HARMONY NOOITGEDACHT TSF AND PIPELINES HYDROLOGICAL ASSESSMENT

Project No. EIM-013

Version 3

May 2025

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HARMONY NOOITGEDACHT TSF AND PIPELINES HYDROLOGICAL ASSESSMENT

Prepared For

EIMS (PTY) LTD

Prepared By

Hydrologic Consulting (Pty) Ltd

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HARMONY NOOITGEDACHT TSF AND PIPELINES HYDROLOGICAL ASSESSMENT

1 INTRODUCTION

Hydrologic Consulting has been appointed by Environmental Impact Management Services (EIMS) to undertake a hydrological assessment of the proposed Harmony Gold Mining Company Limited (Harmony) Nooitgedacht Tailings Storage Facility (TSF), located west of the town of Welkom, in the Free State Province of South Africa.

This report outlines the hydrological baseline relevant to the forthcoming hydrological assessment, which will evaluate the hydrological impact of the proposed TSF, pipelines, and the Low Pressure (LP) Water Storage and Supply System, as well as an indication of flood-lines relevant to the National Environmental Management Act (Act No. 107 of 1998), Department of Water and Sanitation Notice 509 of 2016 and Government Notice 704 (Government Gazette 20118 of June 1999).

1.1 SCOPE OF WORK

The scope of work was achieved by undertaking the following:

- Baseline Assessment – sourcing of baseline climatic and hydrological data. This included the interrogation of rainfall data, site-specific design rainfall (depth/duration/frequency), evaporation, soils, and land-use, as well as a regional and local hydrological assessment.
- Site Examination – the site was visited by Hydrologic Consulting on the 13th of April 2023;
- Flood Modelling – to define the 1:50, 1:100 and probable maximum flood (PMF) events, a PCSWMM model (hydrology) and 2D HEC-RAS (hydraulic) flood model were developed;
- Hydrological Impact Assessment – this was undertaken using a recognised risk assessment methodology developed to enable effective communication of the potential consequences or impacts of activities on the hydrological (surface water) environment; and
- A technical report detailing the achieved scope of work (this report).

1.2 REGIONAL SETTING AND LAYOUT

The Nooitgedacht Tailings Storage Facility, associated pipelines, and the proposed LP Water System (hereafter also collectively referred to as the site) are located at 27° 56'20" S and 26° 39'47" E. The regional setting of the site is illustrated in Figure 1-1, while the layout of the site is presented in Figure 1-2. The TSF includes the following associated infrastructure:

- TSF related:
  - Penstock Pipeline; and
  - Cyclone Embankment.
  - Toe Paddocks
  - Toe Rings
  - Return Water Dam (RWD);

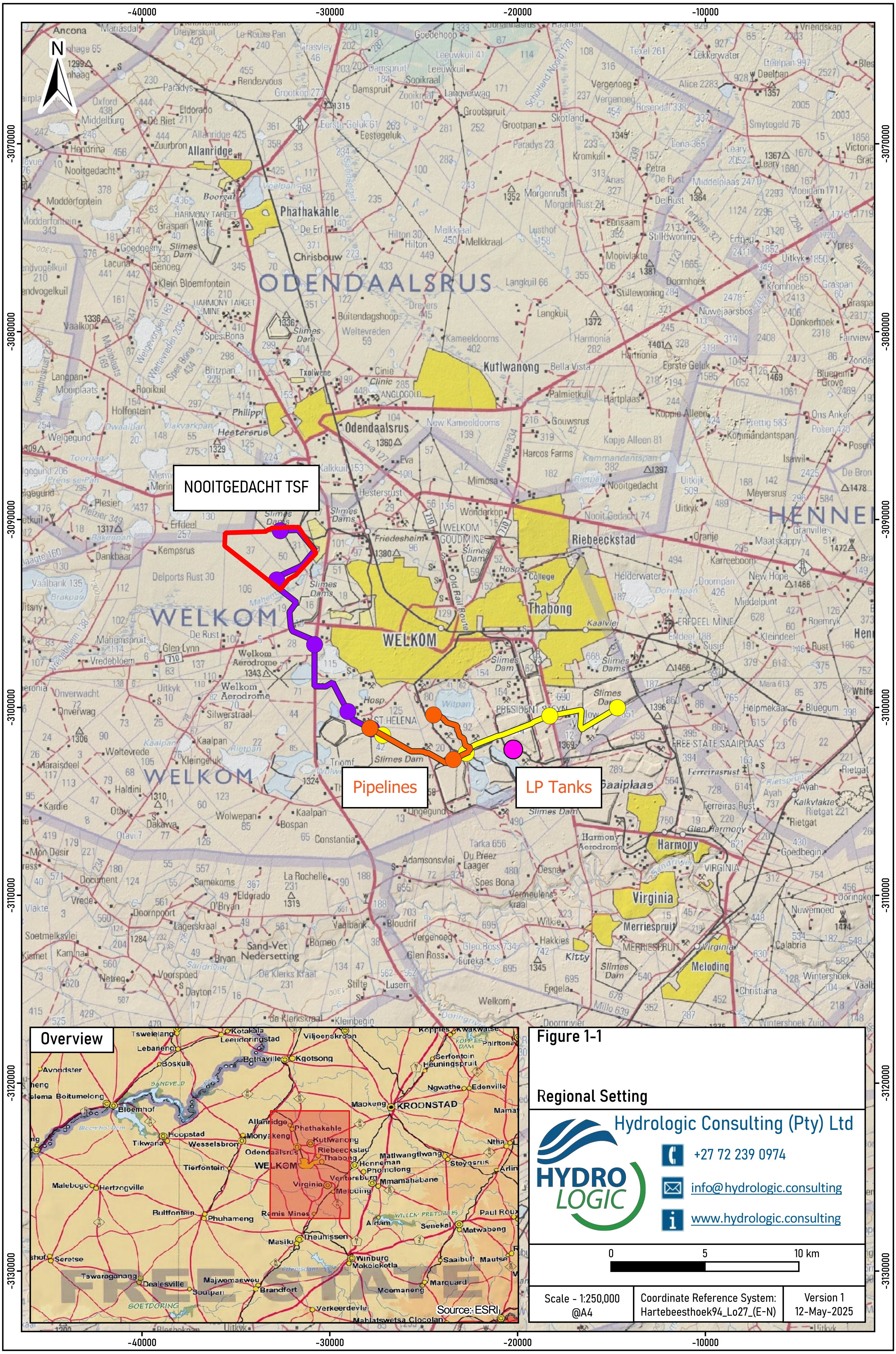
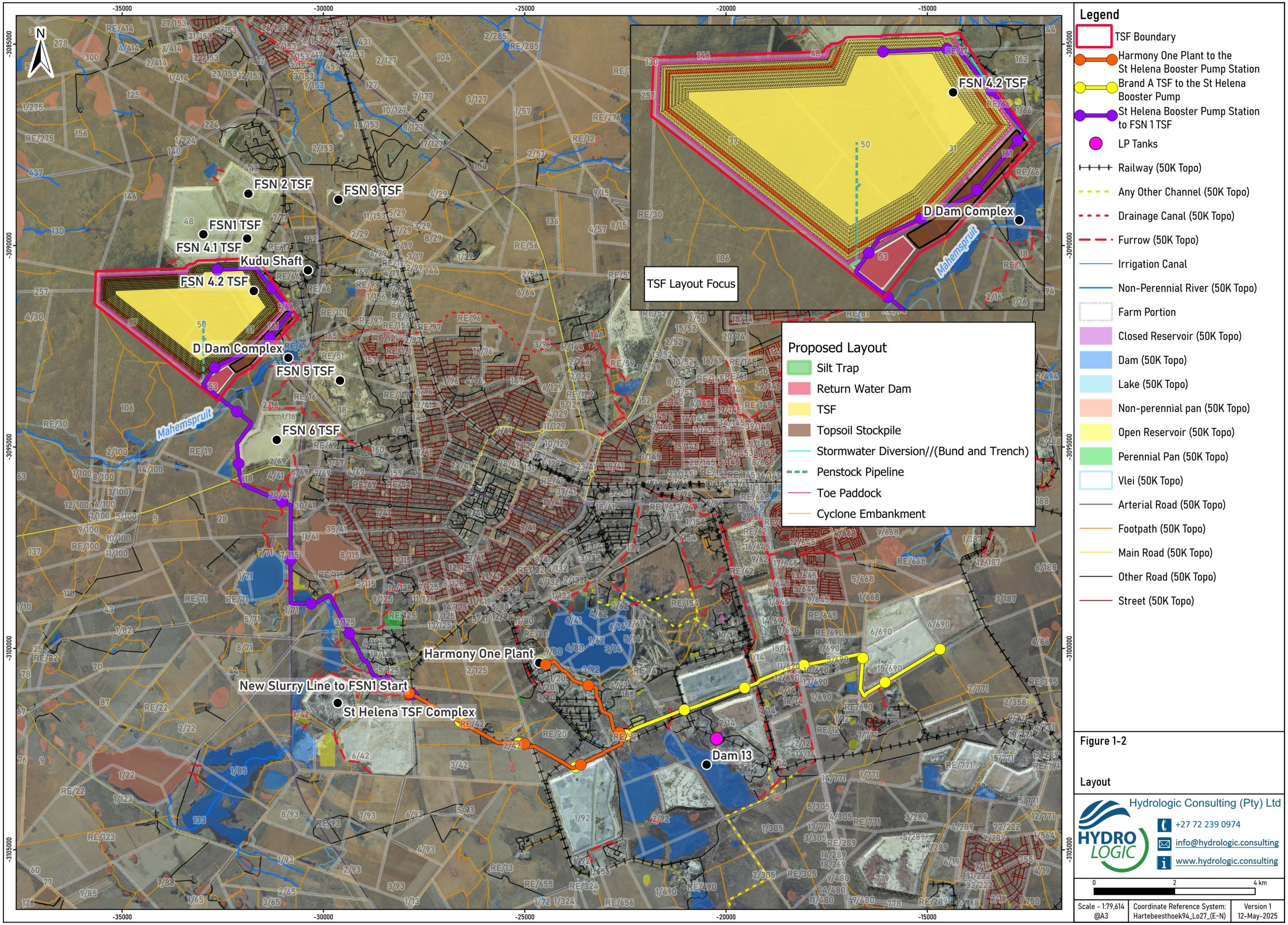


Figure 1-1

Regional Setting



FSN 2 TSF
FSN 3 TSF
FSN1 TSF
FSN 4.1 TSF
Kudu Shaft
FSN 4.2 TSF
D Dam Complex
FSN 5 TSF
FSN 6 TSF
Mahemspruit
Harmony One Plant
New Slurry Line to FSN1 Start
St Helena TSF Complex
Dam 13
TSF Layout Focus
Proposed Layout
Silt Trap
Return Water Dam
TSF
Topsoil Stockpile
Stormwater Diversion//(Bund and Trench)
Penstock Pipeline
Toe Paddock
Cyclone Embankment
Legend
TSF Boundary
Harmony One Plant to the St Helena Booster Pump Station
Brand A TSF to the St Helena Booster Pump
St Helena Booster Pump Station to FSN 1 TSF
LP Tanks
Railway (50K Topo)
Any Other Channel (50K Topo)
Drainage Canal (50K Topo)
Furrow (50K Topo)
Irrigation Canal
Non-Perennial River (50K Topo)
Farm Portion
Closed Reservoir (50K Topo)
Dam (50K Topo)
Lake (50K Topo)
Non-perennial pan (50K Topo)
Open Reservoir (50K Topo)
Perennial Pan (50K Topo)
Vlei (50K Topo)
Arterial Road (50K Topo)
Footpath (50K Topo)
Main Road (50K Topo)
Other Road (50K Topo)
Street (50K Topo)
Figure 1-2
Layout
Hydrologic Consulting (Pty) Ltd
HYDRO LOGIC
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www.hydrologic.consulting
0 2 4 km
Scale - 1:79,614 @A3
Coordinate Reference System: Hartebeesthoek94_Lo27_(E-N)
Version 1
12-May-2025

  - Topsoil Stockpile;
  - Silt Trap; and
  - Stormwater Diversion (Bund and Trench).
- LP Water System Related:
  - Concrete Slab Foundation (95m x 45m)
  - Concrete Apron (2m)
  - Pump Station
- Pipeline Related:
  - Brand A TSF to the St Helena Booster Pump
  - Harmony One Plant to the St Helena Booster Pump Station
  - St Helena Booster Pump Station to FSN 1 TSF

1.3 PROJECT DESCRIPTION

The following is a client-provided (Harmony) description of the proposed site:

A reserve reclamation study, which looked at the reclamation and treatment of the 774Mt of tailings contained in reserve status in TSFs in the Free State through the sequentially reprocessing of tailings through Target Plant and Harmony One Plant, as Run of Mine Ore is depleted, will require deposition space in future.

The Nooitgedacht TSF was identified as a deposition site for residue from the reclamation of tailings during Project Saints in 2007. The properties, Goedgedacht 53, Nooitgedacht 50 and Jacobsdal 37 were subsequently purchased with the intention of constructing a new Tailings Storage Facility on this site (as shown in Figure 1-2).

Harmony commenced with a feasibility assessment for the Nooitgedacht Tailings Deposition Project that will focus on the design and costing of the Nooitgedacht Tailings Storage Facility (TSF). The objective of the project is to secure future deposition capacity for Harmony Free State Operations for residue from both Run of Mine and Tailings Reclamation operations.

With regards to the pipelines, the following is proposed:

- *Two 10km long slurry lines from Harmony One Plant to the St Helena Booster Pump Station;*
- *One 16km long slurry line from Brand A TSF to the St Helena Booster Pump Station; and*
- *One 17km slurry line from the St Helena Booster Pump Station to FSN 1 TSF.*

The pipelines will be flanged steel pipelines of over 0,36m in diameter and installed above-ground on pre-cast concrete plinths and a 3.5m wide access road, adjacent to the pipelines, will be cleared/graded to provide access for construction, maintenance and inspections. The proposed pipelines traverse the following farm portions: Vlakplaats 125 Ptn 3, 4 and 5; Mijannie RE/66 Ptn 0; Toronto RE/115 Ptn 7 and 0; Rietpan 17 Ptn 0; Rietkuil 28 Ptn 0; Rheeders Dam 31 Ptn 0; Farm 41 Ptn 20; Ouders Gift 48 Ptn 0; Nooitgedacht 50 Ptn 0; Goedgedacht

With regards to the LP Water System, the following is proposed in accordance with the Department of Water and Sanitation and the SANS guidelines:

- *Two open top concrete tanks constructed above natural ground level to atmosphere;*

- *A suction outlet pipe 1.5m above the base of the tank; and*
- *Outlets joined with a T-piece to the pump suction manifold.*

The concrete tanks will have an internal cementitious flexible slurry finish for waterproofing with internal and external access ladders for maintenance purposes. They will be 40m in diameter and 18m in height and placed on a 95m x 45m concrete slab foundation, with a 2m concrete apron bordering the foundation perimeter.

1.4 SPECIALIST DECLARATION

Mark Bollaert, as the appointed surface water (hydrological) specialist, hereby declares that:

- Other than fair remuneration for work performed/to be performed in terms of this application, he has no business, financial, personal or other interest in the activity or application and there are no circumstances that may compromise their objectivity
- He has expertise in conducting the specialist report relevant to this application, including knowledge of the Act, Regulations and guidelines that have relevance to the proposed activity;
- He undertakes to disclose, to the competent authority, any material information that has or may have the potential to influence the decision of the competent authority or the objectivity of any report, plan or document required; and
- He is aware that a false declaration is an offence in terms of regulation 48 of the 2014 NEMA EIA Regulations.

1.5 EXPERTISE OF THE AUTHOR

Mr Mark Bollaert has over 17 years of experience working as a consulting hydrologist in the United Kingdom and South Africa since completing his Master of Science (MSc) degree in Hydrology at the University of KwaZulu-Natal. Mark has since supplemented his tertiary education with professional qualifications, which represent his ongoing effort towards maintaining a professional approach and continuing in their professional development. These include qualifications from the UK (Chartered Scientist, Chartered Environmentalist and Chartered Water and Environmental Manager) and South Africa (Professional Natural Scientist in Water Resources).

2 DESCRIPTION OF THE RECEIVING ENVIRONMENT

Baseline information in this section includes discussions on the rainfall, evaporation, design event rainfall, soils, vegetation, and land cover, as well as site topography and regional and local catchment hydrology.

2.1 RAINFALL

Various weather stations managed by both the South African Weather Services (SAWS) and the Department of Water and Sanitation (DWS) were considered in this project. These, together with their proximity to the site can be seen in Figure 2-1.

Numerous SAWS and DWS stations are located near the site. Pegram (2016) provides a collation of SAWS and DWS data into monthly averages. Table 2-1 presents the summary of the site-specific Pegram (2016) average monthly rainfall distribution while Figure 2-1 illustrates the rainfall variation in the region of the site.

TABLE 2-1: AVERAGE MONTHLY RAINFALL DISTRIBUTION (PEGRAM, 2016)

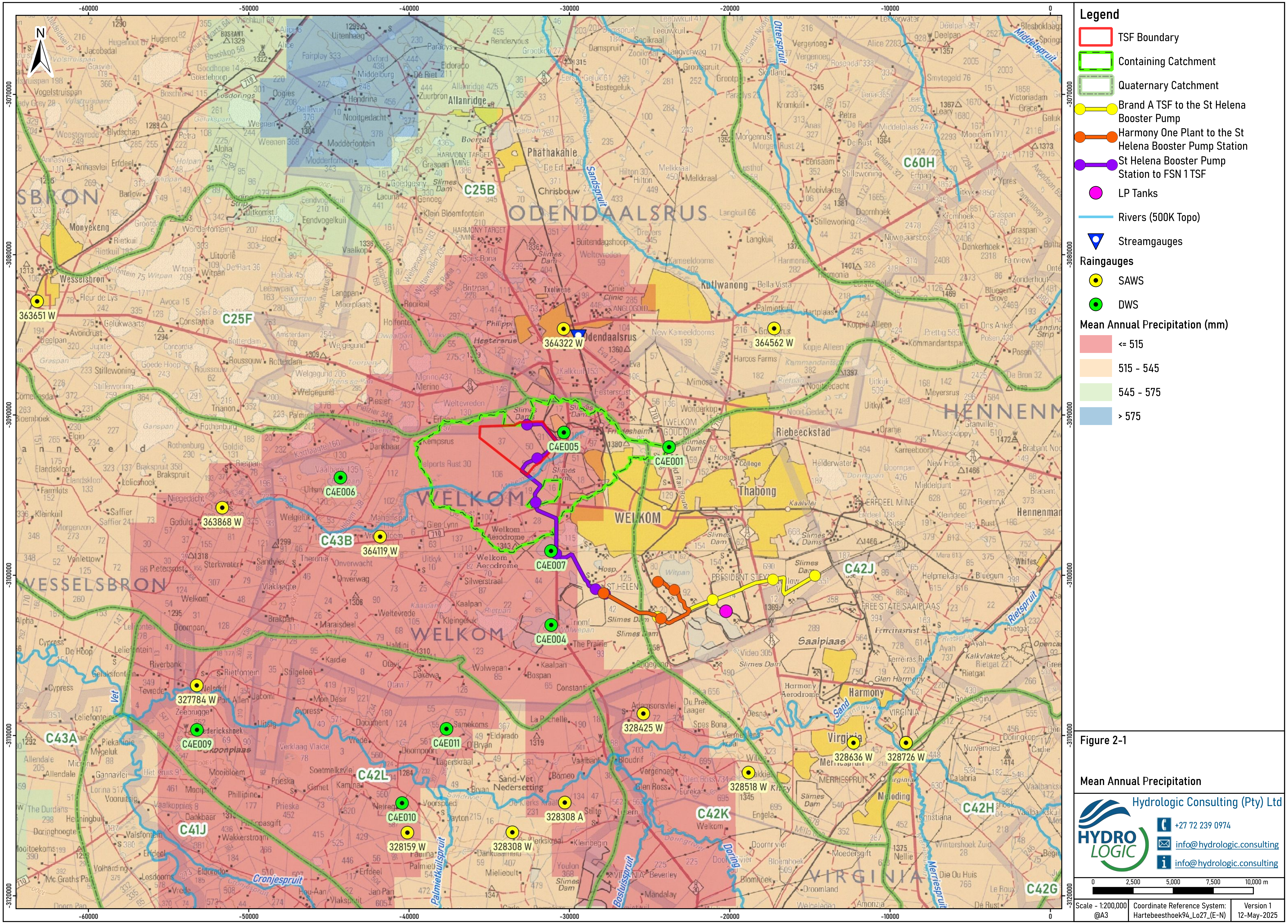
Month	Rainfall (mm)
Jan	77
Feb	65
Mar	65
Apr	39
May	18
Jun	7
Jul	7
Aug	9
Sep	16
Oct	46
Nov	65
Dec	66
Total	**480**

*Estimates were sourced for the centre of the site

2.2 1-DAY DESIGN RAINFALL DEPTHS

For the development of a stormwater management plan and assessment of flooding, design rainfall is the most important rainfall variable to consider, as it is the driver behind peak flows.

