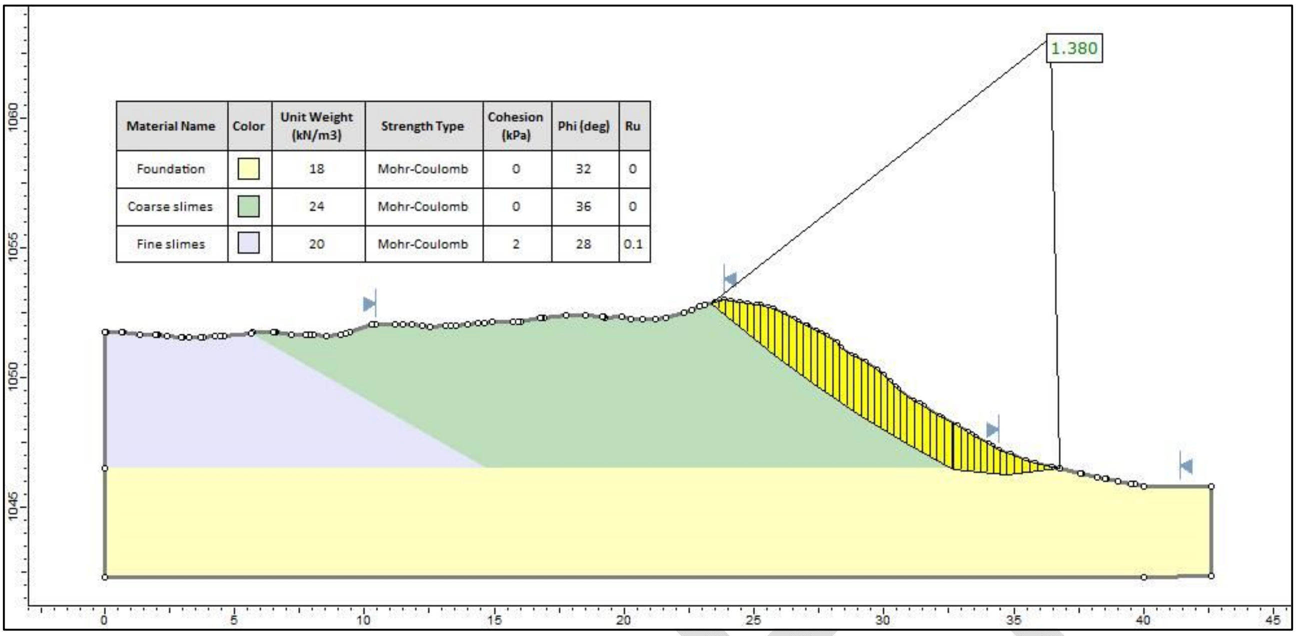


FIGURE 12: SIDE SLOPE STABILITY – NCHWANING COMPARTMENT 1 (SOUTH FLANK)

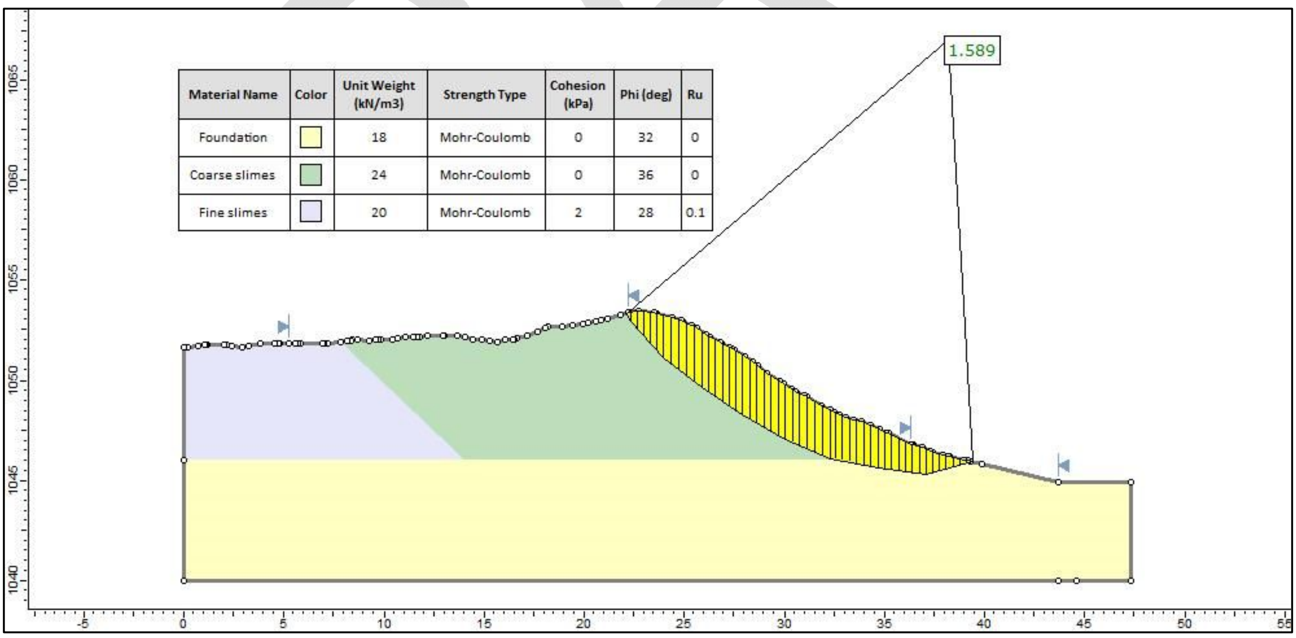


FIGURE 13: SIDE SLOPE STABILITY – NCHWANING COMPARTMENT 2 (SOUTH FLANK)

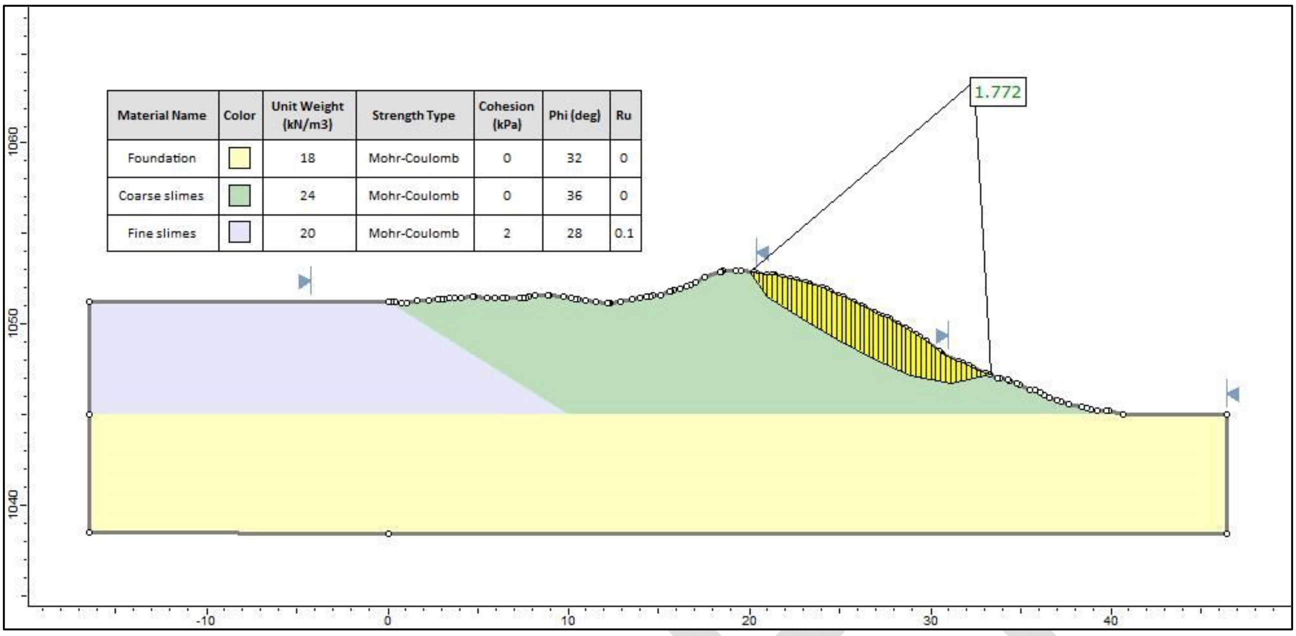


FIGURE 14: SIDE SLOPE STABILITY – NCHWANING COMPARTMENT 2 (EAST FLANK)

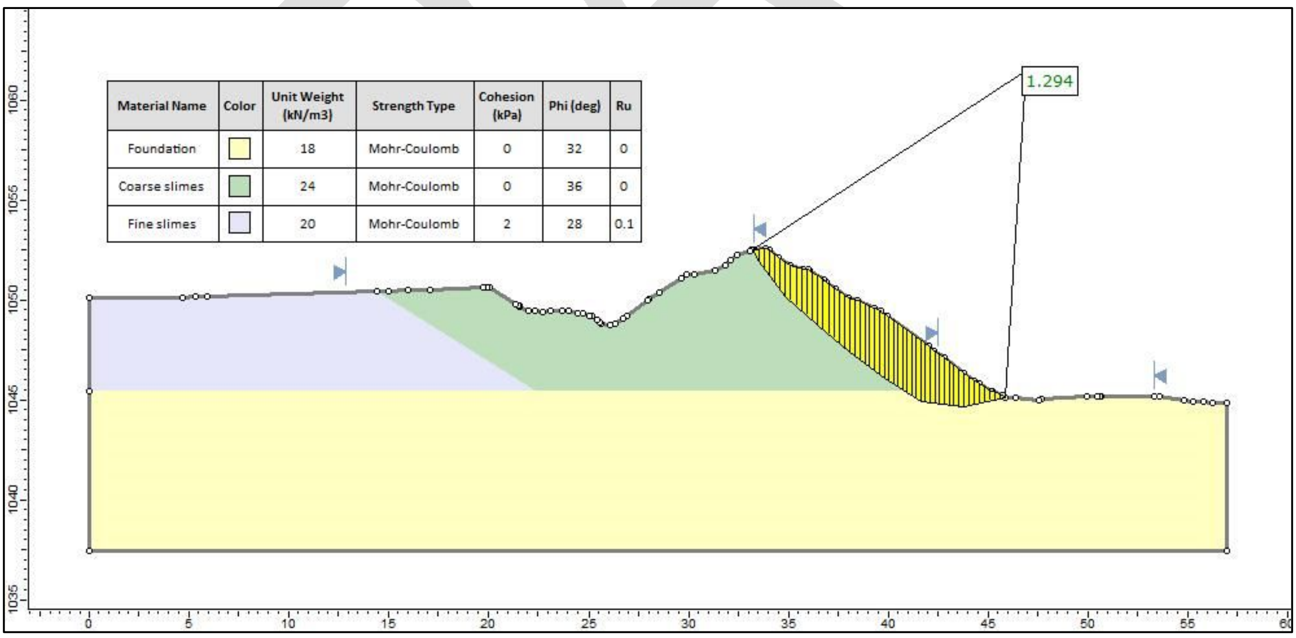


FIGURE 15: SIDE SLOPE STABILITY – NCHWANING COMPARTMENT 2 (NORTHFLANK)

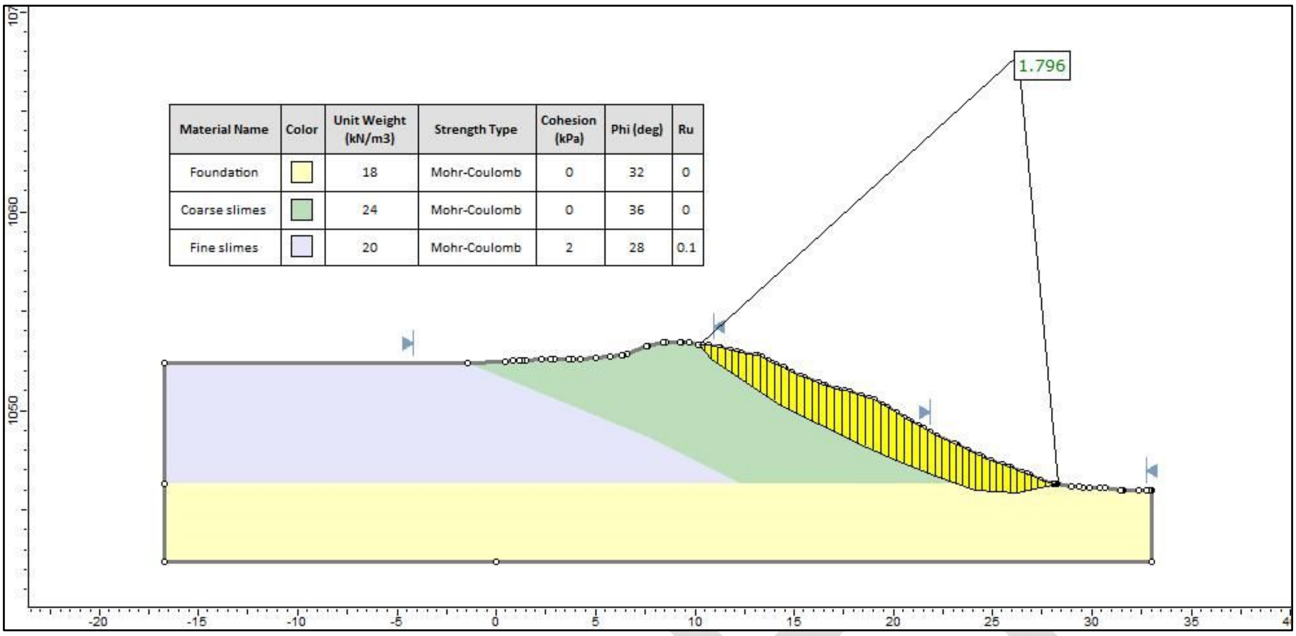


FIGURE 16: SIDE SLOPE STABILITY – NCHWANING COMPARTMENT 3 (NORTH FLANK)

<u>Pool analysis and freeboard analysis - Gloria</u>

The design storms considered are the 50-yr and 100-yr 24-hour storms.

