Western Cape Government

Department of Environmental Affairs
and Development Planning

KLEIN BRAK RIVER ESTUARY AND GROOT BRAK RIVER ESTUARY FLOODLINE ASSESSMENT

DRAFT REPORT: MARCH 2021

Hydrodynamic modelling of floods, waves and sediment dynamics

PURPOSE OF THIS DOCUMENT

The Western Cape Department of Environmental Affairs and Development Planning's (DEA&DP) need to identify risk zones in the demarcation of coastal management lines for the Garden Route District. ASP Technology (Pty) Ltd was appointed by Bigen Africa Services (Pty) Ltd on 31 January 2020 to perform a floodline assessment for the Klein Brak River Estuary and the Groot Brak River Estuary. This draft report documents the determination of the 50-year and 100-year extreme floodlines for the current scenario and the future scenario with climate change impacts. The floodline determination considers the flood flow patterns and sediment dynamics in the estuaries, for initially closed mouth and open mouth conditions, which are subjected to natural hydrological flooding from the upstream rivers as well as coastal processes such as currents, tides, long waves, swell and wind generated short wave runup.

MARCH 2021

bigen

ASP TECH

APPLIED STREAM POWER TECHNOLOGY SERVICES
Hydraulic and Sedimentation Engineering Consultants

Contents

Appendices

List of Figures

List of Tables

1. Introduction

1.1. Background

The Western Cape Department of Environmental Affairs and Development Planning (DEA&DP) is establishing coastal management lines for the Garden Route District. They require the 50-year and 100-year floodlines to be determined for the Klein Brak River and Groot Brak River estuaries to aid the identification of risk zones in the demarcation of coastal management lines. ASP Technology (Pty) Ltd was appointed by Bigen Africa Services (Pty) Ltd on 31 January 2020 to perform the floodline assessment. The location of the study areas for the Klein Brak and Groot Brak River estuaries relative to Mossel Bay is shown in Figure 1.1-1.

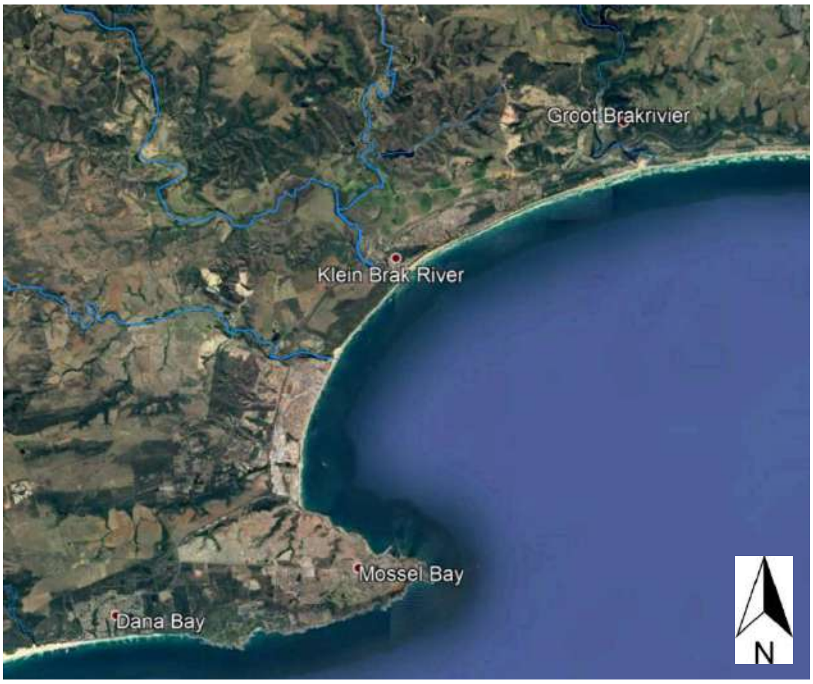


Figure 1.1-1: Klein Brak River and Groot Brak River priority estuary location

1.2. Study methodology

The floodline determination considers the flood flow patterns and sediment dynamics in the estuaries, for initially closed mouth and open mouth conditions, and for the current development and future scenarios. The methodology included the following tasks for the Klein Brak River study and the Groot Brak study:

1. Site visits and sediment sampling.
2. Flood hydrology analysis of observed flood peak data of the Department of Water and Sanitation (DWS). Climate change impacts were also considered.
3. Deep sea MET-Ocean data analysis to quantify wave penetration parameters for an open and closed estuary mouth, as well as a critical swell direction. The analysis includes the effect of tides, long waves, short waves as well as a 50-year and 100-year rise in sea level due to climate change. Berm crest levels were also investigated.
4. Hydrodynamic modelling of flow patterns and fluvial morphology.

A two-dimensional hydrodynamic model with a movable bed was used to simulate the flow patterns and sediment dynamics of the estuary by routing different recurrence interval flood hydrographs through the estuary. The Mike21C DHI model of the Danish Hydraulic Institute was used. More than one sediment fraction was used in the model based on the bed grading analysis of field samples. Open and closed initial mouth conditions, as well as different berm heights, were modelled. The model was also extended into the ocean with a tidal open boundary which included long waves associated with swell waves. The model bathymetry was set up based on up-to-date 0.5 m interval contour surveys of the estuaries provided by the client. The estuaries were surveyed in October-November 2020 by Underwater Surveys (Pty) Ltd (UWS)which was spliced in with Lidar data. The bridges were surveyed separately by UWS for which the structure survey reports are given in **Appendix H**.

5. Modelling of swell and wind generated waves. The "Simulating WAves Nearshore" or SWAN model was used to simulate the transferring of short waves/swell from the offshore wave model boundary concurrent with locally wind generated waves over the modelled area and its penetration into the estuary for selected storm events. Wave runup was then calculated at selected sites.
6. Determination of extreme floodlines for the 50-year and 100-year annual recurrence intervals, by combining the runup and flood levels from the hydrodynamic modelling for the worst-case simulation scenarios.

2. Field work

A site visit was done on 2020/01/16 at Klein Brak and 2020/01/15 at Groot Brak to collect a total of 20 bed grab sediment samples (10 at each site). The locations of the samples are indicated in **Appendix F**. The specific gravity and grading (sieve and hydrometer tests) of the sediment were analysed in a geotechnical laboratory. The data was used in the setup of the hydrodynamic model. The bed is non-cohesive with very little clay and sand.

3. Met-Ocean data

The bathymetric, wave, wind, tidal and barometric data and sea level rise projections were analysed in this study and are enclosed in **Appendix A**. The data was used in the setup of the boundary conditions of both the estuary hydrodynamic model (Mike 21C) and the nearshore wave simulation model (SWAN).

4. Flood hydrology

4.1. Hydrological Analysis for the Klein Brak Estuary

The annual recurrence interval (ARI) flood peaks for the Klein Brak estuary were estimated by a probabilistic analysis of the DWS flow gauging stations K1H004 and K1R005. The flow gauging stations are located on the two tributaries of the Klein Brak River, namely, the Brandwag and Moordkuil Rivers, as shown in Figure 4.1-1. Sufficient data of good quality was available for a period of 37 years and was therefore considered adequate. The catchment for the Klein Brak River has a size of 562 km^2 with a concentration time of 8 hours, and is situated between George and Mossel Bay in the Western Cape.

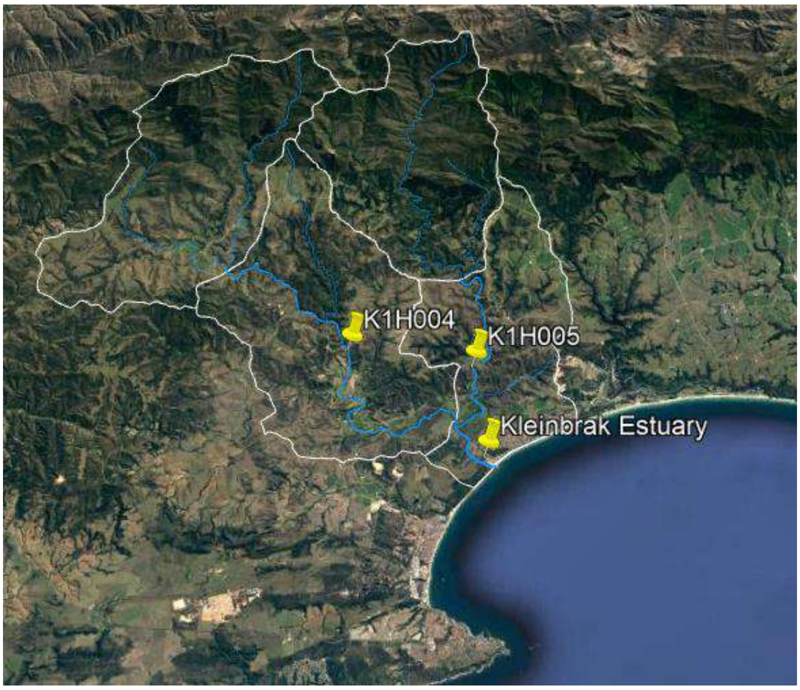


Figure 4.1-1: Catchment area for the Klein Brak River

The LN, LP_3, GEV_{MM} and GEV_{PWM} distributions were considered to calculate the recommended flood peaks, which are summarized in Table 4.1-1 for current and the future scenarios. More detailed information on the flood hydrology calculations are recorded in **Appendix B**.

Appendix B has also been supplemented by deterministic and empirical methods (which rely on rainfall data) for comparison but the deterministic flood peaks were under predicted relative to the probabilistic methods. Because the probabilistic method is based on extensive historical flow data and observed flood peaks, it is considered to be more accurate than the other flood hydrology methods. Note that the recommended 100-year flood is approximately 70% of the 100-year flood based on the Regional Maximum Flood methodology (1 630 m^3/s). The flood hydrographs for the 50- and 100-year recurrence intervals are given in Figure 4.1-2. These are based on the characteristic hydrograph shape observed at K1H005 on 2011/06/08.