Design rainfall estimates for various recurrence intervals (RI) and storm durations were sourced from the Design Rainfall Estimation Software for South Africa (DRESSA), developed by the University of Natal in 2002 as part of a WRC project K5/1060 (Smithers and Schulze, 2002). This method uses a Regional L-Moment Algorithm (RLMA) in conjunction with a Scale Invariance approach to provide site-specific estimates of design rainfall (depth, duration and frequency), based on surrounding station records. WRC Report No. K5/1060 (WRC, 2002) provides more detail on the verification and validation of the method. Table 2-2 presents the 24-hour storm depths for various recurrence intervals.


Legend
TSF Boundary
Containing Catchment
Quaternary Catchment
Brand A TSF to the St Helena Booster Pump
Harmony One Plant to the St Helena Booster Pump Station
St Helena Booster Pump Station to FSN 1 TSF
LP Tanks
Rivers (500K Topo)
Streamgauges
Raingauges
SAWS
DWS
Mean Annual Precipitation (mm)
<= 515
515 - 545
545 - 575
> 575
Figure 2-1
Mean Annual Precipitation
Hydrologic Consulting (Pty) Ltd
HYDRO LOGIC
+27 72 239 0974
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info@hydrologic.consulting
0 2,500 5,000 7,500 10,000 m
Scale - 1:200,000 @A3
Coordinate Reference System: Hartebeesthoek94_Lo27_(E-N)
Version 1 12-May-2025
ODENDAALSRUS
WELKOM
WESSELSBRON
VIRGINIA
C25B
C25F
C43B
C43A
C41J
C42L
C42K
C42J
C42H
C42G
C60H
C4E001
C4E004
C4E005
C4E006
C4E007
C4E009
C4E010
C4E011
363651 W
363868 W
364119 W
364322 W
364562 W
327784 W
328425 W
328518 W
328636 W
328726 W
328308 A
328308 W
328159 W

TABLE 2-2: 24-HOUR STORM DEPTH

Recurrence Interval (Years)	Rainfall Depth (24-hour) (mm)
2	59.3
5	80.1
10	94.5
20	108.9
50	128.3
100	143.4
200	159.0

* Estimates were sourced for the centre of the catchment of relevance.

The relevance of the Probable Maximum Precipitation (PMP) to this study required an alternative approach to the design events estimated from DRESSA. The estimation of PMP is commonly undertaken in South Africa using the Hydrological Research Unit (HRU), 1972 methodology (HRU 1/72) as outlined by SANRAL (2013). The SANRAL (2013) estimation of the PMP uses the maximum observed point rainfall in South Africa, defined according to specific regions and PMP curves, which indicate the hypothetical limit to precipitation. In using SANRAL (2013) to calculate the PMP, a value of **405mm** was estimated for the 24-hour event.

2.3 EVAPORATION

Evaporation data was sourced from the South African Atlas of Climatology and Agrohydrology (Schulze and Lynch, 2006) in the form of A-Pan equivalent potential evaporation. The average monthly evaporation distribution is presented in Table 2-3 and shows the site has an annual potential evaporation of 2,441mm.

TABLE 2-3: AVERAGE MONTHLY A-PAN EQUIVALENT EVAPORATION

Month	Evaporation(mm)
Jan	286
Feb	220
Mar	197
Apr	155
May	133
Jun	102
Jul	118
Aug	164
Sep	222
Oct	267
Nov	276
Dec	301
Total	**2,441**

*Estimates were sourced for the centre of the site

2.4 AVERAGE CLIMATE

The average climate for the site is presented in Figure 2-2 using the outcome of the investigation into rainfall and evaporation for the site. The combination of rainfall (Pegram, 2016) and evaporation and temperature (Schulze and Lynch, 2006) result in a cold arid steppe climate according to the Köppen-Geiger climate classification[1].

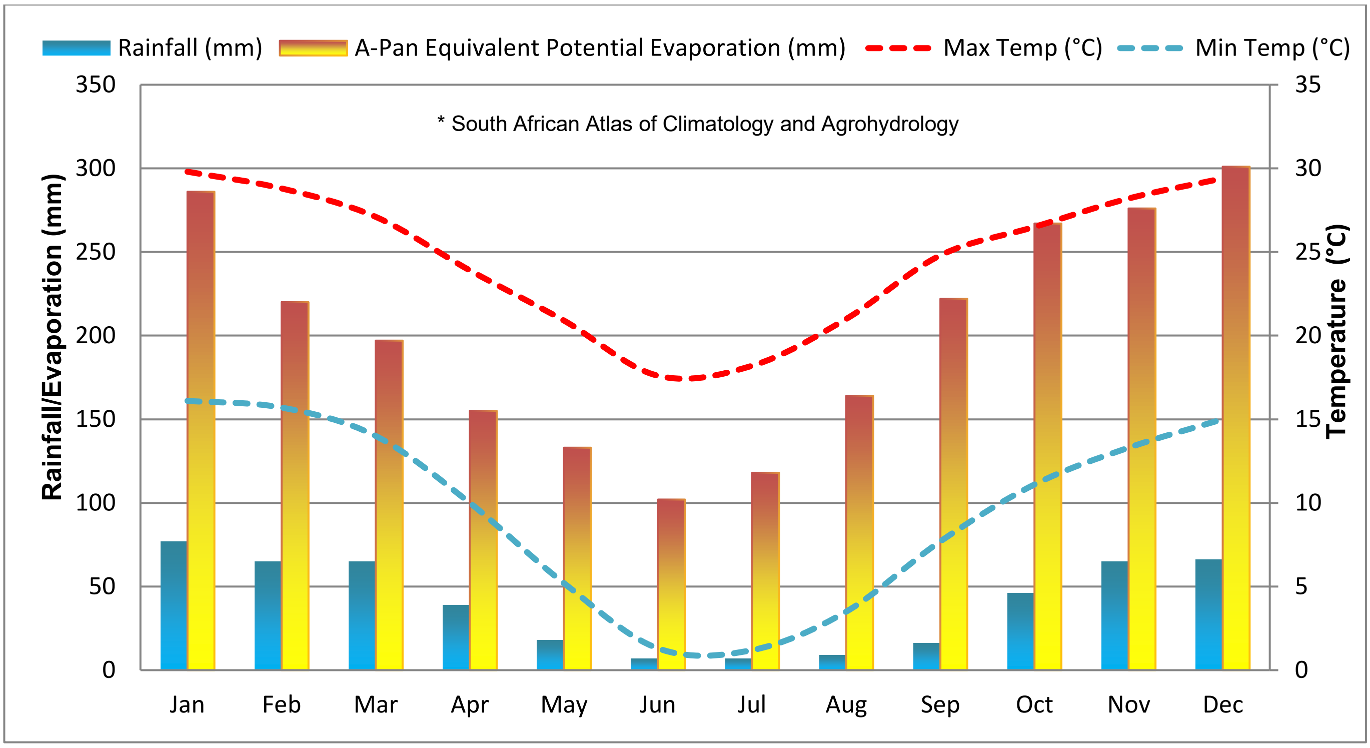

FIGURE 2-2: AVERAGE MONTHLY CLIMATE FOR THE SITE

2.5 CLIMATE CHANGE

The analysis of climate change was not the focus of this study; however, it is of value when considering the outcome of this study (up to this point). Seneviratne et.al (2021) detail the results of the Coupled Model Intercomparison Project (CMIP) 6. This study is the latest version of the CMIP (available at the time of writing) and indicates a decrease (per the ensemble mean) in total precipitation for West Southern Africa (inclusive of Cape Town), with the significance of change dependent on the Shared Socio-economic Pathways (SSP) and associated radiative forcing level (with a higher global warming level resulting in less rainfall (precipitation). The SSP5-8.5 scenario presents the worst-case scenario considered in CMIP6 (where the increased temperature is worse), the results of which are presented in Figure 2-11. Forecasting to a future climate, it is plausible that 1-day precipitation (rainfall) will increase thus exacerbating flooding.

In considering the change in 1-day precipitation, there is up to a maximum 24% increase for a 5-degree increase in global warming levels. This increase informed the probable maximum flood climate change scenario discussed in Section 4; however, a 20% increase (equivalent to an approximately 4.5-degree increase) has been applied (to the estimation of design rainfall affected by climate change). This 20% increase is more consistent with the application of design rainfall in South Africa (e.g. the City of Cape Town applies a standard 15% increase).

[1] http://stepsatest.csir.co.za/climate_koppen_geiger.html

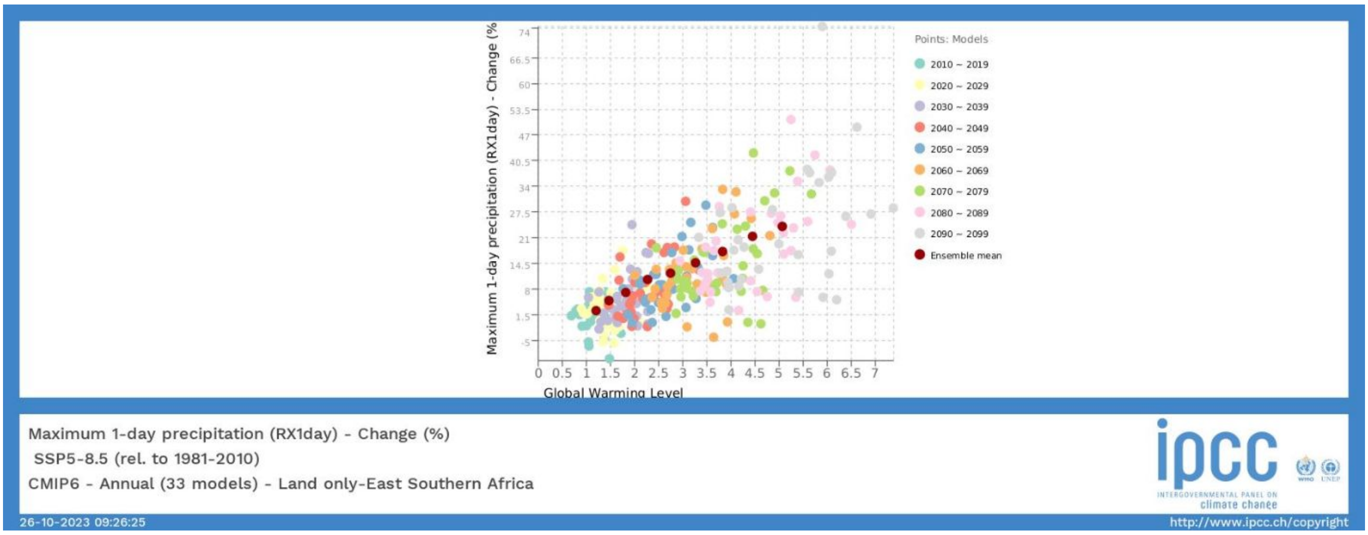

FIGURE 2-3: CIMP6 TOTAL PRECIPITATION CHANGE (SSP5-8.5)

2.6 TERRAIN

Four datasets were used to assess the elevation of the site and its surrounds, namely:

1. A 1m Digital Terrain Model (DTM) interpolated from a client-provided (Harmony) Lidar point cloud dataset (*02.xyz*);
2. A Geosmart 2m Digital Surface Model (DSM);
3. A 30m AW3D30[2] DSM dataset; and
4. NGI 1:50,000 topographical map 20m contours.

The four elevation datasets utilised are illustrated in Figure 2-3.

The resulting 1m DTM from the provided LiDAR dataset was evaluated and found to be a DTM. This is the optimum dataset (DTM vs DSM) since a DTM provides a bare earth model, which enables improved flow path analysis. The 1m DTM is also a reasonably detailed dataset. Limitations of the data, however, include its coverage of only a portion of the containing catchment and the inability of Lidar to penetrate water. The surface water elevations of waterbodies are consequently captured by Lidar.

The 2m DSM provides an elevation (surface) dataset with a resolution of 2m (Vertical accuracy ~50 cm; Horizontal accuracy ~1 m). As DSM, it contains surface features such as buildings. Some inaccuracy in the subsequent analysis of the terrain data using the 2m is consequently expected. A comparison of the 2m DSM to the 1m DTM was also made, with an average vertical difference of -1.47m noted in the area of the proposed flood modelling (to be assessed in a future report). 1.47m was consequently added to the 2m DSM (the 2m DSM is not error corrected and errors in vertical alignment are not unexpected).

The 2m DSM covered the majority of the pipeline except for a section of the Brand A TSF to the St Helena Booster Pump.

[2] https://www.eorc.jaxa.jp/ALOS/en/index_e.htm

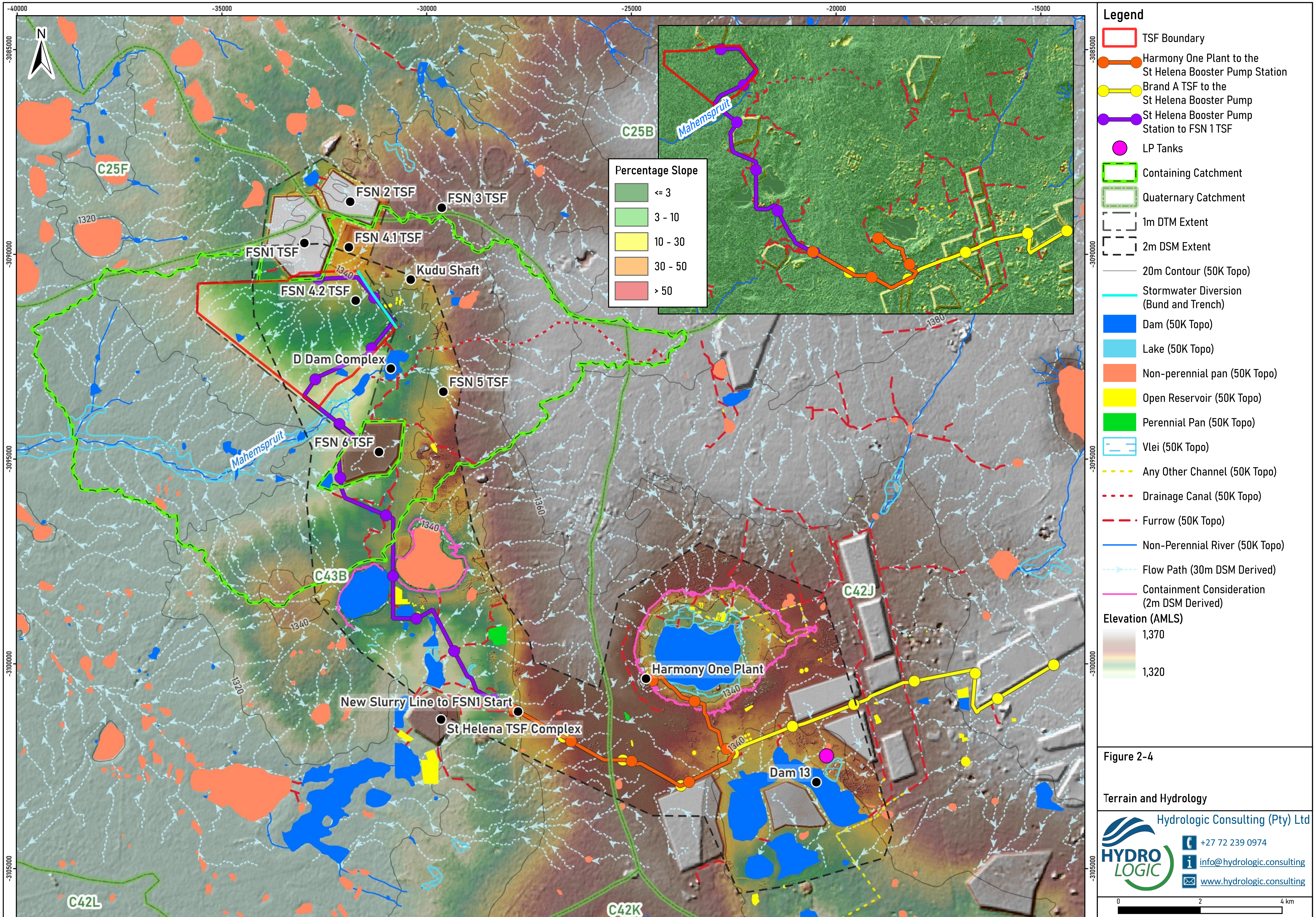

Figure 2-4

Terrain and Hydrology

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www.hydrologic.consulting

Scale - 1:80,000 @A3	Coordinate Reference System: Hartebeesthoek94_Lo27_(E-N)	Version 1 06-Jun-2025

The 30m AW3D30 DSM was used to supplement areas of missing terrain data and is illustrated using a faded colour palette in Figure 2-3. This data as the name suggests uses an approximately 30m cell size and provides a general understanding of the terrain of the site surroundings.

The 20m NGI contours were used as a final terrain dataset to illustrate the general 'lie of the land'. Elevation on the site approximates 1,330mAMSL.

2.7 HYDROLOGY

Figure 2-3 also illustrates the hydrological setting of the site, while Figure 2-1 presents the river network of the greater region. The site is positioned within quaternary catchments C42J and C43B. A defined 1:500,000 river (the Mahemspruit) intersects the pipelines and passes close to the TSF, towards the north.

This river (the Mahemspruit River) is the most significant river relevant to this assessment when considering the more detailed 1:50,000 topographical map data and the position of the proposed pipeline. A secondary river (non-perennial) intersects the St Helena Booter Pump to FSN 1 TSF Pipeline.

The proposed pipelines are positioned near or over numerous waterbodies. These include dams, non-perennial pans, perennial pans and vleis (per the 1:50,000 topographical map data). The pipeline route is consequently hydrologically complex due to the greater Harmony operation and its various containment facilities in operation (whether for stormwater control, water balancing or pollution control). The pipelines additionally intersect or are close to numerous furrows. In the case of Brand A TSF to the St Helena Booster Pump Pipeline, a furrow is in fact a formalised river channel as evidenced by a defined non-perennial river upstream.

Two additional (and significant) dams are within close proximity to the TSF and are the focus of flood modelling (Section 4). This includes D-Dam Complex. This dam complex partitions water in various compartments and adds some complexity to understanding the routing of water towards the Mahemspruit River.

The LP Dam's closest hydrological influence is a wetland (vlei) to the south-east.

All hydrological features have been presented according to the NGI's 1:50,000 topographical map data and this report does not intend to alter their classification.

This report also does not delineate or comment on the significance of any wetlands/vleis – consideration of this would require a wetland specialist. The NGI's 1:50,000 vleis are used for indicative purposes.

2.8 SOILS, VEGETATION AND LAND-COVER

In considering the Soil Conservation Service for South Africa (SCS-SA) dataset of the site, the soils at the location of the TSF and the St Helena Booster Pump Pipeline are classified as being hydrological soil group B/C (moderately low to moderately high runoff potential). The respective natural vegetation is classified as Western Free State Clay Grassland (according to SANBI, 2018). Soils at the location of the LP Water System, the Harmony One Plant Pipeline, and the Brand A TSF Pipeline are classified as being hydrological soil group C (moderately high runoff potential), and the natural vegetation is Vaal-Vet Sandy Grassland (according to SANBI, 2018). 'Grassland' is predominant over the site according to the DEA's 2020 land-cover dataset, with 'mines & quarries' positioned to the east in association with an existing TSF (FSN 4.2).

The distributions of the SCS soil types and natural vegetation are illustrated in Figure 2-5, while Figure 2-6 presents the land-cover of the site. Figures 2-7 and 2-8 present photographs of the site, including descriptions taken during the April 2023 site visit by Hydrologic.