The results can be summarised as follow:

- The existing beach freeboard in the SSF basin is enough to cater for storm water volumes resulting from the design storms considered.
- The pools from a storms event will extend to within the 50 m perimeter buffer zone.
- There is adequate total freeboard to ensure legal compliance.

The likely pool locations associated with the design storms are shown in Figure 17.

<u>Pool analysis and freeboard analysis - Nchwaning</u>

The design storms considered are the 50-yr and 100-yr 24-hour storms.

The results can be summarised as follows:

- The existing beach freeboard in the Nchwaning slimes storage facility basin is enough to cater for storm water volumes resulting from the design storms considered.
- The pools from a storms event will extend to within the 50 m perimeter buffer zone.
- There is adequate total freeboard to ensure legal compliance.

The likely pool locations associated with the design storms are shown in Figure 18.

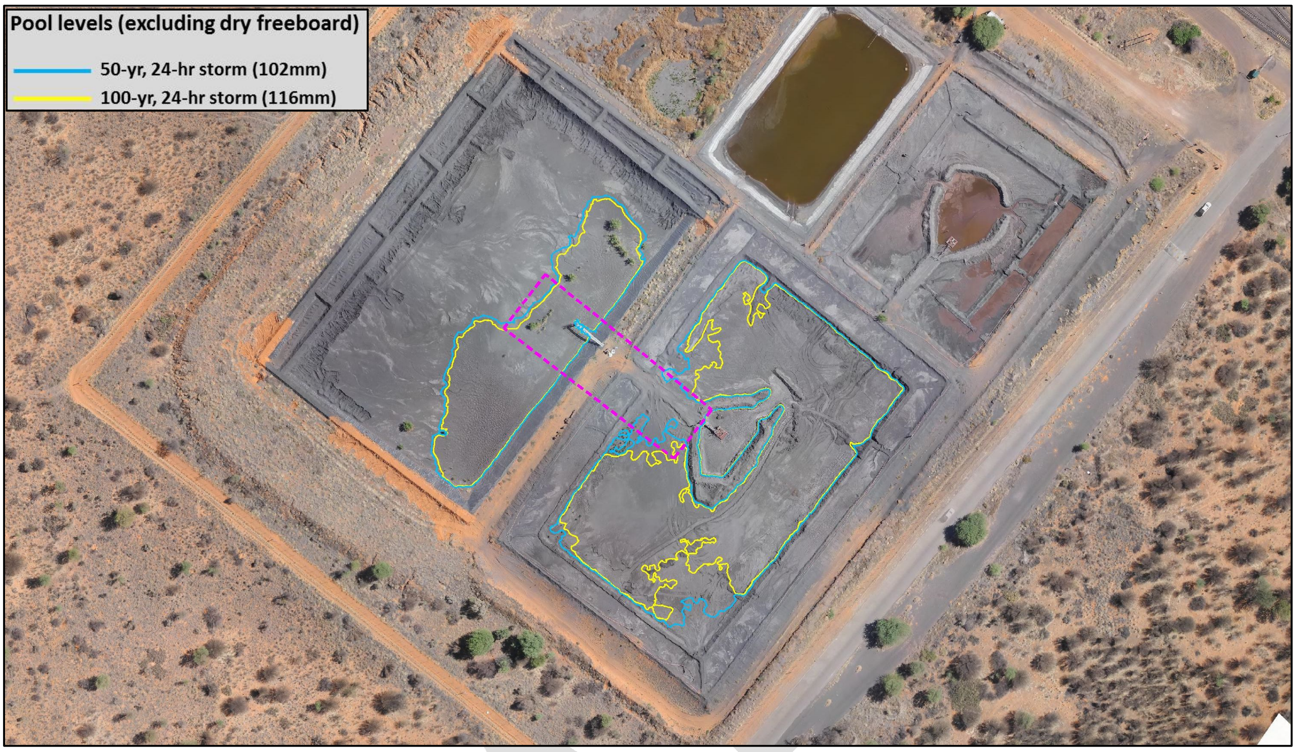


FIGURE 17: LIKELY POOL LOCATIONS AS A RESULT OF EXTREME RAINFALL EVENTS (GLORIA)

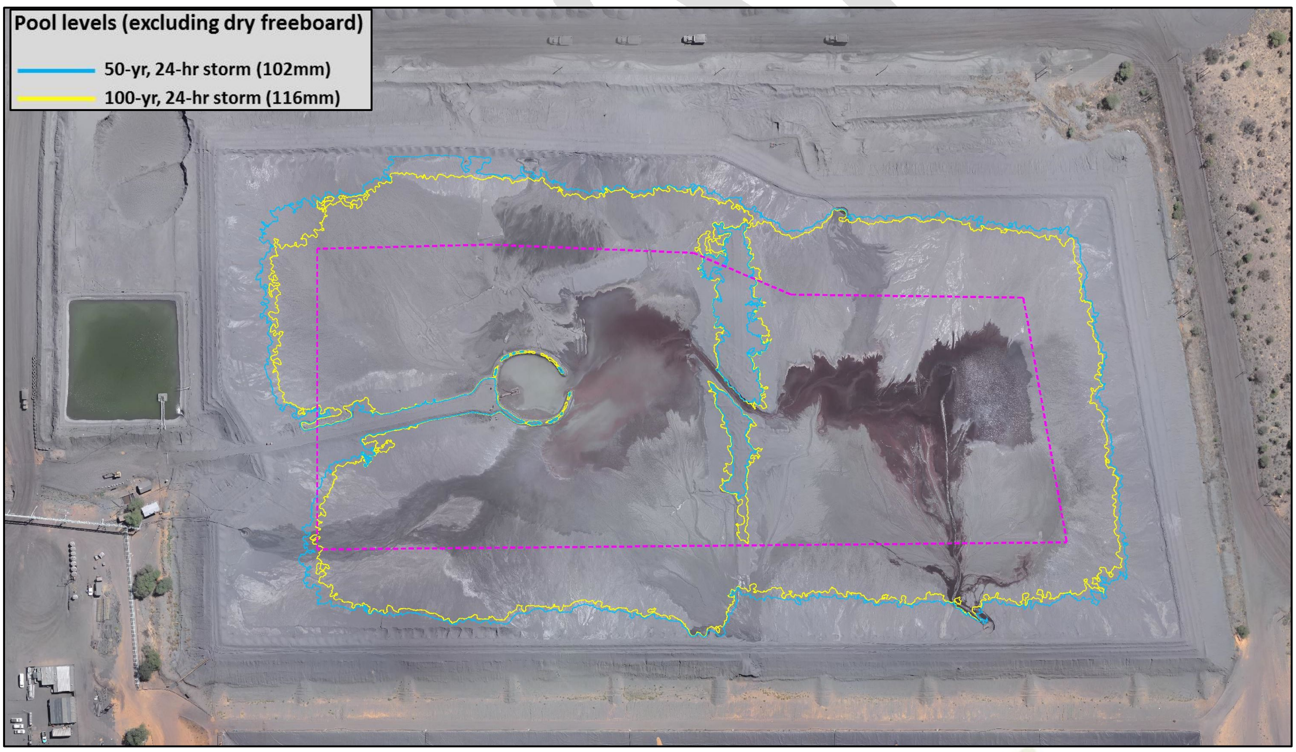


FIGURE 18: LIKELY POOL LOCATIONS AS A RESULT OF EXTREME RAINFALL EVENTS (NCHWANING)

3. CLIMATE DATA

The monthly and mean annual precipitation and evaporation data are presented in the table below.

TABLE 3: AVERAGE MONTHLY AND MEAN ANNUAL CLIMATE DATA SUMMARY

Month	Rainfall	Rain days	Evaporation
Mean Annual*	**266**		**2 399**
January	36.2	3.8	279.8
February	48.1	4.1	212.1
March	45.1	4.0	195.2
April	27.6	2.4	145.6
May	12.2	1.2	115.9
June	8.3	0.5	91.9
July	1.1	0.3	107.1
August	4.8	0.5	155.3
September	4.5	0.7	215.2
October	17.4	1.8	272.4
November	19.1	2.5	286.9
December	42.1	3.2	297.6

** Note: The mean annual rainfall does necessarily correspond to the sum of the monthly average rainfall data.*

Rainfall data for the area was obtained from the CCWR (Computing Centre for Water Research, Natal University) database. Gauge number 0392640 (Mukulu) was used. The gauge is located approximately 4km south, south west of the mine. This data is considered representative of the mine's rainfall. The mean annual evaporation was sourced from the average evaporation for quaternary catchments D41K and D41M, documented in the Water Resources of South Africa, 2005 Study (Middleton and Bailey, 2009). Its monthly distribution was sourced from the Water Resources of South Africa Study data set, zone 8A (Midgley et al., 1990).

3.1 Peak Rainfall Data

The peak 24-hour rainfall depths are presented in the table below.

TABLE 4: PEAK RAINFALL DATA

Recurrence Interval (year)	24-hr depth (mm)
2	38
10	70
20	84
50	102
100	116
200	131
1 000	168
10 000 (PMP)	227

The daily rainfall record was analysed, and the annual maximum series was extracted from the data. This annual maximum series was statistically analysed to determine various T-year recurrence interval 24-hour storm depths. A Log Normal distribution was selected as the most appropriate statistical fit for both the annual maximum series. The rainfall record is long, consists of good data, is representative of the site, and is suitable be used to calculate peak rainfall.

4. TAILINGS RHEOLOGY

Rheology data were available from two sources:

- Tailings properties provided by test work conducted in 2019, and used in Geo Tail's annual audit reports.
- 18 Boger slump tests performed by BM du Plessis Civil Engineering.

FIGURE 19: BOGER SLUMP TESTS

5. FAILURE MODES

5.1 Compartments Considered

5.1.1 Gloria slimes storage facility

Only the Unlined SSF was considered for the old SSF. The Lined and Standby SSFs were not considered. The Lined SSF is mostly below ground level and the Standby SSF sees very little deposition.

Compartment 1 was considered for the new SSF.

5.1.2 Nchwaning slimes storage facility

Only the Old SSF was considered. The New SSF has recently been commissioned and slimes elevations are still below ground level.

5.2 Dam Break Scenarios

The SSFs can have many types of failures, or combinations of these. These types of failures can be aggregated into three main failure types for practical reasons:

- Overtopping failure. This is commonly referred to as the “rainy-day” scenario.
- Slurry/mud flows from within the basin, not linked to overtopping. This is commonly referred to as the “sunny-day” scenario.
- A dry side slope failure.

5.2.1 Overtopping failure

This failure mode occurs when the pool overtops the impoundment embankment, and tailings are released from the basin as a result of this overtopping. An example of this type of failure is the Merrispruit Dam failure in February 1994. Once the breach forms, this failure mode quickly propagates to its full extent.

This scenario will only occur through very poor water management on the SSF. Currently water management practices are good and very little water is stored in the SSF pools. If proper water management practices continue, the SSFs can accommodate the 10 000-yr storm event without overtopping. **It must be noted that under the current water management practices, this failure mode should not be considered.** It was included for completeness or if water management practices deteriorate.

If poor water management on the SSFs occurs and large pools develop on the SSFs, this failure mode should be brought into consideration.

