Flood Level Study for

Melkehoutefontein Farm 480/25

Report

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Table of Contents

1 Introduction 1

1.1 Background 1

1.2 Scope 1

1.3 Site visit notes 2

1.4 Outline and approach 3

2 Coastal aspects 4

2.1 Ocean tidal water levels 4

2.2 Sea level rise 5

2.3 Wave impacts 6

3 Flood hydrology 7

3.1 Catchment and Estuary Characteristics 7

3.2 Quaternary catchment information 8

3.3 Average slope and longest watercourse 9

3.4 Flood determination 10

3.4.1 Previous studies 10

3.4.2 Regional design flood methods 10

3.4.3 Summary and recommended flood 12

4 Flood level determination 13

4.1 Methodology 13

4.2 Assumptions and limitations 13

4.3 Model setup 14

4.3.1 General parameters 14

4.3.2 Model geometry and terrain 14

4.4 Results 16

4.4.1 . River long section 16

4.4.2 River cross-section at proposed new dwelling 17

4.4.3 Water surface elevation maps – Present Case 17

4.4.4 Summary of flood line levels at the proposed new dwelling 20

5 Summary and conclusions 21

5.1 Flood levels 21

5.2 Recommendations for new dwelling 22

APPENDIX A – Flood Hydrology Calculations 25
APPENDIX B - Drawings 27

List of Figures

Figure 1: Aerial image of Farm 480/25 boundary and location of proposed new residential house. 1
Figure 2: Riverbank with reeds 2
Figure 3: Reed riverbank with grass floodplain 3
Figure 4: Goukou River course 4
Figure 5: Extreme frequency analysis of observed tidal levels at Mossel Bay 5
Figure 6: Catchment and river map (QGIS, 2023) 7
Figure 7: Quaternary catchments and MAP (CFM, 2023) 8
Figure 8: Longest water course 9
Figure 9: Watercourse profile 9
Figure 10: Peak discharge probability diagram for Midgley and Pitman (SANRAL, 2013) 11
Figure 11: Peak flows for different return periods 12
Figure 12: Goukou river surveyed cross-sections. 15
Figure 13: Extent of site topographic and bathymetric surveys. 15
Figure 14: Hec-Ras Model Geometry and associated terrain file used for the Melkehoutefontein flood line determination study 16
Figure 15: Goukou River Long Section along the model interest area with water surface elevations for the 1 in 5-year to 1 in 100-year flood events (*Present Case – blue lines; Future Case – red lines*). 16
Figure 16: Goukou River Cross Section at the proposed new dwelling with water surface elevations for the 1 in 5-year to 1 in 100-year flood events ((*Present Case – blue lines; Future Case – red lines*). 17
Figure 17: Water surface elevation (m MSL) for the Present 1 in 5 year flood (Q5_WL5). 17
Figure 18 Water surface elevation (m MSL) for the Present 1 in 10 year flood (Q10_WL10). 18
Figure 19 Present – Water surface elevation (m MSL) for the Present 1 in 20 year flood (Q20_WL20). 18
Figure 20: Water surface elevation (m MSL) for the Present 1 in 50 year flood (Q50_WL50). 19
Figure 21: Water surface elevation (m MSL) for the Present 1 in 100 year flood (Q100_WL100). 19
Figure 22: Goukou Estuary Flood Lines and Extreme Tidal Levels (*Present Case)*. 22

List of Tables

Table 1: Predicted (astronomical) tidal water levels at Mossel Bay (SANHO, 2019) 5
Table 2: Quaternary catchment information (DWS, 2017) 8
Table 3: SDF Peak flows 10
Table 4: Peak discharges for Midgley and Pitman method 11
Table 5: Kovács peak discharges 11
Table 6: Summary of peak discharge for various return periods 12
Table 7: Melkehoutefontein HEC-RAS model general parameters. 14
Table 8: Summary of flood line elevations at the proposed new dwelling on Melkehoutefontein Farm. 20

1 Introduction

1.1 Background

WML Coast has been appointed to conduct a flood level study of the Goukou River in the vicinity of Farm 480/25 Melkehoutefontein. The purpose of this study is to assess the potential flood risk associated with the construction of a new residential house adjacent to the river. The approximate farm boundary and the proposed location of the new house can be seen in Figure 1.

Site-specific flood water level data is required due to the fact that the proposed new house is situated within the 5 m contour line, within a distance of 32 meters from the edge of the Goukou River, and within 100 meters of the high-water mark of the Goukou estuary. Consequently, the proposed development falls within the estuarine functional zone of the Goukou River and is susceptible to periodic flooding. Therefore, it is necessary to thoroughly evaluate the flood risk in this area to ensure the safety and resilience of the proposed development.

Figure 1: Aerial image of Farm 480/25 boundary and location of proposed new residential house.

1.2 Scope

The study scope includes the following:

- One site visit performed by the WML Coast team
- Collection of bathymetric survey information during the site visit
- Assessment of the flood hydrology for the river section under consideration
- Consideration of combined coastal and river flood risk scenarios
- Flood line calculation for the interest area

1.3 Site visit notes

On May 19, 2023, the team from WML Coast conducted a site visit to Melkehoutefontein Farm 480/25. During the visit, bathymetric surveys were carried out using a Garmin EchoMap Chart Plotter. The following observations were made at the site:

- The river edge is typically characterized by a wide bank of reeds with limited access points, such as small jetties (see Figure 2).
- The riverbanks exhibit generally steep slopes.
- Both sides of the river feature floodplains covered mostly with grass, as depicted in Figure 3.
- At the time of the visit, the river was experiencing flooding, which may affect the interpretation of site dynamics, particularly the influence of ocean tides.
- The estuary water level was tidally driven but follows a distinct cycle separate from the ocean tide. Specifically, the water does not drain till the ocean low water level.
- The proposed development area is situated at the far end of a floodplain.
- The riverbed depth typically ranges from 2 to 3 metres, with a deeper section reaching 7.5 metres downstream from the erf.

These on-site observations provide important contextual information for the flood level study, allowing for a more comprehensive understanding of the site's characteristics and potential flood risks.

Figure 2: Riverbank with reeds

Figure 3: Reed riverbank with grass floodplain

1.4 Outline and approach

This study distinguishes between *present* and *future* flood level scenarios. *Present* flood levels are determined based on historical data observations and deterministic calculations derived from current conditions. For instance, the present 1:100-year flood refers to the flood event with a 1% annual exceedance probability in 2023.

On the other hand, *future* flood levels represent projected levels that align with a climate-change scenario anticipated to occur within the next 30 to 100 years. The future scenario incorporates the following adjustments:

- A sea level rise of 0.5 m.[1]
- A 15% increase in storm rainfall intensity.[2]

Section 2 provides an overview of the relevant coastal aspects pertinent to the Melkehoutefontein study. Following that, Section 3 presents the determination of the Goukou River flood hydrology. Subsequently, Section 4 details the calculation of Melkehoutefontein flood levels using 1-dimensional backwater calculations. The USACE HEC-RAS (Hydraulic Engineering Centre - River Analysis System) software package is utilized, taking into account the coastal and hydrological input variables outlined in Sections 2 and 3. It's important to note that this analysis excludes sediment transport and morphological modelling, including scour and dam-break analyses.

[1] Predictions for 2100 range from +0.5 m to +2.0 m; see 2.2 for more info
[2] As prescribed by the City of Cape Town for all future stormwater design and planning

2 Coastal aspects

The Goukou River mouth is situated at a distance of approximately 13 kilometres from the proposed development site at Melkehoutefontein Farm 480/25, as depicted in Figure 4. Consequently, the specific section of the river where the proposed development is located is in relatively close proximity to the ocean. As a result, the water level in this area is significantly influenced by tidal fluctuations.

Figure 4: Goukou River course

2.1 Ocean tidal water levels

Extreme sea levels result from a combination of astronomical and meteorological factors. During a storm, strong winds in conjunction with low atmospheric pressure contribute to elevated sea levels beyond the anticipated astronomical tidal level, a phenomenon known as "storm surge."