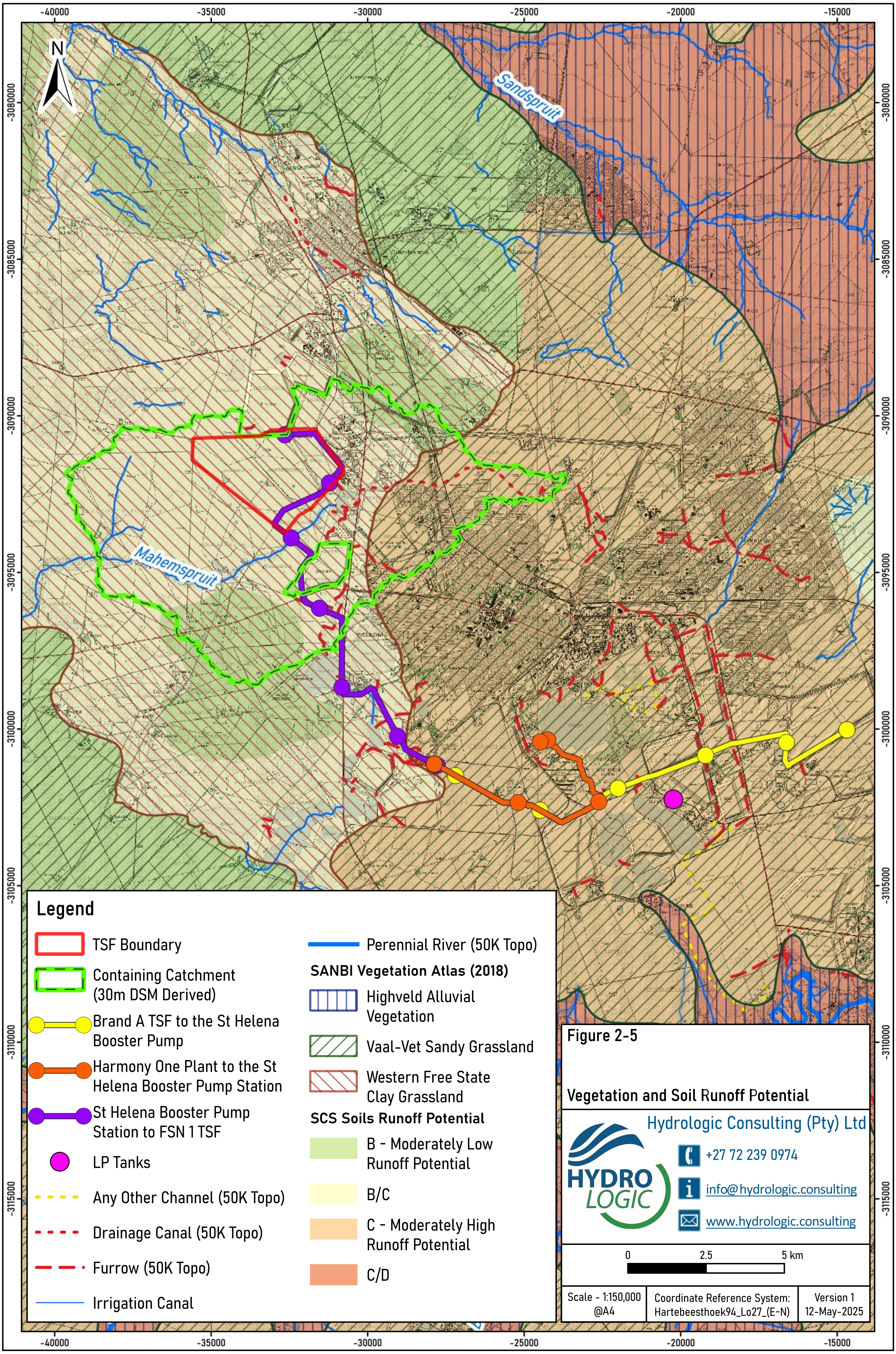
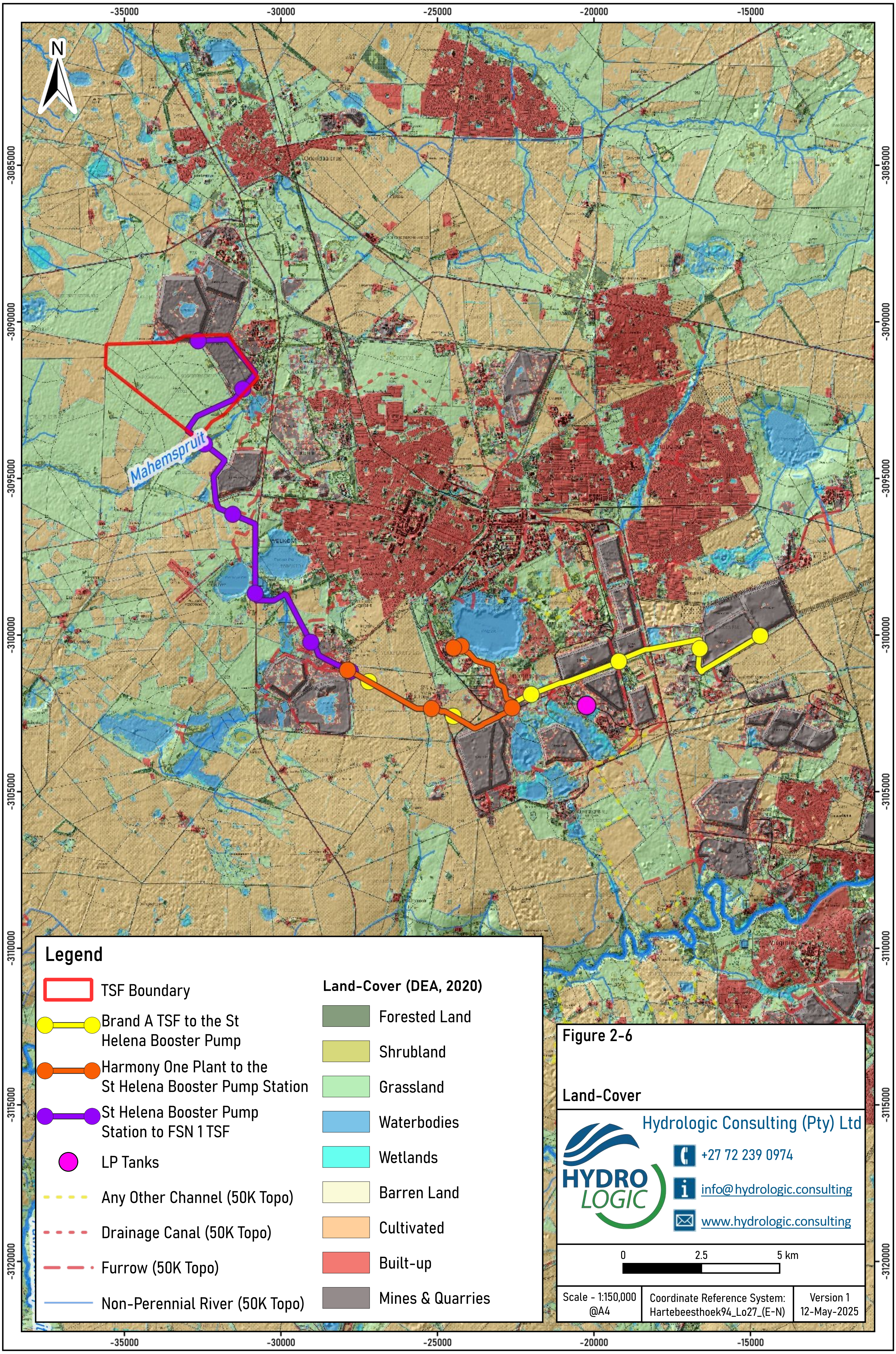


Figure 2-5

Vegetation and Soil Runoff Potential



Mahemspruit
Legend
TSF Boundary
Brand A TSF to the St Helena Booster Pump
Harmony One Plant to the St Helena Booster Pump Station
St Helena Booster Pump Station to FSN 1 TSF
LP Tanks
Any Other Channel (50K Topo)
Drainage Canal (50K Topo)
Furrow (50K Topo)
Non-Perennial River (50K Topo)
Land-Cover (DEA, 2020)
Forested Land
Shrubland
Grassland
Waterbodies
Wetlands
Barren Land
Cultivated
Built-up
Mines & Quarries
Figure 2-6
Land-Cover
Hydrologic Consulting (Pty) Ltd
HYDRO LOGIC
+27 72 239 0974
info@hydrologic.consulting
www.hydrologic.consulting
0
2.5
5 km
Scale - 1:150,000 @A4
Coordinate Reference System: Hartebeesthoek94_Lo27_(E-N)
Version 1
12-May-2025

FIGURE 2-7: PREDOMINANT GRASSLAND OVER THE MAJORITY OF THE TSF SITE

FIGURE 2-8: VIEW TOWARDS THE MAHEMSPRUIT (FROM FSN 4.2 TSF)

3 APPLICABLE GUIDANCE

The guidance that informs the hydrological assessment outlined in this report includes the following:

- National Environmental Management Act (Act No. 107 of 1998) as amended, states that "Every person who causes, has caused or may cause significant pollution or degradation of the environment must take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring…"
- National Water Act (Act No. 36 of 1998) includes Section 21 water uses which require authorisation from the Department of Water and Sanitation (DWS).
- Department of Water and Sanitation Notice 509 of 2016 provides clarity on the regulated area of a watercourse;
- Government Notice 704 (Government Gazette 20118 of June 1999) provides regulations on the use of water for mining and related activities aimed at the protection of water resources;
- Department of Water and Sanitation (DWS) Best Practice Guideline G1 for Stormwater Management;
- Landcom Soils and Construction, Volume 1, 4th edition from 2004 (otherwise known as the Blue Book) has been used widely in the South African context in providing practical recommendations regarding the management of stormwater and associated erosion controls; and
- The South African Roads Agency Limited (SANRAL) 6'th edition Drainage Manual (2013) provides some valuable insight specific to the construction and operation of roads.

3.1 NATIONAL WATER ACT

Definitions applicable to the identification of Section 21 water uses as defined by the National Water Act (Act No 36 of 1998) consist of:

- *"Watercourse"* including:
  - a river or spring;
  - a natural channel in which water flows regularly or intermittently; or
  - a wetland, lake or dam into which, or from which, water flows.
- *"Water resource"* – which includes a watercourse, surface water, estuary, or aquifer;
- "*Waste*" – which includes any solid material or material that is suspended, dissolved or transported in water (including sediment) and which is spilled or deposited on land or into a water resource in such volume, composition or manner as to cause, or to be reasonably likely to cause, the water resource to be polluted;

Section 21 water uses are not reviewed in this report, with EIMS undertaking to identify and authorises these.

3.2 DEPARTMENT OF WATER AND SANITATION NOTICE 4167 OF 2023

DWS Notice 4167 oF 2023 "General Authorisation in Terms Of Section 39 of the National Water Act 36 of 1998 for Water Uses as defined in Section 21(c) Or Section 21(i)" includes the following:

- **Regulated area of a watercourse** – for section 21(c) or (i) of the Act water uses in terms of this Notice means:

(a) The outer edge of the 1 in 100-year flood line or delineated riparian habitat, whichever is the greatest distance, measured from the middle of the watercourse of a river, spring, natural channel, dams and lakes;
(b) In the absence of a determined 1 in 100-year flood line or riparian area as contemplated in (a) above the area within 100m distance from the edge of a watercourse where the edge of the watercourse (excluding flood plains) is the first identifiable annual bank fill flood bench (subject to compliance to section 144 of the National Water Act 36 of 1998);
(c) In respect of a wetland: a 500 m radius around the delineated boundary (extent) of any wetland (including pans);

Where the applicable Section 21 water uses per the above are as follows:

- ***Section 21 (c)*** – impeding or diverting the flow of water in a watercourse;
- ***Section 21 (i)*** – altering the bed, banks, course or characteristics of a watercourse.

3.3 GN 704

The Department of Water Affairs and Forestry (now the Department of Water and Sanitation), established GN 704 to provide regulations on the use of water for mining and related activities aimed at the protection of water resources.

3.3.1 IMPORTANT DEFINITIONS IN GN 704

- **Activity**: (a) any mining related process on the mine including the operation of washing plants, mineral processing facilities, mineral refineries and extraction plants, and (b) the operation and the use of mineral loading and off-loading zones, transport facilities and mineral storage yards, whether situated at the mine or not,
    - (i) in which any substance is stockpiled, stored, accumulated or transported for use in such process; or
    - (ii) out of which process any residue is derived, stored, stockpiled, accumulated, dumped, disposed of or transported;

- **Clean water system:** This includes any dam, other form of impoundment, canal, works, pipeline and any other structure or facility constructed for the retention or conveyance of unpolluted water.

- **Dirty water system:** This includes any dam, other form of impoundment, canal, works, pipeline, residue deposit and any other structure or facility constructed for the retention or conveyance of water containing waste.

- **Dirty area:** This refers to any area at a mine or activity which causes, has caused or is likely to cause pollution of a water resource (i.e. polluted water).

3.3.2 APPLICABLE CONDITIONS IN GN 704

The principal conditions of GN 704 applicable to the site are:

Condition 4 – Restrictions on locality – No person in control of a mine or activity may:

(a) locate or place any residue deposit, dam, reservoir, together with any associated structure or any other facility within the 1:100 year flood-line or within a horizontal distance of 100 metres from any watercourse or estuary, borehole or well, excluding boreholes or wells drilled specifically to monitor the pollution of groundwater, or on water-logged ground, or on ground likely to become water-logged, undermined, unstable or cracked;
(b) except in relation to a matter contemplated in regulation 10 (i.e. Additional regulations relating to winning sand and alluvial minerals from watercourse or estuary), carry on any underground or opencast mining, prospecting or any other operation or activity under or within the 1:50 year flood-line or within a horizontal distance of 100 metres from any watercourse or estuary, whichever is the greatest;
(c) place or dispose of any residue or substance which causes or is likely to cause pollution of a water resource, in the workings of any underground or opencast mine excavation, prospecting diggings, pit or any other excavation; or
(d) use any area or locate any sanitary convenience, fuel depots, reservoir or depots for any substance which causes or is likely to cause pollution of a water resource within the 1:50 year flood-line of any watercourse or estuary.

Condition 5 – Restrictions on use of material

No person in control of a mine or activity may use any residue or substance which causes or is likely to cause pollution of a water resource for the construction of any dam or other impoundment or any embankment, road or railway, or for any other purpose which is likely to cause pollution of a water resource.

Condition 6 - Capacity requirements of clean and dirty water systems

Every person in control of a mine or activity must:

(a) confine any unpolluted water to a clean water system, away from any dirty area;
(b) design, construct, maintain and operate any clean water system at the mine or activity so that it is not likely to spill into any dirty water system more than once in 50 years;
(c) collect the water arising within any dirty area, including water seeping from mining operations. outcrops or any other activity, into a dirty water system;
(d) design, construct, maintain and operate any dirty water system at the mine or activity so that it is not likely to spill into any clean water system more than once in 50 years; and
(e) design, construct, maintain and operate any dam or tailings dam that forms part of a dirty water system to have a minimum freeboard of 0.8 metres above full supply level, unless otherwise specified in terms of Chapter 12 of the Act.
(f) design, construct and maintain all water systems in such a manner as to guarantee the serviceability of such conveyances for flows up to and including those arising as a result of the maximum flood with an average period of recurrence of once in 50 years.

Condition 7 – Protection of water resources

Every person in control of a mine or activity must take reasonable measures to:

(a) prevent water containing waste or any substance which causes or is likely to cause pollution of a water resource from entering any water resource, either by natural flow or by seepage, and must retain or collect such substance or water containing waste for use, re-use, evaporation or for purification and disposal in terms of the Act;

(b) design, modify, locate, construct and maintain all water systems, including residue deposits, in any area so as to prevent the pollution of any water resource through the operation or use thereof and to restrict the possibility of damage to the riparian or in-stream habitat through erosion or sedimentation, or the disturbance of vegetation, or the alteration of flow characteristics;

(c) cause effective measures to be taken to minimise the flow of any surface water or floodwater into mine workings, opencast workings, other workings or subterranean caverns, through cracked or fissured formations, subsided ground, sinkholes, outcrop excavations, adits, entrances or any other openings;

(d) design, modify, construct, maintain and use any dam or any residue deposit or stockpile used for the disposal or storage of mineral tailings, slimes, ash or other hydraulic transported substances, so that the water or waste therein, or falling therein, will not result in the failure thereof or impair the stability thereof;

(e) prevent the erosion or leaching of materials from any residue deposit or stockpile from any area and contain material or substances so eroded or leached in such area by providing suitable barrier dams, evaporation dams or any other effective measures to prevent this material or substance from entering and polluting any water resources;

(f) ensure that water used in any process at a mine or activity is recycled as far as practicable, and any facility, sump, pumping installation, catchment dam or other impoundment used for recycling water, is of adequate design and capacity to prevent the spillage, seepage or release of water containing waste at any time;

(g) at all times keep any water system free from any matter or obstruction which may affect the efficiency thereof; and

(h) cause all domestic waste, including wash-water, which cannot be disposed of in a municipal sewage system, to be disposed of in terms of an authorisation under the Act.

The Minister of the DWS may in writing, authorise an exemption to instances of GN 704 non-compliance.

4 FLOODING MODELLING

The detail of the flood modelling for the site is presented in Appendix A. Since the modelling of flooding is (as undertaken), an approximation of reality, various assumptions and limitations are relevant (when considering the model results). These have been highlighted at various places in this report and are also outlined in Appendix A.

4.1 GOVERNMENT NOTICE 704

The Department of Water Affairs and Forestry (now the Department of Water and Sanitation), established GN 704 to provide regulations on the use of water for mining and related activities aimed at the protection of water resources. There are important definitions in the regulation which require understanding.

The principal condition of GN 704 applicable to the mine concerning flooding is summarised as follows:

- *Condition 4* defines the area in which mine workings or associated structures may be located concerning a watercourse and its associated flooding. The 50-year flood-line and 100-year flood-line are used for defining suitable locations for mine workings (prospecting, underground mining or excavations) and associated structures respectively. Where the flood-line is less than 100 metres away from the watercourse, then a minimum watercourse buffer distance of 100 metres is required for both mine workings and associated structures.

4.2 HYDRAULIC MODEL CHOICE

HEC-RAS 6.4.1 was selected to model flood hydrology and hydraulics using a 2D model approach. HEC-RAS is designed to perform one-dimensional and two-dimensional calculations for a full network of natural and constructed channels. The software is used worldwide and has been thoroughly tested (USACE, 2016, 2018).

4.3 FLOOD APPROACH

A defined 1:50,000 topographical map non-perennial river intersects the proposed pipelines in two locations (in association with the Mahemspruit River and an unnamed non-perennial river). A third formalised river (furrow) intersects the Brand A TSF to the St Helena Booster Pump Pipeline.

Flood modelling of the two defined non-perennial rivers was limited to the Mahemspruit River alone (at D-Dam Complex). The non-perennial associated with the St Helena Booster Pump Station to FSN 1 TSF Pipeline was evaluated based upon the available 2m DSM and aerial imagery and found not to be the recipient of any substantial upslope area. This non-perennial river appears to only receive a minor catchment associated with the wastewater treatment works to the north, and as such, flood modelling is not warranted given the limited flood surge expected. In this way, this non-perennial river should have its flood risk based upon the sensitivity analysis presented in Section 5 (in much the same way as furrows and drainage canals are to be evaluated).

The formalised river (furrow) intersecting the Brand A TSF to the St Helena Booster Pump Pipeline was the focus of another study undertaken by Hydrologic on behalf of EIMS and Harmony. The reader is referred to this report[3].

Other crossings are associated with drainage canals and furrows (i.e. diversions). These additional crossings were excluded from the flood modelling portion of the assessment. Proximity to waterbodies, including the 'containment consideration' presented in Figure 2-3, has also not been modelled. This does not imply that a flood risk does not exist in association with diversions or containment, since in places they manage large upslope areas. The sensitivity analysis presented in Section 5 discusses this in more detail.

The proposed TSF straddles a watershed and does not intersect any defined 1:50,000 topographical map rivers. There is one dam present in the TSF boundary; however, it is not associated with a defined river and has a relatively minor contributing catchment.

The most significant river near the site is the Mahemspruit River to the south-east of the site. This river has a contributing catchment of approximately 32km^2 up to its point of assessment south of the site and was the primary focus of potential flooding to the site, which is made possible by some lower-lying terrain slowly rising towards the TSF boundary.

The extent of the flood model covered approximately 2.3km of the defined non-perennial river (the Mahemspruit). Flood modelling utilised a combination of the 1m DTM, 2m DSM and 30m DSM for the development of the hydrological (PCSWMM) model and a combination of the 1m DTM and 2m DSM for the development of the hydraulic (HEC-RAS) model. In using the 2m DSM, the vertical accuracy of the resulting flood model is 0.5m, since the flood model cannot improve on the inherited accuracy of the 2m DSM (which has a 0.5m vertical accuracy). The defined 1:50,000 topographical map river channel, as illustrated to the north, is functionally present towards the south in association with a drainage canal.

The PCSWMM model utilised 52 subcatchments covering 32km^2 and connected by channels as identified by either 1:50,000 topographical map data, flow path analysis or aerial imagery. Each subcatchment had its hydrological parameters informed by site-specific datasets. The output of PCSWMM was four design event hydrographs: the 1:50 RI, 1:100 RI, probable maximum flood (PMF) and PMF plus climate change events. A PMF event is the largest event likely to ever occur under existing climatic conditions and is substantially greater than the 1:100 RI event. The PMF plus climate change event applied a consistent 20% increase to the PMF rainfall per the findings of Section 2.5.

The availability of a continuous 1m DTM and 2m DSM allowed for the adoption of a 2D flood model approach using HEC-RAS. Unlike a 1D approach (using cross-sections), which samples the DTM at set cross-section locations, a 2D model approach uses a continuous model grid. The advantage of a 2D model is, consequently, its ability to account for more variation in the topographic data since no gaps are present in the model geometry (as is the case with cross-sections).

The estimated design hydrographs (from PCSWMM) were applied to a HEC-RAS model at the position of the road crossing the river channel. This road acts as the downstream wall to the D-Dam Complex, which manages approximately 10km^2 of the upstream catchment. The Complex (and its numerous compartments) mean that the balancing of flows entering the dam cannot be assessed (beyond the scope of this study and the data available for

[3] Hydrologic, 2024, "Hydrological Assessment of the Harmony Brand A Tailings Storage Facility Project", Version 1, June 2024, Project No. EIM-015

this report). Additionally, available data for the dam (the 2m DSM) includes errors concerning waterbodies. This is illustrated in Figure 4-1 whereby the D-Dam Complex has raised ground well above the typical water surface. These are 2m DSM data errors. The result is that the Complex is not well understood, and its influence on flooding is consequently not well represented. It is probable that during significant flood events, the Complex would receive flood water from both its managed 10km^2 upstream catchment and the 15km^2 catchment draining along the drainage canal immediately to the south (due to overtopping). This potential overtopping would add to the influence of the D-Dam Complex on the modelled flooding. In considering the above (the uncertainty regarding the D-Dam Complex), the flood model was set to begin at the western edge of the complex, bypassing the routing of flood waters through the complex.

Lastly, the dam downstream of D-Dam Complex utilised the 1m DTM. This dataset is Lidar-derived, and Lidar cannot penetrate water. This, along with the high degree of vegetation noted over the dam (per aerial imagery), results in a DTM surface water elevation above the actual ground elevation. The storage potential of the dam and its possible attenuating influence on the flood surge are consequently not well represented. This would require a bathymetric survey of the dam.