The mechanism for this failure mode is as follows:

- A large volume of water is stored on the SSF compartment basin. This would typically occur through poor pool management.
- An extreme storm generates enough storm water to cause the pool to overtop. Since these compartments generally carry very little water, the 10 000-yr storm (also referred to as the PMP) is considered as the likely trigger.
- The pool overtops the perimeter embankment at the lowest point on the embankment.
- The overflow erodes the outer embankment. Once the erosion has progressed far enough, tailings get mobilised from within the body of the SSF and a mixture of water and tailings flow out of the SSF.
- This process results in a two-wave hydrograph, i.e. two flood peaks. The initial water outflow is the first flood peak and then the tailings/water mixture outflow is the second flood peak.
- In the case of the SSF, the first flood peak is the larger of the two flood peaks and will have the largest zone of influence, and is used for the analysis.

The location for this type of failure will most likely occur at the lowest point on the perimeter embankment. This embankment is continually constructed as the SSF is raised. The low point on the embankment will therefore change position during the life of the SSF and its location at any point in the future is unknown. The breach location (likely this low point) is therefore also unknown. For the purposes of this study, multiple locations were chosen because the topography surrounding the SSFs is relatively flat and high hazard areas are located all around the SSFs.

5.2.2 Slurry/mud flows from within the basin

This failure mode is not linked to overtopping, but a large pool could create conditions that lead to the failure. This failure would likely occur due to a typical slip circle failure such as those discussed in Section 2.4.2 on page 8. It may be caused by an elevated phreatic surface, piping, earthquakes, insufficient consolidation or another event. A recent example of this type of failure is the Brumadinho dam collapse in January 2019.

On the Gloria SSF, the risk of this failure mode occurring is small because the low height of the SSF. Currently the volume of material that will slough is very small and is unlikely to result in an outflow of liquified tailings as the slip circle is likely to remain in the coarse slimes zone (refer to Figure 10). As the height of the SSF increases the probability that a failure in the coarse slimes zone will result in liquified tailings being released increases. This analysis assumes that the SSF will only breach to the east at current slimes levels.

On the Nchwaning SSF, the risk of this failure mode occurring is more significant than on the Gloria SSF. This is because of:

- A higher facility (approximately 9 m)
- Reduced factors of safety on some of the flanks

However it must be noted that the slip circles are located well within the coarse slimes zones where adequate consolidation is likely. The Boger slump tests have shown no or negligible flowable characteristics at dry densities exceeding 1 800 kg/m^3 and moisture contents less than 28.3%.

While the overtopping failure mode should not currently be considered due to the current water management practices, this failure mode is more likely to occur. For this failure to occur, additional water will need to be introduced into the consolidated slimes or insufficient consolidation would have to have occurred. Both of these are not inherent in the current operations and imply a deterioration of current operational practices. This should be noted in any risk assessment being carried out.

The mechanism for this failure mode is as follows:

- An event triggers the failure of the outer slope or a portion of the outer slope.
- The outer skin of the SSF is no longer able to contain the fine slimes stored within the SSF.
- The tailings will liquify and will flow out of the SSF.

5.2.3 Dry side slope failure

This failure mode is not linked to overtopping. This failure would likely occur due to a typical slip circle failure in the waste rock outer embankment or outer skin of the SSF such as those discussed in Section 2.4.2 on page 6. An elevated phreatic surface, and seismic activities are two likely causes of this type of failure. **While the overtopping failure mode should not be considered due to the current water management practices, this failure mode is more likely to occur.** The difference between this failure mode and slurry/mud flows from within the basin (discussed in the previous section) is that the tailings does not liquify and flow out of the SSF. This failure mode can best be described as a slump in the outer skin of the SSF. SANS 10286 describes this kind of failure mode and the likely impacts.

The extent of this failure mode is twice the height of the SSF at the location of the breach. This is significantly smaller than the other failure modes so no inundation mapping was produced for this failure mode.

6. BREACH VOLUMES

An overtopping failure of the SSF would lead to a discharge of free water within the TSF basin and would mobilise both tailings from the SSF and any construction material from any impoundment embankments or paddocks. The failure volume associated with the initial flood wave is constrained by the basin volume and the volume of tailings eroded from the SSF by the water in the basin. The volume of water that is required to cause overtopping was calculated using the latest survey data provided the mine. A 3D model of the basin was used to calculate these volumes.

It is assumed that once overtopping occurs, the full basin volume will be released as part of the initial flood wave. This assumes the failure mechanism will be the erosion of the outer embankment to such a degree that tailings would be mobilised. The bulk of the water would have been released by the time this occurs so the flood peak would have already passed. Highly diluted tailings would be released. This assumption has no influence of the flood peak and limited influence on the overall release volume.

The mass of solids mobilised as part of the mud flow flood wave was estimated by assuming instantaneous mixing of saturated tailings and pond water at 65% solids content by mass. The volumes used in the modelling are presented in Table 5.

The calculated tailings failure volumes for the two compartments for the two failure modes are presented in Table 5.

TABLE 5: FAILURE VOLUMES

	Gloria SSF	Nchwaning SSF
10 000-yr (PMP) storm volume	2 017 m^3	18 748 m^3
Total basin volume	7 618 m^3	108 420 m^3
Tailings mobilised (slurry/mud flows from within the basin failure)*Ŧ	14 326 m^3	341 561 m^3

7. BREACH HYDROGRAPHS

The numerical breach modelling was performed using the Flo2D Tailings Dam Failure Volume Estimate (2019) software. The Flo2D Tailings Dam Failure Volume Estimate simulates the breach process through the dam and provides the outflow hydrograph due to failure. The resulting breach hydrographs used in the analysis are presented in Figure 20 to Figure 23

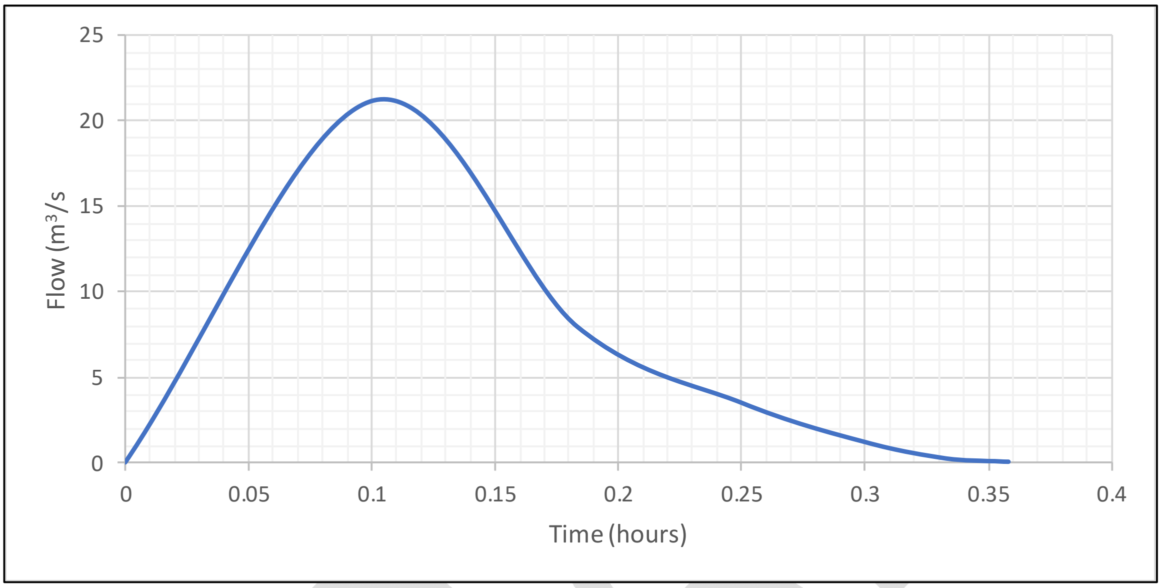


FIGURE 20: BREACH OUTFLOW HYDROGRAPH (OVERTOPPING FAILURE, GLORIA SSF)

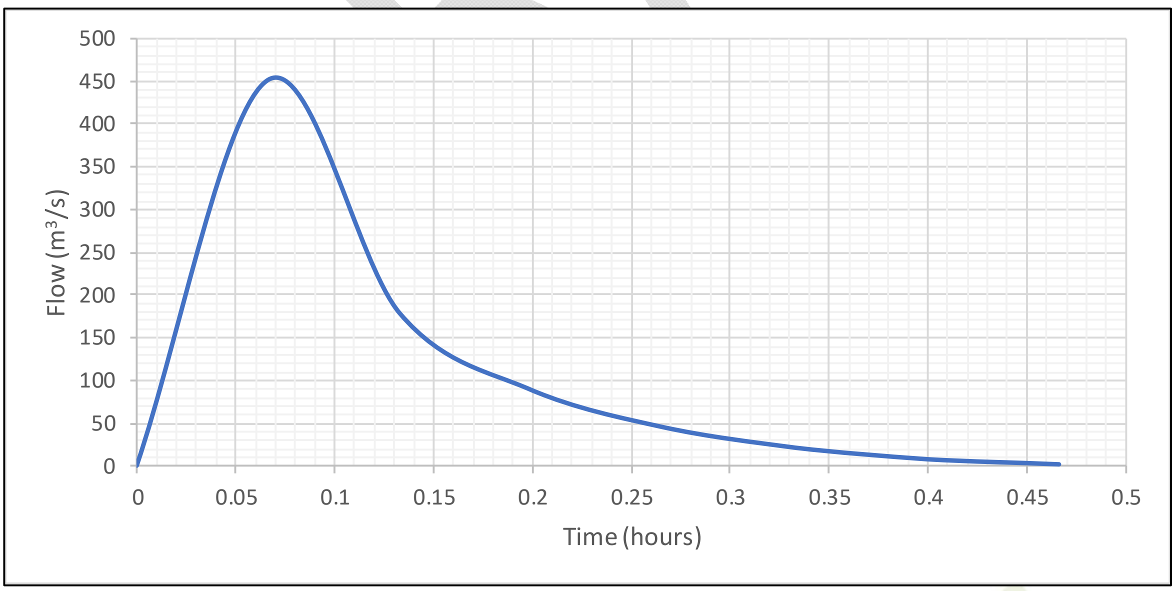


FIGURE 21: BREACH OUTFLOW HYDROGRAPH (OVERTOPPING FAILURE, NCHWANING SSF)

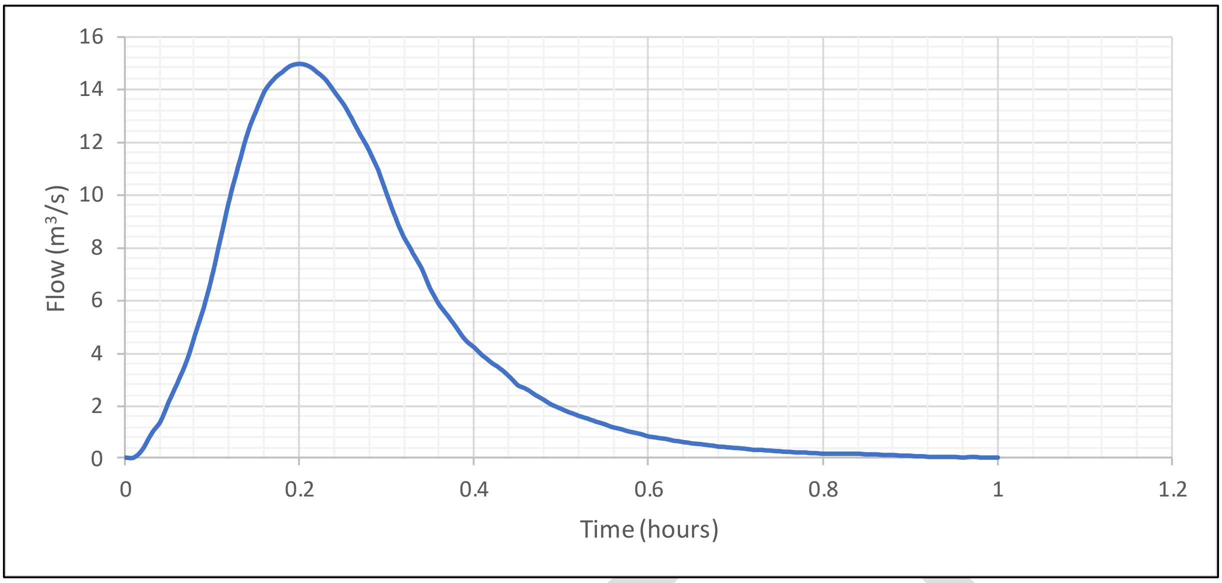


FIGURE 22: BREACH OUTFLOW HYDROGRAPH (SLURRY/MUD FLOWS FROM WITHIN THE BASIN FAILURE, GLORIA SSF)