Table 4.1-1: Recommended flood peaks for the mouth of the Klein Brak Estuary

Recurrence Interval (years)	Proposed Discharge for Current Scenario (m^3/s)
2	145
5	373
10	552
20	731
50	964
100	1 137

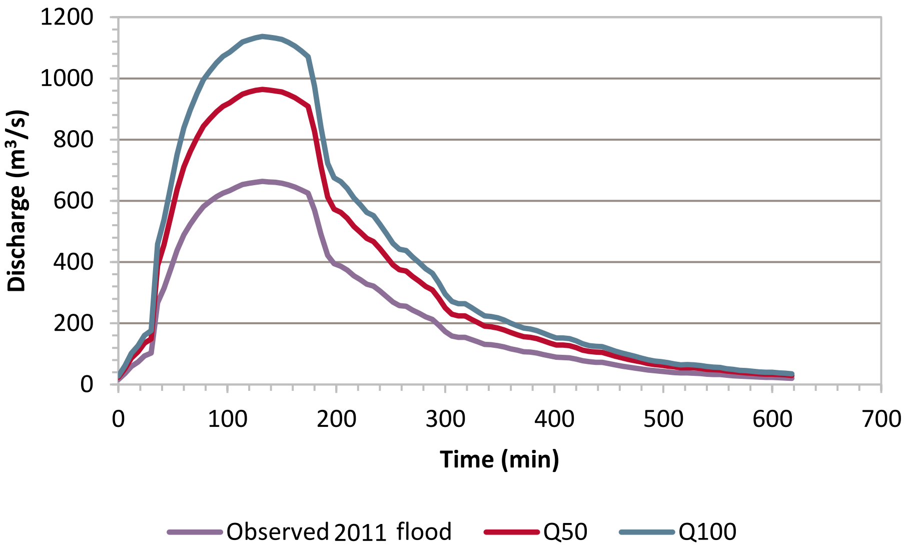


Figure 4.1-2: Flood hydrographs for the mouth of the Klein Brak Estuary

4.2. Hydrological Analysis for the Groot Brak Estuary

The annual recurrence interval (ARI) flood peaks for the Groot Brak estuary were estimated by a probabilistic analysis of the DWS flow gauging stations K2H002 and K2R002 downstream of the Wolwedans Dam. Sufficient data of good quality was available for a period of 56 years and was therefore considered adequate (the data record had no missing data and required no patching). The catchment for the Groot Brak River has a size of 169 km^2 and is shown in Figure 4.2-1, which is located midway between George and Mossel Bay in the Western Cape.

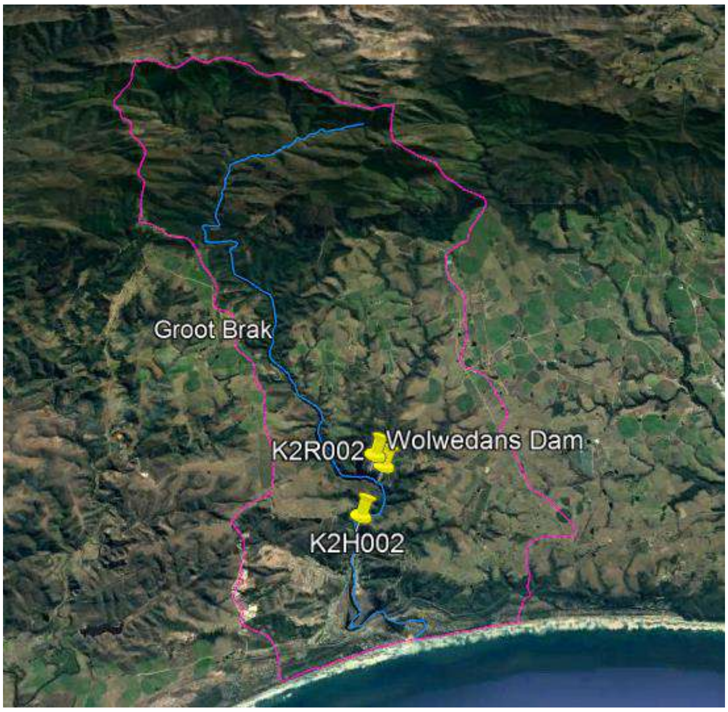


Figure 4.2-1: Catchment area for the Groot Brak River

The LN, GEVMM and GEVPWM distributions were used to calculate the recommended flood peaks, which are summarized in Table 4.2-1. The proposed floods for the different recurrence intervals were taken as a weighted average of the LN, GEV_{MM} and GEV_{PWM} distributions. This was done to ensure the extreme floods were conservatively captured. These proposed floods compare well with the scaled results of a previous study by DWS in 2015. The 100-year flood is approximately half of the Regional Maximum Flood (RMF) of 1 696 m^3/s.

More detailed information on the flood hydrology calculations are recorded in **Appendix B**. The flood hydrographs for the different recurrence intervals are given in Figure 4.2-2. These are based on the characteristic hydrograph shape of the peak inflow observed at the Wolwedans Dam on 2011/06/08.

Note that these flood peaks were calculated for the worst case scenario whereby the Wolwedans Dam was assumed as full or already spilling before an extreme storm event, and therefore no flood attenuation in the reservoir was considered. The observed November 2007 flood illustrated this well with the 2nd flood peak attenuated by only 6 % in the reservoir. The approach followed is considered reasonable according to the Wolwedans Dam Flood Frequency Analysis by the DWS in 2012.

Table 4.2-1: Recommended flood peaks for the mouth of the Groot Brak Estuary

Recurrence Interval (years)	Proposed Discharge for Current Scenario (m^3/s)	DWS Study for Comparison (m^3/s)
2	76	76
5	213	209
10	327	342
20	480	460
50	744	612
100	856	736

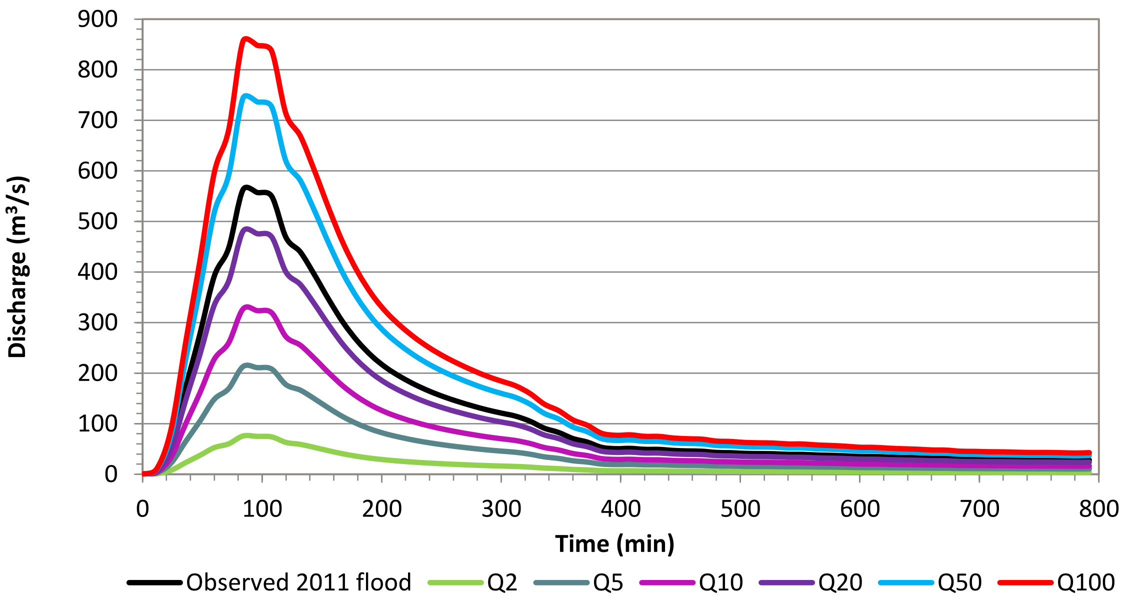


Figure 4.2-2: Flood hydrographs for the mouth of the Groot Brak Estuary without flood attenuation at Wolwedans Dam

To demonstrate the influence of a flood on the water level in Groot Brak Estuary, the maximum recorded flood water level event at DWS gauge K2T004 during the approximately 12 year period, August 2007 to February 2021, is shown in Figure 4.2-3 with the concurrent ocean tidal level recorded at Mossel Bay by the SA Navy.