To obtain relevant data, the nearest tidal gauge station along the open coast is situated at the port of Mossel Bay, located 70 kilometres east of the Goukou River. Records of sea level measurements are maintained by the South African Navy Hydrographic Office (SANHO, 2019). Table 1 provides a comprehensive overview of the predicted (astronomical) tidal levels specifically for Mossel Bay. Additionally, Figure 5 presents an analysis of extreme frequency, incorporating observed tidal levels inclusive of storm surge effects.

The extreme high-water levels corresponding to various return periods, as indicated by the analysis, serve as downstream boundary conditions for the river flood modelling process detailed in Section 4.

Table 1: Predicted (astronomical) tidal water levels at Mossel Bay (SANHO, 2019)

		Tidal Level	
		(m Chart Datum)	(m MSL)
Highest astronomical tide	HAT	2.44	1.51
Mean high water at springs	MHWS	2.10	1.17
Mean high water at neaps	MHWN	1.46	0.53
Mean level	ML	1.17	0.24
Mean low water at neaps	MLWN	0.88	-0.05
Mean low water at springs	MLWS	0.26	-0.67
Lowest astronomical tide	LAT	0	-0.93

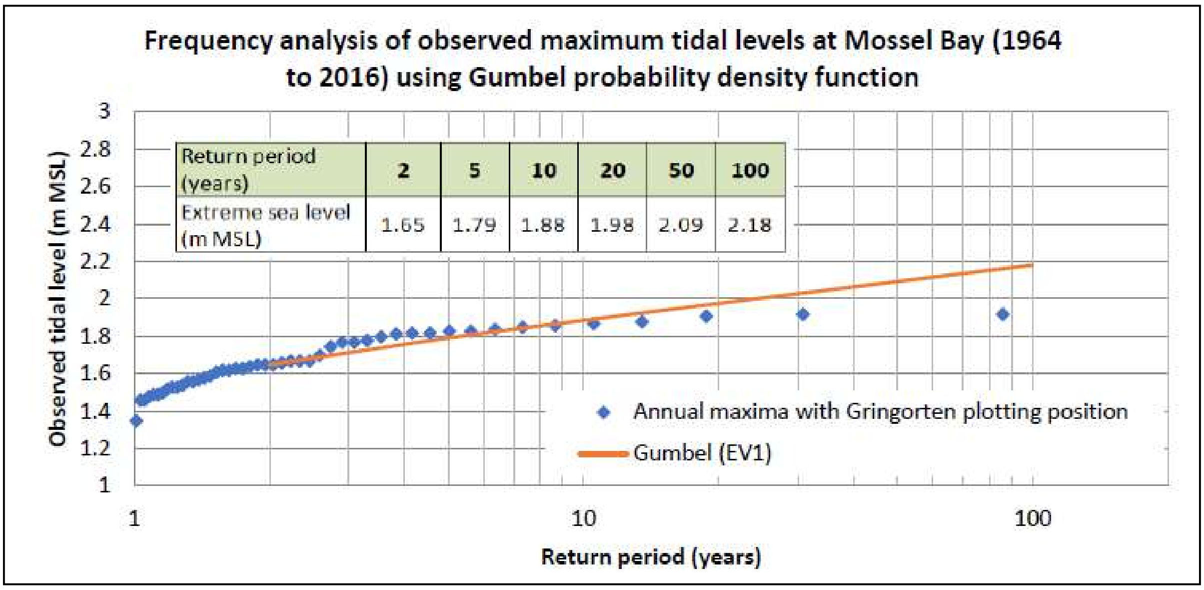

Figure 5: Extreme frequency analysis of observed tidal levels at Mossel Bay

2.2 Sea level rise

Projections of sea level rise for South Africa by the year 2100 range from 0.5 m (best-case scenario) to 1 m (best-estimate) to 2 m (plausible worst-case scenario) according to the CSIR (2014) report. The latest review on climate change conducted by the World Meteorological Organisation highlights that the impacts of climate change are being felt more severely and earlier than previously indicated in climate assessments from a decade ago. The global mean sea level rise has accelerated from an average of 3 mm/year between 1997 and 2006 to 4 mm/year between 2007 and 2016, as reported by the WMO (2019).

Considering the potential sea level rise of 0.5 m within the next 30 to 100 years, the impact on flood levels at Melkehoutefontein Farm 480/25 is taken into account when assessing the flood risks influenced by *near future* climate change. This inclusion allows for a comprehensive evaluation of the potential flood hazards associated with the proposed development, considering the anticipated rise in sea levels.

2.3 Wave impacts

The Goukou River mouth is characterized as a river with a permanently open mouth and a narrow tidal inlet, as documented by the CSIR (2011). Although some wave energy has the potential to enter the estuary, it is important to note that the proposed development site is positioned far upstream of the river mouth. As a result, the influence of wave entry into the river is considerably diminished to the extent of being negligible. Hence, the study does not incorporate the effects of ocean wave energy, given their insignificance in relation to the proposed development site.

3 Flood hydrology

3.1 Catchment and Estuary Characteristics

The Goukou River catchment and its tributaries fall under the jurisdiction of the Hessequa Municipality. As per the CSIR (2011) report, the reported catchment areas for the Goukou River vary between 1 188 km^2 and 1 550 km^2. Stretching across a length of 64 km, the river extends from its source to its confluence with the sea. In addition to smaller streams, the Goukou River receives water from five major tributaries, namely the Soetmelks, Naroo, Brak, Vet, and Kruis rivers, as documented by Carter and Brownlie (1990). Figure 6 provides a visual representation of the tertiary drainage region (H90), the rivers, and their proximity to the development area.

The Goukou Estuary encompasses an area of approximately 250 hectares and spans a length of 19 km. It is situated within a deep valley, as detailed in the CSIR (2011) report. Notably, the estuary is part of the Stilbaai Marine Protected Area (MPA), which was officially established on October 17, 2008. The estuary mouth remains open at all times, with a narrow tidal inlet.

Figure 6: Catchment and river map (QGIS, 2023)

3.2 Quaternary catchment information

The Goukou River is situated within the H90 tertiary drainage region, which comprises five distinct quaternary drainage regions, namely H90A, H90B, H90C, H90D, and H90E. In Figure 7, the quaternary catchments and a plot illustrating the mean annual precipitation of the region are displayed, based on research by Schulze (2009). The average annual precipitation for the entire catchment area is recorded as 482 mm, while the upper catchment area experiences a higher mean annual precipitation of 634 mm, as documented by Carter and Brownlie (1990).