4.4 FLOOD MODELLING RESULTS

The following figures present the simulated flooding outputs:

- Figure 4-1: Flood-Lines
- Figure 4-2: Maximum Flood Depth (1:100 RI Event)
- Figure 4-3: Maximum Flood Depth (PMF Event)
- Figure 4-4: Maximum Flood Depth (PMF +Climate Change Event)
- Figure 4-5: Maximum Flood Velocity (1:100 RI Event)
- Figure 4-6: Maximum Flood Velocity (PMF Event)
- Figure 4-7: Maximum Flood Velocity (PMF +Climate Change Event)

In considering the flood results presented in the figures, the 1:50 and 1:100 RI events are noted as not affecting the site, with the 1:100 RI event coming close to but not intersecting the proposed topsoil stockpile. The situation is different with the PMF events, with both intersecting the proposed topsoil stockpile. These, however, are the only proposed works that are affected by the PMF events with both the TSF itself and the RWD outside of the PMF and PMF plus climate change flood-lines.

With regards to the St Helena Booster Pump Station to FSN 1 TSF Pipeline, an intersection with an area of flooding is noted, although this is inevitable (intersection with flooding) when a pipeline crosses a river.

Inaccuracies in the flood modelling (due to both general limitations in modelling, such as the limit of the 1m DTM, as well as the poorly understood influence of the D-Dam Complex) should be factored into the interpretation of the results (i.e. an additional freeboard could still be relevant due to potential error).

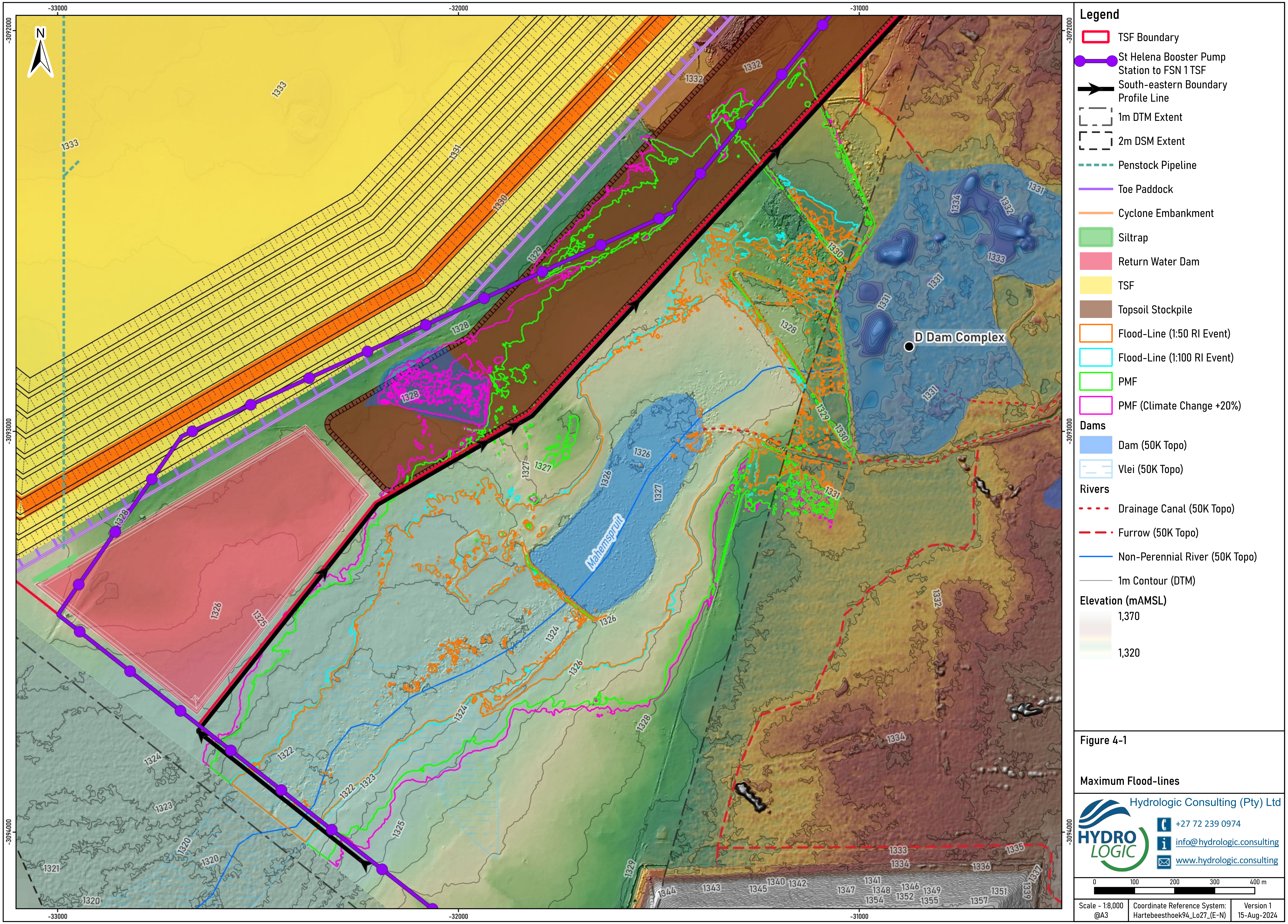
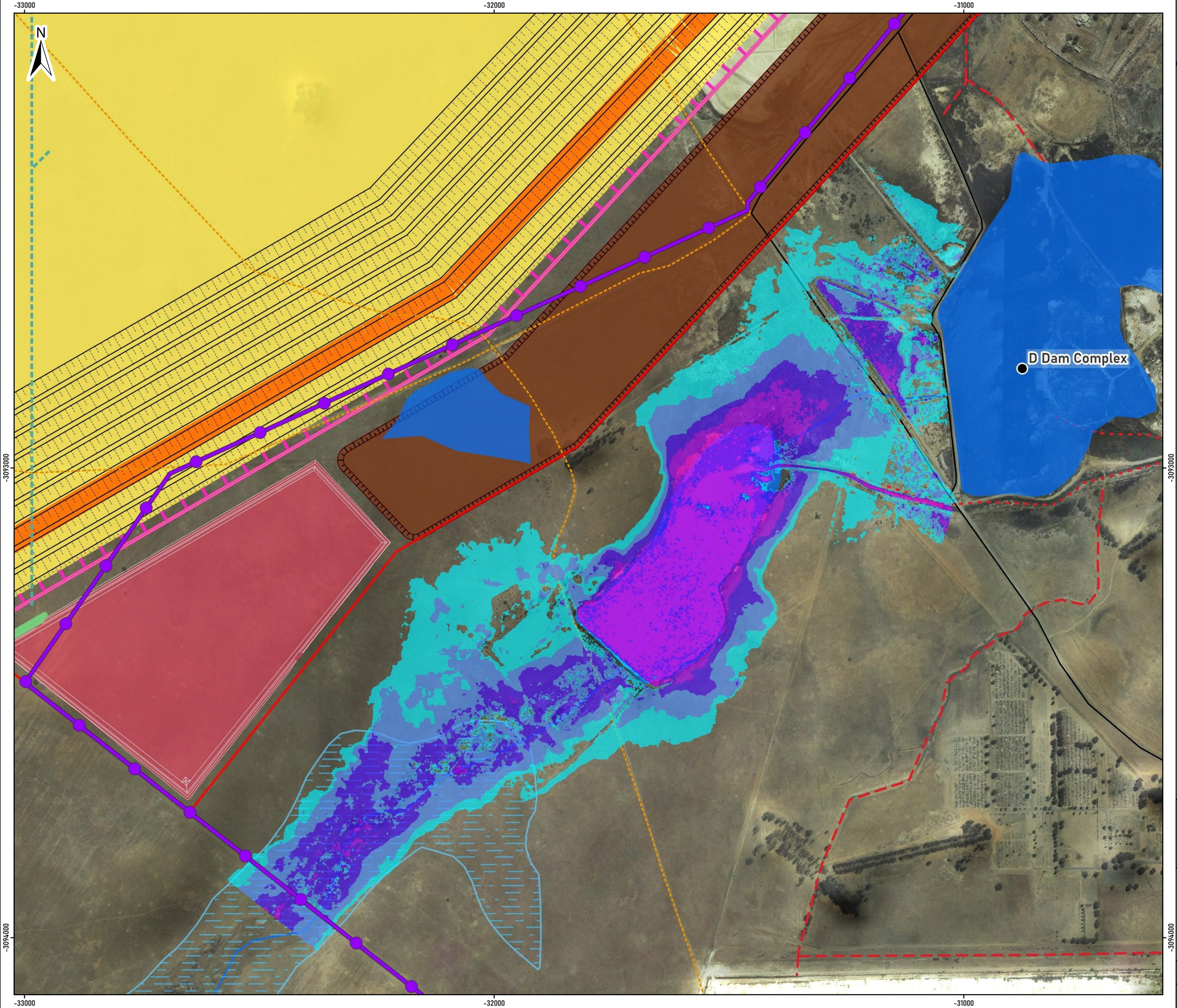


Figure 4-1

Maximum Flood-lines



Legend

- TSF Boundary
- St Helena Booster Pump Station to FSN 1 TSF
- Toe Paddock
- Penstock Pipeline
- Siltrap
- TSF
- Topsoil Stockpile
- Return Water Dam

Roads

- Footpath (50K Topo)
- Other Road (50K Topo)

Rivers

- Drainage Canal (50K Topo)
- Furrow (50K Topo)
- Non-Perennial River (50K Topo)

1:100 RI - Max. Depth (m)

- <= 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- > 1.00

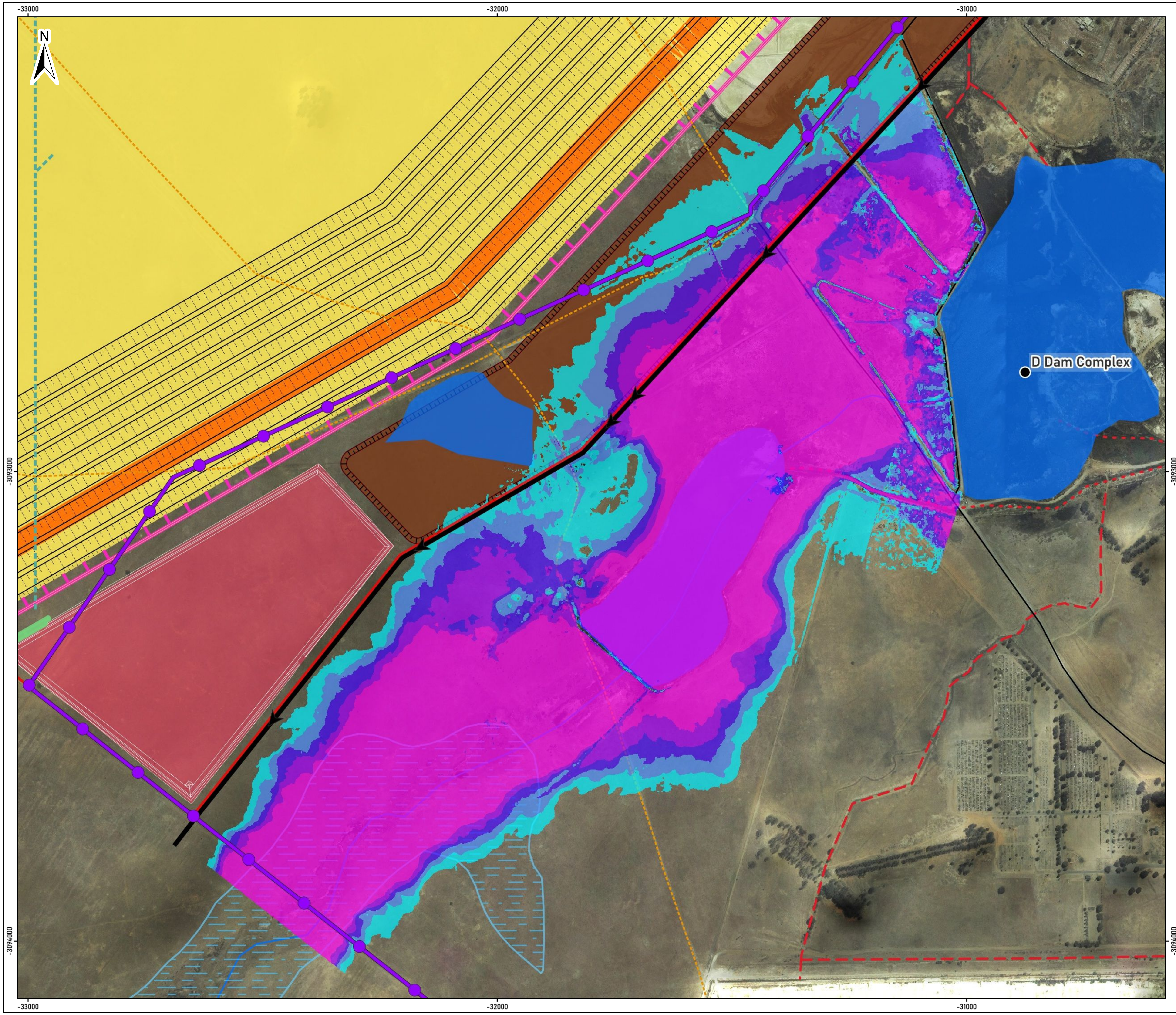
Figure 4-2

Maximum Flood Depth (1:100 RI Event)

Hydrologic Consulting (Pty) Ltd
HYDRO LOGIC
+27 72 239 0974
info@hydrologic.consulting
www.hydrologic.consulting

0 100 200 300 400 m

Scale - 1:7,500 @A3	Coordinate Reference System: Hartebeesthoek94_Lo27_(E-N)	Version 1 15-Aug-2024



Legend

- TSF Boundary
- St Helena Booster Pump Station to FSN 1 TSF
- South-eastern Boundary Profile Line
- Toe Paddock
- Penstock Pipeline
- Siltrap
- TSF
- Topsoil Stockpile
- Return Water Dam

Roads

- Footpath (50K Topo)
- Other Road (50K Topo)

Rivers

- Drainage Canal (50K Topo)
- Furrow (50K Topo)
- Non-Perennial River (50K Topo)

PMF - Max. Depth (m)

- <= 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- > 1.00

Figure 4-3

Maximum Flood Depth (PMF Event)

Hydrologic Consulting (Pty) Ltd
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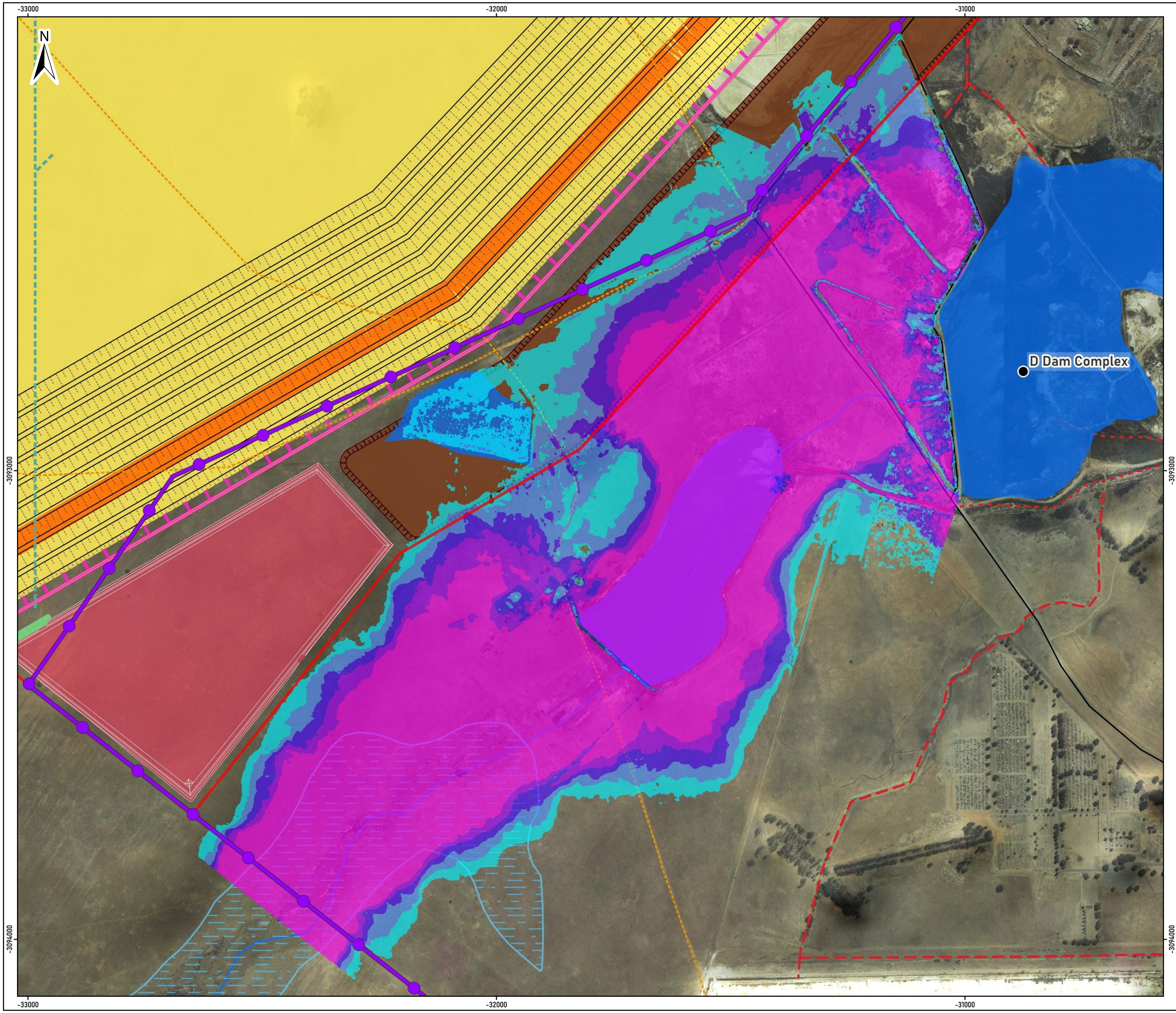
+27 72 239 0974
info@hydrologic.consulting
www.hydrologic.consulting

0 100 200 300 400 m

Scale - 1:7,500 @A3	Coordinate Reference System: Hartebeesthoek94_Lo27_(E-N)	Version 1 15-Aug-2024



Legend

- TSF Boundary
- St Helena Booster Pump Station to FSN 1 TSF
- Toe Paddock
- Penstock Pipeline
- Siltrap
- TSF
- Topsoil Stockpile
- Return Water Dam

Roads

- Footpath (50K Topo)
- Other Road (50K Topo)

Rivers

- Drainage Canal (50K Topo)
- Furrow (50K Topo)
- Non-Perennial River (50K Topo)

PMF + CC - Max. Depth (m)

- <= 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- > 1.00

Figure 4-4

Maximum Flood Depth (PMF + Climate Change Event)

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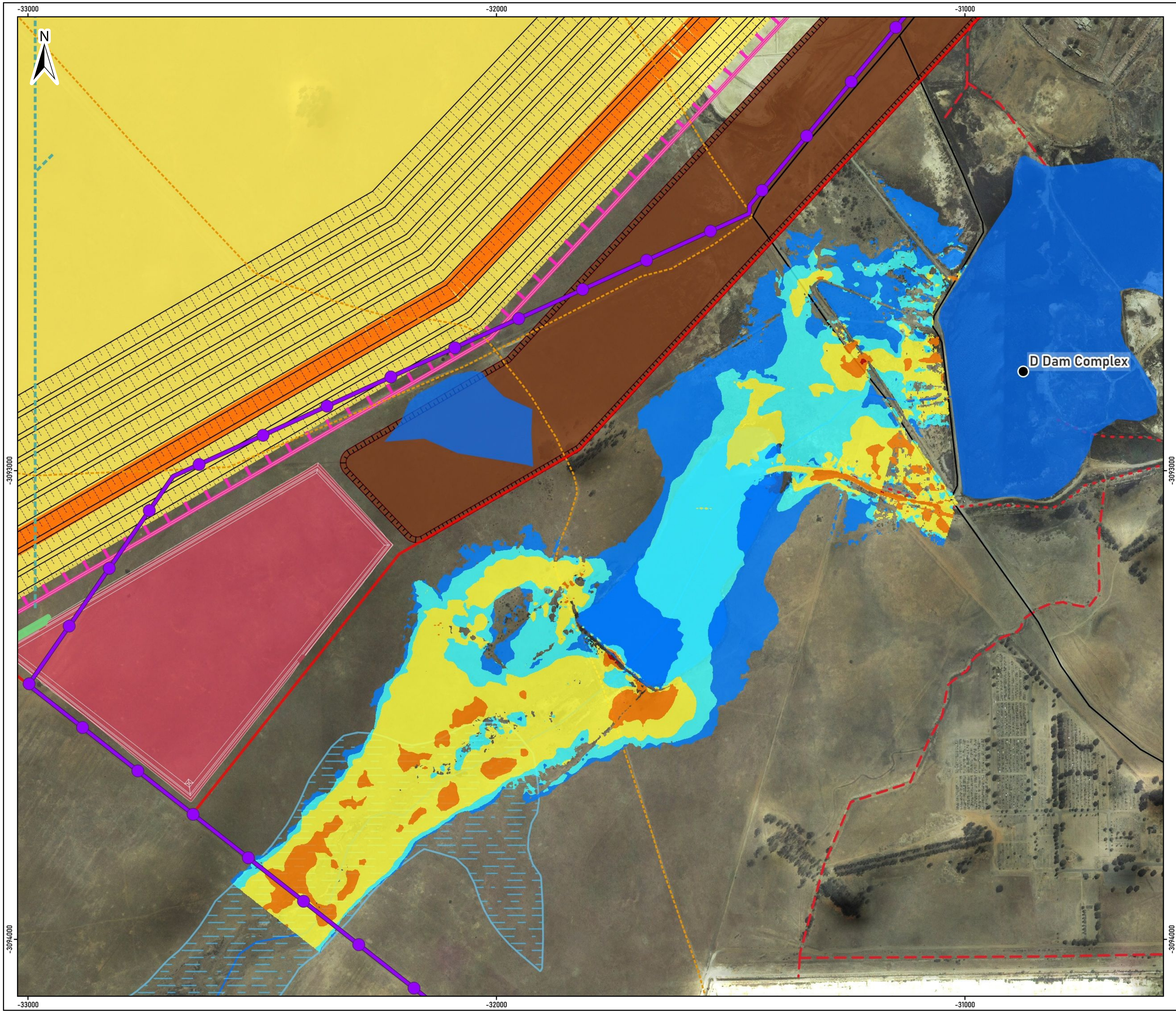
+27 72 239 0974
info@hydrologic.consulting
www.hydrologic.consulting