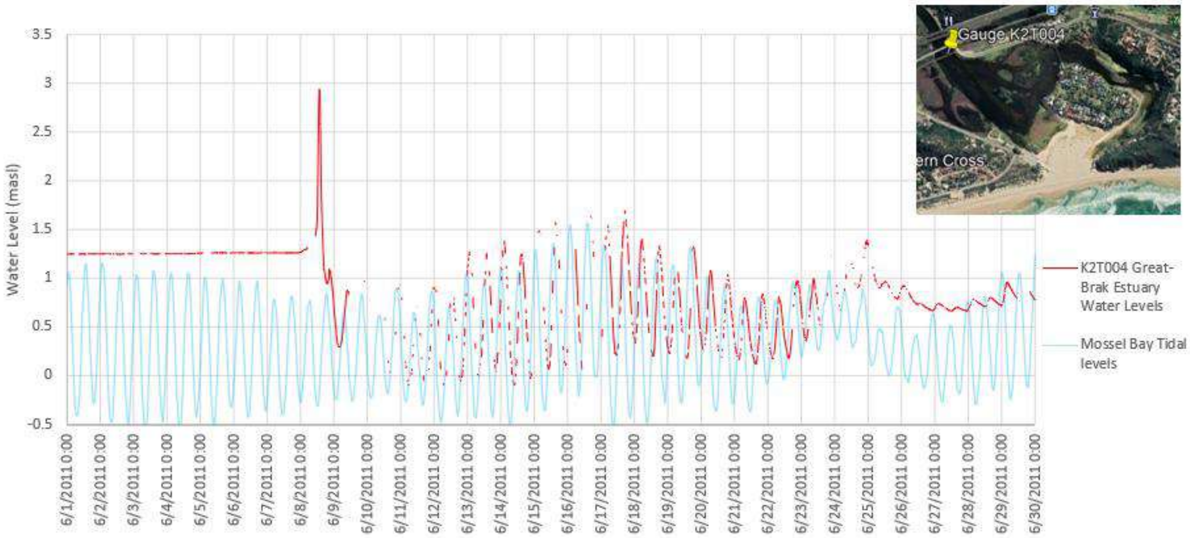


Figure 4.2-3: Water level variation in Groot Brak River estuary during June 2011 (when the 2011/06/08 flood occurred) with the concurrent ocean tidal level recorded at Mossel Bay

The 2011/06/08 flood occurred during a period when the mouth was closed (reflected by the near constant water level preceding the event). The crest level of the sand berm in the mouth at the time of the flood could not be obtained and neither if the berm was pre-skimmed to a predetermine level. However, the water level in the estuary increased from 1.25 masl to nearly 3 masl (an increase of near 1.75 m) in a very short period i.e. from 1.5 masl to nearly 3 masl in 2 hours as shown in more detail in Figure 4.2-4 below.

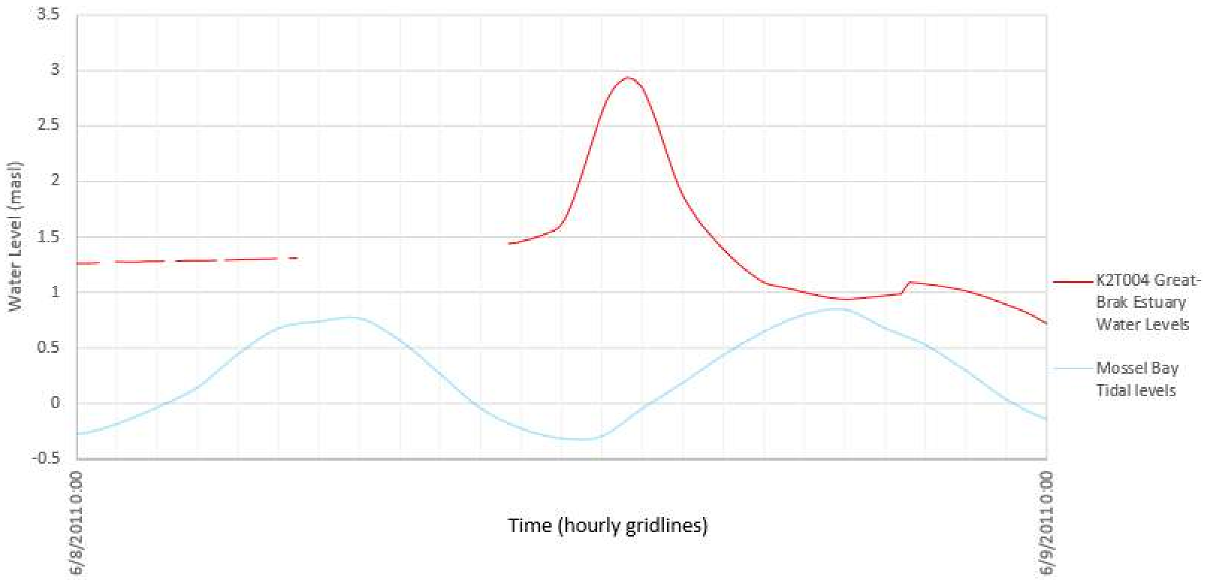


Figure 4.2-4: Water level variation in the Groot Brak River estuary during flood on 2011/06/08 with the concurrent ocean tidal level recorded at Mossel Bay

4.3. Climate change impacts

A DEA study of 2014 investigated the predictions of 5 climate models for SA. It was found that flood peaks in the K region could decrease between 2018 and 2080. All the climate models are however not in agreement. For this study the flood peaks of future scenarios were increased by 15%, similar to the approach of the City of Cape Town.

5. Hydrodynamic modelling of flood hydrographs

5.1. Background

The 2D model Mike 21C of the Danish Hydraulic Institute (DHI) was used to simulate the flood levels in the Klein Brak and Groot Brak Rivers. The model is fully hydrodynamic and specifically developed to investigate alluvial river processes. The model has been widely used, calibrated and validated on similar projects in Southern Africa. Two separate hydrodynamic models were simulated for the Klein Brak River and Groot Brak River.

The model bathymetry was set up based on up-to-date Lidar surveys of the estuaries (**Appendix H1**) while sea bed levels were obtained from the General Bathymetric Chart of the Oceans (GEBCO). The model bathymetry is shown in Figures 5.1-1 and 5.1-2, which was incorporated in Mike 21C with a curvilinear grid and movable bed.

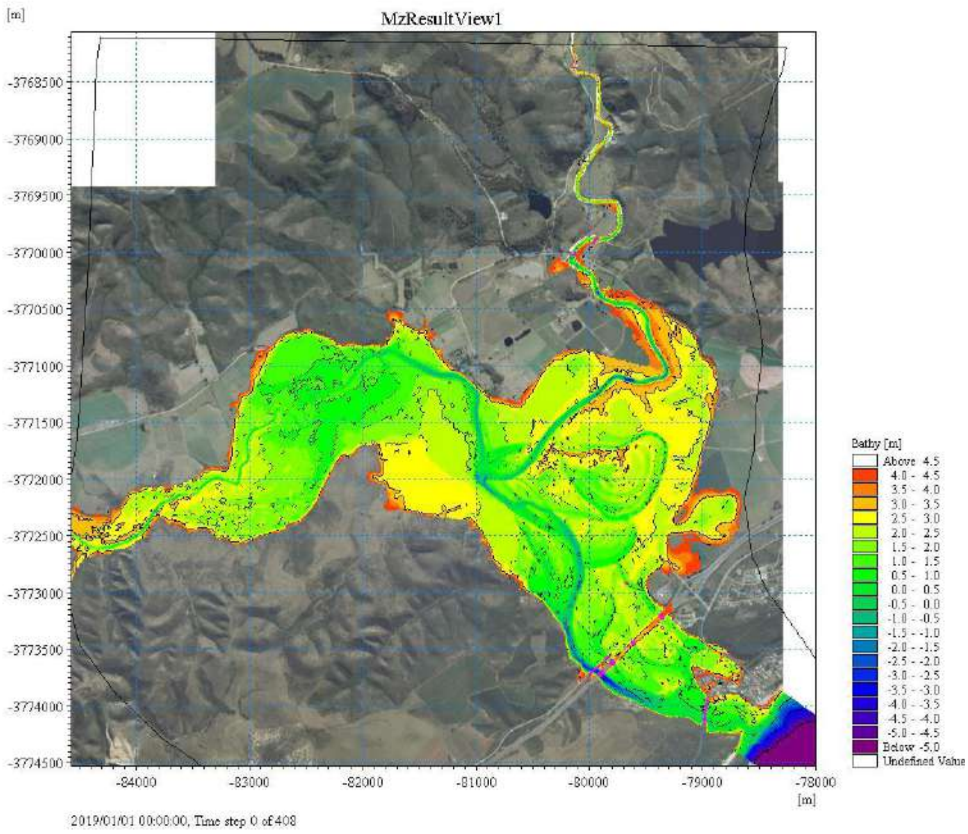


Figure 5.1-1: Bathymetry of the Lower Klein Brak Estuary near the mouth (masl)

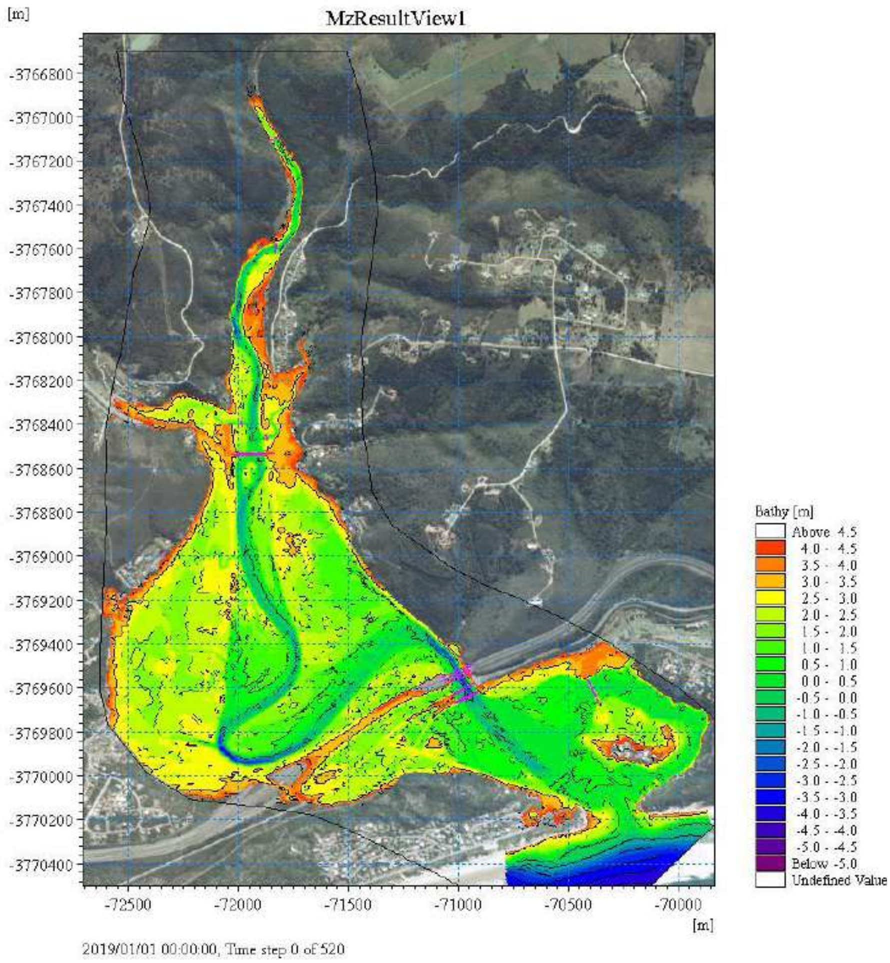


Figure 5.1-2: Bathymetry of the Lower Groot Brak Estuary near the mouth (masl)

5.2. Hydrodynamic model scenarios and boundary conditions

At the upstream end of the estuaries, the corresponding flood hydrograph was specified at the model boundary. The tidal boundary in the hydrodynamic model was set constant at the respective recurrence interval maximum tidal levels (based on observed data). The long wave with a period of 180s and wave height indicated in Tables 5.2-1 and 5.2-2 was also specified at the open boundary.