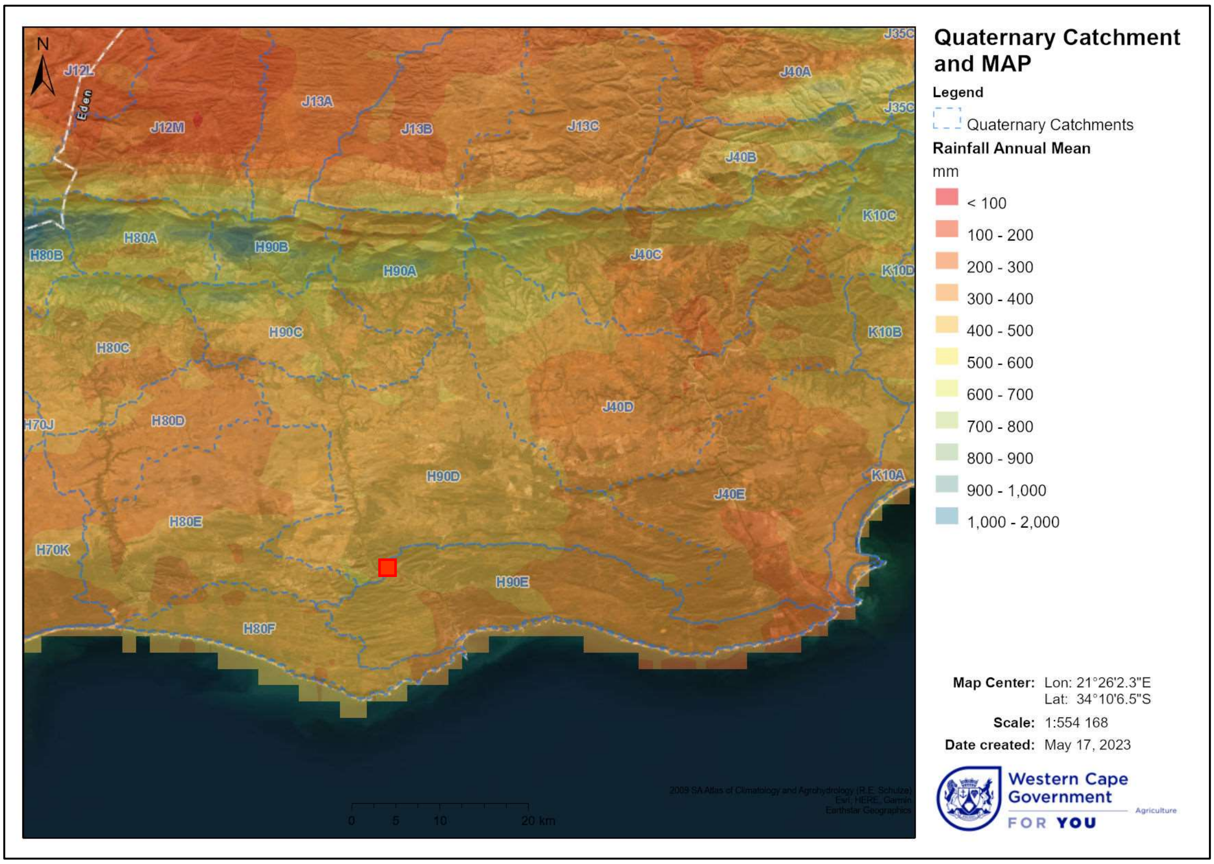

Figure 7: Quaternary catchments and MAP (CFM, 2023)

Table 2 provides a comprehensive summary of the significant hydrological characteristics of each quaternary catchment area. Notably, the proposed development site is situated at the boundary between the H90D and H90E quaternary catchment regions. As a result, the flood at the proposed development site is influenced by the contributions from quaternary catchments H90A, H90B, H90C, and H90D. The combined area of these catchments, which is considered for the analysis, amounts to 1 117 km^2.

Table 2: Quaternary catchment information (DWS, 2017)

Quaternary ID	Area [km^2]	*CMAP [mm]
H90A	179.09	644.68
H90B	118.18	663.76
H90C	217.58	466.68
H90D	602.12	425.13
H90E	495.65	489.62

*CMAP refers to a collection of precipitation data sets.

3.3 Average slope and longest watercourse

Figure 8 shows the longest water course for the region. The distance from the origin of the watercourse to the proposed development site measures 53.4 km. The average slope, denoted as S_{av}, was determined using the 1085-Slope method and computed as 0.005, where the vertical-to-horizontal ratio (V:H) is 1:200. To further illustrate the watercourse and the 1085-Slope method, refer to Figure 9. The formula for calculating the average slope using the 1085-Slope method is as follows:

$$S_{av} = \frac{H_{0.85L} - H_{0.10L}}{(1000)(0.75L)}$$

Where,

S_{av} is the average slope (m/m) = 0.005
$H_{0,10L}$ is the elevation height at 10% of the length of the watercourse (m) = 213.1m
$H_{0,85L}$ is the elevation height at 85% of the length of the watercourse (m) = 15.4m
L length of watercourse (km) = 53.4 km

Figure 8: Longest water course

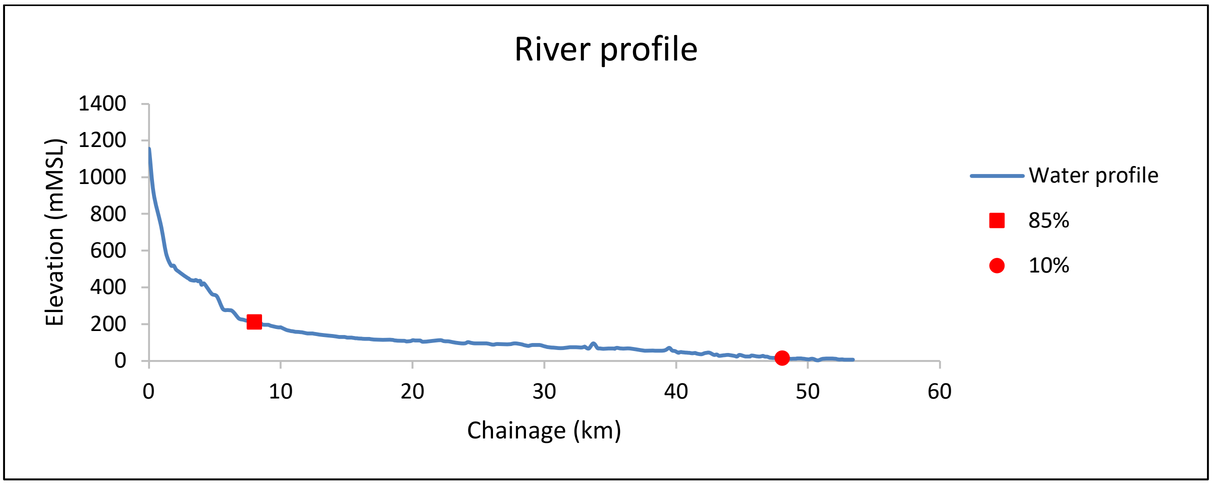

Figure 9: Watercourse profile

3.4 Flood determination

3.4.1 Previous studies

The estimated mean annual runoff (MAR) for the Goukou River is 106.42 million m^3, as reported by Pitman *et al.* (1981). Flood events with runoff exceeding 150 million m^3 occur on average every 3.2 years, while the yearly average MAR is surpassed every 2.8 years. However, according to Taljaard *et al.* (2015), the MAR entering the Goukou Estuary is recorded as 91.73 million m^3, indicating a 21% decrease compared to the natural MAR of 115.95 million m^3.

The largest recorded flood peak in the history of the Goukou River occurred on 25 January 1981, measuring 358 m^3/s. It is estimated that this flood event has a return period of 20 years. The 1:100-year flood has been estimated to be around 1 400 m^3, as documented by Carter and Brownlie (1990).

The Korentepoort Dam, located northwest of Riversdale on the Vet River, is the only major dam within the Goukou catchment. It has a capacity of 8.3 x 10^6 m^3 and was constructed during the period of 1963 - 1965 to provide water for the Korente-Vet River Irrigation canal and the town of Riversdale, as outlined by Carter and Brownlie (1990). It is important to note that the CSIR (2011) report mentions the lack of measured runoff data for the Goukou catchment, which is crucial for obtaining more precise flood estimations. In light of this limitation, the flood estimations provided by Carter and Brownlie (1990) will be considered as the most comprehensive and reliable scientific knowledge available up to the present time for this study.

Furthermore, Carter and Brownlie (1990) state that the influence of tides extends up to 19 km from the river mouth, indicating that the proposed development site falls well within the tidal influence zone.

3.4.2 Regional design flood methods

Standard Design Flood (Alexander, 2002)

The Standard Design Flood (SDF) method was used to verify the results of previous studies as mentioned in the previous section. The methodology as per the SANRAL (2013) was followed. The results from the SDF method are summarised in Table 3 later in this section. It should be noted that the area in consideration falls on the boundary of SDF basin 18 and 19. Basin 18 uses La Motte as a representative site whereas Basin 19 uses Letjiesbos. La Motte is typically a wetter region than the Goukou area, whereas Letjiesbos is dryer than the Goukou area – when considering the MAP. Hydrology calculations are presented in APPENDIX A and also the various inputs for the SDF method.