0 100 200 300 400 m

Scale - 1:7,500 @A3	Coordinate Reference System: Hartebeesthoek94_Lo27_(E-N)	Version 1 15-Aug-2024



Legend

- TSF Boundary
- St Helena Booster Pump Station to FSN 1 TSF
- Toe Paddock
- Penstock Pipeline
- Siltrap
- TSF
- Topsoil Stockpile
- Return Water Dam

Roads

- Footpath (50K Topo)
- Other Road (50K Topo)

Rivers

- Drainage Canal (50K Topo)
- Furrow (50K Topo)
- Non-Perennial River (50K Topo)

1:100 RI - Max. Velocity (m/s)

- <= 0.25
- 0.25 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- > 2.00

Figure 4-5

Maximum Flood Velocity (1:100 RI Event)

Hydrologic Consulting (Pty) Ltd
HYDRO LOGIC
+27 72 239 0974
info@hydrologic.consulting
www.hydrologic.consulting

0 100 200 300 400 m

Scale - 1:7,500 @A3	Coordinate Reference System: Hartebeesthoek94_Lo27_(E-N)	Version 1 15-Aug-2024

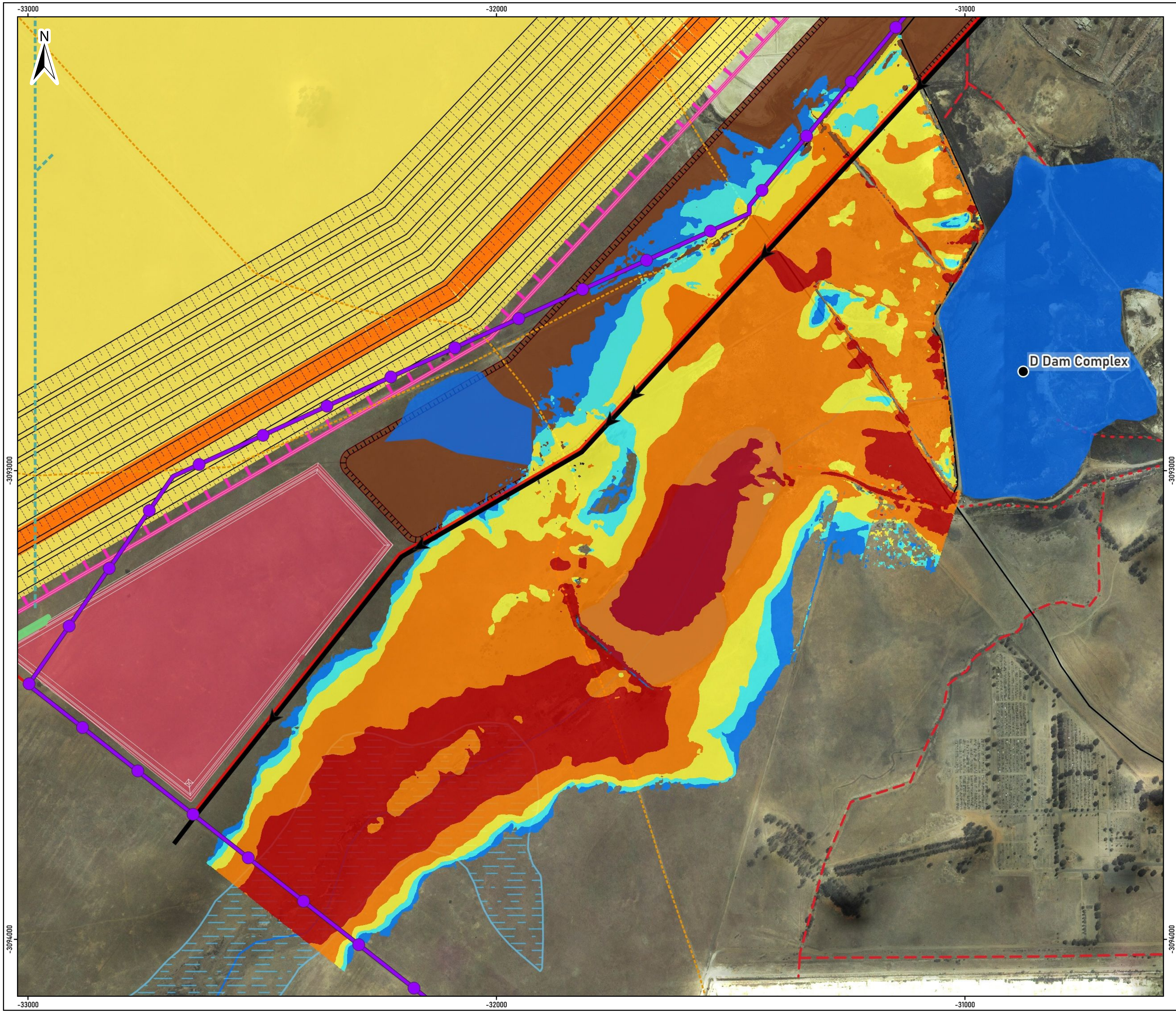


Figure 4-6

Maximum Flood Velocity (PMF Event)

Hydrologic Consulting (Pty) Ltd
+27 72 239 0974
info@hydrologic.consulting
www.hydrologic.consulting

0 100 200 300 400 m

Scale - 1:7,500 @A3 | Coordinate Reference System: Hartebeesthoek94_Lo27_(E-N) | Version 1 15-Aug-2024

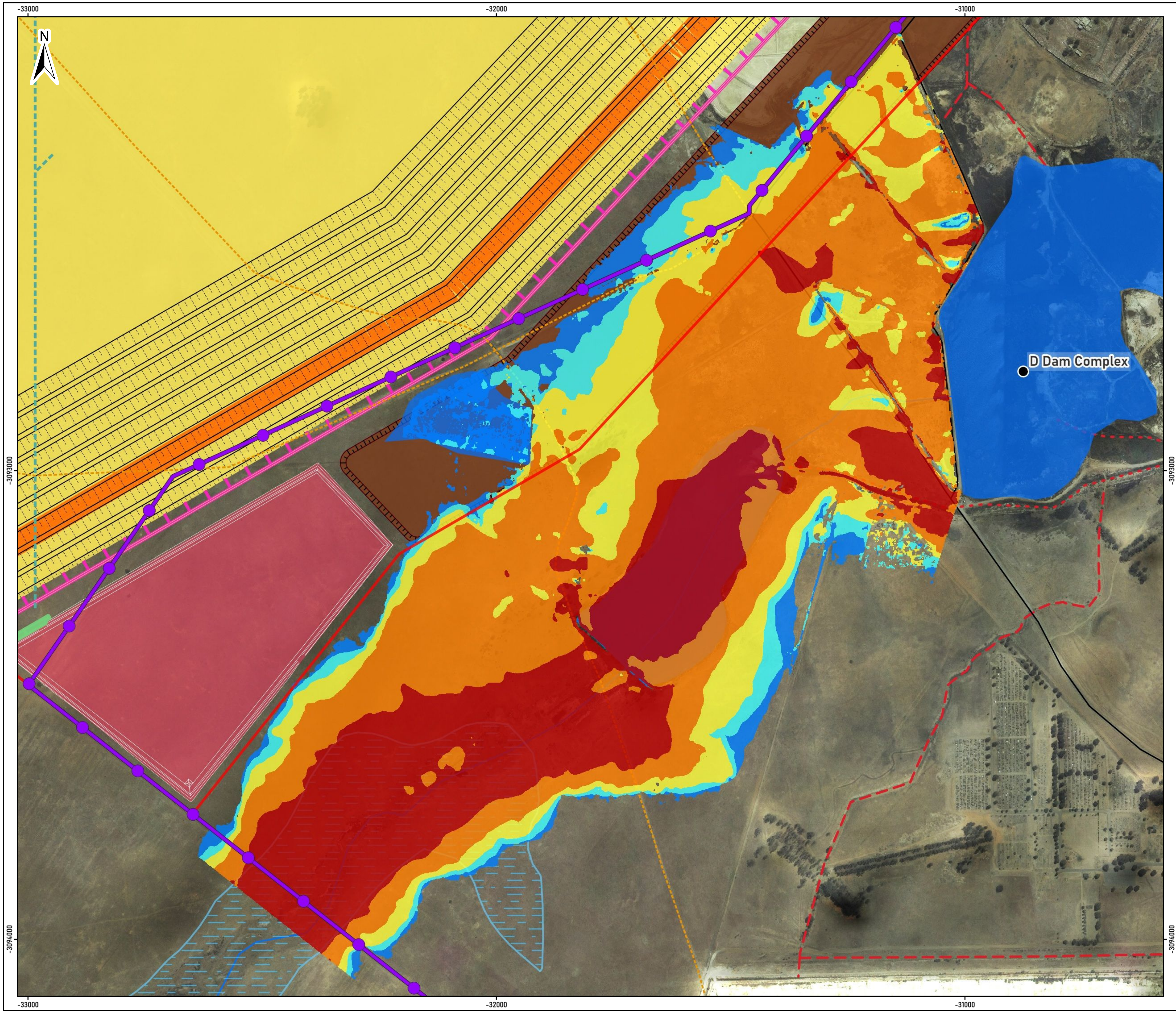


Figure 4-7

Maximum Flood Velocity
(PMF + Climate Change Event)

Hydrologic Consulting (Pty) Ltd
HYDRO LOGIC
+27 72 239 0974
info@hydrologic.consulting
www.hydrologic.consulting

0 100 200 300 400 m

Scale - 1:7,500 @A3	Coordinate Reference System: Hartebeesthoek94_Lo27_(E-N)	Version 1 15-Aug-2024

In reviewing flood velocities, there are instances of flooding above 1m/s over the PMF events which intersect the topsoil stockpile. In general, velocities over 2 m/s are high enough to cause erosion of grass-lined channels, while velocities over 2.5 m/s can erode concrete linings with joints or cracks, with an upper limit of 8 m/s in the case of reinforced concrete. The South African National Roads Agency Limited (SANRAL) drainage manual (SANRAL, 2013) guides maximum permissible velocities and should be consulted during the detailed design phase.

4.5 POTENTIAL MITIGATION

The addition of flood defences may be a necessary consideration, depending on the degree of protection desired at the TSF and RWD. This protection would likely be in the form of a flood protection berm running the length of the site's southeastern boundary.

To consider the potential design of a flood protection berm, Figure 4-8 presents the flood depth along the site's south-eastern boundary (see Figure 4-1 for the profile line's location). This depth reaches up to 1.4m (in association with the PMF plus climate change event), over the footprint-edge of the proposed topsoil stockpile. A 2m berm running the length of the south-eastern boundary would consequently protect the site from PMF flooding. Crossing over the Mahemspruit, flood depths reach over 2.5m (PMF).

The topsoil stockpile (between the TSF and the Mahemspruit) is intended to double as a flood protection berm, due to its linear nature and its position between the TSF and the river. Adequate engineering of the topsoil stockpile will consequently be necessary if this is to be its secondary purpose. The topsoil stockpile is, however, not continuous along the site's southeastern boundary, with the RWD remaining unprotected and a possible flow path existing between the RWD and stockpile. Flood protection of the site would need to consider this.

The influence of a flood protection berm has not been considered since only baseline (current) flooding has been simulated. The placement of a berm has the potential to constrict flooding adjacent to the topsoil stockpile, exacerbating flooding elsewhere. This needs to be considered given the close proximity of flooding to the proposed RWD and the consequent sensitivity of the RWD to any increase in flooding.

With regards to the St Helena Booster Pump Station to FSN 1 TSF Pipeline, a raised pipeline which passes above the defined flooding is recommended.

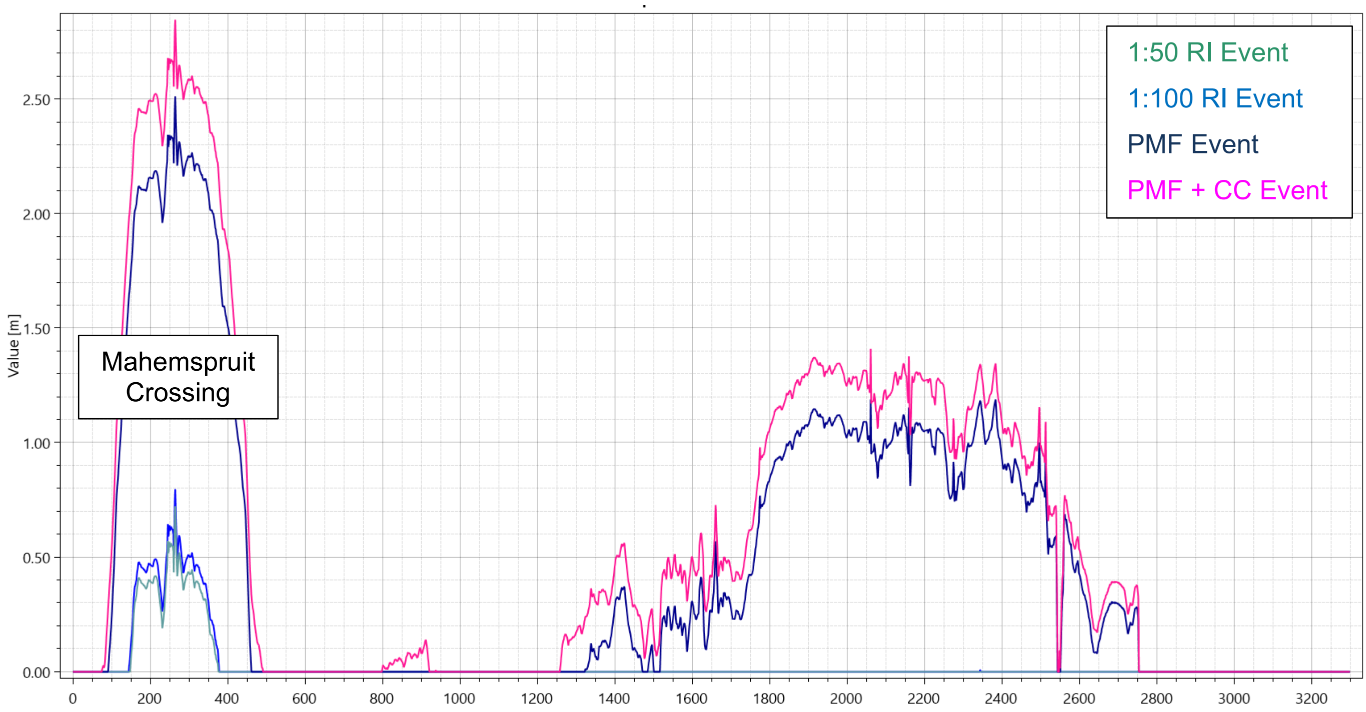


FIGURE 4-8: FLOOD DEPTH PROFILE LINE

5 IDENTIFIED SITE SENSITIVITIES

Sensitivity mapping was undertaken to identify sensitive features relating to the hydrological (surface water) environment within the site. A 1000m buffer from the proposed infrastructure was used as the area under consideration.

The Department of Water Affairs and Forestry (now the Department of Water and Sanitation), established GN 704 to provide regulations on the use of water for mining and related activities aimed at the protection of water resources. This includes the following condition:

Condition 4 – Restrictions on locality – No person in control of a mine or activity may:

(e) locate or place any residue deposit, dam, reservoir, together with any associated structure or any other facility within the 1:100 year flood-line or within a horizontal distance of 100 metres from any watercourse or estuary, borehole or well, excluding boreholes or wells drilled specifically to monitor the pollution of groundwater, or on water-logged ground, or on ground likely to become water-logged, undermined, unstable or cracked;

The 100m watercourse buffer is consequently one of the main guiding aspects in the assessment of site sensitivities given its relevance to GN 704, and its applicability to both flooding and the potential for contaminants to enter a watercourse (i.e. a wider river buffer is more likely to keep infrastructure/works outside of areas prone to regular or irregular flooding while enabling more time for containments within runoff, to settle out before entering the watercourse). A 100m watercourse buffer distance is, however, limited in its application since the proposed works/infrastructure will either fall within or outside this buffer distance, with no grading in site sensitivity possible. An expanded approach to the 100m river buffer was consequently adopted, utilising a variation in buffer distances, modelled flooding, and contour analysis.

The proposed TSF's position lies north of the Mahemspruit (non-perennial) River, defined per the 1:50,000 topographical map. The remaining drainage is constructed either as a drainage canals or a furrows. Large areas are nevertheless managed by these constructed diversions and as such, they fall within the conceptual definition of a watercourse insofar as they have the potential to cause flooding and route pollutants downstream.

Watercourse buffers have consequently been derived from the 1:50,000 topographical map features, including dams, drainage canals, furrows, non-perennial rivers, non-perennial pans, perennial pans and vleis. Open reservoirs have been excluded on the basis that inflows are managed (and that there is no significant upslope catchment area of relevance). Watercourse buffers are technically applicable from the edge (top of the bank) of the watercourse and not from the centreline (as in the case of rivers, drainage canals and furrows). The absence of a river survey means that the river centreline has nevertheless been used to define buffers.

The proposed TSF's position near the D-Dam complex and Mahemspruit River was the focus of the flooding assessment as illustrated by the flood results in Section 4. This has been used in sensitivity analysis. Flooding results from the Brand A assessment[4] have also been used.

[4] Hydrologic, 2024, "Hydrological Assessment of the Harmony Brand A Tailings Storage Facility Project", Version 1, June 2024, Project No. EIM-015

Figure 2-4 also presents the results of the containment consideration using the 2m DSM for the two endorheic areas (pans; although the one to the east is classified as a dam, yet is clearly a pan according to terrain data). This analysis used derived contours (from the 2m DSM) to outline the potential extent of pans before spilling (i.e. an approximation of the possible maximum water surface extent). This has been used in sensitivity analysis. Improvements in this analysis would be possible in the event that a more detailed dataset were applied (such as Lidar), instead of the 2m DSM.