Open and closed initial condition mouths were simulated. Therefore, historical closed mouth conditions were evaluated in this study in more detail on the berm crest levels in order to identify the worst case scenarios (**Appendix G**). As such, unskimmed / natural mouth berm crest levels were assumed because skimmed berms to manage the trigger levels could give lower floodline levels. The hydrodynamic model routes the flood hydrograph through the estuary, fills the lower estuary upstream of a closed initial berm, and eventually spills over the berm, eroding the sandy berm until the berm ultimately breaches.

For future climate change scenarios the initial closed berm crest levels will be higher as shown in Tables 5.2.1 and 2. It is assumed that the sea level will rise by 0.5 m and 1.0 m in 50 and 100-years' time respectively, due to climate change.

Table 5.2-1: Hydrodynamic model scenarios and boundary conditions for Klein Brak

NO	SCENARIO	FLOOD	PEAK DISCHARGE (M^3/S)	INITIAL BERM CONDITION	INITIAL BERM HEIGHT (MASL)	MAX TIDAL LEVEL (MASL)	LONGWAVE HEIGHT (M)
1	Current	Q50	964	Open	Current survey	2.07	0.83
2	Current	Q100	1137	Open	Current survey	2.16	0.84
3	Current	Q50	964	Closed	3.5	2.07	0.83
4	Current	Q100	1137	Closed	3.5	2.16	0.84
5	Future	Q50	1109	Open	Current survey	3.07	0.83
6	Future	Q100	1307	Open	Current survey	3.16	0.84
7	Future	Q50	1109	Closed	4.5	3.07	0.83
8	Future	Q100	1307	Closed	4.5	3.16	0.84

Table 5.2-2: Hydrodynamic model scenarios and boundary conditions for Groot Brak

NO	SCENARIO	FLOOD	PEAK DISCHARGE (M3/S)	INITIAL BERM CONDITION	INITIAL BERM HEIGHT (MASL)	MAX TIDAL LEVEL (MASL)	LONGWAVE HEIGHT (M)
1	Current	Q50	744	Open	Current survey	2.07	0.83
2	Current	Q100	856	Open	Current survey	2.16	0.84
3	Current	Q50	744	Closed	4	2.07	0.83
4	Current	Q100	856	Closed	4	2.16	0.84
5	Future	Q50	855	Open	Current survey	3.07	0.83
6	Future	Q100	985	Open	Current survey	3.16	0.84
7	Future	Q50	855	Closed	5	3.07	0.83
8	Future	Q100	985	Closed	5	3.16	0.84

5.3. Hydrodynamic model flood simulation results for Klein Brak

The simulated output for all the scenarios is enclosed in **Appendix C1**. Typical output for the 100-year flood, future scenario and with closed initial mouth conditions are shown below in Figures 5.3-1 to 5.3-4. Several of the erven along the left bank of the mouth, especially upstream of the railway bridge, are flooded. Figure 5.3-5 shows the bed level change at the end of the 100-year flood, future scenario, but with open initial mouth conditions. The flooding and erosion is less severe for the 50-year flood scenarios.

The simulated water levels in the Klein Brak River estuary is shown in Figure 5.3-6 for all the scenarios relative to the soffits of 4 bridges and the K1H005 weir. The low water bridge is submerged for all scenarios while the other bridges are sufficiently high (excluding short waves and runup). The initially closed mouth scenarios have higher water levels (in the order of 0.5 m) to those with the mouth open while the future scenarios are approximately 0.35 m higher than the current scenarios.

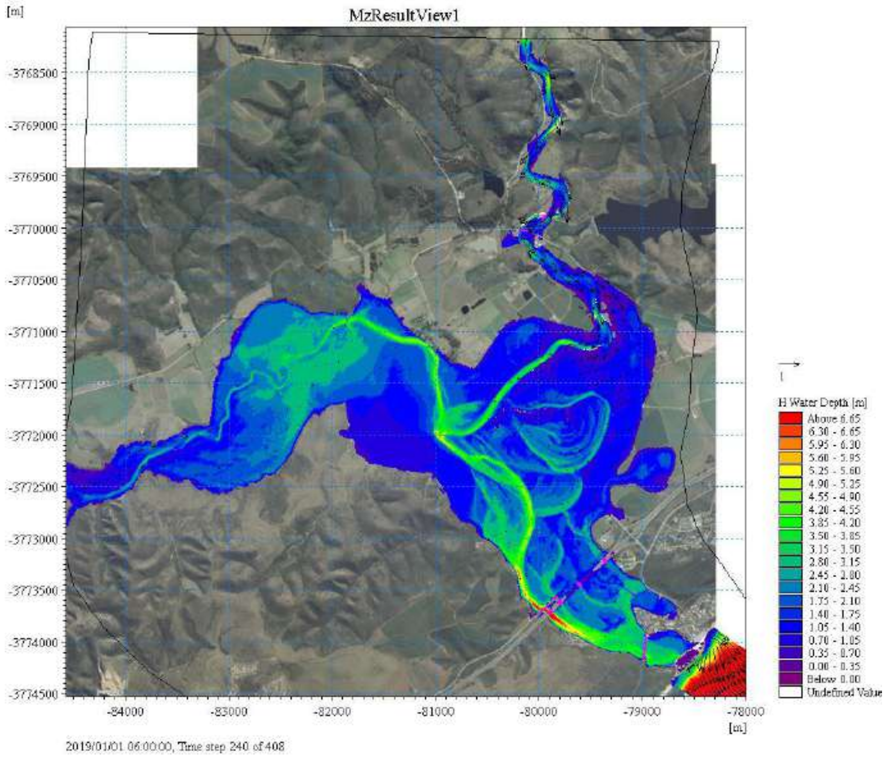


Figure 5.3-1: Simulated flow depths at the peak of the flood for the future Scenario 8 in the lower estuary (Q100 future & initially closed mouth) for Klein Brak

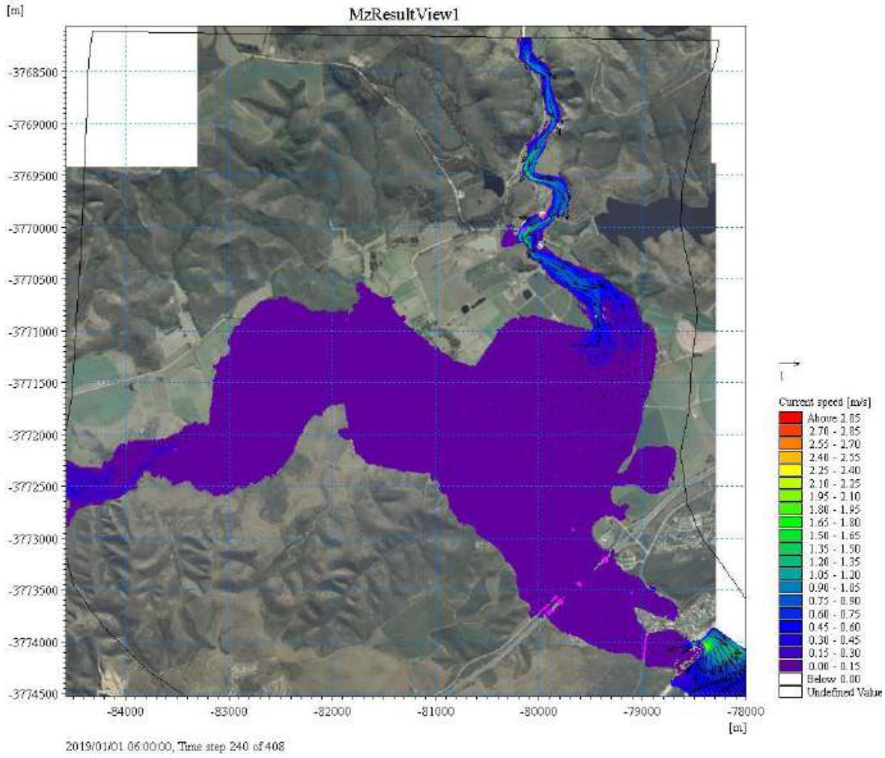


Figure 5.3-2: Simulated flow velocities at the peak of the flood for the future Scenario 8 in the lower estuary (Q100 future & closed mouth initially) for Klein Brak