Table 3: SDF Peak flows

Basin	Peak flow (m^3/s)						
	2	5	10	20	50	100	200
18	243	531	761	1010	1371	1673	1992
19	61	205	335	487	725	935	1171

Midgley and Pitman (Rural I) – MIPI (1971)

Midgley and Pitman (1971) compiled regional curves of flood peaks, with the size of the catchment and the return period as variables. South Africa was divided into seven homogeneous flood regions. The Goukou River catchment falls under region 3. The results are summarised in Table 4.

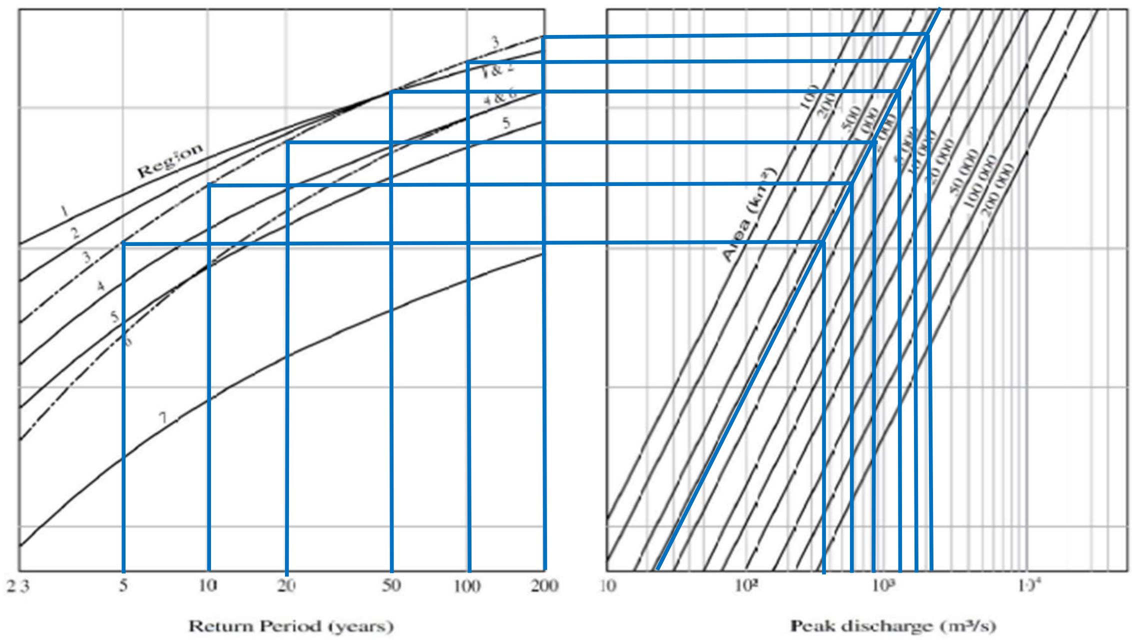

Figure 10: Peak discharge probability diagram for Midgley and Pitman (SANRAL, 2013)

Table 4: Peak discharges for Midgley and Pitman method

Peak flow	**Return period**					
	5	**10**	**20**	**50**	**100**	**200**
Q_T (m³/s)	380	540	850	1300	1700	2100

Kovács method (1980)

The Kovács (1980) method is typically used to estimate floods with return periods more than 100 years. However, it is sometimes desirable or necessary to obtain realistic values for extreme peak floods and the accompanying water levels; particularly where human lives may be endangered and/or valuable property may be damaged. For this development these longer periods are of lesser importance, however the Kovács methods was extended to include shorter return period floods. The Goukou river system is located in region K5 The related formulae are:

$$Q_{RMF} = \ 10^6 \left(\frac{A}{10^8}\right)^{1-0.1K} = 3342\ m^3/s$$

Where:

Q_{RMF} is the regional maximum flood peak flow rate (m³/s)
K is the regional constant

The Q_T/Q_{RMF} factors for region K5 was applied for to an approximated effective catchment area (1000km²), and the results are summarised in Table 5:

Table 5: Kovács peak discharges

Peak flow	**Return period**			
	50	**100**	**200**	**RMF**
Q_T (m³/s)	1775	2186	2530	3342

3.4.3 Summary and recommended flood

The results from previous studies and regional scale flood estimations are given in Table 6 and illustrated in Figure 11. The SDF estimation for the dryer region is similar to the 1:20 flood estimation based on previous studies. The 1:100-year flood from previous studies is significantly more than the SDF method for the dryer region, but similar to the wetter region as well as the Midgley and Pitman (1971) method. It should be noted that flood hydrology is difficult to quantify and predict which results in the wide spread of estimated flood peaks. A conservative approach should be considered. The recommended flood values are based on the previous studies and judgement when taking into account the results of the regional methods.

Table 6: Summary of peak discharge for various return periods

Method	Peak discharge (m^3/s)				
	5	10	20	50	100
Previous studies	-	-	358	-	1400
SDF – Wetter region	531	761	1010	1371	1673
SDF – Dryer region	205	335	487	725	935
Midgley and Pitman	380	540	850	1300	1700
Kovács	-	-	-	1775	2186
Recommended – Present	200	330	360	1000	1400
Recommended – Future*	230	380	414	1150	1610

* Allowance for 15% increase in peak flood discharge due to climate change

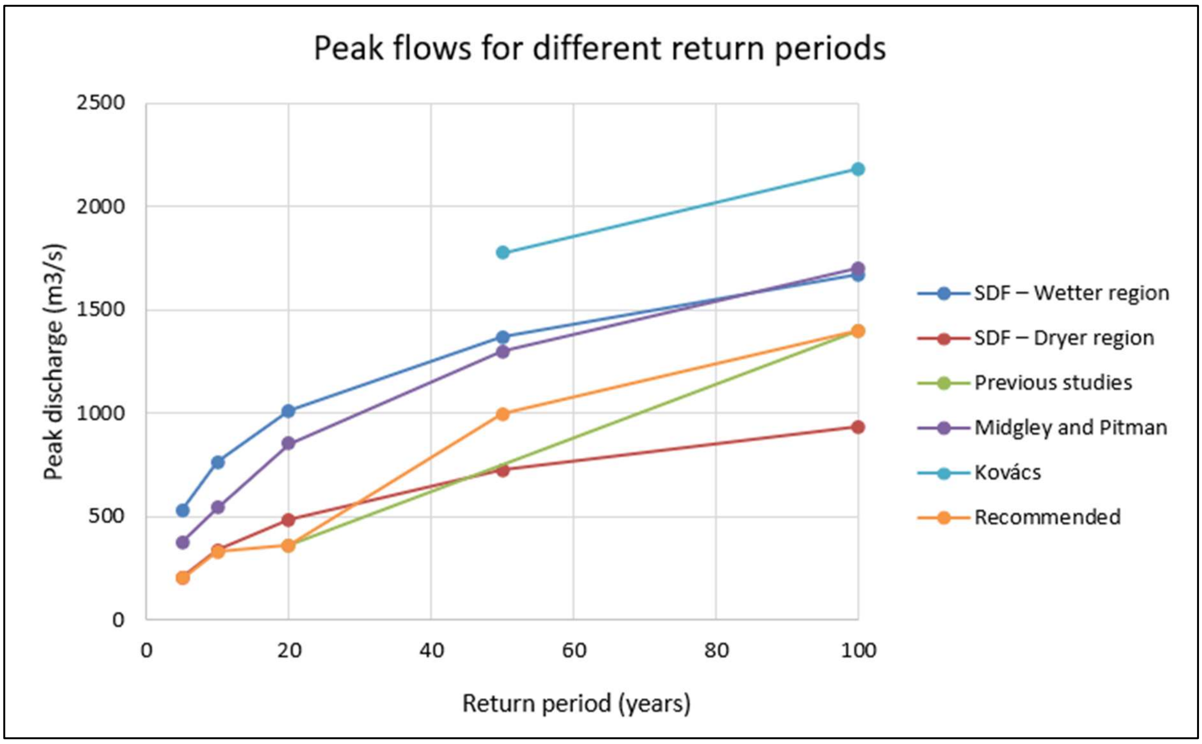

Figure 11: Peak flows for different return periods

4 Flood level determination

4.1 Methodology

Flood lines were determined using the HEC-RAS (Hydraulic Engineering Centre – River Analysis System) software package. The analysis involved performing 1-dimensional steady-state simulations, specifically "backwater calculations," using river cross sections and peak flood flows obtained from Section 3 of this study. Hydraulic parameters were estimated based on on-site observations.