The following sensitivity bands were classified:

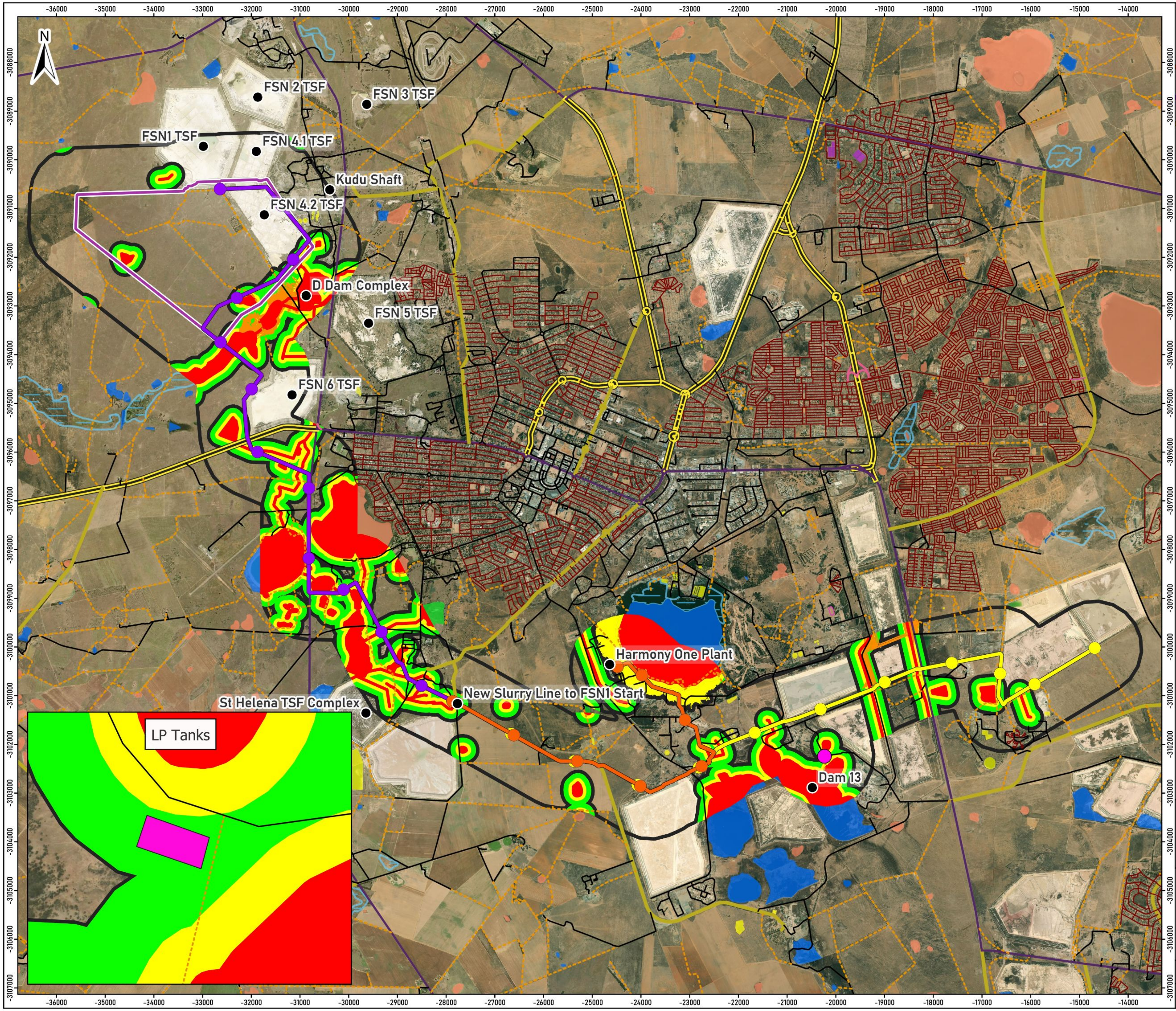
- Prevent Development
    - A 32m watercourse buffer (also applicable to NEMA activities) was used to define the functional area of the watercourse.
    - This 32m buffer factors in the potential error in the 1:50,000 topographical map dataset.
    - All development should be prevented in this area unless water-compatible or otherwise crossing over a watercourse (with flood risk factored in).
- High
    - The defined 1:50 RI flood-line also applies to GN 704 and presents a probable area in which flooding could occur (once every 50-years).
    - There is a strong disincentive towards development within this area.
- Medium
    - A 100m buffer distance matches GN 704's and DWS Notice 509 of 2016 prescribed buffer distance and is the minimum distance to a watercourse requiring motivation if works/infrastructure are going to be permitted, including a written exemption from the Minister of the Department of Water and Sanitation.
    - GN 704 and DWS Notice 509 of 2016 also refer to the 1:100 RI flood event, which has been used as a secondary consideration for the medium sensitivity analysis.
    - The containment consideration related to pans factors in a potential area of inundation associated with these waterbodies when full.
    - There is a medium disincentive towards development within this area.
- Low
    - A 200m buffer distance is a reasoned maximum distance from a watercourse, which in most instances will reflect the largest distance over which flooding would need to be considered.
    - The PMF plus climate change flood-line for the Mahemspruit is the maximum hypothetical extent of flooding that may be generated from this river and consequently has the lowest sensitivity rating.
    - There is a low disincentive towards development within this area.
- Remainder:
    - There is no sensitivity classification for the remainder of the site.

GN 704 restricts development within 100m of a watercourse (i.e. dam or river), and the above outline does not attempt to remove this restriction but is instead a high-level 'scaled' version of this buffer distance.

This classification does not consider the 500m wetland buffer that applies. This wetland buffer is expected to be included as part of a wetland survey of the site and not the higher-level datasets present with the NGI's 1:50,000 topographical map dataset. No assessment of wetlands has been undertaken in this report.

Figure 5-1 presents the results of the identified site sensitives as they relate to the surface water environment. As mentioned in Section 2.6, hydrological features have been defined according to the NGI's 1:50,000 topographical map data, and this report does not intend to alter their classification. The sensitivity analysis is based on the 1:50,000 topographical map data, and errors in the data's classification will affect the accuracy of the sensitivity classification.

Figure 5-1 illustrates that there are parts of the TSF that are within sensitive areas. This includes the influence of two dams located within the TSF and the dam on the Mahemspruit, otherwise, the sensitive areas affecting the TSF relate to the influence of the PMF flood results (including the PMF plus climate change results) since the 1:100 RI flood event (medium sensitivity) falls out of the site. The two dams on the site are expected to be removed and will therefore not be of relevance, while the influence of the PMF flood events and the dam on the Mahemspruit remain the other sources of site sensitivities.



Legend

- TSF Boundary
- Harmony One Plant to the St Helena Booster Pump Station
- St Helena Booster Pump Station to
- Brand A TSF to the St Helena Boost
- LP Tanks

Roads

- Arterial Road (50K Topo)
- Footpath (50K Topo)
- Main Road (50K Topo)
- On/Off Ramp (50K Topo)
- Other Road (50K Topo)
- Secondary Road (50K Topo)
- Street (50K Topo)
- Track (50K Topo)

Dams

- Closed Reservoir (50K Topo)
- Dam (50K Topo)
- Lake (50K Topo)
- Non-perennial pan (50K Topo)
- Open Reservoir (50K Topo)
- Perennial Pan (50K Topo)
- Vlei (50K Topo)

Site Sensitivities

- Unclassified
- Low
- Medium
- High
- Prevent Development

Figure 5-1

Site Sensitivities

Hydrologic Consulting (Pty) Ltd

HYDRO LOGIC

+27 72 239 0974

0 1,000 2,000 3,000 4,000 m

Scale - 1:72,000 @A3	Coordinate Reference System: Hartebeesthoek94_Lo27_(E-N)	Version 1 13-May-2025

6 HYDROLOGICAL IMPACTS AND MITIGATION MEASURES

An impact is essentially any change (positive or negative) to a resource or receptor brought about by the presence of the project component or by the execution of a project-related activity.

The potential impacts of the project have been evaluated using a recognised risk assessment methodology developed to ensure communication of the potential consequences or impacts of activities on the hydrological (surface water) environment as set out in the National Environmental Management Act (NEMA). A quantitative approach was taken in determining environmental significance since this enables a cross-disciplinary assessment of impact whereby the interpretation of impact significance is the same (i.e. a high impact on the surface water environment has the same interpretation as a high impact on ecology).

6.1 METHOD OF ASSESSING IMPACTS

The broad approach to the significance rating methodology is to determine the environmental risk (ER) by considering the consequence (C) of each impact (comprising Nature, Extent, Duration, Magnitude, and Reversibility) and relating this to the probability/likelihood (P) of the impact occurring. This determines the environmental risk. In addition, other factors, including cumulative impacts, public concern, and potential for irreplaceable loss of resources, are used to determine a prioritisation factor (PF) which is applied to the ER to determine the overall significance (S).

6.1.1 DETERMINATION OF ENVIRONMENTAL RISK

The significance (S) of an impact is determined by applying a prioritisation factor (PF) to the environmental risk (ER).

The environmental risk is dependent on the consequence (C) of the particular impact and the probability (P) of the impact occurring. Consequence is determined through the consideration of the Nature (N), Extent (E), Duration (D), Magnitude (M), and reversibility (R) applicable to the specific impact.

For the purpose of this methodology, the consequence of the impact is represented by:

$$C = \frac{E + D + M + R}{4} \times N$$

Each individual aspect in the determination of the consequence is represented by a rating scale as defined in Table 7-1.

TABLE 6-1: CRITERIA FOR DETERMINING IMPACT CONSEQUENCE

Aspect	Score	Definition
Nature	- 1	Likely to result in a negative/ detrimental impact
	+1	Likely to result in a positive/ beneficial impact
Extent	1	Activity (i.e. limited to the area applicable to the specific activity)
	2	Site (i.e. within the development property boundary),
	3	Local (i.e. the area within 5 km of the site),
	4	Regional (i.e. extends between 5 and 50 km from the site
	5	Provincial / National (i.e. extends beyond 50 km from the site)
Duration	1	Immediate (<1 year)
	2	Short term (1-5 years),
	3	Medium term (6-15 years),
	4	Long term (the impact will cease after the operational life span of the project),
	5	Permanent (no mitigation measure of natural process will reduce the impact after construction).
Magnitude/ Intensity	1	Minor (where the impact affects the environment in such a way that natural, cultural and social functions and processes are not affected),
	2	Low (where the impact affects the environment in such a way that natural, cultural and social functions and processes are slightly affected),
	3	Moderate (where the affected environment is altered but natural, cultural and social functions and processes continue albeit in a modified way),
	4	High (where natural, cultural or social functions or processes are altered to the extent that it will temporarily cease), or
	5	Very high / don't know (where natural, cultural or social functions or processes are altered to the extent that it will permanently cease).
Reversibility	1	Impact is reversible without any time and cost.
	2	Impact is reversible without incurring significant time and cost.
	3	Impact is reversible only by incurring significant time and cost.
	4	Impact is reversible only by incurring prohibitively high time and cost.
	5	Irreversible Impact

Once the C has been determined the ER is determined in accordance with the standard risk assessment relationship by multiplying the C and the P. Probability is rated/scored as per Table 7-2.

TABLE 6-2: PROBABILITY SCORING

Probability Score	Description
1	Improbable (the possibility of the impact materialising is very low as a result of design, historic experience, or implementation of adequate corrective actions; <25%),
2	Low probability (there is a possibility that the impact will occur; >25% and <50%),
3	Medium probability (the impact may occur; >50% and <75%),
4	High probability (it is most likely that the impact will occur- > 75% probability), or
5	Definite (the impact will occur),

The result is a qualitative representation of relative ER associated with the impact. ER is therefore calculated as follows:

$$ER = C \ x \ P$$

TABLE 6-3: DETERMINATION OF ENVIRONMENTAL RISK

Consequence						
	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
		1	2	3	4	5
	Probability					

The outcome of the environmental risk assessment will result in a range of scores, ranging from 1 through to 25. These ER scores are then grouped into respective classes as described in Table 7-4.

TABLE 6-4: SIGNIFICANCE CLASSES

Environmental Risk Score	Description
< 9	Low (i.e. where this impact is unlikely to be a significant environmental risk),
≥9 & <17	Medium (i.e. where the impact could have a significant environmental risk),
≥ 17	High (i.e. where the impact will have a significant environmental risk).

The impact ER will be determined for each impact without relevant management and mitigation measures (pre-mitigation), as well as post-implementation of relevant management and mitigation measures (post-mitigation). This allows for a prediction of the degree to which the impact can be managed/mitigated.

6.1.2 IMPACT PRIORITISATION

Further to the assessment criteria presented in the section above, it is necessary to assess each potentially significant impact in terms of:

- Cumulative impacts; and
- The degree to which the impact may cause irreplaceable loss of resources.

To ensure that these factors are considered, an impact prioritisation factor (PF) will be applied to each impact ER (post-mitigation). This prioritisation factor does not aim to detract from the risk ratings but rather to focus the attention of the decision-making authority on the higher priority/significance issues and impacts. The PF will be applied to the ER score based on the assumption that relevant suggested management/mitigation impacts are implemented.

TABLE 6-5: CRITERIA FOR DETERMINING PRIORITISATION

Cumulative Impact (CI)	Low (1)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikely that the impact will result in spatial and temporal cumulative change.
	Medium (2)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cumulative change.
	High (3)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is highly probable/definite that the impact will result in spatial and temporal cumulative change.
Irreplaceable Loss of Resources (LR)	Low (1)	Where the impact is unlikely to result in irreplaceable loss of resources.
	Medium (2)	Where the impact may result in the irreplaceable loss (cannot be replaced or substituted) of resources but the value (services and/or functions) of these resources is limited.
	High (3)	Where the impact may result in the irreplaceable loss of resources of high value (services and/or functions).

The value for the final impact priority is represented as a single consolidated priority, determined as the sum of each individual criterion represented in Table 5-5. The impact priority is therefore determined as follows:

$$Priority = CI + LR$$

The result is a priority score which ranges from 2 to 6 and a consequent PF ranging from 1 to 1.5 (Refer to Table 7-6).

TABLE 6-6: DETERMINATION OF PRIORITISATION FACTOR

Priority	Prioritisation Factor
2	**1**
3	**1.125**
4	**1.25**
5	**1.375**
6	**1.5**

In order to determine the final impact significance, the PF is multiplied by the ER of the post mitigation scoring. The ultimate aim of the PF is an attempt to increase the post mitigation environmental risk rating by a factor of 0.5, if all the priority attributes are high (i.e. if an impact comes out with a high medium environmental risk after the conventional impact rating, but there is significant cumulative impact potential and significant potential for irreplaceable loss of resources, then the net result would be to upscale the impact to a high significance).

TABLE 6-7: FINAL ENVIRONMENTAL SIGNIFICANCE RATING

Rating	Description
≤ -17	High negative (i.e. where the impact must have an influence on the decision process to develop in the area).
> -17 ≤ -9	Medium negative (i.e. where the impact could influence the decision to develop in the area).
> -9 < 0	Low negative (i.e. where this impact would not have a direct influence on the decision to develop in the area).

0	No impact
>0 <9	Low positive (i.e. where this impact would not have a direct influence on the decision to develop in the area).
≥ 9 < 17	Medium positive (i.e. where the impact could influence the decision to develop in the area).
≥ 17	High positive (i.e. where the impact must have an influence on the decision process to develop in the area).

6.2 PROJECT PHASES

This impact assessment has been developed on the understanding that the project is comprised of the following phases:

- Construction – surface infrastructure will be built on land cleared for that purpose;
- Operation – operation will commence.
- Decommissioning – all operations will cease with certain surface infrastructure removed; and
- Rehab/Closure – disturbed surface areas will undergo rehabilitation.

The proposed TSF establishment involves the removal of topsoil, the addition of surface infrastructure like roads, embankments, linings, silt traps and toe paddocks, and the transport of materials over the site. The proposed Pipelines involve the removal of topsoil, the addition of surface infrastructure like roads for access and maintenance, the addition of concrete plinths, and the transport of materials over the site. The proposed location of the LP Water System is a reclaimed brownfield site, and establishment involves the removal of topsoil, vegetation, and concrete foundations for the development of surface infrastructure. The proposed TSF and associated infrastructure are of relevance to this impact assessment, which is smaller in scale than the overall Harmony operation (which is not evaluated).

The following were options for the LP Water System: two HDPE-lined earth dams, two concrete tanks, and twelve Steel tanks. The concrete tanks have been prioritised as they have the smallest footprint.

6.3 IDENTIFIED SURFACE WATER IMPACTS

6.3.1 EROSION OF SOILS

Eroded soils have the potential to cause sedimentation of downstream watercourses. The construction of infrastructure will lead to new areas being disturbed, resulting in the potential for soil erosion to occur during times of rainfall or through persistent streamflow, while the decommissioning of this infrastructure will result in the same. If not mitigated, erosion could continue during the operational phase, although it is expected soils would settle to a degree, reducing the potential volume of erosion for any given rainfall event. The rehab/closure phase would have a similar risk of erosion to the construction phase.

During operation, the TSF is surrounded by toe paddocks reporting to the RWD, which has a silt trap at its entry. This will limit the potential for eroded soils or sediment to enter the environment.

While not chemically dirty, a proposed Topsoil Stockpile is noted to the east of the TSF. This stockpile requires stormwater management or concurrent remediation through or stabilisation of soils (assuming there are no potential sources of contaminant within the soil that necessitate removal) to limit the entrainment of sediment in runoff which may otherwise enter the surface water environment. Soil erosion may otherwise occur during all phases (from this stockpile).

During all phases, the proposed pipelines and associated infrastructure (concrete plinths) have the potential to increase soil erosion, and therefore, it is important to ensure the stability of the pre-cast concrete plinths.

The proposed LP Water System site is a disturbed area, as it is a reclaimed brownfield site previously hosting a thickener station for dredging operations that occurred at Dam 13. The replacement of existing infrastructure threatens the soil stability, therefore increasing the likelihood of erosion (however minimal compared to the TSF).

Disturbed areas should consequently be stabilised, with erosion control methods used where stabilisation is not possible. Rehabilitation for the site should include topsoil replacement and revegetation of disturbed areas. River channels, furrows and drainage canals should not have any infrastructure placed within them unless essential. Consideration should be given to the enhanced erosion potential in this instance.

TABLE 6-8: EROSION OF SOILS (CONSTRUCTION AND DECOMMISSIONING PHASE)

Impact Name	**Erosion of Soils**				
Phase	Construction & Decommissioning				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature	-1	-1	Magnitude	2	2
Extent	3	1	Reversibility	2	2
Duration	4	2	Probability	4	3
Environmental Risk (Pre-mitigation)					-11.0
Mitigation Measures					

- *Implement a GN 704 compliant stormwater management plan.*
- *Suitable erosion control should be utilised.*
- *The disturbed footprint should be minimised as far as practically possible.*
- *Clearing of vegetation and associated excavation should be kept to a minimum, particularly in areas where soils are unstable.*
- *Construction should, where possible, be scheduled to take place during the dry season when rainfall and associated erosion potential is at its lowest. For longer construction periods of more than six months, construction should be scheduled such that exposure of soils (before the addition of hardstanding or rehabilitation) occurs mostly within the dry season as far as possible.*

• *All disturbed areas must be rehabilitated (as soon as practically possible) to represent the previous undisturbed environment (soil, land-cover, slope) to limit the impact on receiving water resources (by limiting soil erosion).* • *Disturbed areas or areas rehabilitated with soils should be stabilised as soon as possible using plants (e.g. grass) or other mechanical methods (e.g. profiling or erosion control blankets).* • *Where erosion is nevertheless likely to occur, it is recommended to use settling facilities or silt fences.* • *Rehabilitation should include topsoil replacement, re-vegetation and maintenance/aftercare for disturbed areas insofar as it should be developed for disturbed areas.* • *Additional guidance on erosion control is available in: Landcom Soils and Construction, Volume 1, 4th edition from 2004 (otherwise known as the Blue Book).* • *Ensure pipelines stability by ensuring that the stability of the pre-cast concrete plinths is not undermined by erosion.* • *Ensure LP Water System stability by ensuring that the foundation of the concrete slab is not undermined by erosion.*	
Environmental Risk (Post-mitigation)	-5.25
Degree of confidence in impact prediction:	Medium
Impact Prioritisation	
Cumulative Impacts	2
Medium: Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cumulative change.	
Degree of potential irreplaceable loss of resources	1
Low: Where the impact is unlikely to result in irreplaceable loss of resources.	
Prioritisation Factor	1.13
Final Significance	-5.91

TABLE 6-9: EROSION OF SOILS (OPERATIONAL AND REHAB/CLOSURE PHASE)

Impact Name	**Erosion of Soils**				
Phase	Operational & Rehabilitation/Closure				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature	-1	-1	Magnitude	2	2
Extent	3	1	Reversibility	2	2
Duration	4	2	Probability	3	3
Environmental Risk (Pre-mitigation)					-8.25
Mitigation Measures					
• *Maintain a GN 704 compliant stormwater management plan.* • *Suitable erosion control should be utilised.* • *The disturbed footprint should be minimised as far as practically possible.* • *Clearing of vegetation and associated excavation should be kept to a minimum, particularly in areas where soils are unstable.* • *Construction should ideally be scheduled to take place during the dry season when rainfall and associated erosion potential is at its lowest. For longer construction periods of more than six months, construction should be scheduled such that exposure of soils (before the addition of hardstanding or rehabilitation) occurs mostly within the dry season as far as possible.* • *All disturbed areas must be rehabilitated (as soon as practically possible) to represent the previous undisturbed environment (soil, land-cover, slope) to limit the impact on receiving water resources (by limiting soil erosion).* • *Disturbed areas or areas rehabilitated with soils should be stabilised as soon as possible using plants (e.g. grass) or other mechanical methods (e.g. profiling or erosion control blankets).* • *Where erosion is nevertheless likely to occur, it is recommended to use settling facilities or silt fences.* • *Rehabilitation should include topsoil replacement, re-vegetation and maintenance/aftercare for disturbed areas insofar as it should be developed for disturbed areas.* • *Additional guidance on erosion control is available in: Landcom Soils and Construction, Volume 1, 4th edition from 2004 (otherwise known as the Blue Book).* • *Concurrent rehabilitation of the TSF should ideally occur during the life of the TSF. This would likely include cladding of TSF side slopes and subsequent revegetation with final TSF rehabilitation resulting in fully vegetated site.* • *Ensure pipeline stability by ensuring that the stability of the pre-cast concrete plinths is not undermined by erosion.* • *Ensure LP Water System stability by ensuring that the foundation of the concrete slab is not undermined by erosion.*					
Environmental Risk (Post-mitigation)					-5.25
Degree of confidence in impact prediction:					Medium
Impact Prioritisation					
Cumulative Impacts					2

Medium: Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cumulative change.	
Degree of potential irreplaceable loss of resources	1
Low: Where the impact is unlikely to result in irreplaceable loss of resources.	
Prioritisation Factor	1.13
Final Significance	-5.91

6.3.2 POLLUTANTS ENTERING THE SURFACE WATER ENVIRONMENT

Operation of earthmoving machinery or maintenance of vehicles on-site during construction, operation, decommissioning, and rehab/closure (including the possible storage or handling of hydrocarbons) poses a potential source of hydrocarbon contamination regarding the surface water environment. Vehicles and machinery should consequently be well maintained, stored/parked with drip trays and with an emergency response strategy for unforeseen hydrocarbon spills. For the most part, potential pollutants are already limited by the design of the project, given the contained nature of the TSF.