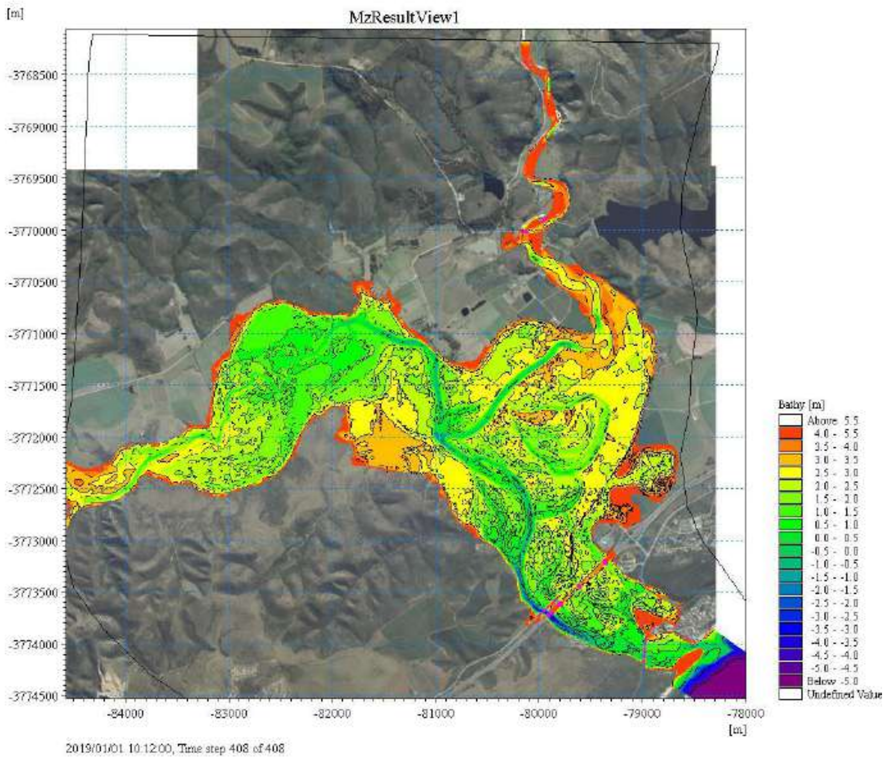


Figure 5.3-3: Simulated bed levels above sea level (masl) after the flood for Scenario 8 (Q100 future & closed mouth initially) for Klein Brak

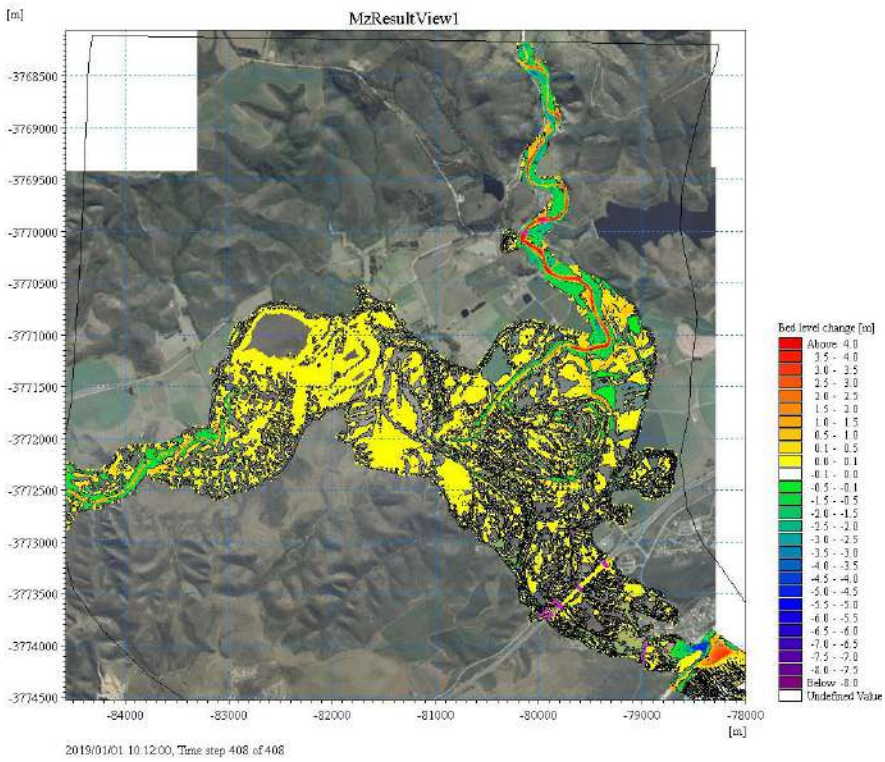


Figure 5.3-4: Simulated bed levels change at the end of the flood in the lower estuary for Scenario 8 (Q100 future & closed mouth initially): negative values = erosion for Klein Brak

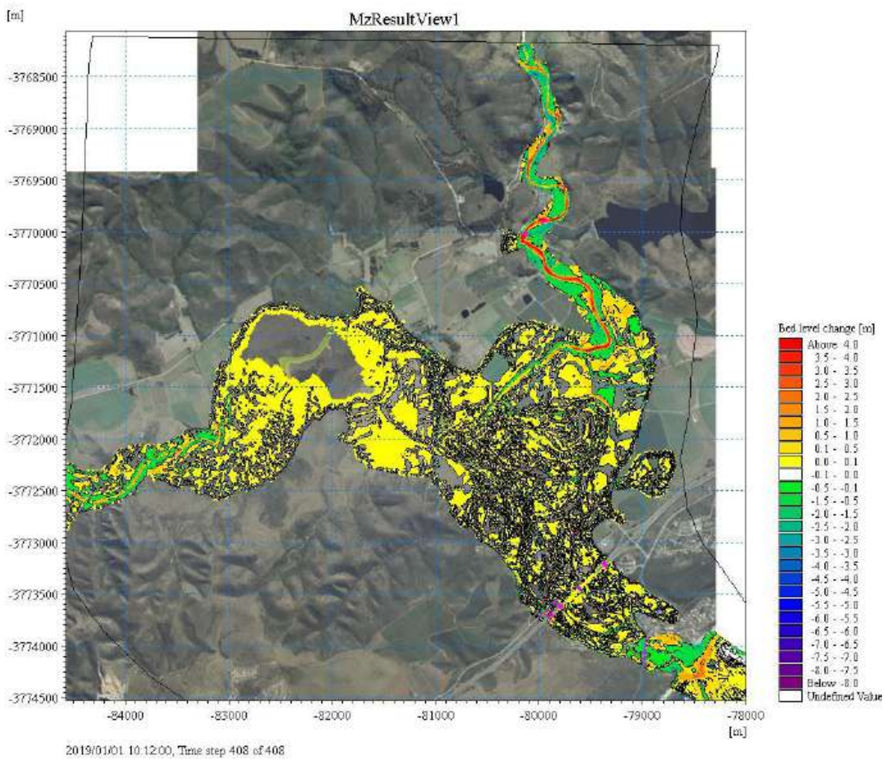


Figure 5.3-5: Simulated bed level (change) at end of the 100-year flood – future scenario with open mouth for Klein Brak (Scenario 6)

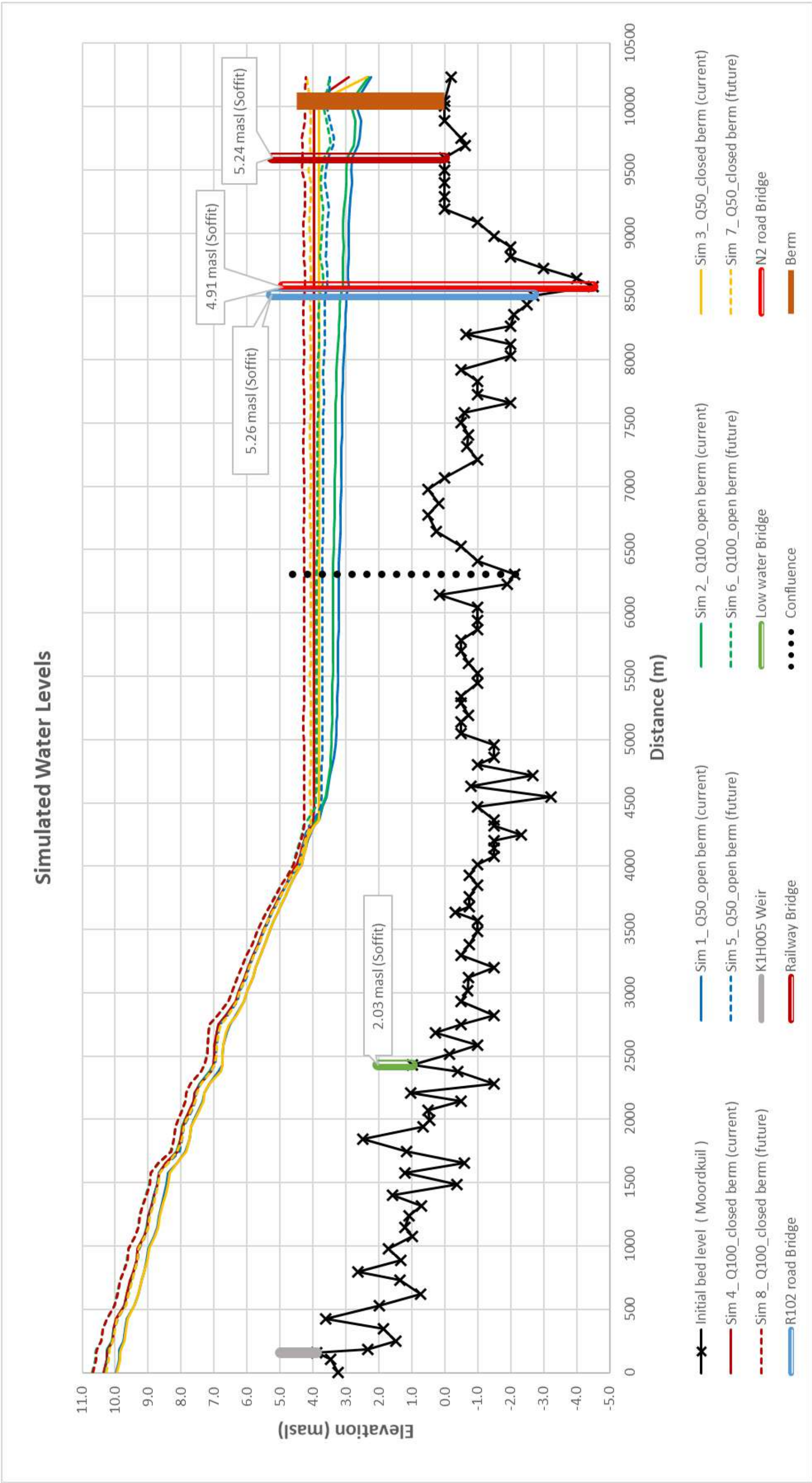


Figure 5.3-6: Simulated water levels for all the scenarios in the Klein Brak River estuary (excluding wave and runup contributions)

5.4. Hydrodynamic model flood simulation results for Groot Brak

The simulated output for all the scenarios is enclosed in **Appendix C2**. Typical output for the 100-year flood, future scenario and with closed initial mouth conditions are shown below in Figures 5.4-1 to 5.4-4. Figure 5.4-5 shows the bed level change for open initial mouth conditions which is almost identical that of Figure 5.4-4. The flood flow velocities are approximately 1.5 to 2.0 m/s along the main channel, while the flow depth is close to 6 m.

