FLOOD-LINE ASSESSMENT OF THE PROPOSED HARMONY PIPELINE BETWEEN SAVUKA AND KUSASALETHU

Project No. EIM-010

Version 1

February, 2023

HYDROLOGIC CONSULTING

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FLOOD-LINE ASSESSMENT THE PROPOSED HARMONY PIPELINE BETWEEN SAVUKA AND KUSASALETHU

Prepared For

EIMS (PTY) LTD

Prepared By

Hydrologic Consulting (Pty) Ltd

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FLOOD-LINE ASSESSMENT OF THE PROPOSED HARMONY PIPELINE BETWEEN SAVUKA AND KUSASALETHU

1 INTRODUCTION

1.1 BACKGROUND

Hydrologic Consulting has been appointed by Environmental Impact Management Services (EIMS) to undertake a flood-line assessment of the proposed Harmony pipelines located between its Savuka and Kusasalethu plants. A separate slurry and water pipeline is proposed with an identical route except for the final section towards Savuka (which is only associated with the slurry pipeline).

This study does not consider the influence of the pipelines on flooding, instead presenting the baseline (current) flooding to inform pipeline design and layout. Additionally, only the primary watercourse crossing associated with the pipeline (costing of both the slurry and water pipeline) is evaluated. The implication is that there is no need to differentiate between the two pipelines (for this study) and they have consequently been combined into a single pipeline (for reference).

This flood-line assessment aims to inform the relevant water use licencing application (WULA) per the Department of Water and Sanitation (DWS) requirements, as well as Government Notice 704 (Government Gazette 20118 of June 1999 GN704) guidance as applicable.

1.2 SCOPE OF WORK

The scope of work was achieved by undertaking the following:

- Baseline Assessment – sourcing of baseline climatic and hydrological data. This included site-specific design rainfall (depth/duration/frequency), soils, and land-cover, as well as a hydrological assessment.
- Flood Modelling - this was undertaken using a 2D HEC-RAS model approach which maximised the use of available terrain data; and
- A technical report detailing the achieved scope of work (this report).

1.3 REGIONAL SETTING AND LAYOUT

The proposed pipeline (hereafter also referred to as the site) is located at 26° 25' 45" S and 27° 22' 7" E. Figure 1-1 presents the regional setting of the site with Figure 1-2 presenting the layout of the pipeline (relative to the two plants). The primary river crossing of relevance is illustrated in Figure 1-3. This is an annotated figure provided by Harmony which indicates the dimensions of the two culverts passing beneath the road at this location. The pipeline will be required to cross the non-perennial river at this point. This is the only defined river the pipeline crosses (per the 1:50,000 topographical map rivers) and is a double system (two separated culverts). Per the figure, the left culvert features a constructed concrete channel while the right culvert receives the natural watercourse. Additional non-perennial rivers and furrows are present near the pipeline route.