The focus of this study is the area surrounding the proposed development site. Consequently, the flood line model was extended several kilometres upstream and downstream of this area to ensure that any potential boundary effects were minimized. A more detailed survey was conducted in the vicinity of the proposed development site to enhance the accuracy of the model for this specific area. No hydraulic structures such as weirs or bridges are present in this area. Therefore, the model exclusively represents the river channel and its associated characteristics. Sediment transport and morphological modelling were not included in the analysis.

4.2 Assumptions and limitations

The following assumptions were made in determining the flood lines:

- The variation in operation of the Korentepoort dam does not significantly affect the flood peaks.
- The flood peak with a T-year return period corresponds to the T-year return period extreme sea level at the Goukou Estuary, representing the worst-case scenario.
- Refer to Table 6 for the river flood peaks used for flood line calculations

4.3 Model setup

4.3.1 General parameters

Table 7: Melkehoutefontein HEC-RAS model general parameters.

Project Name	Melkehoutefontein Flood Line Study
Coordinate system	Model - UTM 34S EPSG32734, Survey - Hartebeesthoek94_Lo21 ESRI:102483
Datum level	Metres above mean sea level – m MSL
Channel Roughness	Manning n = 0.04, see Chow (1959), Fetter (2001), and Tak et al. (2016)
Floodplain Roughness	Manning n = 0.045, see Chow (1959), Fetter (2001), and Tak et al. (2016)
Terrain	1 m resolution GeoTiff
Flow type	Subcritical
Upstream boundary	Normal flow depth with 0.005 m/m slope
Downstream boundary	Multiple: Known water surface elevation (extreme sea levels), normal flow depth with 0.005 m/m slope
Simulation type	Steady State

4.3.2 Model geometry and terrain

A digital terrain model of the model domain was compiled from the following data sources:

- A topographical land survey at the interest area and at 8 cross sections – shown on Figure 12
- A bathymetric survey of the river conducted by WML Coast on the 19th of May 2023 – as shown on Figure 13
- South African Chief Directorate: National Geo-spatial Information (NG) contour lines for terrain above 5 m MSL
- Aerial imagery and elevation data captured with a drone

The model was extended upstream and downstream of the interest area with historical cross-section data of the river obtained from survey missions conducted by the CSIR, NGI topographical data and satellite aerial imagery and elevation data.

Model cross-sections were defined at appropriate locations, and the cross-section profiles were then derived from the digital terrain model. The terrain model, river cross-sections, river bank lines and total model extent is shown on Figure 14

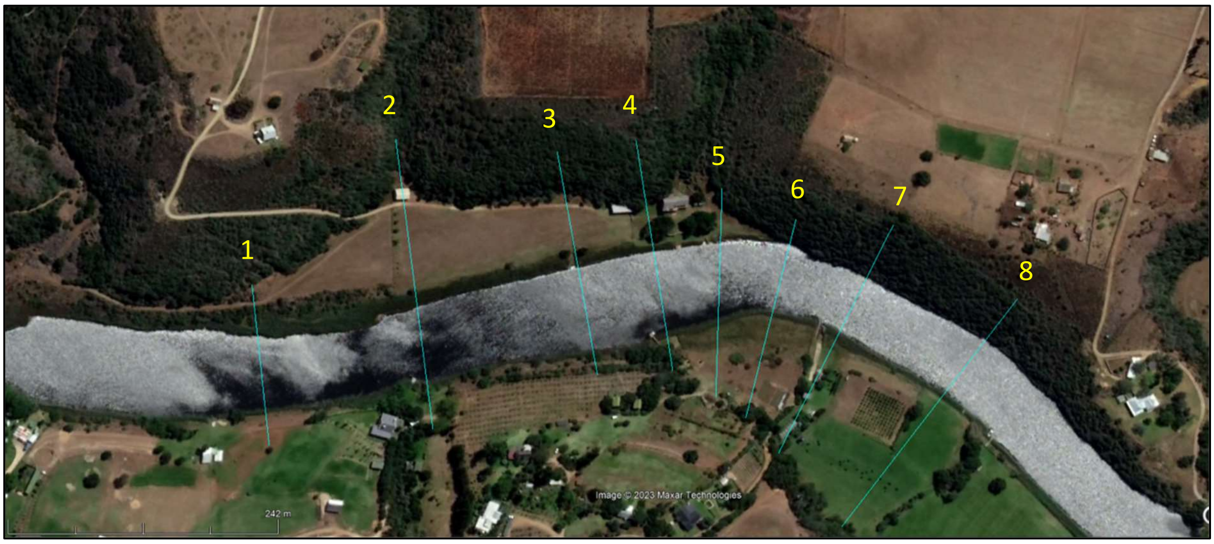

Figure 12: Goukou river surveyed cross-sections.

Figure 13: Extent of site topographic and bathymetric surveys.

Figure 14: Hec-Ras Model Geometry and associated terrain file used for the Melkehoutefontein flood line determination study.

4.4 Results

4.4.1 . River long section

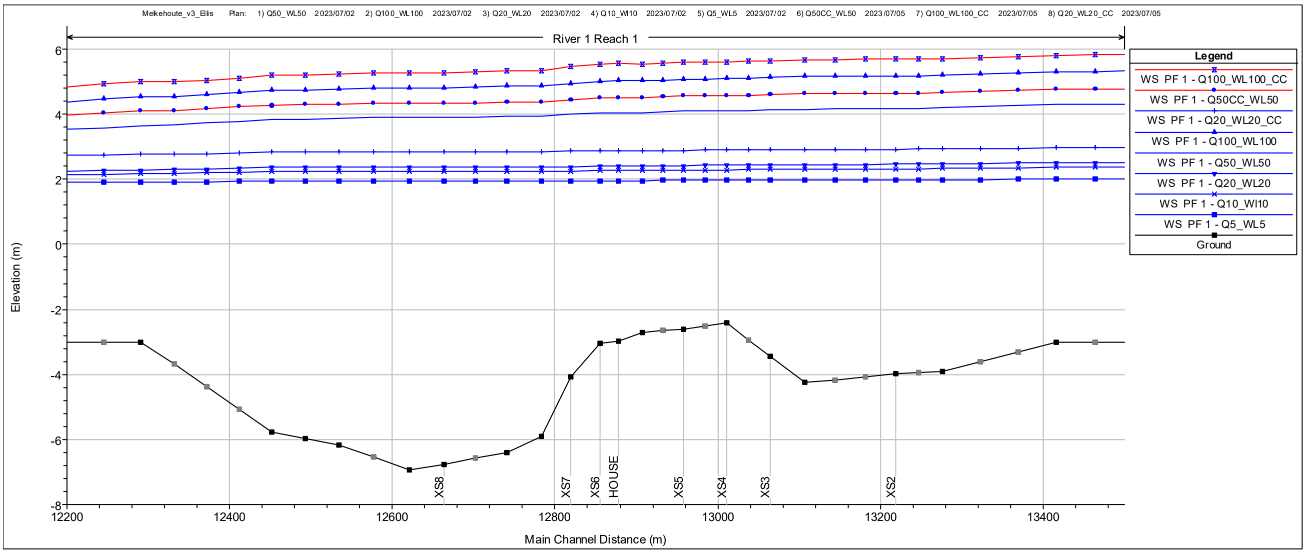

Figure 15: Goukou River Long Section along the model interest area with water surface elevations for the 1 in 5-year to 1 in 100-year flood events (*Present Case – blue lines; Future Case – red lines*).