The simulated water levels in the Groot Brak River estuary is shown in Figure 5.4-6 for all the scenarios relative to the soffits of 6 bridges and the K2T004 weir. All the bridges will be submerged for all scenarios except for the N2 Road Bridge (excluding short waves and runup). The R102 Road Bridge is only submerged for scenarios with the mouth closed. The closed mouth scenarios have much higher water levels (in the order of 1 to 2 m) to those with the mouth open. The difference between current and future scenarios is marginal.

Note that the island in the Groot Brak estuary is almost completely submerged during the 100-year future flood.

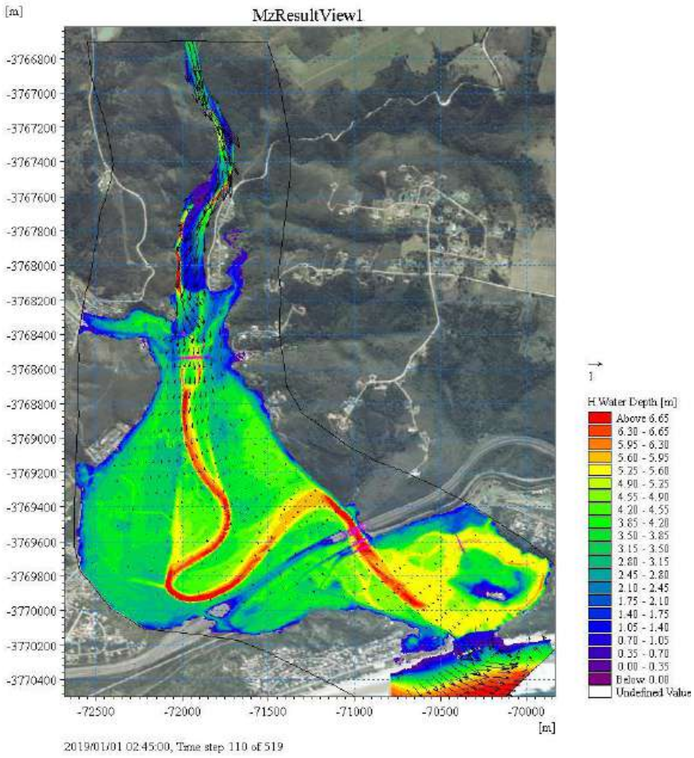


Figure 5.4-1: Simulated flow depths at the peak of the flood for the future Scenario 8 in the lower estuary (Q100 future & initially closed mouth) for Groot Brak

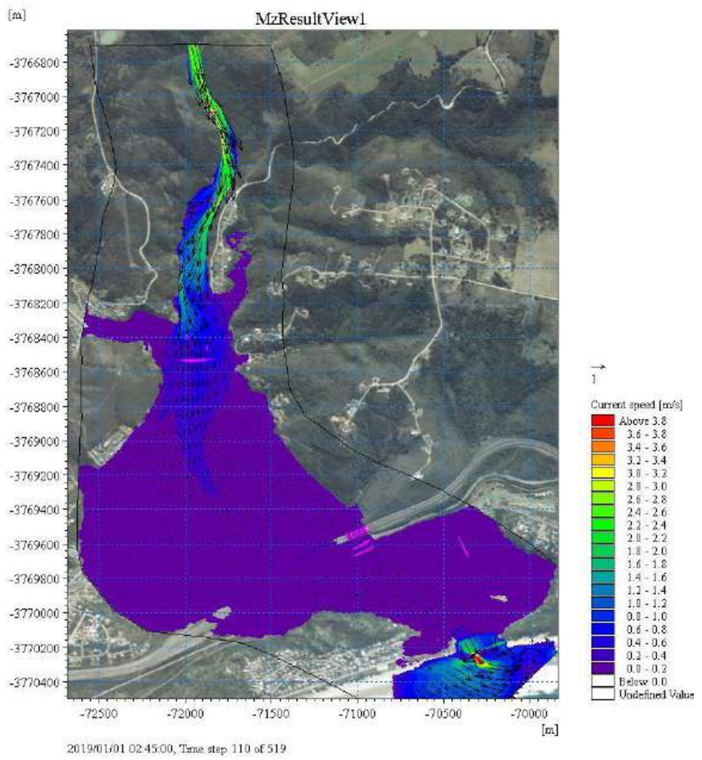


Figure 5.4-2: Simulated flow velocities at the peak of the flood for the future Scenario 8 in the lower estuary (Q100 future & closed mouth initially) for Groot Brak

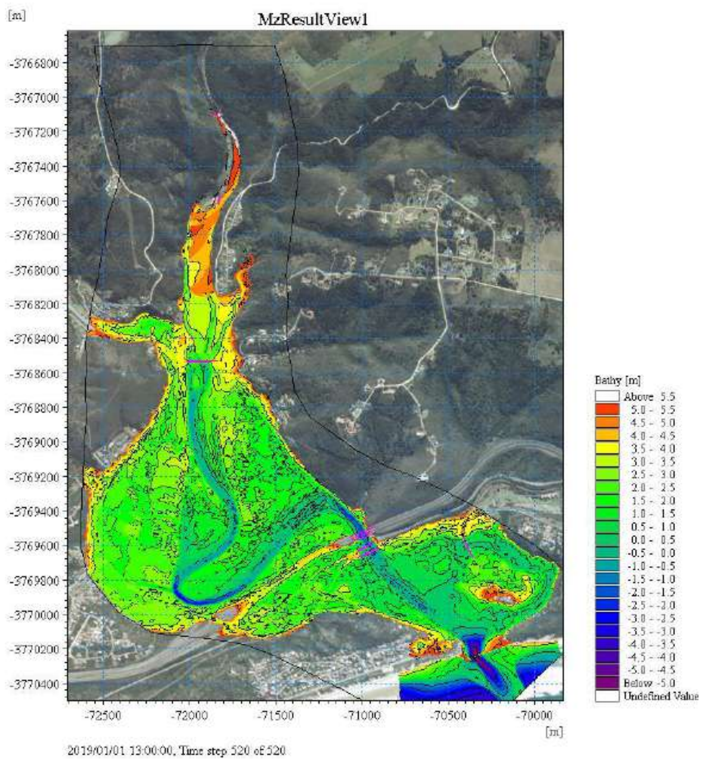


Figure 5.4-3: Simulated bed levels above sea level (masl) after the flood for Scenario 8 (Q100 future & closed mouth initially) for Groot Brak

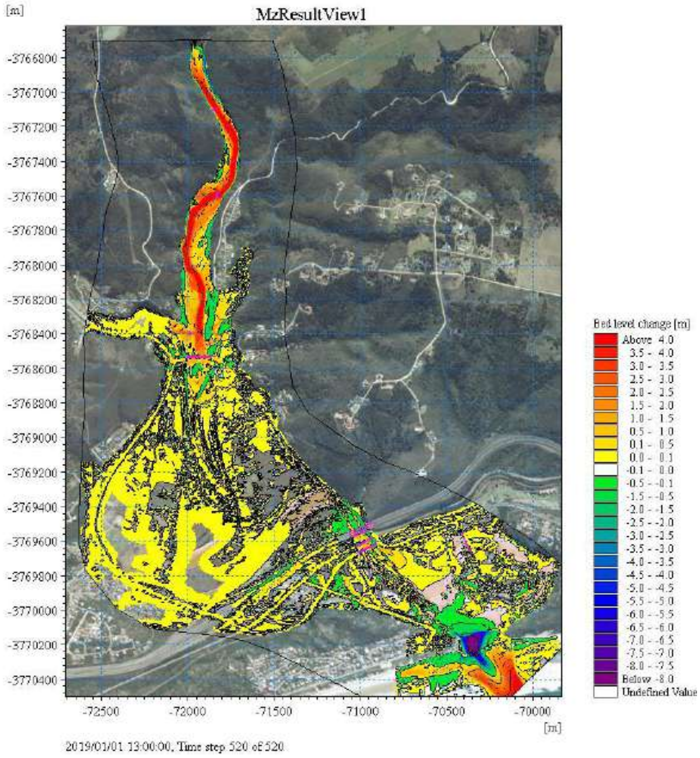


Figure 5.4-4: Simulated bed levels change at the end of the flood in the lower estuary for Scenario 8 (Q100 future & closed mouth initially): negative values = erosion (m) for Groot Brak