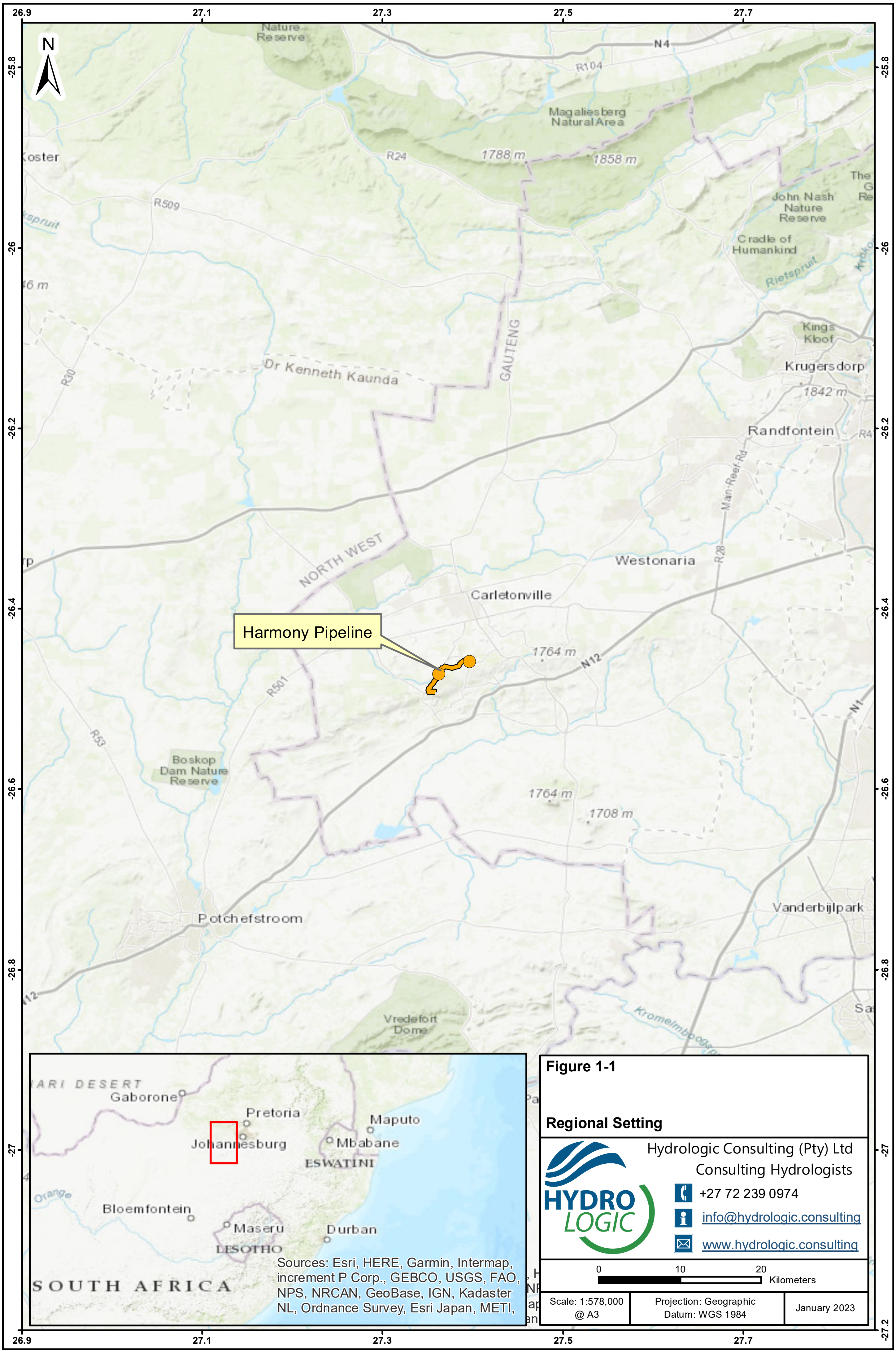
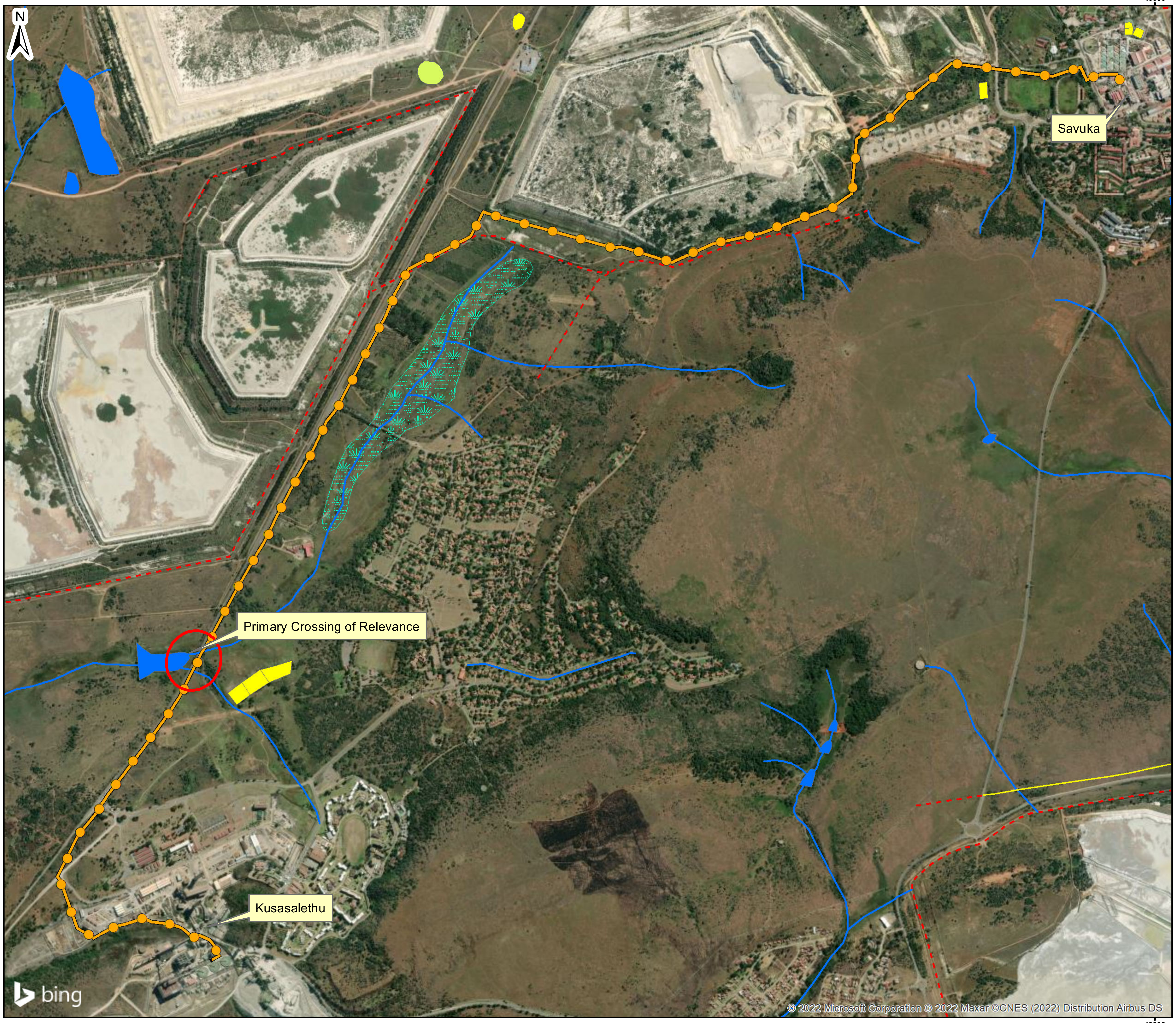


Figure 1-1

Regional Setting



Legend

- Proposed Pipeline
- Any Other Channel (50K Topo)
- Furrow (50K Topo)
- Non-Perennial River (50K Topo)
- Dam (50K Topo)
- Non-Perennial pan (50K Topo)
- Open Reservoir (50K Topo)
- Vlei (50K Topo)

Figure 1-2

Layout

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0 500
Meters

Scale: 1:11,400 @ A3	Projection: Transverse Mercator Datum: Hartebeesthoek LO27	January 2023