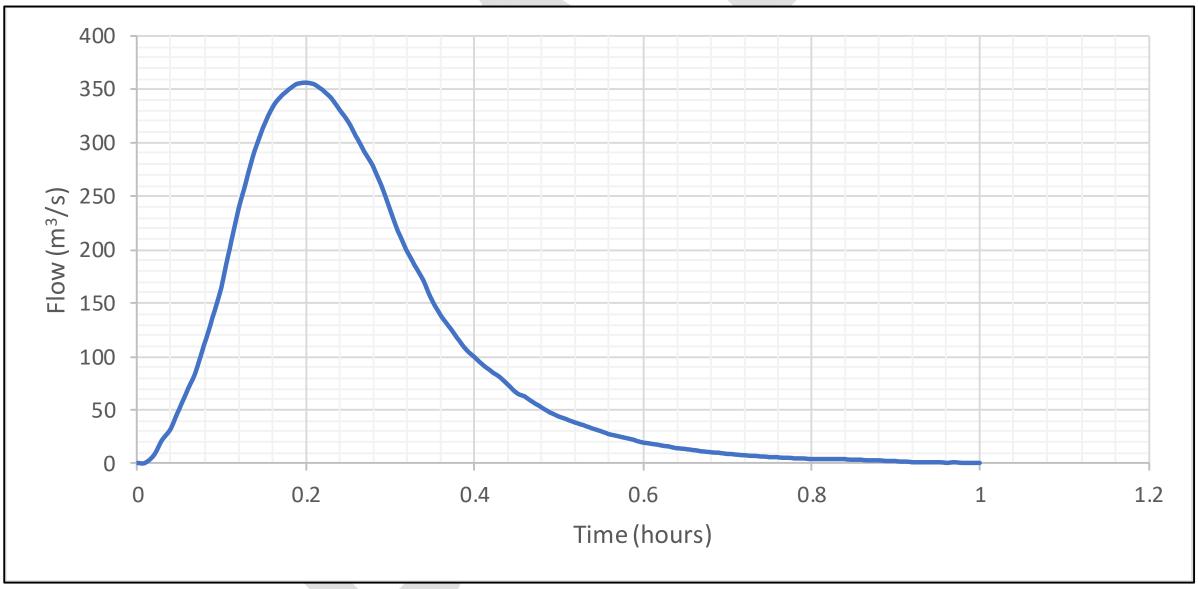


FIGURE 23: BREACH OUTFLOW HYDROGRAPH (SLURRY/MUD FLOWS FROM WITHIN THE BASIN FAILURE, NCHWANING SSF)

8. DOWNSTREAM FLOOD WAVE ANALYSIS AND MAPPING

Flood wave analyses were performed to estimate the hydraulic characteristics of the breach outflows as they travel downstream of the SSF. Numerical modelling was performed using the Flo2D software. A Manning's roughness value of 0.04 was selected to represent the hydraulic roughness of the downstream areas. A grid size of 20 m was used.

8.1 Hazard Identification – Gloria

The inundation zones are shown in Appendix A.

One permanent population at risk was identified within the inundation zones. This is the slimes dam operator that provides access control to the Gloria SSF. This post is likely to be manned 24 hours a day. The close proximity to the SSF and the permanent nature of the post makes this a high hazard area.

Temporary population at risk include persons working on or downstream of the tailings dam at the time of failure, as well as travellers on the access road and the Black Rock siding (railway line). Should the SSF fail to the east, the access road will experience high velocities (>5 m/s) and depths (>1 m) These flows are unsafe for vehicles and pedestrians and the hazard is considered high. Flows into the plant are considered low hazard as velocities and flow depths will be low.

While it is recommended that every effort be made to warn users of the access road, railway line, and workers in the plant that a dam breach flood is eminent, it is not considered feasible to implement an advance warning system.

The dry side slope failure will have a maximum extent of ≈4-6 m and will likely not overrun the access road.

8.2 Hazard Identification – Nchwaning

The inundation zones are shown in Appendix B.

Permanent population at risk was identified outside of the survey extents. The results indicate that with a breach on the eastern side of the Nchwaning SSF, the homesteads located to the east of the SSF will likely be in the inundation zone. The survey data available does not include these homesteads so this cannot be verified with certainty. Should flows occur into these houses, the hazard is considered low risk as the velocities and flow depths are low.

Temporary population at risk include persons working on or downstream of the tailings dam at the time of failure. High flow velocities (>5 m/s) and depths (>1 m) are noted at contractor camps adjacent to the SSF. These flows are unsafe for vehicles and pedestrians and the hazard is considered high.

Impacted infrastructure for an overtopping failure includes the shaft and large areas of the plant. The shaft hazard is considered low as flow depth and flow velocities are low. The analysis shows that the new SSF will be impacted in the case of an overtopping failure to the south, and a mudflow failure to the west and to the south. The time between the development of a breach and the flood wave reaching the shaft and surrounding plant infrastructure is very short (< 5 min).

While it is recommended that every effort be made to warn contractors in the contractors yards adjacent to the SSF and workers in the plant that a dam breach flood is eminent, it is not considered feasible to implement an advance warning system for those within 800 m of the breach location.

The dry side slope failure will have a maximum extent of ≈18 m and will likely not damage any infrastructure.

9. STATISTICAL RISK ANALYSIS

The chance of receiving various 24-hour design storms at least once during the next year and the next 8 years are shown in Table 6.

TABLE 6: PROBABILITY OF RECEIVING LARGE STORMS DURING THE NEXT YEAR AND THE NEXT 8 YEARS

Storm recurrence interval	Probability of occurrence	
	In the next year	In the next 8 years
50-yr	2.0%	15%
100-yr	1.0%	8%
200-yr	0.5%	3.9%
1 000-yr	0.1%	0.8%
10 000-yr	0.01%	0.08%

10. CONCLUSIONS

This report documents the hazards associated with a dam breach, not the risk of such events occurring. It assumes that the dam breach *will* occur. This report should be read in conjunction with a risk assessment. This report must also feed into any risk assessments, as certain failure modes are considered implausible with current operational practices and current SSF configurations.

The SSF can have many types of failures, or combinations of these. These types of failures can be aggregated into three main failure types for practical reasons:

- Overtopping failure. This is commonly referred to as the “rainy-day” scenario.
- Slurry/mud flows from within the basin, not linked to overtopping. This is commonly referred to as the “sunny-day” scenario.
- A dry side slope failure.

10.1 Overtopping Failure

This scenario will only occur through very poor water management on the SSFs. Currently water management practices are good and very little water is stored in the SSF pools. If proper water management practices continue, the SSFs can accommodate the 10 000-yr storm event without overtopping. It must be noted that under the current water management practices, this failure mode should not be considered. It was included for completeness or if water management practices deteriorate.

10.2 Slurry/Mud Flows from Within the Basin

On the Nchwaning SSF, the risk of this failure mode occurring is more significant than on the Gloria SSF. This is because of:

- A higher facility (approximately 9 m)
- Reduced factors of safety on some of the flanks

It must be noted that the slip circles are located well within the coarse slimes zones where adequate consolidation is likely. The Boger slump tests have shown no or negligible flowable characteristics at dry densities exceeding 1 800 kg/m^3 and moisture contents less than 28.3%.

While the overtopping failure mode should not currently be considered due to the current water management practices, this failure mode is more likely to occur. For this failure to occur, additional water will need to be introduced into the consolidated slimes or insufficient consolidation would have to have occurred. Both of these are not inherent in the current operations and imply a deterioration of current operational practices. This should be noted in any risk assessment being carried out.

10.3 Dry Side Slope Failure

While the overtopping failure mode should not be considered due to the current water management practices, this failure mode is more likely to occur. The difference between this failure mode and slurry/mud flows from within the basin (discussed in the previous section) is that the tailings does not liquify and flow out of the SSF. This failure mode can best be described as a slump in the outer skin of the SSF with an inundation zone of less than 6 m and 18 m for the Gloria and Nchwaning SSFs respectively.

10.4 Hazard Identification

10.4.1Gloria SSF

One permanent population at risk was identified within the inundation zones. This is the slimes dam operator that provides access control to the Gloria SSF. This post is likely to be manned 24 hours a day. The close proximity to the SSF and the permanent nature of the post makes this a high hazard area.

Temporary population at risk include persons working on or downstream of the tailings dam at the time of failure, as well as travellers on the access road and the Black Rock siding (railway line). Should the SSF fail to the east, the access road will experience high velocities (>5 m/s) and depths (>1 m) These flows are unsafe for vehicles and pedestrians and the hazard is considered high. Flows into the plant are considered low hazard as velocities and flow depths will be low.

While it is recommended that every effort be made to warn users of the access road, railway line, and workers in the plant that a dam breach flood is eminent, it is not considered feasible to implement an advance warning system.

The dry side slope failure will have a maximum extent of ≈4-6 m and will likely not overrun the access road.

10.4.2Nchwaning SSF

The inundation zones are shown in Appendix B.

Permanent population at risk was identified outside of the survey extents. The results indicate that with a breach on the eastern side of the Nchwaning SSF, the homesteads located to the east of the SSF will likely be in the inundation zone. The survey data available does not include these homesteads so this cannot be verified with certainty. Should flows occur into these houses, the hazard is considered low risk as the velocities and flow depths are low.

Temporary population at risk include persons working on or downstream of the tailings dam at the time of failure. High flow velocities (>5 m/s) and depths (>1 m) are noted at contractor camps adjacent to the SSF. These flows are unsafe for vehicles and pedestrians and the hazard is considered high.

Impacted infrastructure for an overtopping failure includes the shaft and large areas of the plant. The shaft hazard is considered low as flow depth and flow velocities are low. The analysis shows that the new SSF will be impacted in the case of an overtopping failure to the south, and a mudflow failure to the west and to the south. The time between the development of a breach and the flood wave reaching the shaft and surrounding plant infrastructure is very short (< 5 min).

While it is recommended that every effort be made to warn contractors in the contractors yards adjacent to the SSF and workers in the plant that a dam breach flood is eminent, it is not considered feasible to implement an advance warning system for those within 800 m of the breach location.

The dry side slope failure will have a maximum extent of ≈18 m and will likely not damage any infrastructure.