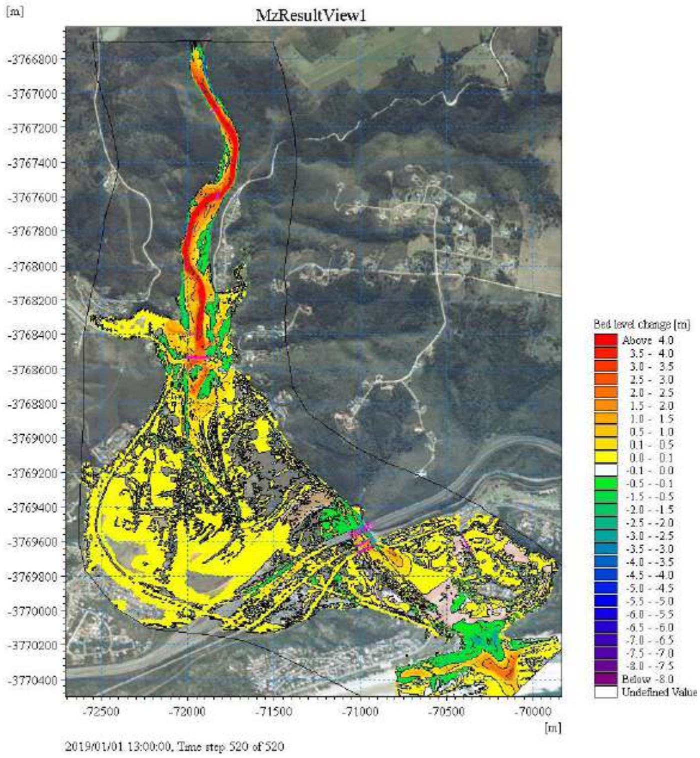


Figure 5.4-5: Simulated bed level (change) at end of the 100-year flood – future scenario with open mouth for Groot Brak (Scenario 6)

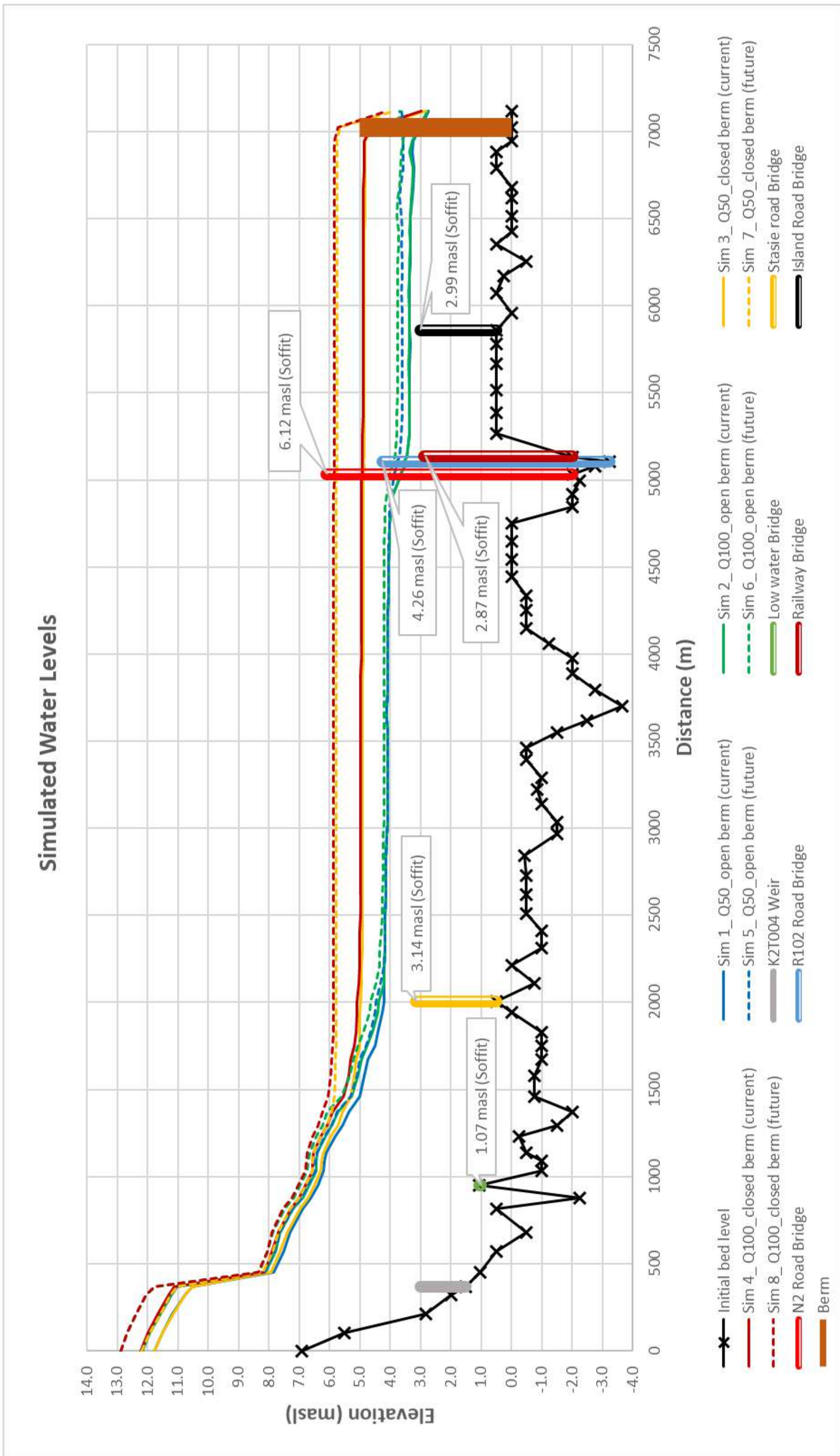


Figure 5.4-6: Simulated water levels for all the scenarios in the Groot Brak River estuary (excluding wave and runup contributions)

6. Modelling of wind wave generated short waves and wave runup in estuaries

6.1. Background

Waves that originate from deep sea (swell) can penetrate an open estuary mouth and can contribute to more extensive flood levels when the consequent wave runup is superimposed on a concurrent river flood level. Therefore, the most critical swell direction causing maximum penetration into the lower estuary (i.e. swell from the south-easterly direction) was considered. South-easterly swell was simulated from deep sea through an open mouth into the estuaries by means of the nearshore wave model, SWAN. The transfer of the swell from deep sea was modelled concurrently with a local wind blowing from the same sector over the entire SWAN model area. The resultant wave penetration into the estuary was thus a combination of deep sea swell and locally wind generated waves. The 50 and 100-year wave and wind conditions were used to determine the spatial distribution of the penetrated wave conditions in the estuaries and its consequent wave runup at a few locations were determined for the current and future scenarios.

Deep sea swell also causes long waves, or surf beat, with periods between approximately 90s and 180s. The penetration of the long waves through an open mouth into the estuary was simulated as an integrated part of the 2D river flood model (Mike21C). The penetration of deep sea swell into the estuary and locally generated wind waves were simulated by applying the numerical wave model (SWAN) while short wave runup was derived with empirical equations. Wave setup was neglected because its contribution to the conditions investigated is small (~0.02 m) in comparison to wave runup due to short and long waves.

6.2. Mathematical modelling by SWAN

SWAN is a third-generation wave model based on the wave action balance equation. The model was developed by the Technical University of Delft and has been identified as the standard for nearshore wave modelling studies (SANCOLD, 2011). The main input data required by the two SWAN models for Klein Brak and Groot Brak included the bathymetry and estuary water levels as per the hydrodynamic models Mike21C for the different scenarios. A nesting approach was implemented whereby the waves were first computed on a coarse grid with a 500 m resolution, covering a larger seabed region (see Figure A.1-1 in **Appendix A**). The waves were then computed on a finer grid with a 10 m resolution over the smaller region of interest (nested in the larger region) by employing the boundary conditions that were generated by the coarse grid computation. This approach was deemed necessary to ensure the mesh nearshore was sufficiently refined and to ensure the boundaries were distanced sufficiently far from the area of interest in the mouth. In total, approximately 20 iterations were performed for each scenario resulting in a final accuracy exceeding the 90% prerequisite.

The assumptions implemented in the mathematical model are summarized below and were based on the critical parameters identified from the MET-Ocean data in **Appendix A**. These wave parameters were applied at the wet boundaries of the coarse grid. Specifically, a Joint North Sea Wave Project (JONSWAP) spectrum with a peak enhancement factor (or wave spectrum gamma) of 1.75 and wave direction spreading of 30° was used to define the shape of the spectra at the grid boundaries (refer to **Appendix A** for the basis of these parameters).

The significant deep sea swell wave height Hs and the corresponding peak wave period Tp, as well as the wind speeds, are summarized in Table 6.2.1 for the 50 and 100-year recurrence intervals. Simultaneous with the deep-sea swell, simulations were performed with a local wind blowing over the modelled area with a nautical wind direction specified. The wave direction was identified as the critical swell condition for penetration into the estuary while the wind direction was identified as the critical locally generated condition which could be generated in the nearshore and penetrate into the estuary.

Simulations with the closed mouth conditions (Table 6.2-2) adopted a different approach whereby penetration of deep sea swell into the estuary was not permitted. Instead, short waves were caused by locally generated wind for the critical condition that would achieve the maximum straight line fetch (i.e. parallel with the longitudinal alignment of the estuary).

Table 6.2-1: Wave, wind conditions and tidal levels for the different flood recurrence intervals for the offshore boundary input of the SWAN model simulations for open mouth conditions

	KLEIN BRAK		GROOT BRAK	
Ocean swell direction	**ESE**		**SE**	
Recurrence Interval	**100**	**50**	**100**	**50**
Flood event	**Q100**	**Q50**	**Q100**	**Q50**
Significant wave height (m)	7.6	7.2	7.6	7.2
Wave direction	110°		135°	
Peak wave period (sec)	12.5	12	12.5	12
Wind speed (m/s)	24.4	23.5	24.4	23.5
Wind direction	110°		135°	
Extreme tidal levels (m)	2.16	2.07	2.16	2.07

Table 6.2-2: Wind conditions for the different flood recurrence intervals for the offshore boundary input of the SWAN model simulations for closed mouth conditions

		KLEIN BRAK		GROOT BRAK	
Ocean swell direction		**ESE**		**SE**	
Recurrence Interval		**100**	**50**	**100**	**50**
W'ly	Wind direction	275°		275°	
	Wind speed (m/s)	20		20	
E'ly	Wind direction	95°		95°	
	Wind speed (m/s)	17		17	

A conservative approach was followed by assuming that the same recurrence interval for the flood, wave, wind and tidal level occurred simultaneously for the simulation of an event. For example, the 100-year flood event would simultaneously occur with the 100-year wave, wind and tidal event. Although this is a conservative approach, it is not considered unrealistic since values of wave height, wind, velocity and tidal level for the different recurrence intervals used in the simulations do not differ significantly.