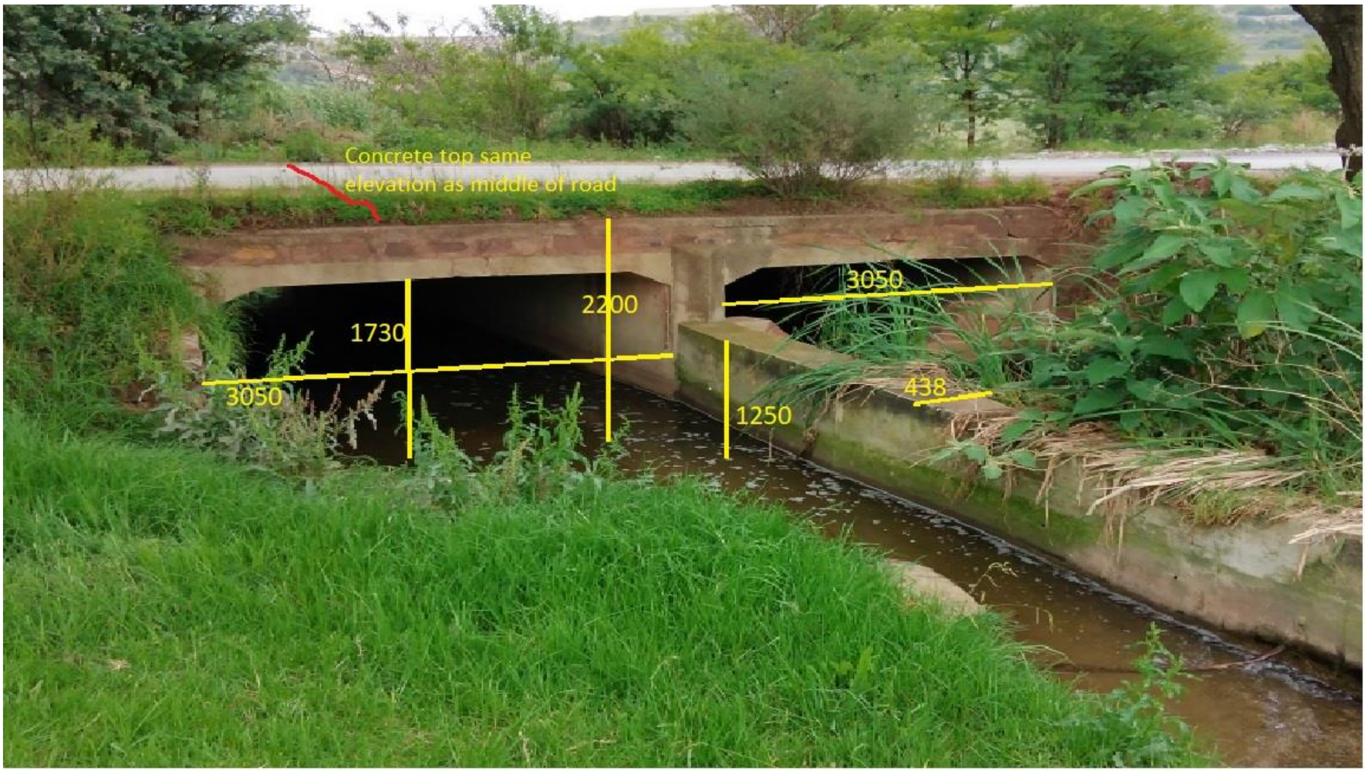


FIGURE 1-3: PHOTO OF THE CURRENT CULVERTS/RIVER ASSOCIATED WITH THE PIPELINE CROSSING

2 BASELINE INFORMATION

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

2.1 DESIGN RAINFALL

For modelling flooding, design rainfall is one of the most important variables to consider as it is the driver behind runoff volumes and peak flows.

Design rainfall estimates for various recurrence intervals (RI) and durations were sourced from the Design Rainfall Estimation Software for South Africa (DRESSA), developed by the University of Natal in 2002 as part of WRC project K5/1060 (WRC, 2002). This method uses a regional l-moment algorithm 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 (2002) provides more detail on this method of design rainfall estimation. Table 2-2 presents the DRESSA design rainfall estimates.

TABLE 2-1: DRESSA 24-HOUR RAINFALL DEPTH

Recurrence Interval (Years)	Rainfall Depth (24-hour) (mm)
2	61.9
5	82.6
10	96.4
20	109.9
50	127.5
100	140.8
200	154.2

* Values are representative of the centre of the catchment

It is important to note, that no allowances for climate change were included in this study. A risk analysis using the expected life of a structure or process will indicate the relevance of considering climate change (i.e. as the expected life increases the influence of climate change increases). Climate change is expected to exacerbate any flooding due to an increase in rainfall intensities.

2.2 AVERAGE CLIMATE

The average climate for the site is presented in Figure 2-2. While evaporation is showing as greatly exceeding rainfall, this is representative of the maximum A-Pan equivalent potential evapotranspiration that could occur assuming no limitations are placed on evaporative demand. The combination of rainfall, evaporation and temperature result in a warm temperate climate with dry winters and warm summers according to the Köppen-Geiger climate classification[1].

[1] http://stepsa.org/climate_koppen_geiger.html

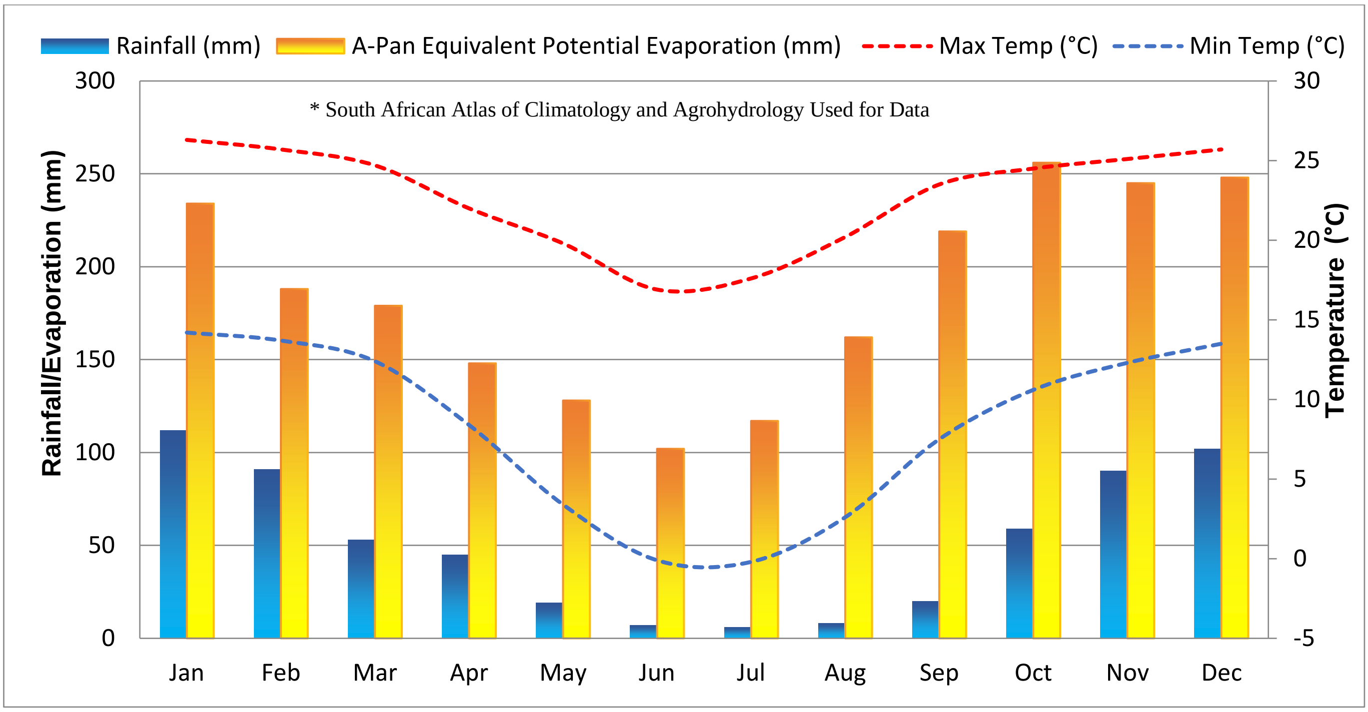


FIGURE 2-1: AVERAGE MONTHLY CLIMATE FOR THE SITE

2.3 TERRAIN

The following terrain (elevation) dataset was used in this study:

- 1m digital terrain model (DTM) interpolated from a Harmony provided Lidar dataset;

This terrain dataset was provided by Harmony and presents the 'bare earth' terrain, with surface features such as vegetation and buildings removed. The parent dataset was provided as a dataset of 30 xyz files and is understood to have been generated from a Lidar survey. The xyz files were combined into a single file before interpolation of the point cloud into a 1m DTM.