A stormwater management plan per GN 704 requirements is likely necessary on the basis that the TSF is designed not to spill (and therefore shouldn't spill more than once every 50 years). A pipeline rupture or leak is a possibility, and the pipeline route should consequently be positioned within managed dirty areas where possible (those currently managed or anticipated to be managed as part of Harmony's compliance with GN 704). Uncontrolled release of tailings or contaminated return water is possible and would be considered a residual risk (post-mitigation). Pipeline and LP Water System monitoring and maintenance will be an essential part of mitigation.

A TSF failure, while a highly unlikely event, has the potential to cause severe pollution of the downstream environment, while poor operation of the TSF and RWD could see unplanned spills from the RWD. Adequate engineering and operation of the TSF would mitigate these two potential impacts. Failure of the proposed LP Water System, whilst an unlikely event, has the potential to pollute the downstream environment.

Similarly, poor operation of the TSF, pipelines, and LP Water System could see unplanned leakage and spills, polluting the surrounding environment, with the pipelines having the highest risk of leakage given their extent. Adequate engineering, operation, and maintenance of the TSF, pipelines, and LP Water System would mitigate these potential impacts.

Important. It should also be noted that the potentially severe impact of a TSF failure is not adequately conveyed by the impact table below since the probability is low, resulting in the impact appearing less significant than may be warranted.

TABLE 6-10: POLLUTANTS ENTERING THE SURFACE WATER ENVIRONMENT (CONSTRUCTION PHASE)

Impact Name	**Pollutants Entering the Surface Water Environment**				
Phase	Construction				
Impact Name					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature	-1	-1	Magnitude	3	1
Extent	4	3	Reversibility	5	5
Duration	2	2	Probability	4	2
Environmental Risk (Pre-mitigation)					-12
Mitigation Measures					

• *Implement a GN 704 compliant stormwater management plan.* • *Keep activity within the managed dirty water footprint where possible.* • *Store hydrocarbons off-site where possible or otherwise implement hydrocarbon storage with adequate bunding.* • *Handle hydrocarbons carefully to limit spillage.* • *Ensure vehicles are regularly serviced so that hydrocarbon leaks are limited.* • *Use drips trays for stationary vehicles or otherwise park over areas suited to their storage (e.g. with an oil interceptor)* • *Designate a single location for refuelling and maintenance where possible.* • *Keep a spill kit on site to deal with any hydrocarbon leaks.* • *Remove soil from the site which has been contaminated by hydrocarbon spillage.* • *Undertake surface water monitoring to enable change detection related to contaminants originating from the site.* • *Develop the TSF, pipelines, and LP Water System using sound engineering to limit the likelihood of a failure.* • *Keep pipelines within the managed dirty water footprint where possible.* • *Keep pipelines and LP Water System well-maintained to prevent leakage.* • *Monitor pipelines and LP Water System to identify any leaks.* • *Pollution potential to watercourses must be considered in the designs to stop an unforeseen leak or rupture.*	
Environmental Risk (Post-mitigation)	-4.5
Degree of confidence in impact prediction:	Medium
Impact Prioritisation	
Cumulative Impacts	1
Medium: Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cumulative change.	
Degree of potential irreplaceable loss of resources	1
High: May result in the irreplaceable loss of resources of high value	
Prioritisation Factor	1.00
Final Significance	-4.5

TABLE 6-11: POLLUTANTS ENTERING THE SURFACE WATER ENVIRONMENT (OPERATIONAL AND DECOMMISSIONING)

Impact Name	**Pollutants Entering the Surface Water Environment**				
Phase	Operational and Decommissioning				
Impact Name					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature	-1	-1	Magnitude	5	5
Extent	5	5	Reversibility	5	5
Duration	4	2	Probability	3	2
Environmental Risk (Pre-mitigation)					-14.25
Mitigation Measures					
• *Maintain a GN 704 compliant stormwater management plan.* • *Keep activity within the managed dirty water footprint where possible.* • *Pollution potential within watercourses must be considered in the designs to stop an unforeseen failure or breach.* • *Store hydrocarbons off-site where possible or otherwise implement hydrocarbon storage with adequate bunding.* • *Handle hydrocarbons carefully to limit spillage.* • *Ensure vehicles are regularly serviced so that hydrocarbon leaks are limited.* • *Use drip trays for stationary vehicles or otherwise park over areas suited to their storage (e.g. with an oil interceptor)* • *Designate a single location for refuelling and maintenance where possible.* • *Keep a spill kit on site to deal with any hydrocarbon leaks.* • *Remove soil from the site which has been contaminated by hydrocarbon spillage.* • *Undertake surface water monitoring to enable change detection related to contaminants originating from the site.* • *Develop the TS, pipelines, and LP Water System using sound engineering to limit the likelihood of a failure.* • *Maintain and operate the TSF/RWD to limit the potential for overfilling that leads to a spill.* • *Monitor the TSF to identify any potential failures/slumps.* • *Keep pipelines within the managed dirty water footprint where possible.* • *Keep pipelines and LP Water System well-maintained to prevent leakage.* • *Monitor pipelines and LP Water System to identify any leaks.* • *Monitor the LP Water System to identify any potential failures.* • *Pollution potential to watercourses must be considered in the designs to stop an unforeseen leak or rupture.*					
Environmental Risk (Post-mitigation)					-8.5
Degree of confidence in impact prediction:					Medium

Impact Prioritisation	
Cumulative Impacts	2
Medium: Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cumulative change.	
Degree of potential irreplaceable loss of resources	3
High: May result in the irreplaceable loss of resources of high-value	
Prioritisation Factor	1.38
Final Significance	-11.69

TABLE 6-12: POLLUTANTS ENTERING THE SURFACE WATER ENVIRONMENT (REHABILITATION/CLOSURE PHASE)

Impact Name	Pollutants Entering the Surface Water Environment				
Phase	Rehabilitation/Closure				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature	-1	-1	Magnitude	5	5
Extent	5	5	Reversibility	5	5
Duration	4	2	Probability	1	1
Environmental Risk (Pre-mitigation)					-4.75
Mitigation Measures					
• *Keep activity within the managed dirty water footprint where possible.* • *Store hydrocarbons off-site where possible or otherwise implement hydrocarbon storage with adequate bunding.* • *Handle hydrocarbons carefully to limit spillage.* • *Ensure vehicles are regularly serviced so that hydrocarbon leaks are limited.* • *Use drip trays for stationary vehicles or otherwise park over areas suited to their storage (e.g. with an oil interceptor)* • *Designate a single location for refuelling and maintenance where possible.* • *Keep a spill kit on site to deal with any hydrocarbon leaks.* • *Remove soil from the site which has been contaminated by hydrocarbon spillage.* • *Undertake surface water monitoring to enable change detection related to contaminants originating from the site.* • *Monitor the TSF to identify any potential failures/slumps.* • *Monitor the pipelines and LP Water System to identify any potential failures/leaks.*					
Environmental Risk (Post-mitigation)					-4.25
Degree of confidence in impact prediction:					Medium
Impact Prioritisation					
Cumulative Impacts					2
Medium: Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cumulative change.					
Degree of potential irreplaceable loss of resources					3
High: May result in the irreplaceable loss of resources of high value					
Prioritisation Factor					1.38
Final Significance					-5.84

6.3.3 DECREASE IN RUNOFF

The proposed construction of the TSF and related surface infrastructure will increase impermeable hardstanding; however, with a containment philosophy in place as enabled by the self-contained TSF basin, toe paddocks and RWD, overall runoff from the site will be decreased to near zero.

The proposed construction of the pipelines (plinths) will increase impermeable hardstanding and thereby runoff, although the impermeable area is expected to be negligible compared to the greater Harmony operation. The anticipated access road beside the pipeline is expected to be gravel or dirt-based, in which case its impact will relate more to compaction. There is consequently a limited area of hardstanding that would increase runoff, with changes in runoff possibly negligible. The proposed LP Water System (concrete tanks and foundation slab) will increase the impermeable hardstanding and thereby reduce runoff, although the impermeable area is expected to be negligible compared to the greater Harmony operation. Overall, the TSF is expected to be the dominant influence on runoff, resulting in a net decrease.

A decrease in runoff is a typical impact associated with the containment of dirty areas on mines, and the mitigation of this impact is often not practical or possible with a reduction in mean annual runoff as an expected outcome.

This mean annual runoff reduction is informed by the area of the contained TSF/RWD to that of the containing catchment and quaternary catchment of relevance. At a containing catchment level (80.1km^2), the TSF/RWD containment results in a proportional containment of 10.8%, while at a quaternary level (723.4km^2) the proportional containment is 1.2%.

TABLE 6-13: DECREASE IN RUNOFF (CONSTRUCTION, OPERATIONAL, AND DECOMMISSIONING PHASE)

Impact Name	**Decrease in Runoff**				
Phase	Construction, Operation, and Decommissioning				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature	-1	-1	Magnitude	2	2
Extent	4	4	Reversibility	5	5
Duration	4	4	Probability	5	5
Environmental Risk (Pre-mitigation)					-18.75
Mitigation Measures					
• *Limiting the time and area over which machinery operates will limit the compaction of soils on the site.* • *Laydown areas should likewise be kept to a minimum with regards to area and time.* • *Keeping the contained dirty area to a minimum thereby limiting this impact.* • *Discharge excess water of an acceptable quality back into the surface water environment (river).*					
Environmental Risk (Post-mitigation)					-18.75
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Cumulative Impacts					2
Low: Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikely that the impact will result in spatial and temporal cumulative change.					
Degree of potential irreplaceable loss of resources					1
Low: Where the impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.13
Final Significance					-21.09

TABLE 6-14: DECREASE IN RUNOFF (REHABILITATION/CLOSURE PHASE)

Impact Name	**Decrease in Runoff**				
Phase	Rehabilitation/Closure				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature	-1	-1	Magnitude	2	1
Extent	4	1	Reversibility	5	1
Duration	4	1	Probability	5	5
Environmental Risk (Pre-mitigation)					-18.75
Mitigation Measures					
• *Limiting the time and area over which machinery operates will limit the compaction of soils on the site.* • *Laydown areas should likewise be kept to a minimum with regards to area and time.* • *Keeping the contained dirty area to a minimum thereby limiting this impact.* • *Discharge excess water of an acceptable quality back into the surface water environment (river).*					

Environmental Risk (Post-mitigation)	-5.0
Degree of confidence in impact prediction:	Medium
Impact Prioritisation	
Cumulative Impacts	2
Low: Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikely that the impact will result in spatial and temporal cumulative change.	
Degree of potential irreplaceable loss of resources	1
Low: Where the impact is unlikely to result in irreplaceable loss of resources.	
Prioritisation Factor	1.13
Final Significance	-5.63

6.3.4 FLOOD RISK

Flood risk is both an impact on the proposed TSF (flooding originating beyond the TSF) and on the environment (flooding originating from the TSF), and includes:

- A TSF failure resulting in downstream flooding (flooding originating from the TSF);
- Flooding from the Mahemspruit River (flooding originating beyond the TSF); and
- Surface water run-on towards the TSF (flooding originating beyond the TSF).

This risk is expected to be present during the construction, operational, decommissioning and rehab/closure phases (flooding originating beyond the TSF) and during the operational, decommissioning and rehab/closure phases (flooding originating from the TSF).

Section 4 presents a flooding assessment for the only defined river crossed by the pipeline. Section 5, however, expands the definition of relevant watercourses to both furrows and drainage canals. It additionally reviews dams and pans, which may present a flood risk. The site sensitivity grading should consequently be considered with regard to potential flood risk.

The consequence of flooding is potentially severe, however, flooding originating beyond the TSF has been mitigated through the addition of a stormwater bund and trench collecting runoff (surface water run-on) originating to the east of the site (see Figure 2-4) while the positioning of the TSF and associated infrastructure places the facility away from modelled flooding as outlined in Section 4. This includes the PMF flood results (plus climate change), which do not intersect the RWD and TSF, and the topsoil stockpile, which is positioned outside of the 1:100 RI flood-line. Since the topsoil stockpile is not a sensitive piece of site works (if affected by flooding), its avoidance of the 1:100 RI flood-line and not the PMF flood-line is warranted.

Flooding originating from the TSF, due to a failure (which is highly unlikely), has both flooding and pollutant implications (discussed in 6.3.2). In a similar sense, flooding originating beyond the TSF (caused by surface water run-on) could see the toe-paddock and RWD storage capacity compromised, leading to a spill of pollutants. Flooding also has possible feedback to Section 6.3.2 (pollutants entering the surface water environment), if flooding causes a rupture of the proposed pipeline/s. The location, stability, and self-contained nature of the LP Water System minimises its vulnerability to surface water run-on and flooding.

Important. It should be noted that the potentially severe impact of flood risk is not adequately conveyed by the impact table below since the probability of extreme flooding is low, resulting in the impact appearing less significant than may be warranted.

TABLE 6-15: RIVER AND SURFACE WATER FLOOD RISK

Impact Name	Flood Risk				
Phase	Construction, Operational, Decommissioning, and Rehabilitation/Closure				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature	-1	-1	Magnitude	5	5
Extent	4	4	Reversibility	5	5
Duration	1	1	Probability	1	1
Environmental Risk (Pre-mitigation)					-3.75
Mitigation Measures					
• *Implement a GN 704 compliant stormwater management plan to manage run-on towards the TSF.* • *Develop the TSF/pipelines/LP Water System using sound engineering to limit the likelihood of a failure.* • *Maintain and operate the TSF/pipelines/LP Water System to limit the potential for failure.* • *Monitor the TSF to identify any potential failures/slumps.* • *Monitor the pipelines/LP Water System to identify any potential failures/leaks.* • *Considering a flood-protection berm on the south-eastern side of the TSF (as discussed in Section 4.5 of this report).* • *Works should ideally not take place, nor infrastructure placed within 100m of any defined watercourse or within the 1:100 year flood-line given the applicability of GN 704. The linear nature of the pipeline means that some watercourse crossings, proximity to a watercourse or intersection with a flood-line are expected.* • *Pipelines are to be installed above-ground on pre-cast concrete plinths. These plinths should make adequate allowance for flooding, whether from a river, drainage canal, furrow or from surface water (runoff).* • *The concrete LP Water System (tanks) are to be established above-ground on a concrete foundation slab which will improve flood resistance.*					
Environmental Risk (Post-mitigation)					-3.75
Degree of confidence in impact prediction:					Low
Impact Prioritisation					
Cumulative Impacts					1
Medium: Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cumulative change.					
Degree of potential irreplaceable loss of resources					3
Low: Where the impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.25
Final Significance					-4.69

6.4 ADDITIONAL CONSIDERATIONS

Flooding and pollutants entering the surface water environment are the two primary impacts indicated by the impact assessment. Both impacts are poorly represented in the impact assessment due to their probability of occurrence (improbable).

7 SURFACE WATER MONITORING

Regular surface water quality monitoring is required to enable change detection resulting from the potential contamination of surface water by the TSF or any pipeline leaks. Surface water monitoring points presently active over the greater Harmony Operation have been provided and are presented in Figure 7-1.

Since a surface water monitoring plan is already underway with a wide coverage of monitoring points, the only clear location where there is no monitoring is at the end of the containing catchment). The addition of a monitoring point here would enable the full TSF influence to be considered since any spill from the operation would be registered by this monitoring point.

7.1 MONITORING PROGRAMME

Potential contaminants of concern that need to be monitored are expected to have already been identified based on the historical quarterly surface water quality monitoring that has been undertaken. The understanding of the mine's processes and the associated contaminants that might be released in the event of a failure in an aspect of the TSF (e.g., toe paddock rupture, RWD overflow or soil erosion of the topsoil stockpile) and the pipelines and LP Water System (e.g., leak or rupture) is likewise expected to be clearly understood with monitoring reflecting this.

The one additional point referred to above should ideally be added to the current monitoring for the greater Harmony Operation. Quarterly monitoring reports should be produced to differentiate seasonal variations and general trends due to the mining activities, with a comparison of water samples to standards and guidelines set by the Department of Water and Sanitation (DWS) and an analysis of parameters over time so that trends can be established.

The recommended monitoring point is illustrated in Figure 7-1 and is presented in Table 7-1.

TABLE 7-1: ADDITIONAL MONITORING POINT RECOMMENDED

Monitoring Point	Coordinate
SWM01	27° 57' 49" S and 26° 36' 25" E

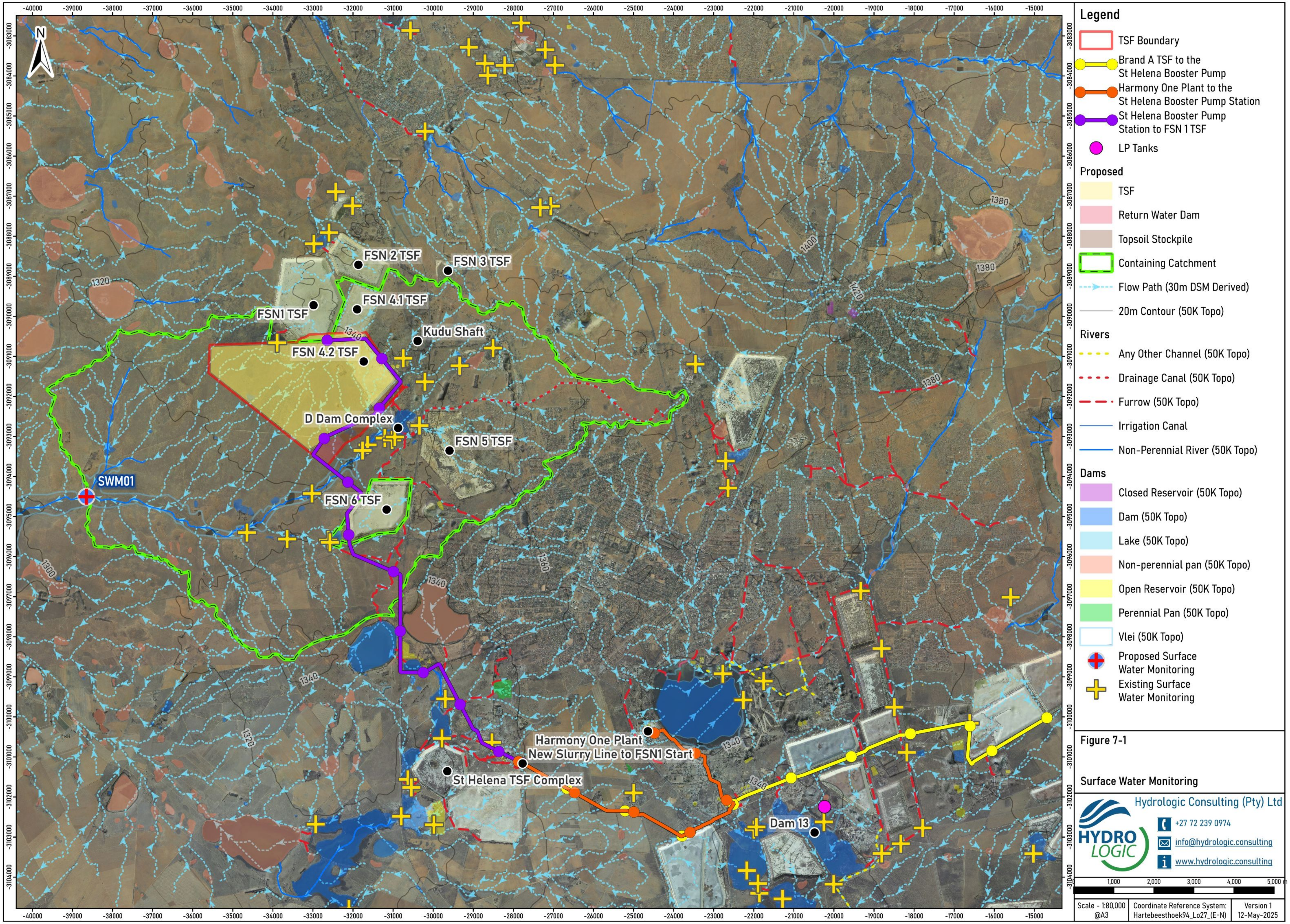


Figure 7-1

Surface Water Monitoring

8 CONCLUSION AND RECOMMENDATIONS

Harmony Gold Mining Company Limited (Harmony) is proposing the addition of the Nooitgedacht Tailings Storage Facility, Pipelines, and a Low Pressure Water Supply and Storage System and associated infrastructure.

Baseline information including rainfall, evaporation, design event rainfall, soils, vegetation and land-cover, as well as site terrain, flooding and regional and local catchment hydrology have been considered for the proposed pipelines.

Applicable Guidance

The primary guidance applicable to this assessment is as follows:

- National Environmental Management Act (Act No. 107 of 1998) as amended, states that "Every person who causes, has caused or may cause significant pollution or degradation of the environment must take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring…";
- National Water Act (Act No. 36 of 1998) includes Section 21 water uses which require authorisation from the Department of Water and Sanitation (DWS);
- Department of Water and Sanitation Notice 509 of 2016 provides clarity on the regulated area of a watercourse; and
- Government Notice 704 (Government Gazette 20118 of June 1999) provides regulations on the use of water for mining and related activities aimed at the protection of water resources.

Flood Modelling

The detail of the flood modelling for the site is presented in Appendix A. Since the modelling of flooding is (as undertaken), an approximation of reality, various assumptions and limitations are relevant (when considering the model results). These have been highlighted at various places in this report and are also outlined in Appendix A.