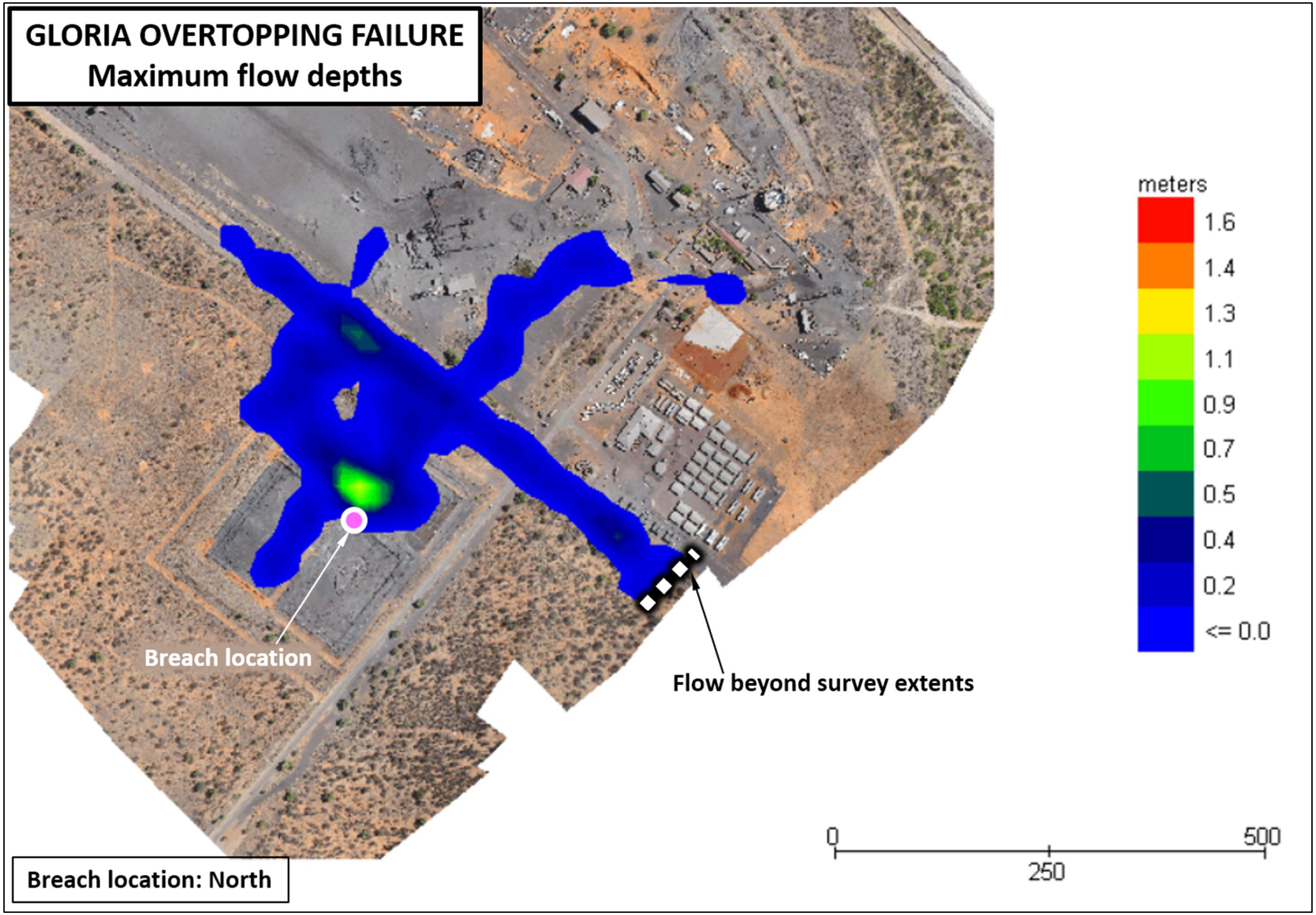
10.5 Recommendations

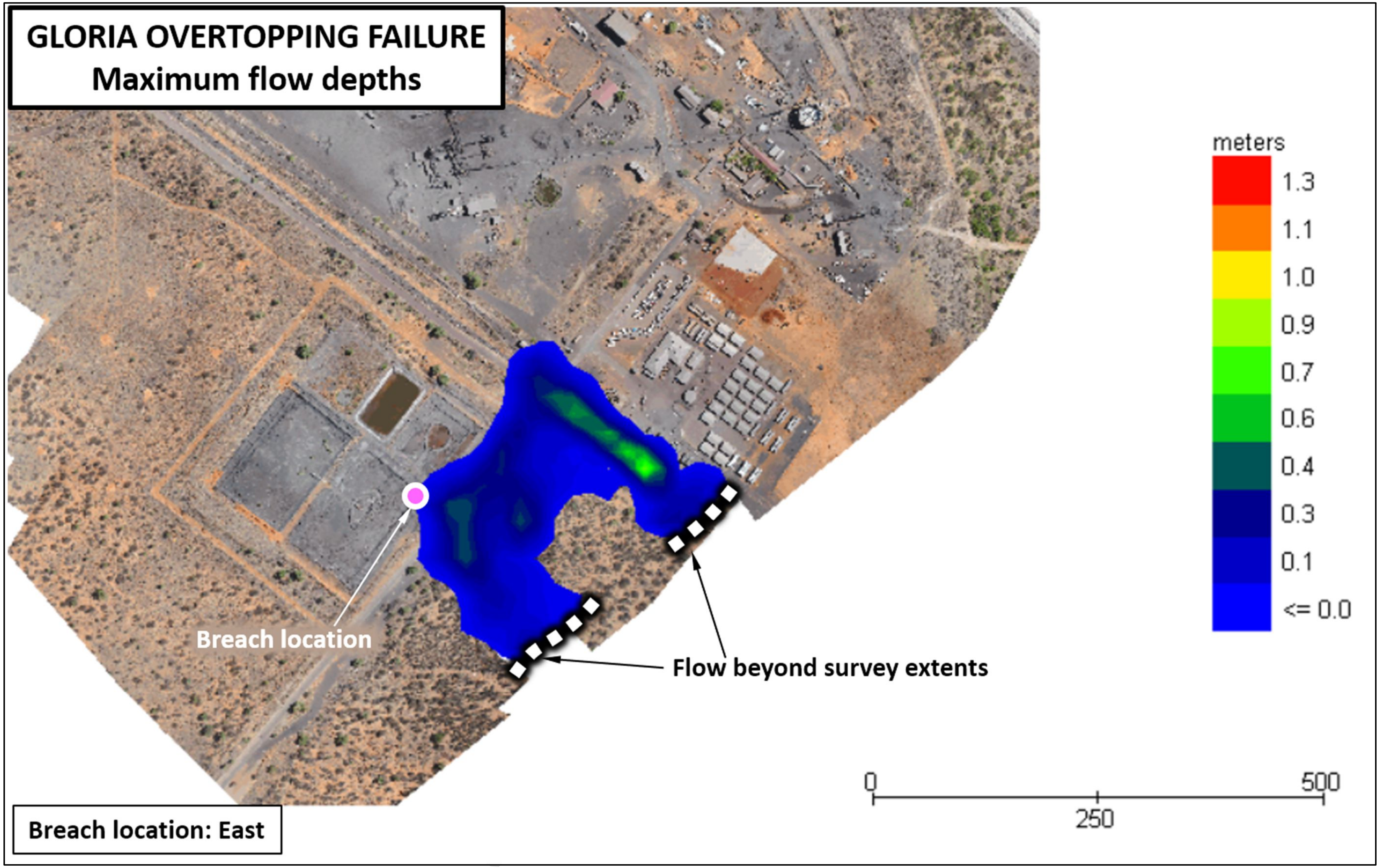
It is recommended that the dam breach analysis be repeated every 2-3 years.

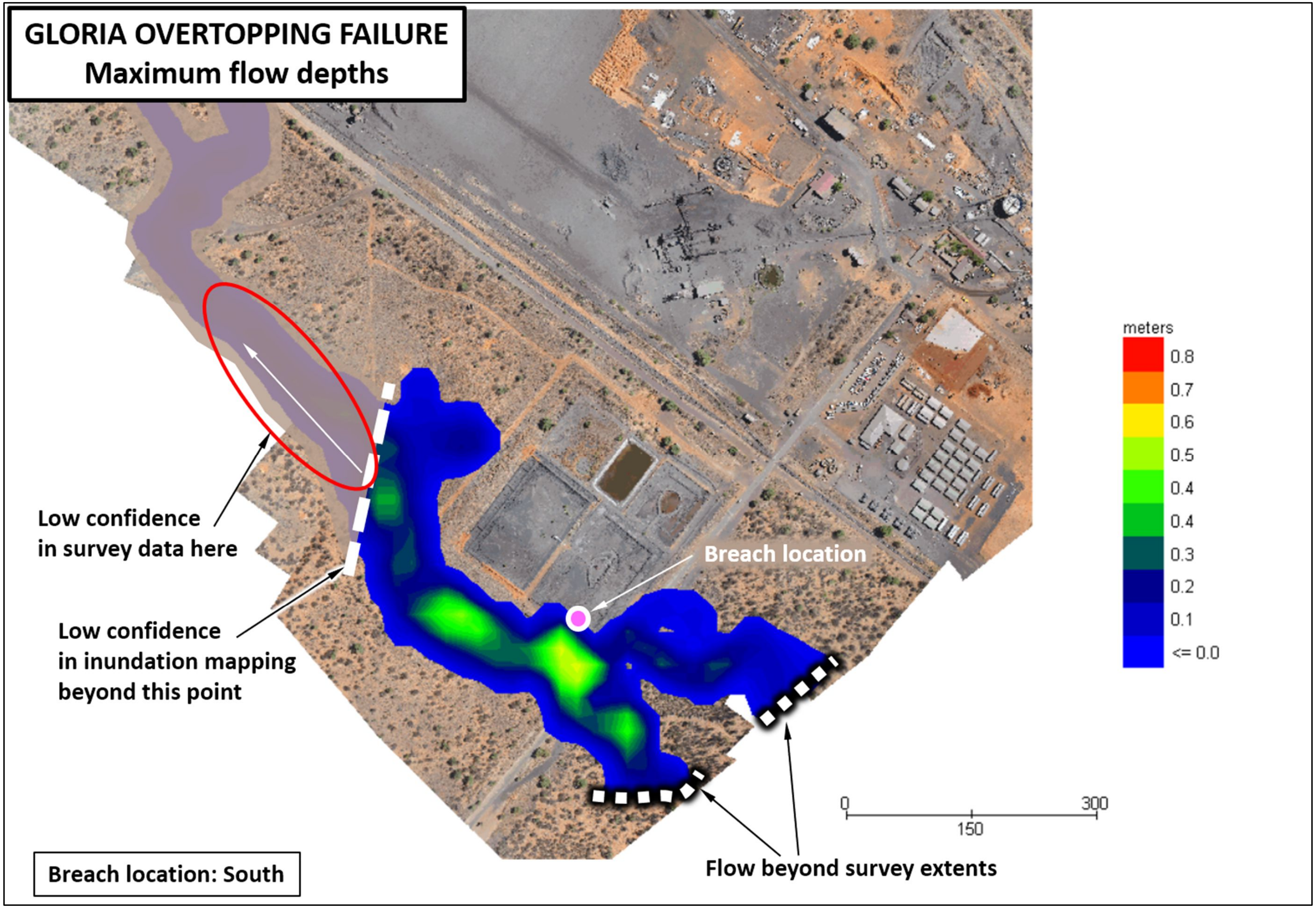
For subsequent analyses, the survey of the Nchwaning SSF should be extended to the east to include the homesteads.

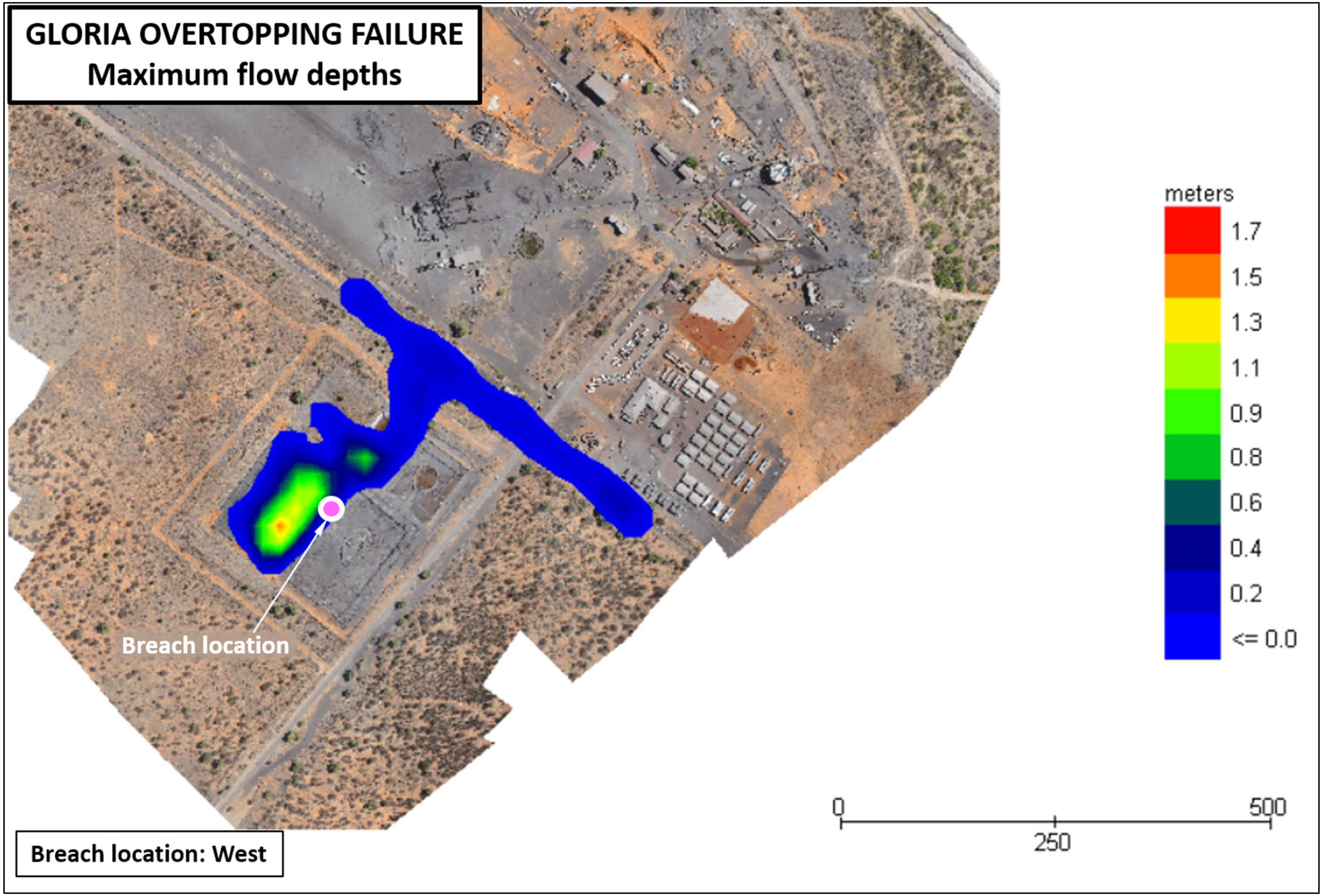
Survey of the Gloria SSF should be extended to the west to allow for more accurate determination of breaches to the south of the Gloria SSF.