4.4.2 River cross-section at proposed new dwelling

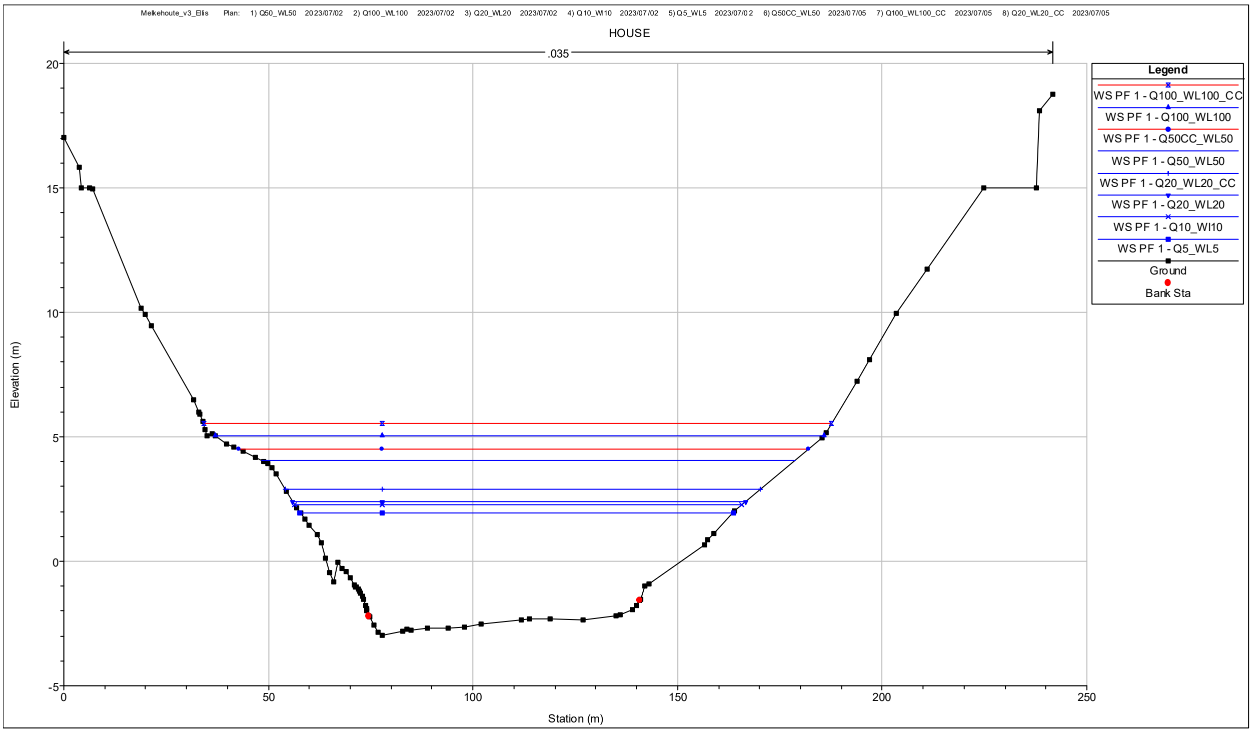

Figure 16: Goukou River Cross Section at the proposed new dwelling with water surface elevations for the 1 in 5-year to 1 in 100-year flood events ((*Present Case – blue lines; Future Case – red lines*).

4.4.3 Water surface elevation maps – Present Case

Figure 17: Water surface elevation (m MSL) for the Present 1 in 5 year flood (Q5_WL5).

Figure 18 Water surface elevation (m MSL) for the Present 1 in 10 year flood (Q10_WL10).

Figure 19 Present – Water surface elevation (m MSL) for the Present 1 in 20 year flood (Q20_WL20).

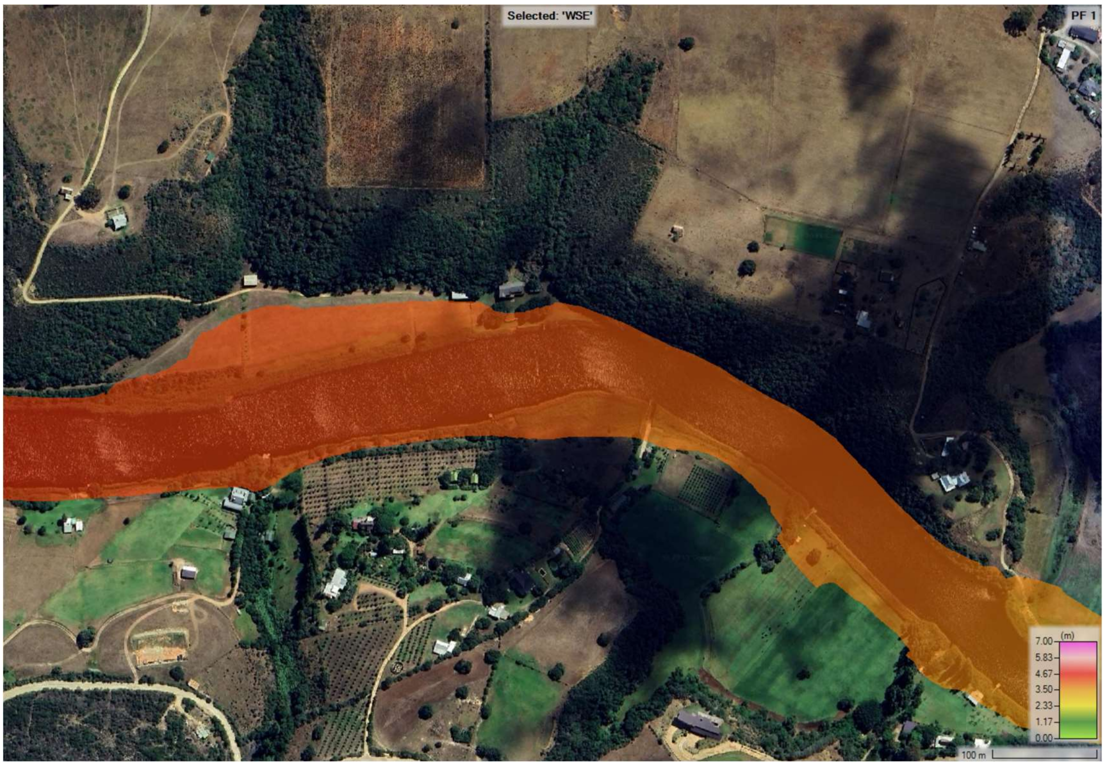

Figure 20: Water surface elevation (m MSL) for the Present 1 in 50 year flood (Q50_WL50).

Figure 21: Water surface elevation (m MSL) for the Present 1 in 100 year flood (Q100_WL100).

4.4.4 Summary of flood line levels at the proposed new dwelling

Table 8: Summary of flood line elevations at the proposed new dwelling on Melkehoutefontein Farm.

		Return Period (years)				
		5	**10**	**20**	**50**	**100**
UPSTREAM BOUNDARY 1 - Present Flood peak flow (m^3/s) Goukou River		200	330	360	1000	1400
UPSTREAM BOUNDARY 2 - Future Flood peak flow (m^3/s) Goukou River		230	380	414	1150	1610
DOWNSTREAM BOUNDARY - Present Extreme high sea level (m MSL) Mossel Bay		1.79	1.88	1.98	2.09	2.18
DOWNSTREAM BOUNDARY - Future Extreme high sea level (m MSL) Mossel Bay		2.29	2.38	2.48	2.59	2.68
RESULTS						
Flood water level at proposed new dwelling	Present	1.96	2.27	2.41	4.05	5.04
(m MSL)	Future			2.88	4.52	5.55

5 Summary and conclusions

5.1 Flood levels

The flood levels at Melkehoutefontein Farm 480/25 were determined with the HEC-RAS numerical model with boundary conditions considering combined coastal and river flood risk scenarios. This study distinguishes between *present* and *future* flood level scenarios.