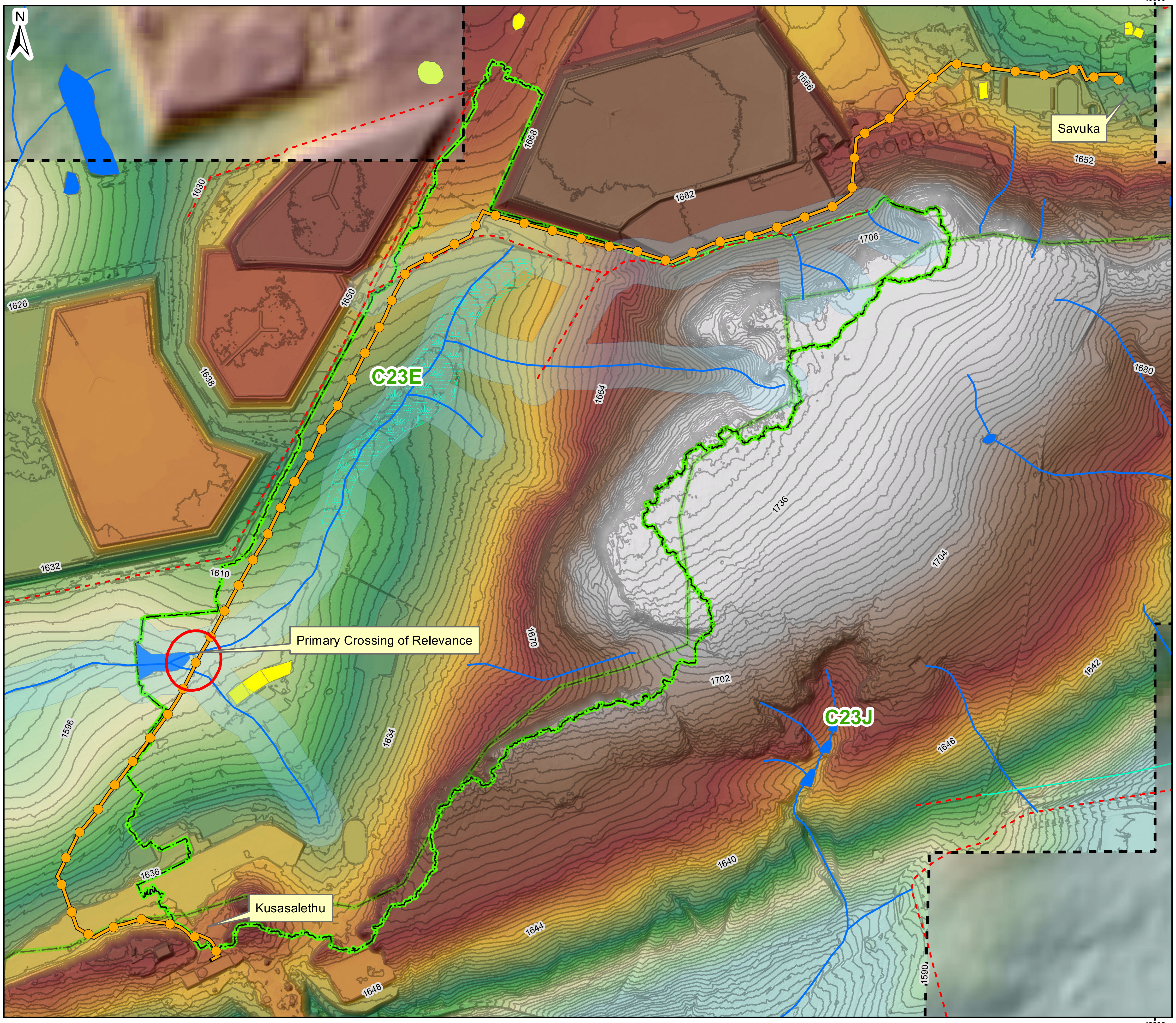
This 1m DTM was sufficient (in extent) for modelling as detailed in this report.

Elevation at the primary crossing is approximately 1,600mAMSL.

2.4 HYDROLOGY

Figure 2-2 illustrates the topographical and hydrological setting of the site. The site is positioned within quaternary catchments C23E.

The river network leading up to the primary crossing of relevance is comprised of non-perennial rivers as defined by the 1:50,000 topographical map data. The contributing catchment feeding these rivers has been delineated according to the 1m DTM. Tailings storage facilities were assumed to be self-contained, however, all other areas were allowed to drain as defined by the DTM data (when defining the contributing catchment).



Legend

- Proposed Pipeline
- Dam (50K Topo)
- Non-Perennial pan (50K Topo)
- Open Reservoir (50K Topo)
- Vlei (50K Topo)
- Survey Extent
- 2m Contour (Survey)
- Any Other Channel (50K Topo)
- Furrow (50K Topo)
- Non-Perennial River (50K Topo)
- Contributing Catchment
- Quaternary Catchments
- 100m Watercourse Buffer

Elevation (mAMSL)

High : 1730

Low : 1580

Figure 2-2

Terrain and Hydrology

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0 500 Meters

Scale: 1:14,700 @ A3	Projection: Transverse Mercator Datum: Hartebeesthoek LO27	January 2023