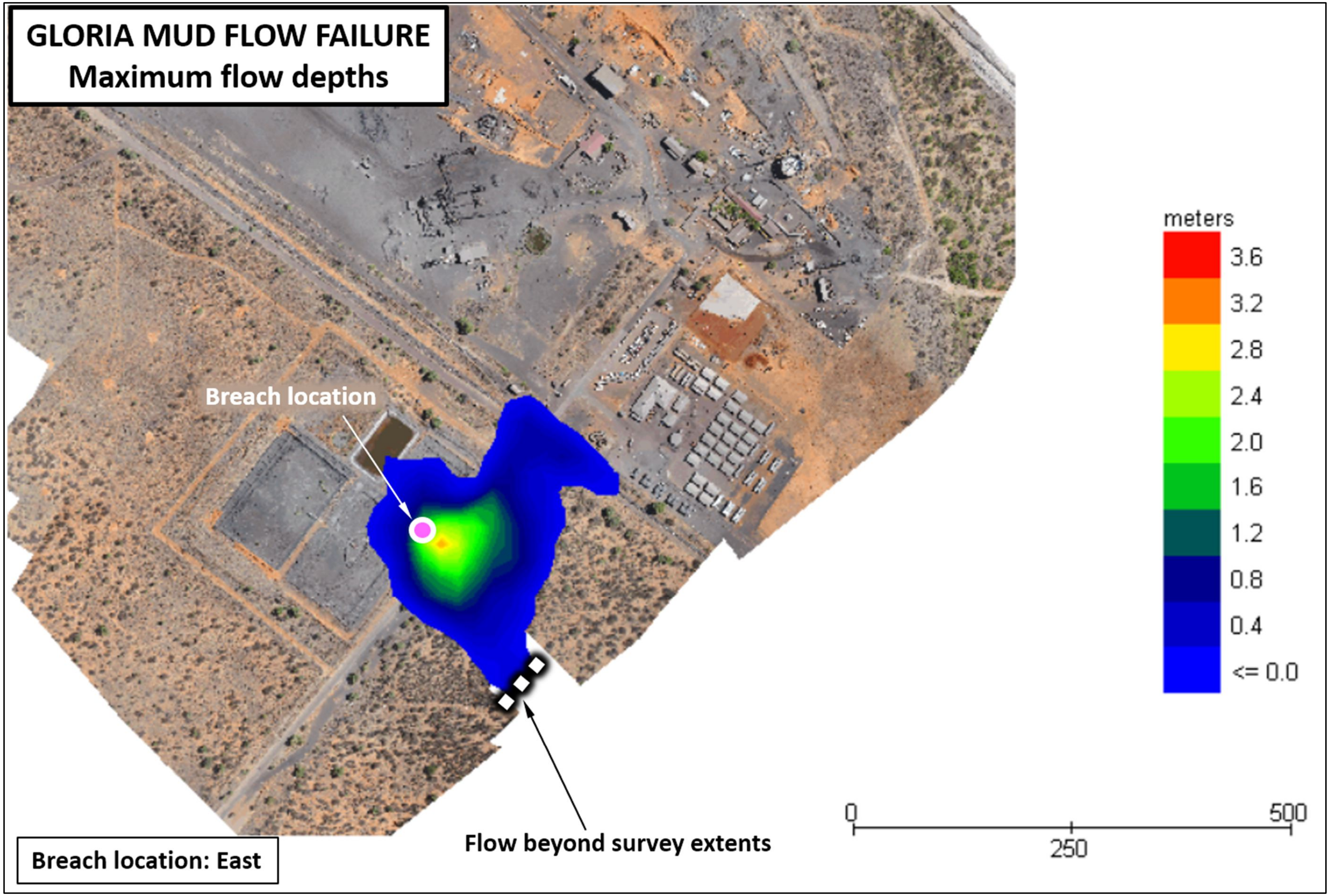
Appendix A: Gloria Inundation Zones

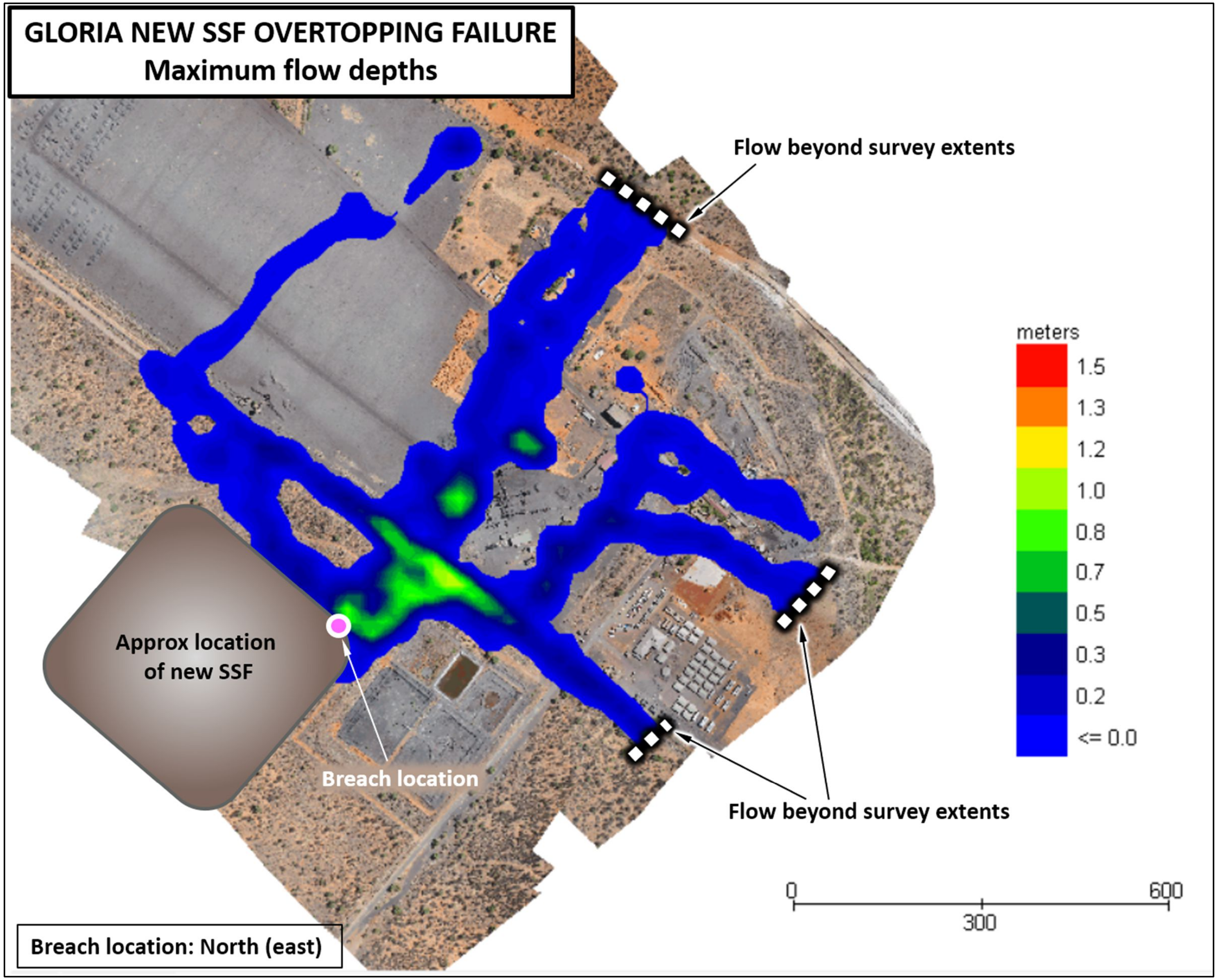

GLORIA OVERTOPPING FAILURE
Maximum flow depths
meters
1.6
1.4
1.3
1.1
0.9
0.7
0.5
0.4
0.2
<= 0.0
Breach location
Flow beyond survey extents
0
250
500
Breach location: North

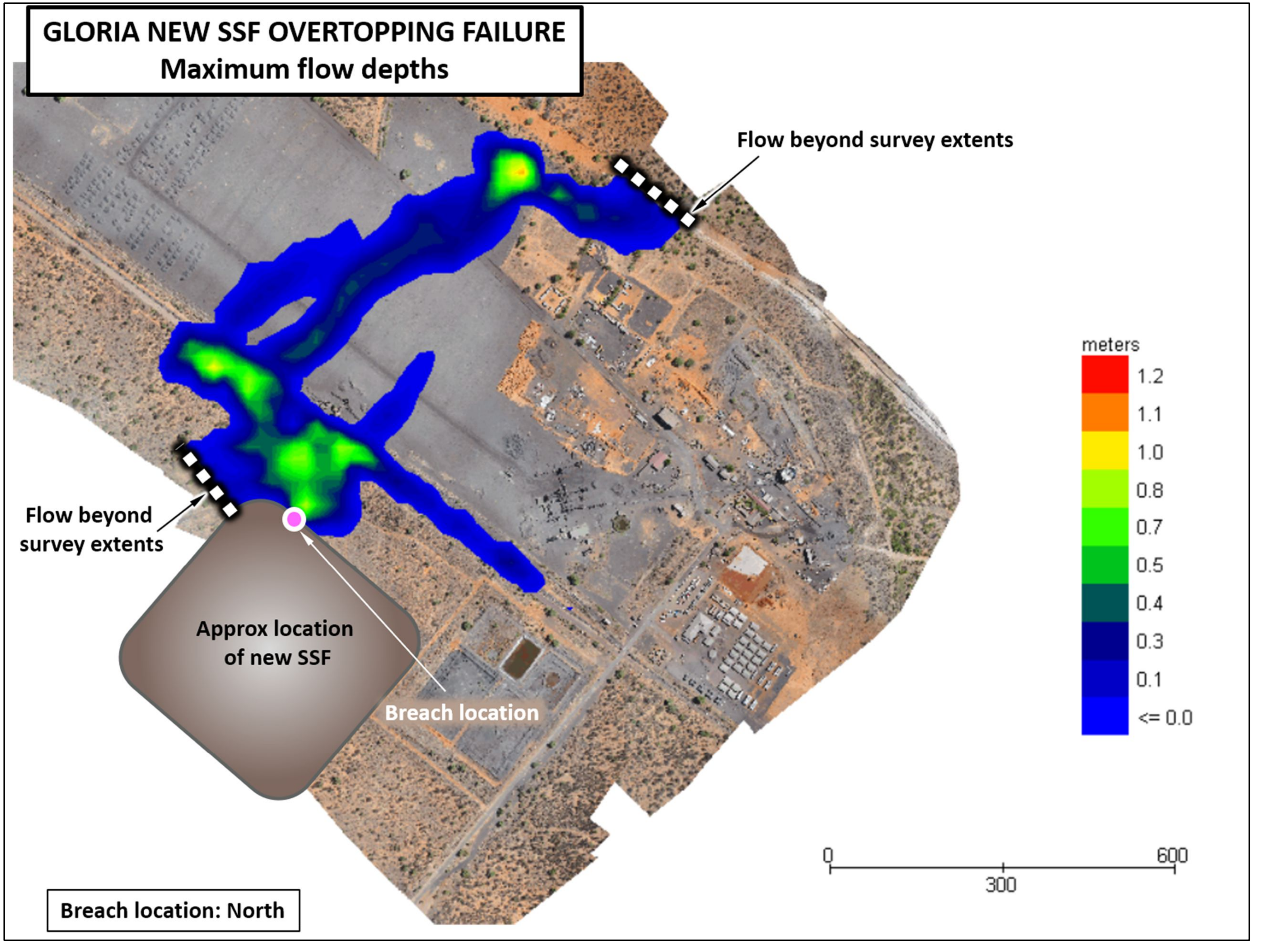

GLORIA OVERTOPPING FAILURE
Maximum flow depths
meters
1.3
1.1
1.0
0.9
0.7
0.6
0.4
0.3
0.1
<= 0.0
Breach location
Flow beyond survey extents
0
250
500
Breach location: East


GLORIA OVERTOPPING FAILURE
Maximum flow depths
Low confidence in survey data here
Low confidence in inundation mapping beyond this point
Breach location
Flow beyond survey extents
Breach location: South
meters
0.8
0.7
0.6
0.5
0.4
0.4
0.3
0.2
0.1
<= 0.0
0
150
300