The most significant river near the site is the Mahemspruit River to the south-east of the site. This river has a contributing catchment of approximately 32km^2 up to its point of assessment south of the proposed TSF and was the primary focus of potential flooding to the site, which is made possible by some lower-lying terrain slowly rising towards the TSF boundary. The extent of the flood model covered approximately 2.3km of the defined non-perennial river (the Mahemspruit). Flood modelling utilised a combination of the 1m DTM, 2m DSM and 30m DSM for the development of the hydrological (PCSWMM) model and a combination of the 1m DTM and 2m DSM for the development of the hydraulic (HEC-RAS) model. The availability of a continuous 1m DTM and 2m DSM allowed for the adoption of a 2D flood model approach using HEC-RAS.

In considering the flood results presented in the figures, the 1:50 and 1:100 RI events are noted as not affecting the site, with the 1:100 RI event coming close to but not intersecting the proposed topsoil stockpile. The situation is different with the PMF events, with both intersecting the proposed topsoil stockpile. These, however, are the only proposed works that are affected by the PMF events with both the TSF itself and the RWD outside of the PMF and PMF plus climate change flood-lines.

Inaccuracies in the flood modelling (due to both general limitations in modelling, such as the limit of the 1m DTM, as well as the poorly understood influence of the D-Dam Complex) should be factored into the interpretation of the results (i.e. an additional freeboard could still be relevant due to potential error).

Site Sensitivities

Figure 5-1 presents the results of the identified site sensitivities as they relate to the surface water environment. This figure illustrates that there are parts of the TSF that are within sensitive areas. This includes the influence of two dams located within the TSF and the dam on the Mahemspruit, otherwise the sensitive areas affecting the TSF relate to the influence of the PMF flood results (including the PMF plus climate change results), since the 1:100 RI flood event (medium sensitivity) falls out of the site.

The two dams on the TSF site are expected to be removed and will therefore not be of relevance, while the influence of the PMF flood events and the dam on the Mahemspruit remain the only other sources of TSF site sensitivities.

In the case of the proposed pipelines, there are various sensitivities intersected due to the pipeline traversing various rivers, furrows and areas of modelled flooding (At Brand A and at the proposed TSF). The LP Tanks are the least affected by site sensitivity, falling with a ‘low’ classification.

It should be noted that this report does not consider the influence of wetlands, which will require consideration by a wetland specialist.

Identified Impacts

Flooding and pollutants entering the surface water environment are the two primary impacts, whether or not indicated by the impact assessment. Both impacts are poorly represented in the impact assessment due to their probability of occurrence (improbable).

In the case of flooding, there is flooding originating beyond the TSF(from the Mahemspruit River and from surface water run-on) and flooding originating from the TSF (due to a TSF failure). The latter presents the largest risk to this study, both concerning flood risk and with regard to pollutants entering the surface water environment. A secondary pollutant risk is poor management of the TSF’s RWD, resulting in a spill. Relative to the TSF, potential impacts relating to the proposed pipelines and the LP Tanks are less than the TSF, although the pipelines have the highest risk of accidental leakage given their extent.

Surface Water Monitoring

Regular surface water quality monitoring is required to enable change detection concerning the potential contamination of surface water by any pipeline leaks. Surface water monitoring points presently active over the greater Harmony Operation have been provided and are presented in Figure 7-1. Since a surface water monitoring plan is already underway with a wide coverage of monitoring points, there is only one additional point required at the downstream end of the containing catchment to identify any TSF spills.

Authorisation

The proposed Nooitgedacht Tailings Storage Facility and associated infrastructure can consequently be authorised with regard to the hydrological (surface water) environment, inclusive of the recommended mitigation measures presented in Section 6 and in consideration of the flood modelling results presented in Section 4. An update to Harmony’s overall surface water monitoring plan will also be required.

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BSc, Professional Land Surveyor (GPrLS 1539)
Survey/Modelling/Mapping

Mark Bollaert
MSc, CSci, CEnv, C.WEM, PrSciNat
Project Manager/Reviewer

DISCLAIMER

9 REFERENCES

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APPENDIX A: FLOOD MODELLING

A.1 HYDROLOGICAL MODEL

A hydrological model was required to first be developed for the catchment of relevance (approximately 32km^2).

A.1.1 HYDROLOGICAL MODEL CHOICE

PCSWMM is a model package that makes use of the USEPA Storm Water Management Model (SWMM), which is a computer program that computes dynamic rainfall-runoff from developed urban and undeveloped or rural areas (Rossman, 2008).

The SWMM model suited application to this study since it could account for:

- Time-varying rainfall;
- Rainfall interception in depression storage;
- Infiltration of rainfall into unsaturated soil layers;
- Routing of overland flow;
- Dynamic wave flow routing of flood waters; and
- Capture and retention of rainfall/runoff.

The hydrological modelling as it pertains to the development of stormwater management plans and flooding assessments using SWMM has been undertaken for many thousands of studies throughout the world (Rossman, 2008), including South Africa and was well suited to deriving the upstream inflows and effective rainfall as input into the hydraulic component of this study.

A.1.2 HYDROLOGICAL MODEL DOMAIN

The 1m DTM, 2m DSM and 30m DSM formed the basis of the hydrological model domain, informing the partitioning of subcatchments, the accumulation of flow and some parameterisation of the model (e.g. subcatchment slope). Subcatchments of interest were derived through geoprocessing of the available elevation data. Sequential computations of flow direction, flow accumulation and stream definition were then used to delineate subcatchments with a total subcatchment area of 52 subcatchments covering 32km^2.

A.1.3 SUBCATCHMENT PARAMETERISATION

Land cover parameters were estimated according to the SCS-SA soil for the area of interest, DEA land-cover, the terrain data and satellite imagery, for each of the 52 subcatchments. These were used to populate model attributes relating to depression storage, surface roughness, infiltration loss, slope and impervious areas.

A.1.4 DESIGN RAINFALL

In assessing flooding, it was necessary to define the associated rainfall that would cause this flooding. A hypothetical storm consequently needed to be developed. This hypothetical storm is the design rainfall that will produce the highest degree of flooding at each location independent of catchment response time (which is the index of the rate at which stormflow moves through a catchment). To calculate the hypothetical storm, the DRESSA and probable maximum precipitation (defined by SANRAL, 2013) for various durations (e.g. 5 minutes, 30 minutes and 2 hours) was transformed into a synthetic rainfall distribution or design hyetograph.

When considering the catchment area upstream, it was not necessary to include an areal reduction factor that considers the difference between the design rainfall estimate for a point versus that over a large catchment (since larger catchments are less likely to experience high-intensity storms over the full catchment area).

A.1.5 DESIGN HYDROGRAPHS

The 1:50 and 1:100 RI design hydrographs were extracted from the PCSWMM model for a single location (at the downstream end of the 32km^2 catchment). A comparison of the downstream modelled hydrographs estimated using PCSWMM to the Regional Maximum Flood (RMF) and Standard Design Flood (SDF) methods was made. These alternate flood estimation methods provide peak flow estimates that are generated using a regional approach and can sometimes be used as a high-level validation of modelled stormflows. Their influence on the PCSWMM model resulted in the PCSWMM model being revised to produce higher peaks (since both the RMF and SDF demonstrated higher peaks than PCSWMM), however, the RMF and SDF peaks remain significantly higher. Differences between the regional RMF and SDF methods and the site-specific PCSWMM estimates are expected, however, with Figure A-1 illustrating this difference. This difference is potentially explained by the regional approach (of the RMF and SDF) which may not reflect site conditions including the influence of D-Dam Complex.

The hydrological characteristics of the 52 subcatchments and connecting channels making up the PCSWMM model lead to one of the largest uncertainties concerning the flood modelling undertaken. The parameterisation of these subcatchments has utilised site-specific datasets, however, some inaccuracy is expected with the potential for the peak flows and design hydrographs to vary in reality. Lack of calibration due to an absence of observed flows means that the PCSWMM model results couldn't be verified.

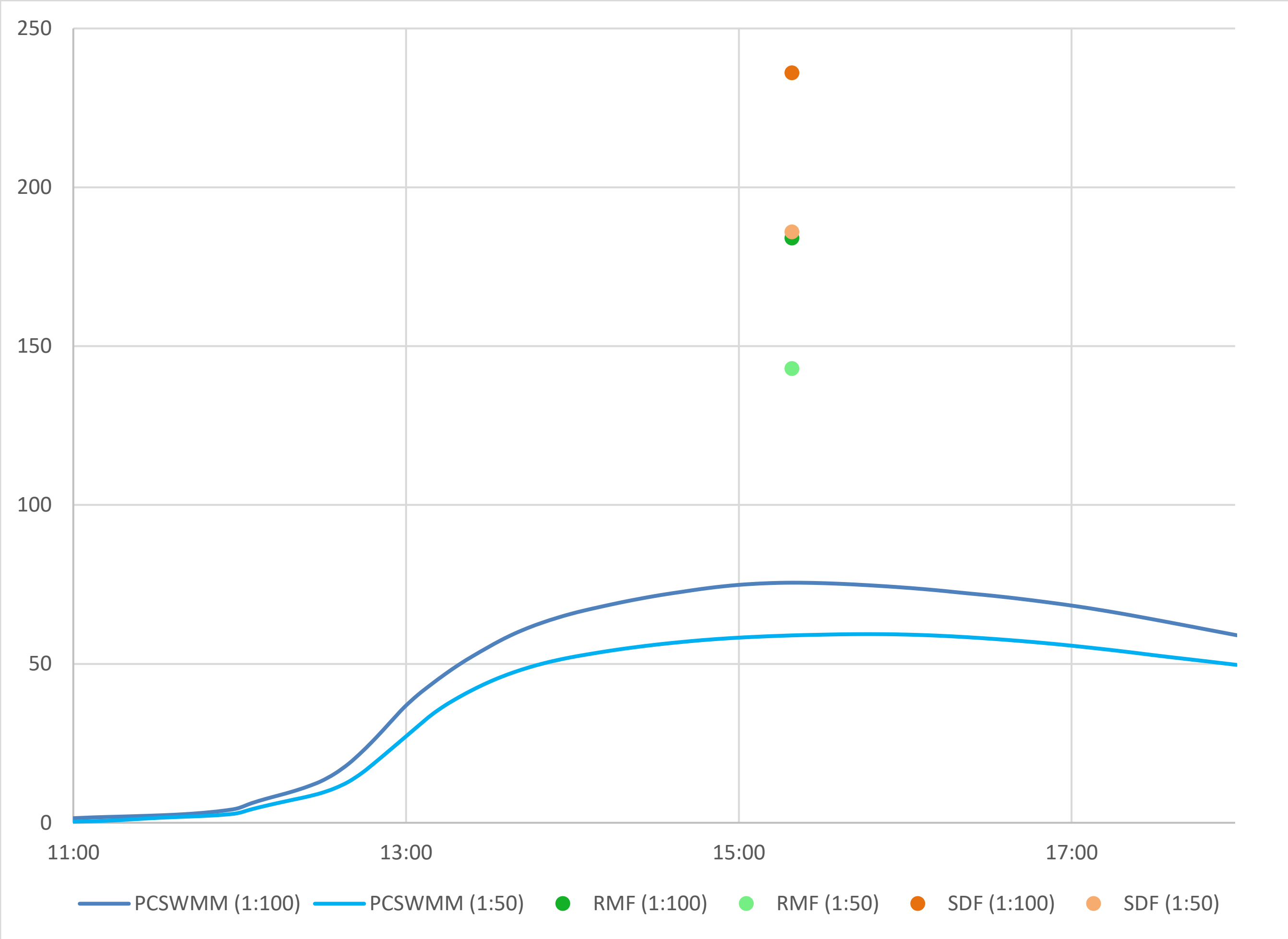


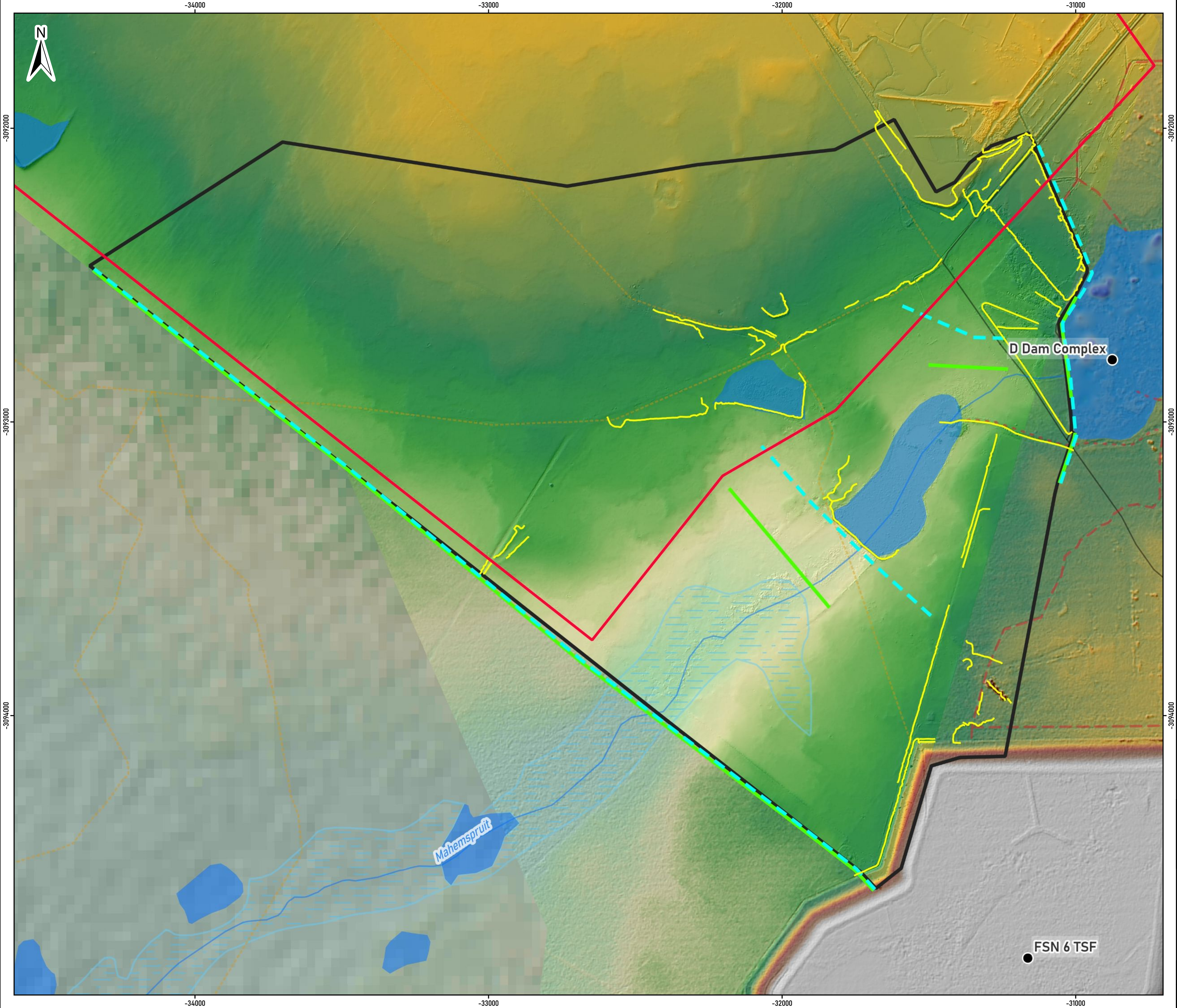
FIGURE A-1: DESIGN HYDROGRAPHS AND COMPARATIVE RMF AND SDF PEAK FLOWS

A.2 HYDRAULIC (FLOOD) MODELLING

The hydraulic model developed for modelling the 1:50, 1:100 and PMF events needed to utilise available terrain data in the form of the 1m DTM and 2m DSM. Figure A-2 presents the hydraulic model setup.

A.2.1 HYDRAULIC MODEL CHOICE

HEC-RAS 6.4.1 was selected to model the hydraulic flooding on the two rivers of interest. HEC-RAS is designed to perform one-dimensional and two-dimensional hydraulic calculations for a full network of natural and constructed channels. The software is used worldwide and the 1D component of the model has been thoroughly tested through numerous case studies. The 2D component to the HEC-RAS model is a more recent addition having been released in 2015 although robust benchmarking (USACE, 2016) and verification and validation tests (USACE, 2018) have been performed to prove the 2D component of the model works as intended.



Legend

- Site Boundary
- 2D Model Boundary
- Breakline
- Boundary Condition (PMF)
- Boundary Condition (1:50 & 1:00 RI)

Rivers

- Drainage Canal (50K Topo)
- Furrow (50K Topo)
- Non-Perennial River (50K Topo)

Roads

- Footpath (50K Topo)
- Other Road (50K Topo)

Dams

- Dam (50K Topo)
- Vlei (50K Topo)

Elevation (m AMSL)

1 355

1 320

Figure A-2

2D Hydraulic Model Setup

Hydrologic Consulting (Pty) Ltd

+27 72 239 0974

info@hydrologic.consulting

www.hydrologic.consulting

0 100 200 300 400 500 m

Scale - 1:12,000 @A3	Coordinate Reference System: Hartebeesthoek94_Lo27_(E-N)	Version 1 26-Oct-2023

A.2.2 TOPOGRAPHIC DATA

The 1m DTM and 2m DSM data (detailed in Section 2.3) provided the available terrain data for the hydraulic model build. This terrain data was reasonably detailed to poorly detailed (1m DTM to 2m DSM respectively). Surface water features (which create errors in both datasets) were not well represented. This included both the downstream dam and the D-Dam Complex.

A.2.3 COMPUTATIONAL MODEL MESH

In developing a 2D HEC-RAS model, it was necessary to first delineate the model boundary. The model boundary was then used to define the model grid, with a 10m model mesh spacing selected to maximise spatial detail while limiting unnecessary model complexity.

The computational model mesh is the primary element making up the HEC-RAS 2D model. This mesh contains the data about the terrain of the underlying elevation data, the presence of linear features and surface roughness.

One of HEC-RAS's major advances to hydraulic modelling has been the addition of a subgrid. The subgrid extracts the detail available in the underlying terrain (e.g. the 1x1m DTM) into a hydraulic properties table for each cell and cell face in the model mesh. This includes variables such as the elevation/volume relationship per cell and the cross-section, elevation/area, and wetted perimeter for each cell face. This results in HEC-RAS models being able to use a larger cell size while still representing much of the underlying terrain, thereby producing an improved model result.

Aside from added hydraulic detail, the visual benefit from HEC-RAS using a subgrid, is that a more representative result of the expected flooding is possible since HEC-RAS will show only partial flooding for a mesh cell (where applicable).

A.2.4 BOUNDARY CONDITIONS AND BREAKLINES

Upstream and downstream boundaries were defined for the model using a normal depth slope. This 'normal depth' is estimated according to the river bed slope.

The inflow hydrograph was applied to the upstream end of the relevant river reaches within the hydraulic model, despite being representative of the accumulated flows at the downstream end of the respective reach. This is common practice, whereby the design hydrographs for a point at the end of a modelled river reach are applied to a point upstream and result in some conservatism (where more flooding is conservative).

Breaklines were used to represent linear features that may otherwise have been missed by the application of a consistent model mesh (e.g. 10m mesh).

A.2.5 ROUGHNESS VALUES

A Manning's 'n' value shapefile was developed for the site based upon a review of aerial imagery. Values ranged between 0.02 (dams) to 0.09 (denser bush). The PMF event values were reduced slightly in recognition of the higher depths of flooding and the anticipated reduction in the influence of surface roughness. Manning's 'n' values are approximate only and assume uniformity in areas (where some localised variation is expected).

A.2.7 MODEL RUN

More accurate full momentum equations were used in the running of the flood model.

A.2.8 ASSUMPTIONS AND LIMITATIONS

Various assumptions were required in the development of the hydraulic model, with resultant limitations in the accuracy of the modelled flooding. They included (but are not limited to) the following:

- *PCSWMM parameterisation* – Design hydrographs estimated using PCSWMM are accurate given the potential for large deviations in their estimation to significantly influence resulting flooding.
- *Rainfall depth* – the DRESSA and probable maximum rainfall depths are correct – as defined by SANRAL (2013). The 20% increase assumed for the PMF (plus climate change) is also assumed a representative increase in the potential increase in rainfall intensity in the future.
- *Accuracy of terrain datasets* – the 1m DTM was assumed accurate while the 2m DSM was likewise assumed accurate (following a vertical shift to align with the 1m DTM).
- *Culverts* – no culverts were modelled since no survey was available while upstream channel detail was absent (in the 2m DSM). There is a culvert immediately upstream of the flood model boundary that would affect flood model results.
- *Mesh detail* – the default mesh utilised a 10m mesh size. While one of HEC-RAS's major strengths is the use of a subgrid, the obstructing or routing influence of linear features that are smaller than the mesh resolution will not be well defined.
- *Breaklines* – To compensate for mesh detail, linear features (and ridges in particular) were digitised as breaklines and then applied to the model mesh. The application of these breaklines is assumed correct/sufficient.
- *Roughness values* – The selected Manning's 'n' values were representative of the areas they covered, including being representative regardless of the depth of flooding.
- *Model calibration* – no calibration of the model was undertaken as there is no observed data for calibration purposes.
- *Software Performance* - The software and methods utilised are assumed accurate with regards to their utilisation of input data and the processes they simulate.