Present flood levels are determined based on historical data observations and deterministic calculations derived from current conditions. On the other hand, *future* flood levels represent projected levels that align with a climate-change scenario anticipated to occur within the next 30 to 100 years. The future scenario incorporates the following adjustments:

- A sea level rise of 0.5 m.[3]
- A 15% increase in storm rainfall intensity.[4]

The flood line elevations at the proposed new dwelling, for the present and future scenario, as well as the boundary conditions used are given in Table 8.

A drawing showing the present flood level scenario is shown on Figure 22 and included in Appendix B. The setting out points of the proposed new dwelling are also shown on this drawing (“HUIS1” – “HUIS5”). The drawing indicates the *Present* 20-, 50- and 100-year flood lines, as well as the 1 in 100-year ocean water elevation (storm surge) and the highest astronomical tide that can be expected in this area.

[3] Predictions for 2100 range from +0.5 m to +2.0 m; see 2.2 for more info
[4] As prescribed by the City of Cape Town for all future stormwater design and planning

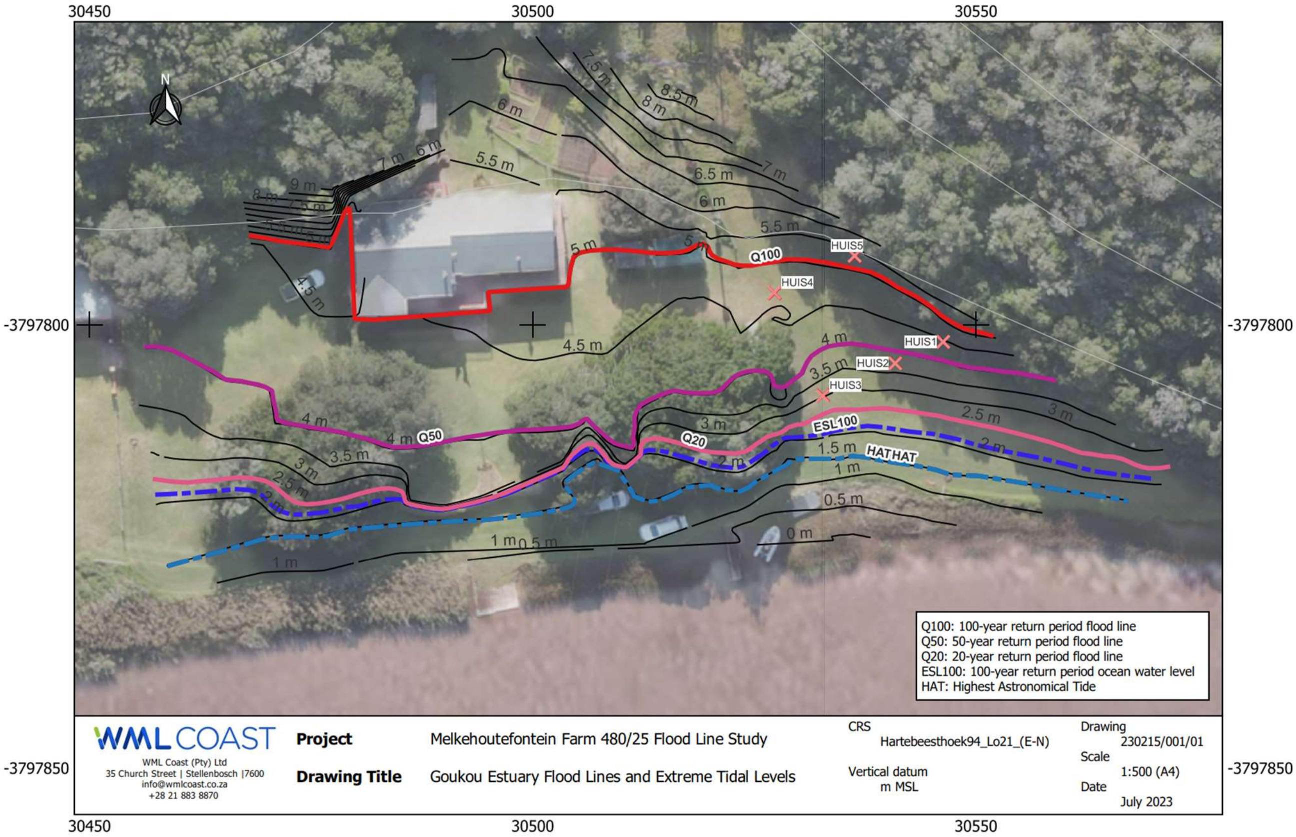

Figure 22: Goukou Estuary Flood Lines and Extreme Tidal Levels (*Present Case*).

5.2 Recommendations for new dwelling

This study predicts that the present 50-year flood line level is at 4.05 m MSL, this level does not account for the kinematic energy of the water and therefore further run-up can be expected.

The footprint of the proposed new dwelling extends from the 5.25 m MSL contour to the 3 m MSL contour on the river side. The setting out points of the new dwelling is shown on Figure 22 (“HUIS1” to “HUIS5”).

The following recommendation are made:

- The dwelling should be built on piled supports (pillars)
- The floor level of the dwelling should be above the 1 in 100-year flood level to limit flood risk;
  - Setting out point “HUIS5” is situated on an elevation of 5.25 m MSL, if this level is used as the house floor level, the house will be elevated above the *present* 1 in 100-year flood level.
  - To account for the *future* 1 in 100-year flood event the floor level should be above 5.5 m MSL, which is easily achievable within the current development footprint.
- Riverbank scour could result in undermining of the foundations of the house, the design of the house should consider potential scour of the riverbank due to flood events, however;
  - Model predicted scour velocities for the 1 in 100-year flood event at point “HUIS3” are in the order of 0.7 m/s.
  - This flow velocity is mild and it is not expected that the riverbank, at the house footprint will be scoured significantly.

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APPENDIX A – Flood Hydrology Calculations

Time of concentration

The US Soil Conservation Service formula was used to obtain the time of concentration T_c (hours) as suggested in HRU1/72 (Alexander, 1976).

$$T_c = \left[\frac{0.87L^2}{1000S_{av}}\right]^{0.385}$$

Where:

T_c is the time of concentration (hours) ≈ 11 hours

L is the watercourse length (km) = 53.5km

S_{av} is the average slope (m/m) = 0.005

Precipitation depth

The point precipitation depth $P_{t,T}$ (mm) for the time of concentration t (min) and a return period of T (years) was computed by interpolation between the values obtained using the modified Hersfield (Alexander, 2001) equation (6 hours limit) and TR102 for a 1 day duration. The modified Hersfield equation is:

$$P_{t,T} = 1.13\ (0.41 + 0.64lnT)(-0.11 + 0.27lnt)(0.79M^{0.69}R^{0.20})$$

Where:

$P_{t,T}$ is the precipitation depth for a duration of t minutes and a return period of T years

t is the storm duration in minutes (upper limit of 6 hours)

T is the return period

M is the 2-year return period daily rainfall from TR102

R is the average number of days per year on which thunder was heard

Area reduction factor and return period factors

The average rainfall intensity is calculated by multiplying an area reduction factor with the precipitation depth. The area reduction factor ARF (%) was calculated by:

$$ARF = (90000 - 12800lnA + 9830lnt)^{0.4} = \ 83.6\%$$

Refer to SANRAL (2013) for information regarding the return period factors to be used and the formula to calculate it.