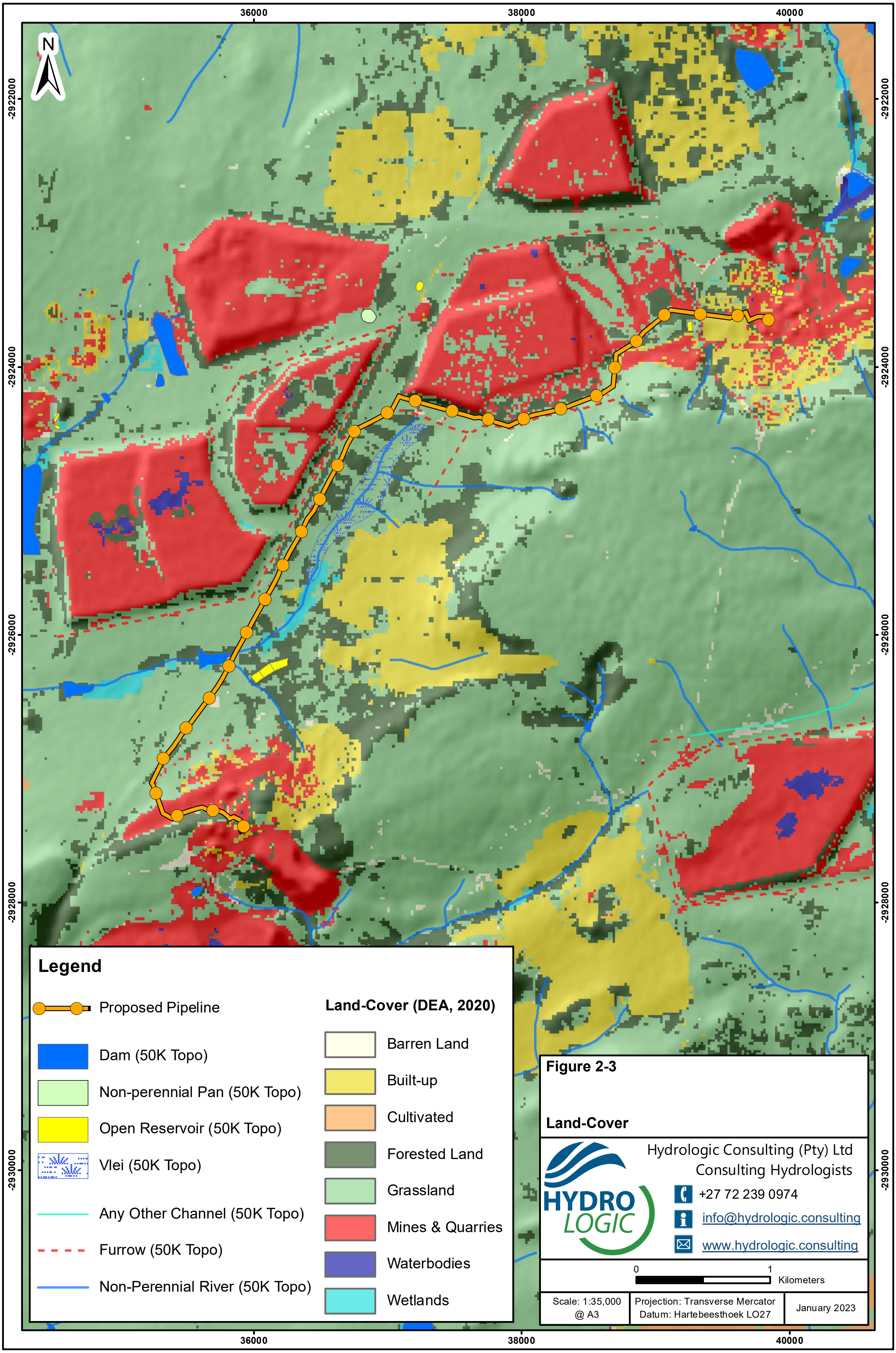
The non-perennial rivers or receiving furrows (that are connected to a river) within the contributing catchment were buffered by 100m as this is a distance applicable to both WULAs and GN 704. This indicates that the furrow to the north (which acts as a river diversion for upstream non-perennials) is within 100m distance to the proposed pipeline (running adjacent to the pipeline). This furrow is not the focus of this assessment, however, the design of the pipeline should nevertheless take this furrow and its receiving catchment into account.

The primary crossing of relevance is otherwise the only non-perennial river that intersects the proposed pipeline route. This crossing is associated with two non-perennial rivers, however, the southern river has had its catchment modified by the addition of a constructed concrete channel managing runoff from Kusasalethu. As per Figure 1-3, the constructed channel and natural channel converge and pass underneath the road via two rectangular culverts. These culverts discharge into a wetland which is associated with a dam that has since been breached (i.e. the dam does not hold water). The dam does, however, have an attenuating influence on flood flows due to the narrow outlet and the remaining dam wall.

2.5 SOILS, VEGETATION AND LAND-COVER

According to the Soil Conservation Service for South Africa (SCS-SA) dataset of the subcatchments of relevance, soils are classified as being predominantly in hydrological soil group C (moderately high runoff potential).

According to the Department of Environmental Affairs (DEA) 2020 dataset, land-cover over the site is classified as predominantly ‘grassland’, ‘mines and quarries’ and ‘built-up’


36000
38000
40000
-2922000
-2924000
-2926000
-2928000
-2930000
N
Legend
Proposed Pipeline
Dam (50K Topo)
Non-perennial Pan (50K Topo)
Open Reservoir (50K Topo)
Vlei (50K Topo)
Any Other Channel (50K Topo)
Furrow (50K Topo)
Non-Perennial River (50K Topo)
Land-Cover (DEA, 2020)
Barren Land
Built-up
Cultivated
Forested Land
Grassland
Mines & Quarries
Waterbodies
Wetlands
Figure 2-3
Land-Cover
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Scale: 1:35,000 @ A3
Projection: Transverse Mercator
Datum: Hartebeesthoek LO27
January 2023

3 FLOODING ASSESSMENT

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.

3.1 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 principle 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 with regard to 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.

3.2 HYDRAULIC MODEL CHOICE

HEC-RAS 6.3.1 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).

3.3 FLOOD APPROACH

The defined 1:50,000 topographical map rivers intersecting the primary crossing of relevance were selected (for flood modelling). The extent of the flood model covered approximately 1.3km of the defined river.

Flood modelling utilised the 1m DTM for the development of the hydrological (PCSWMM) model and hydraulic (HEC-RAS) model.

The PCSWMM model utilised 63 subcatchments connected by hypothetical channels. Each subcatchment had its hydrological parameters informed by site-specific datasets. The output of PCSWMM was two 1:100 RI, 24-hour design hydrographs that were applied to the two non-perennial rivers upstream of the primary crossing.

The availability of a continuous 1m DTM 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).