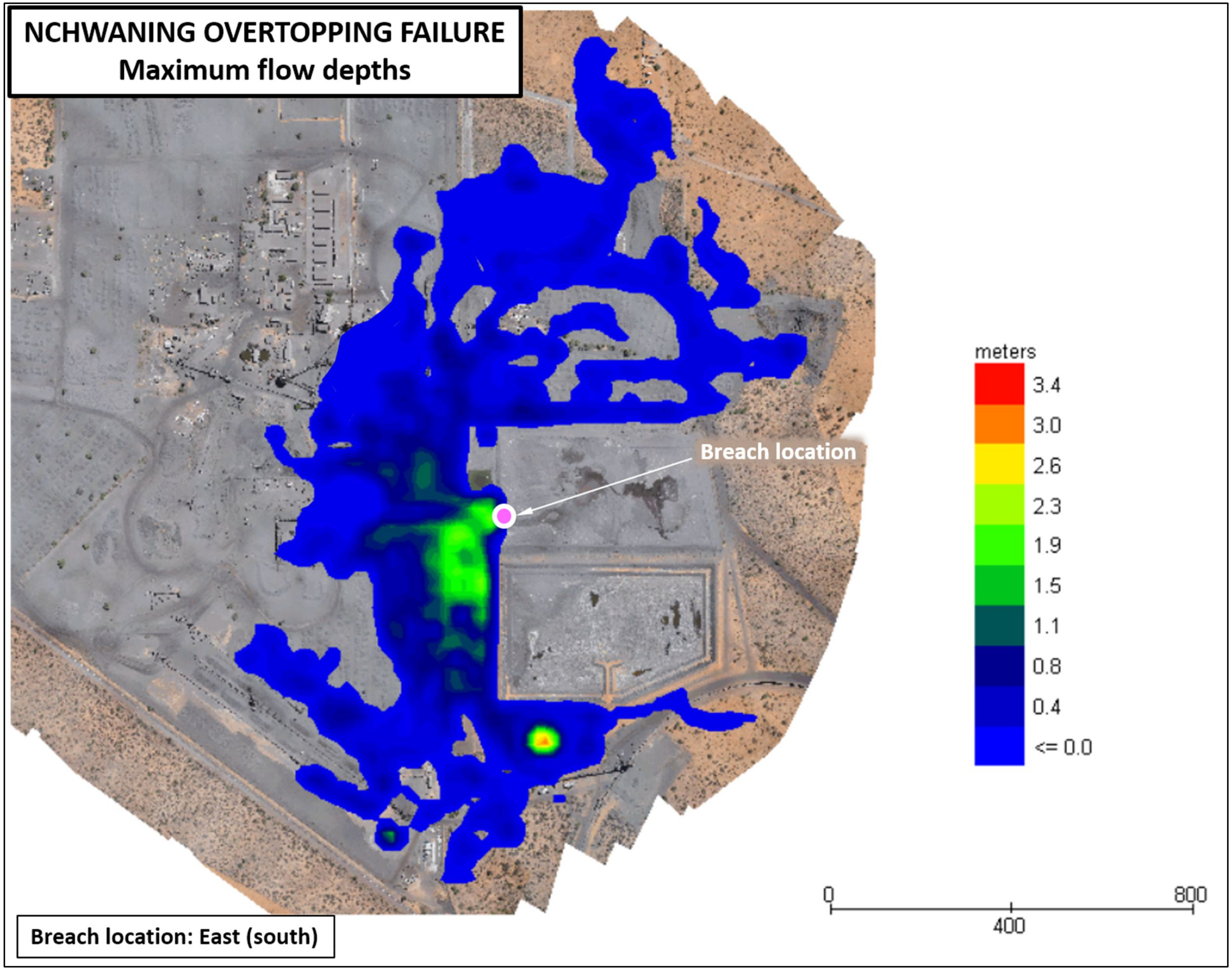

GLORIA OVERTOPPING FAILURE
Maximum flow depths
meters
1.7
1.5
1.3
1.1
0.9
0.8
0.6
0.4
0.2
<= 0.0
Breach location
0
250
500
Breach location: West

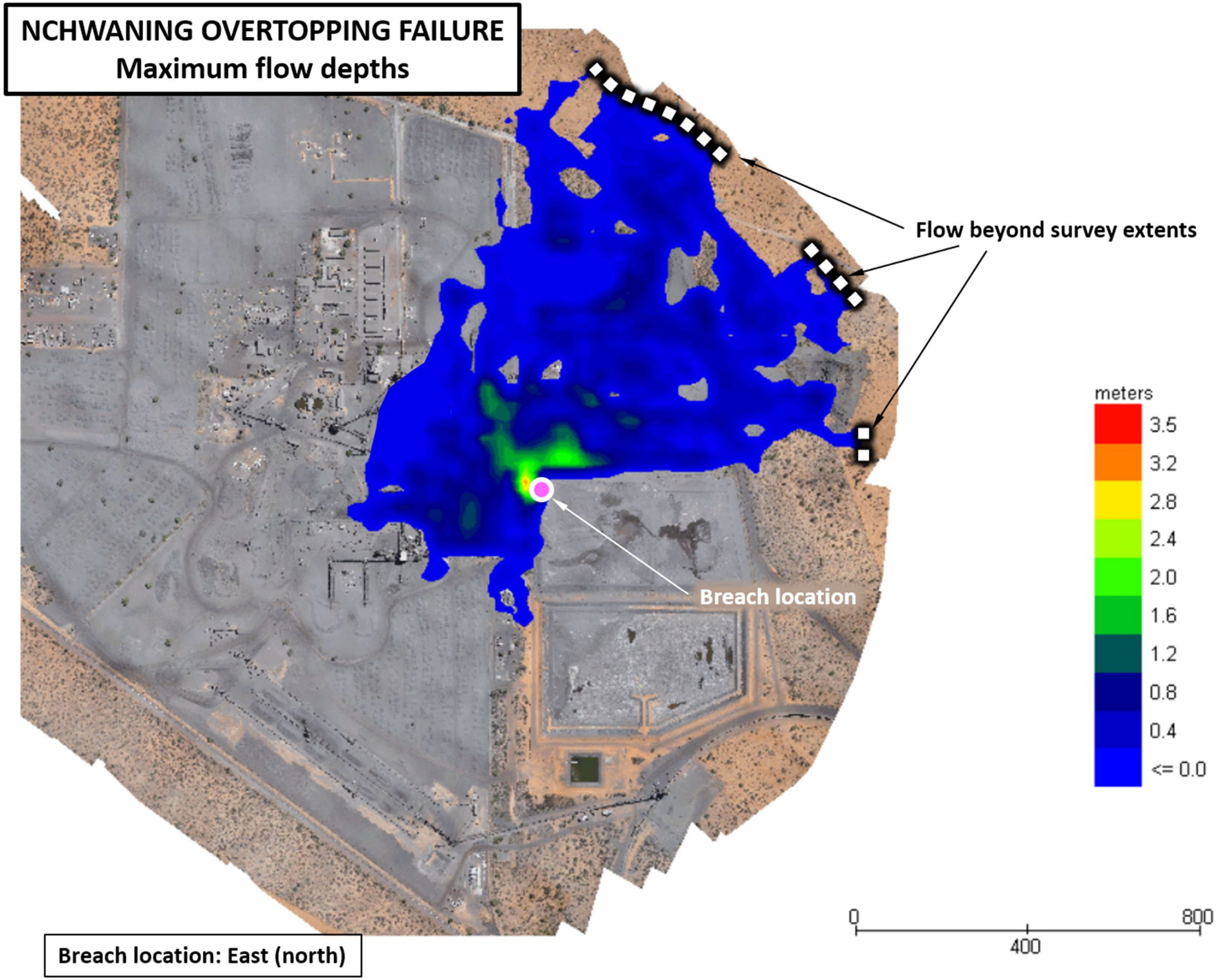

GLORIA MUD FLOW FAILURE
Maximum flow depths
Breach location
meters
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
<= 0.0
0
250
500
Flow beyond survey extents
Breach location: East

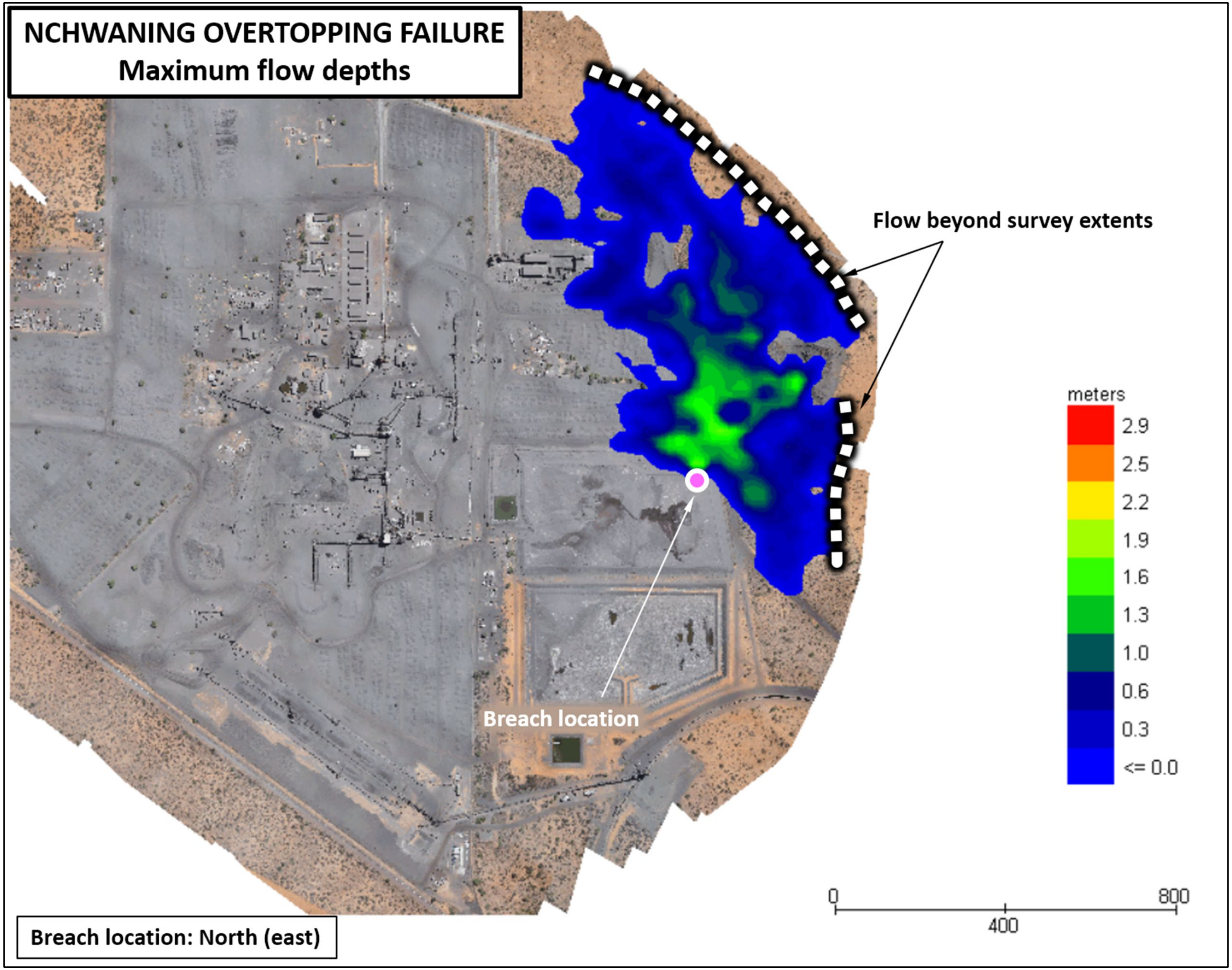

GLORIA NEW SSF OVERTOPPING FAILURE
Maximum flow depths
Flow beyond survey extents
meters
1.5
1.3
1.2
1.0
0.8
0.7
0.5
0.3
0.2
<= 0.0
Approx location of new SSF
Breach location
Flow beyond survey extents
0
300
600
Breach location: North (east)