Flood peak

The flood peak Q_T (m^3/s) for various return periods T is calculated from:

$$Q_T = \frac{C_T I_T A}{3.6}$$

Where:

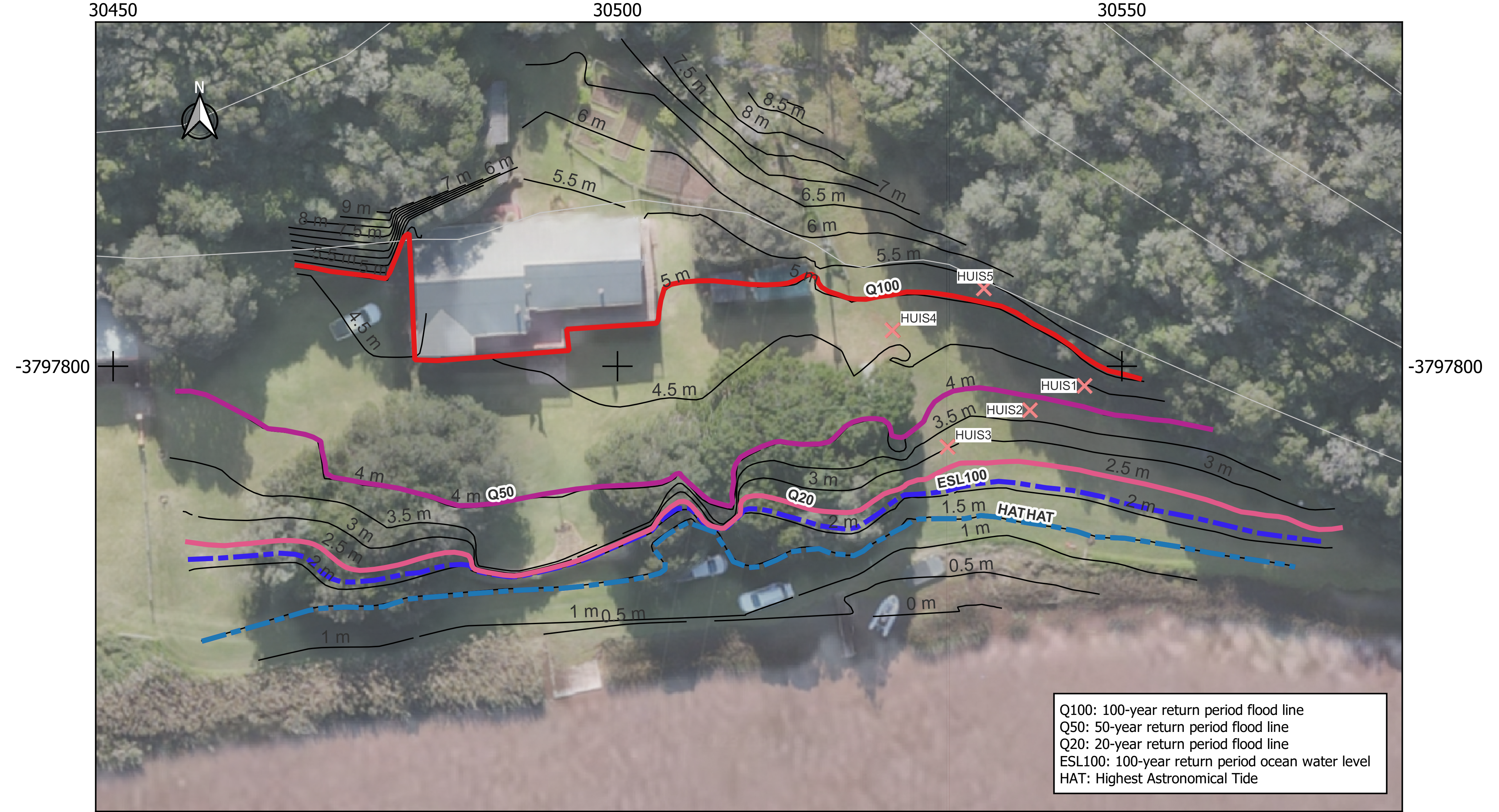
I_T is the average intensity (mm)

A is the area of the region considered (km)

STANDARD DESIGN FLOOD METHOD - BASIN 18							
Description of catchment	Catchement H90A,H90B, H90C and H90D						
River detail	Goukou River						
Calculated by	Danie Theron				Date	May-23	
Physical characteristics							
Size of the catchment (A)	1117	km^2	$Tc = \left(\frac{0.87 L^2}{1000 S_{av}} \right)^{0.385}$			10.9	hours
Longest watercourse (L)	53.5	km					
Average slope (S_{av})	0.005	m/m	Time of concentration, t(min)			656	minutes
SDF Basin	18		Days of thunder per year (R)			4	days/year
2-year return period rainfall (M)	59	mm					
TR102 n-day rainfall data							
Weather service station	La Motte		Mean annual precipitation (MAP)			810	mm
Weather service number	22113		Coordinates		33 ° 53' S	&	19 ° 04' E
Duration (days)	Return period (years)						
	2	**5**	**10**	**20**	**50**	**100**	**200**
1-day	59	77	91	105	125	142	160
Rainfall							
Return period (years), T	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Point precipitation (mm), P_T	24.8	46.4	60.7	75.0	93.9	108.2	122.5
Interpolated precipitation (mm), P	34.2	54.8	69.0	83.2	102.4	117.4	132.7
ARF (Area reduction factor) (%)	83.6	83.6	83.6	83.6	83.6	83.6	83.6
Average intensity (mm/h)	2.61	4.19	5.28	6.37	7.84	8.99	10.16
Run-off coefficient							
Calibration factors :	C_2(2-year return period) :		30	C_{100}(100-year return period):			60
Return period (years), T	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Return period factors (Y_T)	0	0.84	1.28	1.64	2.05	2.33	2.58
Run-off coefficient (C_T)	0.30	0.41	0.46	0.51	0.56	0.60	0.63
Peak flow (m^3/s)	243	531	761	1010	1371	1673	1992

STANDARD DESIGN FLOOD METHOD - BASIN 19							
Description of catchment	Catchement H90A,H90B, H90C and H90D						
River detail	Goukou River						
Calculated by	Danie Theron				Date	May-23	
Physical characteristics							
Size of the catchment (A)	1117	km^2	$Tc = \left(\frac{0.87 L^2}{1000 S_{av}} \right)^{0.385}$			10.9	hours
Longest watercourse (L)	53.5	km					
Average slope (S_{av})	0.005	m/m	Time of concentration, t(min)			656	minutes
SDF Basin	19		Days of thunder per year (R)			16	days/year
2-year return period rainfall (M)	34	mm					
TR102 n-day rainfall data							
Weather service station	Letjiesbos		Mean annual precipitation (MAP)			165	mm
Weather service number	69 483		Coordinates		32 ° 33' S	&	22 ° 17' E
Duration (days)	Return period (years)						
	2	**5**	**10**	**20**	**50**	**100**	**200**
1-day	34	55	72	92	124	152	185
Rainfall							
Return period (years), T	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Point precipitation (mm), P_T	22.4	41.9	54.7	67.6	84.7	97.6	110.5
Interpolated precipitation (mm), P	25.5	45.5	59.5	74.3	95.4	112.5	130.9
ARF (Area reduction factor) (%)	83.6	83.6	83.6	83.6	83.6	83.6	83.6
Average intensity (mm/h)	1.96	3.48	4.55	5.69	7.30	8.61	10.01
Run-off coefficient							
Calibration factors :	C_2(2-year return period) :		10	C_{100}(100-year return period):			35
Return period (years), T	**2**	**5**	**10**	**20**	**50**	**100**	**200**
Return period factors (Y_T)	0	0.84	1.28	1.64	2.05	2.33	2.58
Run-off coefficient (C_T)	0.10	0.19	0.24	0.28	0.32	0.35	0.38
Peak flow (m^3/s)	61	205	335	487	725	935	1171

APPENDIX B - Drawings



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Project Melkehoutefontein Farm 480/25 Flood Line Study

Drawing Title Goukou Estuary Flood Lines and Extreme Tidal Levels

CRS: Hartebeesthoek94_Lo21_(E-N)

Vertical datum: m MSL

Drawing: 230215/001/01

Scale: 1:500 (A4)

Date: July 2023