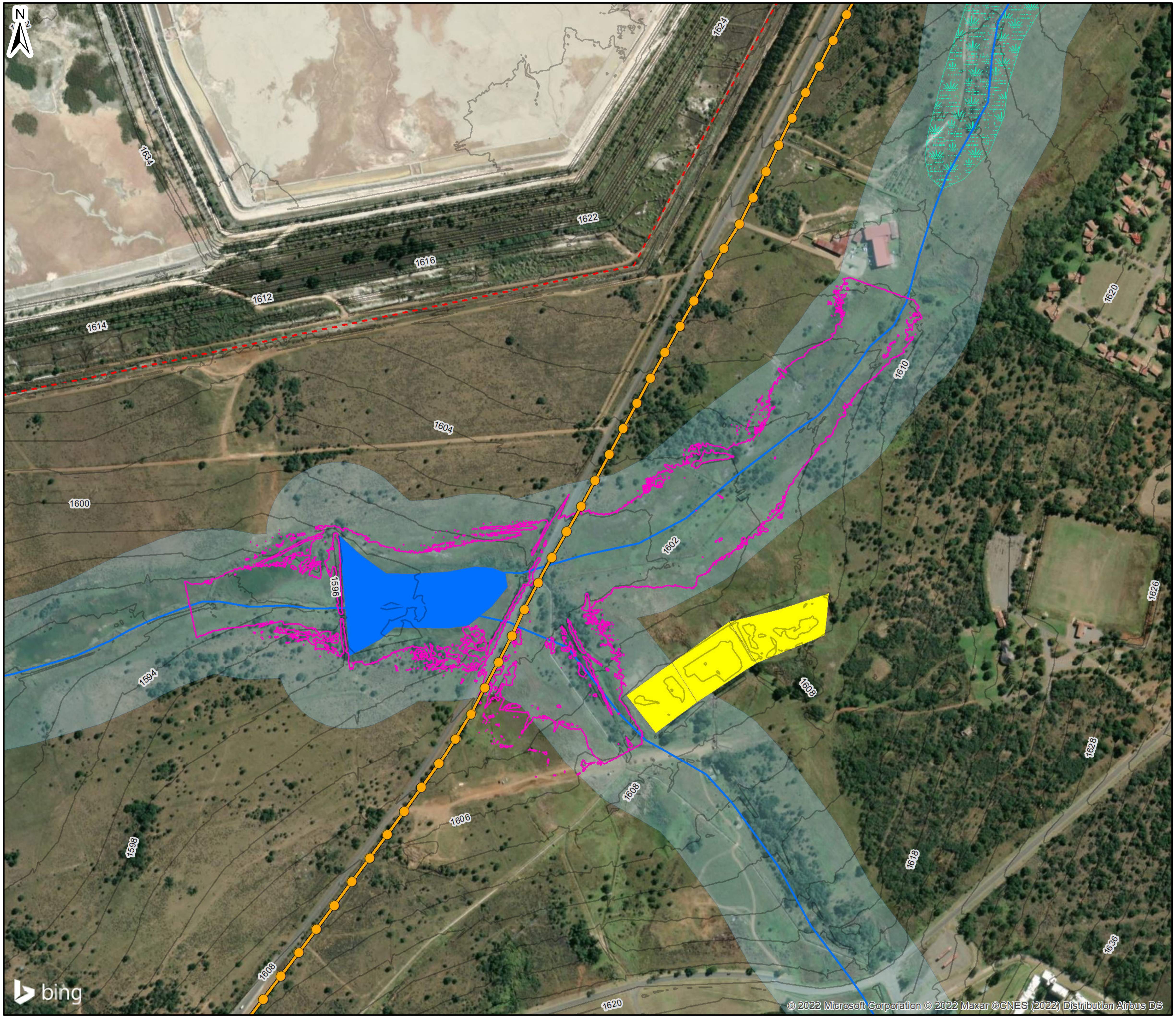
The single road crossing was added to the HEC-RAS model using the dimensions provided in Figure 1-3.

3.4 FLOOD MODELLING RESULTS

The overall results of the flood modelling are presented in Figure 3-1, which illustrates the 1:100 year RI flood-lines. A 100m watercourse buffer (defined according to the NGI's 1:50,000 topographical map dataset) is also presented in Figure 3-1. Figure 3-2 presents the maximum depth associated with the 1:100 RI flood event while Figure 3-3 illustrates the maximum flood velocity.

Flood-lines are typically contained by the 100m buffer with only a small area of modelled flooding to the north holding extending beyond the buffer.

In considering the maximum flood depth results in Figure 3-2, the road and dam wall both serve as a bottleneck to flooding, with flood waters expanding upstream of them. Figure 3-3 (velocity) reveals the increased flow velocity immediately after the double culvert as well as the narrow dam wall breach.



Legend

- Proposed Pipeline
- 2m Contour (Survey)
- Furrow (50K Topo)
- Non-Perennial River (50K Topo)
- 100m Watercourse Buffer
- Dam (50K Topo)
- Open Reservoir (50K Topo)
- Vlei (50K Topo)
- Flood-Line (1:100 RI)

Figure 3-1

Flood-Line (1:100 RI)

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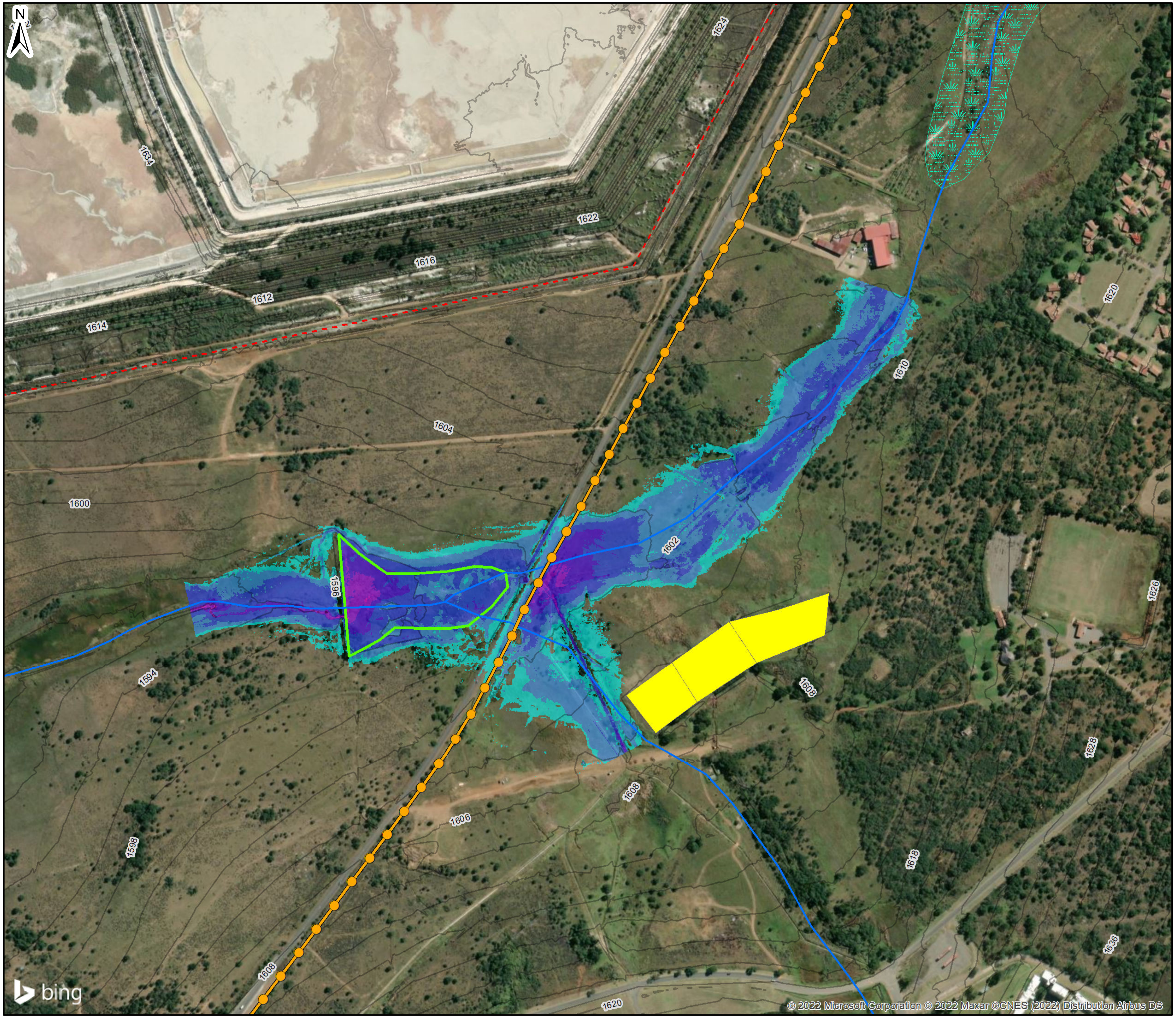
0 200 Meters