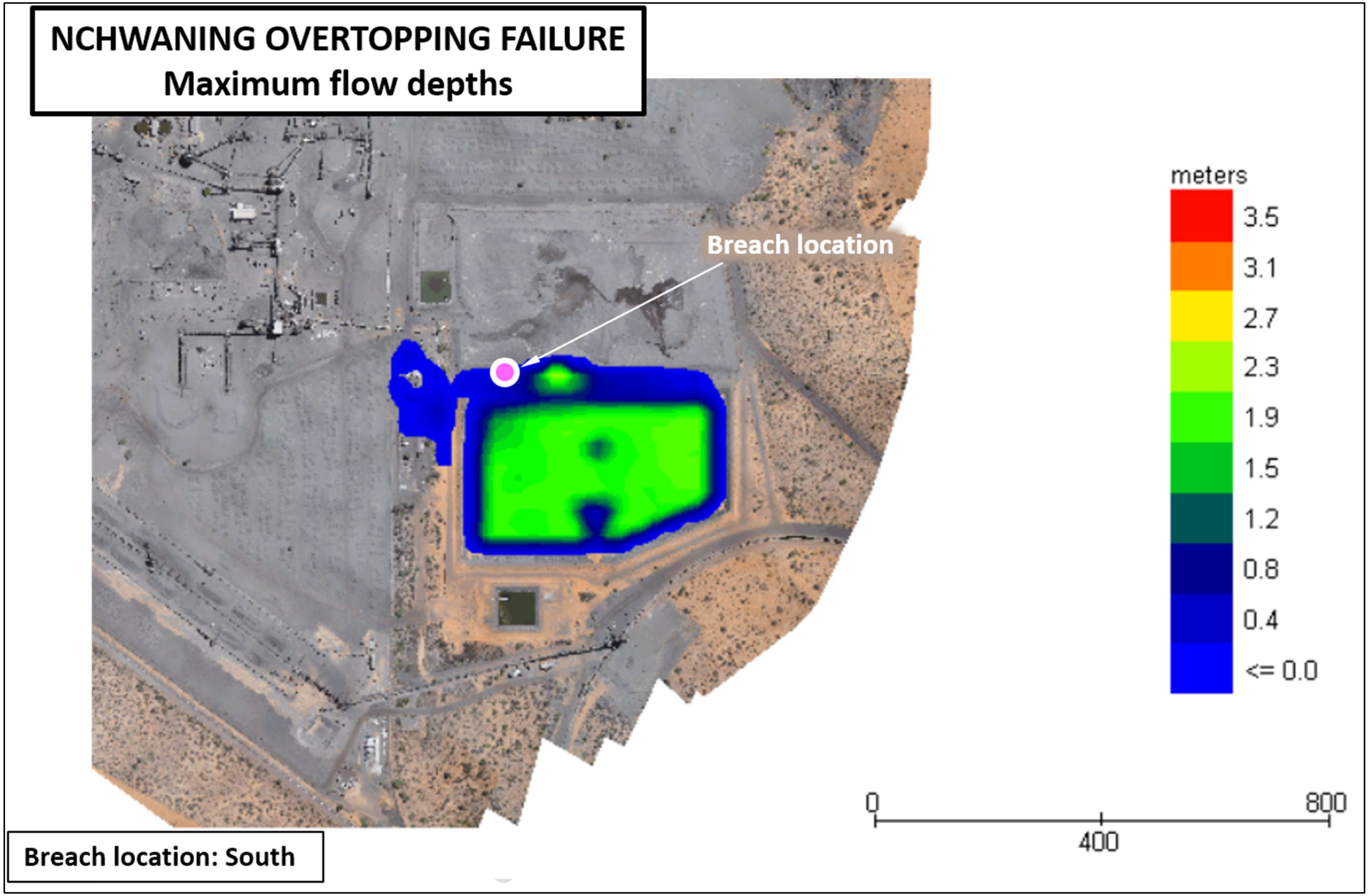

GLORIA NEW SSF OVERTOPPING FAILURE
Maximum flow depths
Flow beyond survey extents
Flow beyond survey extents
Approx location of new SSF
Breach location
meters
1.2
1.1
1.0
0.8
0.7
0.5
0.4
0.3
0.1
<= 0.0
0
300
600
Breach location: North

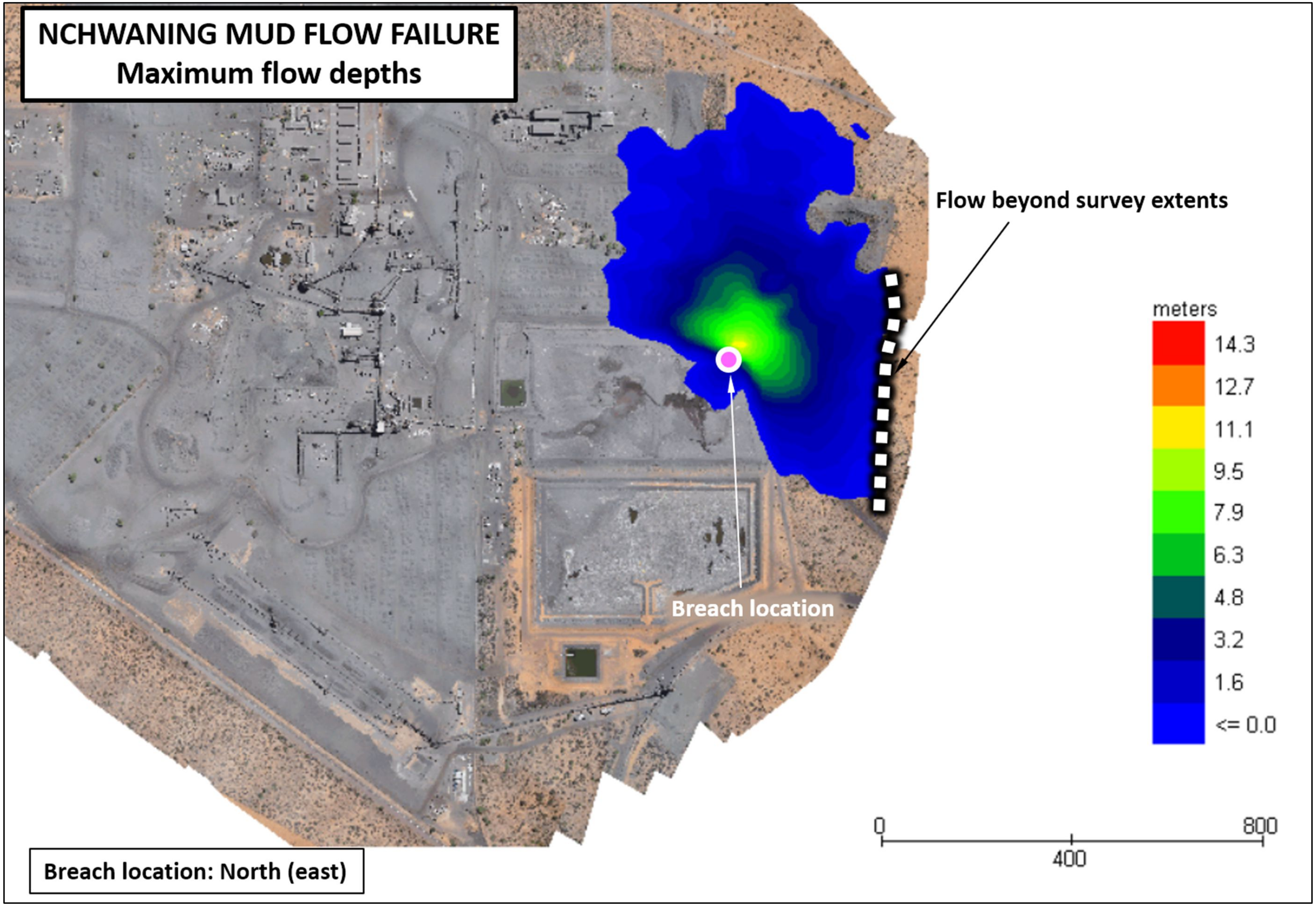
Appendix B: Nchwaning Inundation Zones

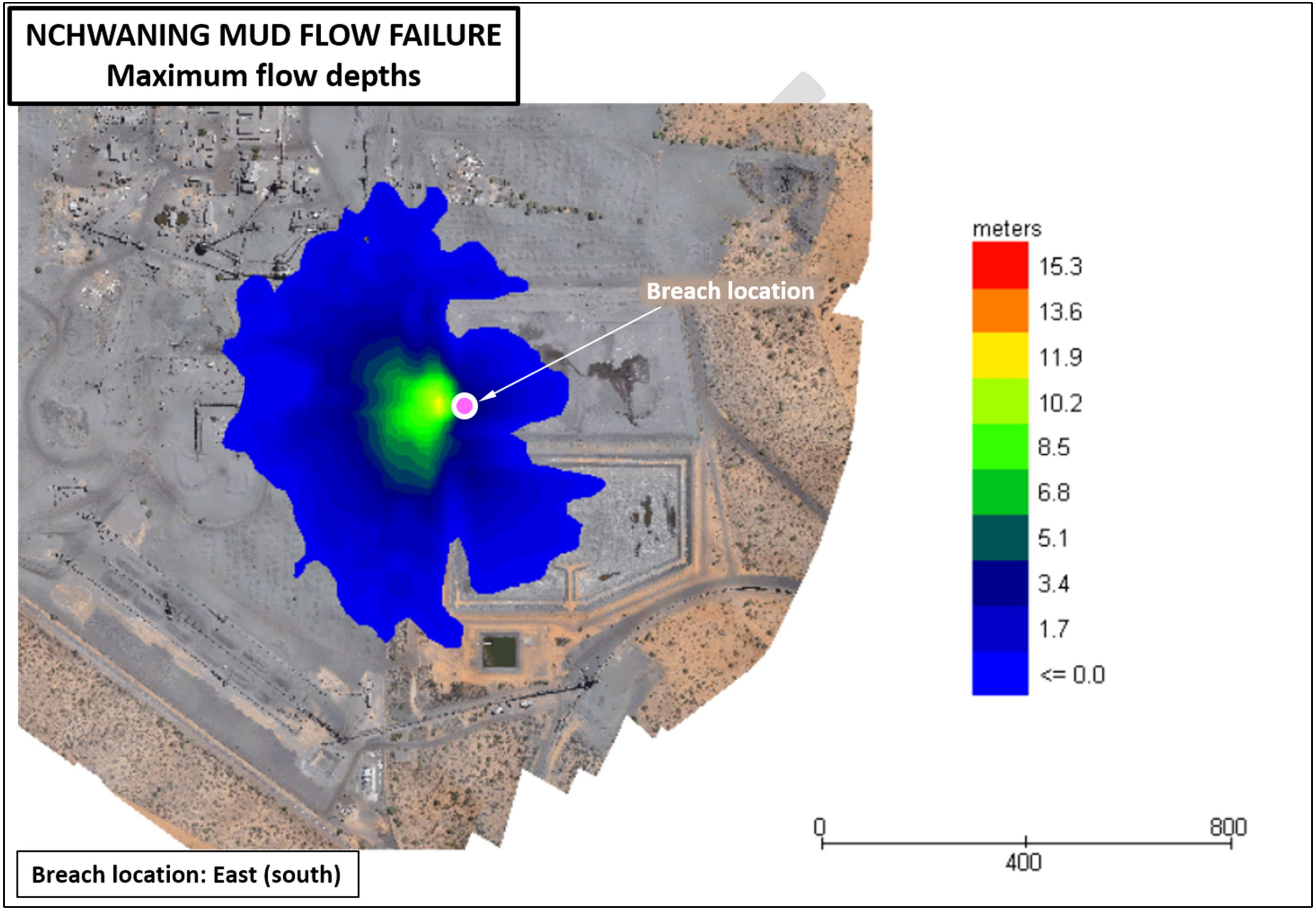

NCHWANING OVERTOPPING FAILURE
Maximum flow depths
Breach location
meters
3.4
3.0
2.6
2.3
1.9
1.5
1.1
0.8
0.4
<= 0.0
0
400
800
Breach location: East (south)


NCHWANING OVERTOPPING FAILURE
Maximum flow depths
Flow beyond survey extents
Breach location
meters
3.5
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
<= 0.0
0
400
800
Breach location: East (north)


NCHWANING OVERTOPPING FAILURE
Maximum flow depths
Flow beyond survey extents
meters
2.9
2.5
2.2
1.9
1.6
1.3
1.0
0.6
0.3
<= 0.0
Breach location
0
400
800
Breach location: North (east)


NCHWANING OVERTOPPING FAILURE
Maximum flow depths
Breach location
meters
3.5
3.1
2.7
2.3
1.9
1.5
1.2
0.8
0.4
<= 0.0
0
400
800
Breach location: South


NCHWANING MUD FLOW FAILURE
Maximum flow depths
Flow beyond survey extents
meters
14.3
12.7
11.1
9.5
7.9
6.3
4.8
3.2
1.6
<= 0.0
Breach location
0
400
800
Breach location: North (east)


NCHWANING MUD FLOW FAILURE
Maximum flow depths
Breach location
meters
15.3
13.6
11.9
10.2
8.5
6.8
5.1
3.4
1.7
<= 0.0
0
400
800
Breach location: East (south)