Scale: 1:5 000 @ A3	Projection: Transverse Mercator Datum: Hartebeesthoek LO27	January 2023



Legend

- Proposed Pipeline
- Furrow (50K Topo)
- Non-Perennial River (50K Topo)
- 2m Contour (Survey)
- Dam (50K Topo)
- Open Reservoir (50K Topo)
- Vlei (50K Topo)

Maximum Depth (m)

- < 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- > 2.0

Figure 3-2

Maximum Flood Depth (1:100 RI)

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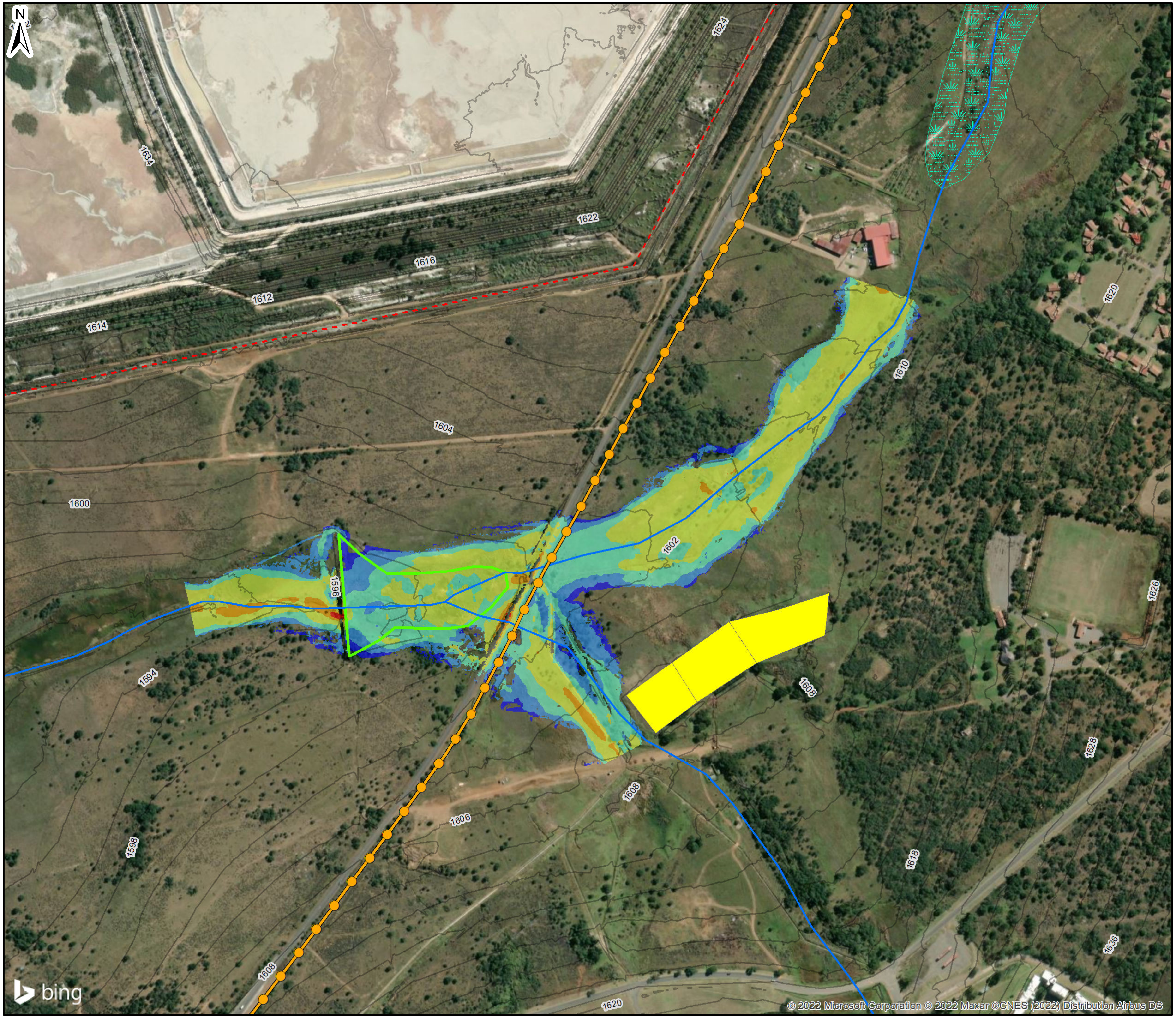
0 200 Meters

Scale: 1:5 000 @ A3	Projection: Transverse Mercator Datum: Hartebeesthoek LO27	January 2023



Legend

Proposed Pipeline

Furrow (50K Topo)

Non-Perennial River (50K Topo)

2m Contour (Survey)

Dam (50K Topo)

Open Reservoir (50K Topo)

Vlei (50K Topo)

Maximum Velocity (cumecs)

< 0.2

0.2 - 0.5

0.5 - 1

1 - 2

2 - 3

> 3

Figure 3-3

Maximum Flood Velocity (1:100 RI)

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0 200 Meters

Scale: 1:5 000 @ A3

Projection: Transverse Mercator
Datum: Hartebeesthoek LO27

January 2023

4 CONCLUSIONS

Hydrologic Consulting was appointed by EIMS, to undertake a flood-line assessment of the rivers intersecting the proposed Harmony pipeline between Kusasalethu and Savuka.

Baseline information including rainfall, soils, land-cover, terrain and the hydrological setting was considered for the site.

The non-perennial rivers or receiving furrows (that are connected to a river) within the contributing catchment were buffered by 100m as this is a distance applicable to both WULAs and GN 704. This indicates that the furrow to the north (which acts as a river diversion for upstream non-perennials) is within 100m distance to the proposed pipeline (running adjacent the pipeline). This furrow is not the focus of this assessment, however, the design of the pipeline should nevertheless take this furrow and its receiving catchment into account.

The specific focus of this study was the assessment of the current (baseline) flooding at the primary crossing of relevance (which is the only location where a defined 1:50,000 topographical river or furrow is crossed by the proposed pipeline). A PCSWMM model was developed to simulate the 1:100 year design hydrograph necessary as input into the hydraulic (flood) model.

A 2D HEC-RAS model was subsequently developed using the 1m DTM data. A single river crossing was included in this model which represented the current double culvert passing beneath the road (at the location of the primary pipeline crossing of relevance).

The results of the modelling are presented in Figures 3-1 to 3-3. 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.

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(MSc, CSci, CEnv, C.WEM, PrSciNat)
Project Manager/Author

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Department of Water Affairs and Forestry, 1999. *Government Notice 704 (Government Gazette 20118 of June 1999)*

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APPENDIX A: FLOOD MODELLING

A.1 HYDROLOGICAL MODEL

A hydrological model was required to first be developed for the contributing catchment routing through the current double culvert.

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 storm water 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 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 based upon a contributing area of 10ha were then used to delineate subcatchments with a total subcatchment area of 5.81km^2 being modelled.

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 1m DTM and satellite imagery, for each of the 63 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 which utilised the depth-duration-frequency (DDF) data provided by DRESSA (see Section 2.2). 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 1:50 and 1:100 year RI rainfall depths for various durations (e.g. 5 minutes, 30 minutes and 2 hours) were transformed into a synthetic rainfall distribution or design hyetograph. The DRESSA estimates used were those relevant to the flooding component of the study.

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 1:100 year RI design hydrographs were extracted from the PCSWMM model at two locations (for application on the two river reaches to be modelled). 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).

Differences between the regional RMF and SDF methods and the site-specific PCSWMM estimates are expected, however, with Figure A-1 illustrating this difference. The PCSWMM model was adjusted to produce higher flows (than those produced from the original model).

It is, however, also the specific hydrological characteristics of the subcatchments upstream of the crossing, which 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.

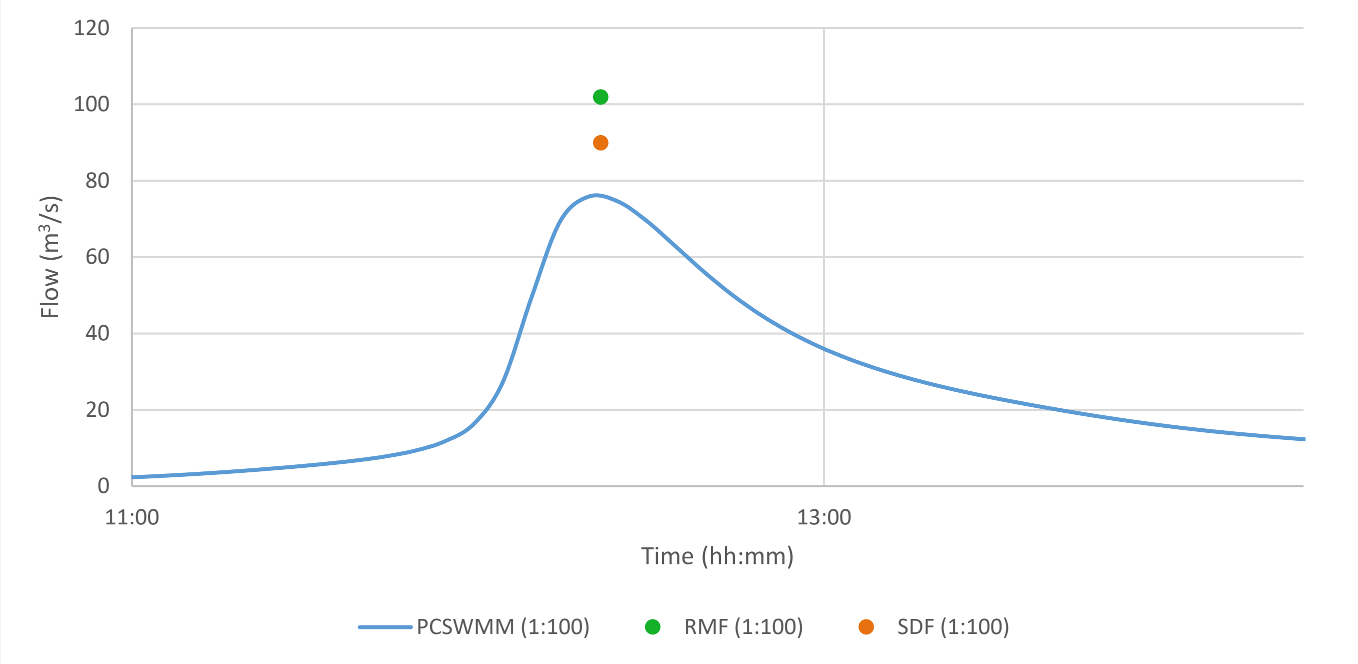

FIGURE A-1: 1:100 YEAR RI HYDROGRAPHS AND COMPARATIVE PEAK FLOWS

A.2 HYDRAULIC (FLOOD) MODELLING

The hydraulic model developed for modelling 1:100 year RI flood-lines needed to utilise available terrain data in the form of the 1m DTM.

A.2.1 HYDRAULIC MODEL CHOICE

HEC-RAS 6.3.1 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.

A.2.2 TOPOGRAPHIC DATA

The 1m DTM data (detailed in Section 2.3) provided the available terrain data for the hydraulic model build. This terrain data was reasonably detailed, although close inspection during the model build did reveal some areas of poorer accuracy (mostly associated with either thick vegetation or water). The model was, however, reliant on the 1m DTM and aside from the introduction of a narrow 1x1m concrete channel (draining runoff from Kusasalethu) and the introduction of the dividing wall present in Figure 1-3, the 1m DTM was otherwise not adjusted.

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 5m 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 (i.e. the 2x2m DEM) 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 two inflow hydrographs were applied to the upstream ends of the relevant river reach 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 results 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. 5m 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 0.015(concrete channel) to 1.0 (building). 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 model. A stable model run was achieved.

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 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* – DRESSA rainfall depths are assumed accurate, with normal DRESSA values applied to this study. DRESSA also includes upper values representative of upper confidence limits.
- *Accuracy of terrain datasets* – the 1m DTM was assumed accurate with only minor changes to account for the concrete channel and dividing wall.
- *Culvert Dimensions* – culvert dimensions and dividing wall dimensions were measured without reference to terrain (i.e. they were not in mAMSL) and also did not utilise specific survey controls. There is consequently some error expected in the way culverts were included in the model.
- *Mesh detail* – the default mesh utilised a 5 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.