The resulting significant wave heights and wave direction vectors, as well as the mean wave periods, are shown in **Appendix D**. Surfer® was used to generate these contour plots from the SWAN output. Significant wave heights greater than 1.4 m occur at sea but the Klein Brak estuary only experiences maximum wave heights of up to 0.6 m for the 50-year scenario and 1.2 m for the 100-year scenario. Compared to Klein Brak, the Groot Brak estuary is subjected to slightly larger maximum wave heights of 1.1 m and 1.2 m for the 50- and 100-year scenarios respectively. The maximum significant wave heights for the different scenarios are summarized in Table 6.2-3. Evidently, the differences between 50- and 100- year scenarios, as well as between current and future scenarios, are generally marginal (< 0.1 m). Larger wave heights are expected for open mouth conditions while W'ly winds produce larger waves than E'ly winds for the closed mouth conditions. These waves do not penetrate the estuary mouths far inwards and have a limited impact on both the Klein Brak and Groot Brak Rivers. Excerpts of the simulated wave heights are shown in Figures 6.2-1 and 6.2-2 for Klein Brak and in Figures 6.2-3 and 6.2-4 for Groot Brak for the worst case scenarios i.e. the 100-year flood future scenarios (open mouth and closed mouth with W'ly wind).

Table 6.2-3: Maximum significant wave heights simulated within the Klein Brak River and Groot Brak River estuaries

	KLEIN BRAK				GROOT BRAK			
Mouth condition	**Q50 current**	**Q50 future**	**Q100 current**	**Q100 future**	**Q50 current**	**Q50 future**	**Q100 current**	**Q100 future**
Open	0.51	0.48	0.76	1.17	0.91	1.09	0.85	1.15
Closed E'ly wind	0.46	0.55	0.47	0.48	0.42	0.46	0.42	0.47
Closed W'ly wind	0.51	0.48	0.54	0.58	0.47	0.52	0.48	0.51

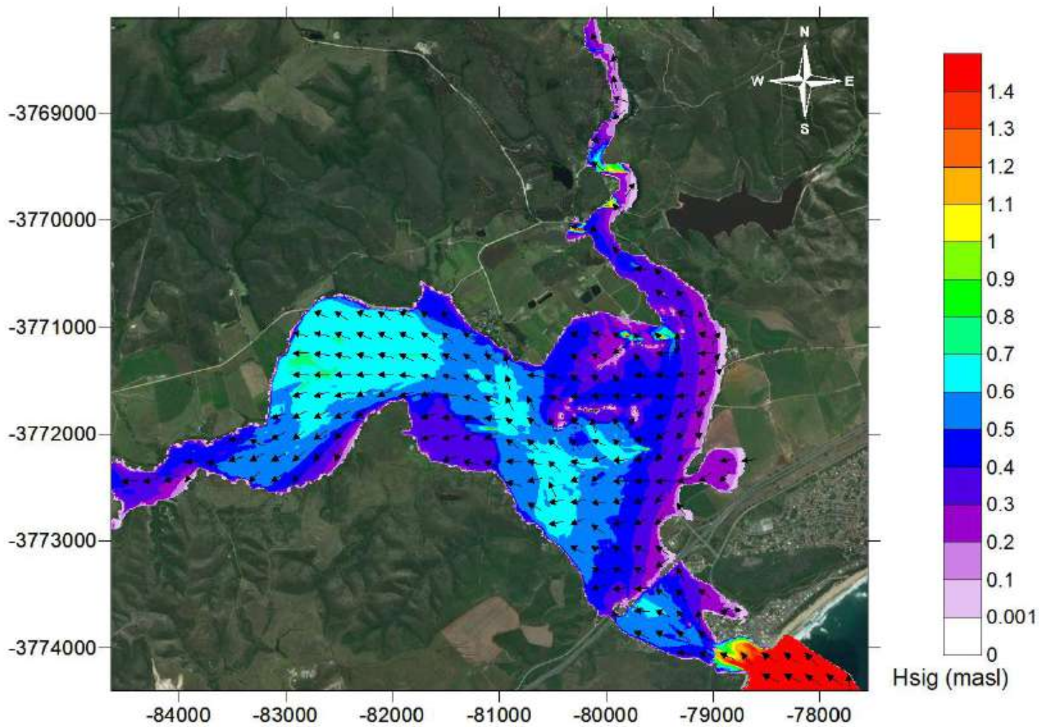


Figure 6.2-1: Contour map showing the significant wave height with peak wave direction vectors for Scenario 6 for Klein Brak River

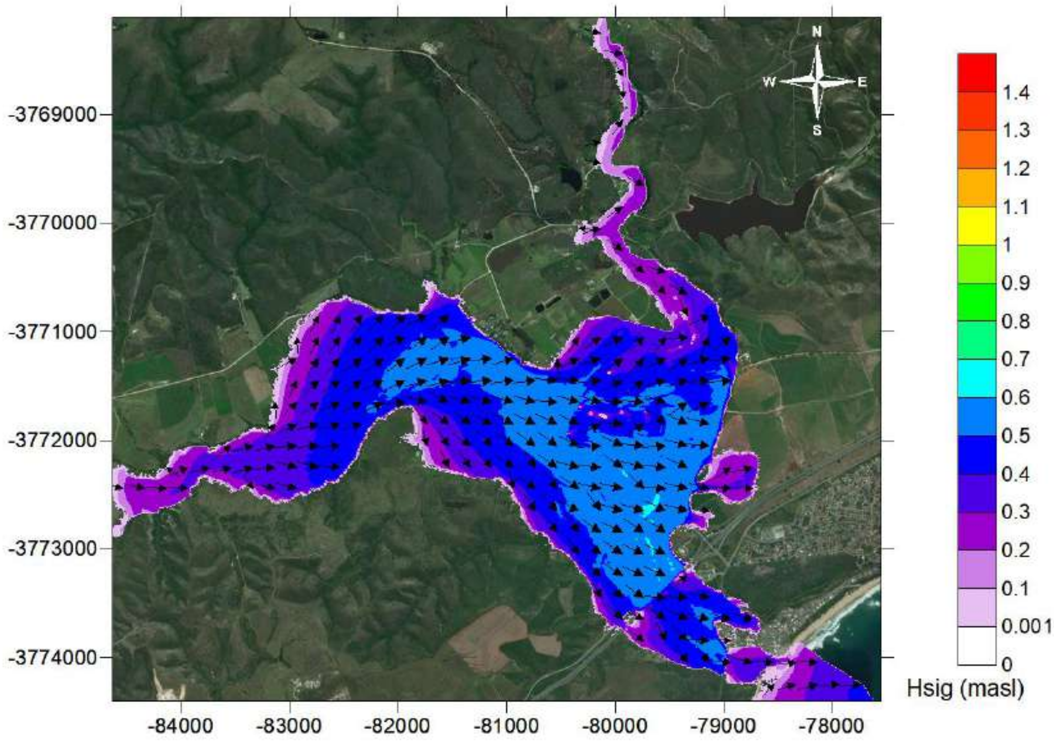


Figure 6.2-2: Contour map showing the significant wave height with peak wave direction vectors for Scenario 8 for Klein Brak River with W'ly wind

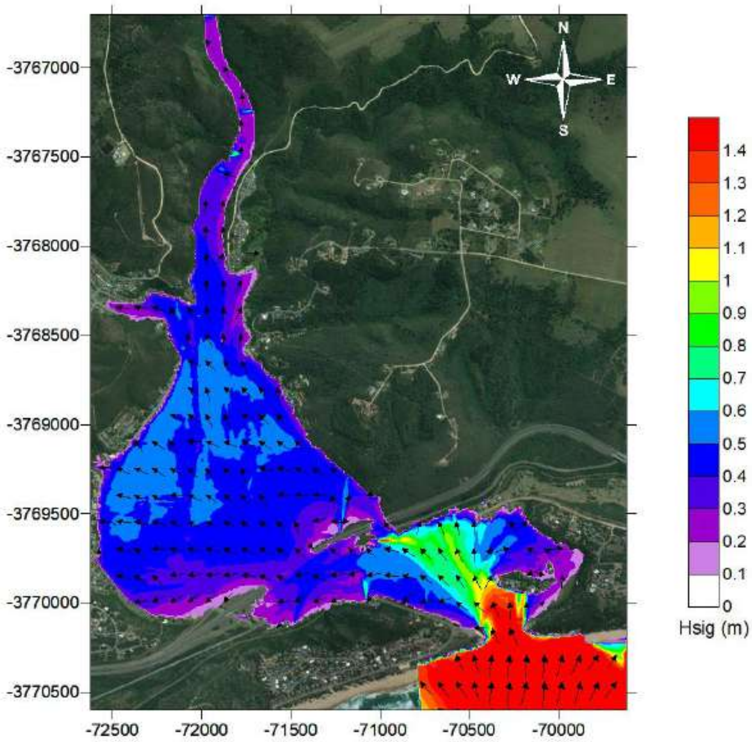


Figure 6.2-3: Contour map showing the significant wave height with peak wave direction vectors for Scenario 6 for Groot Brak River

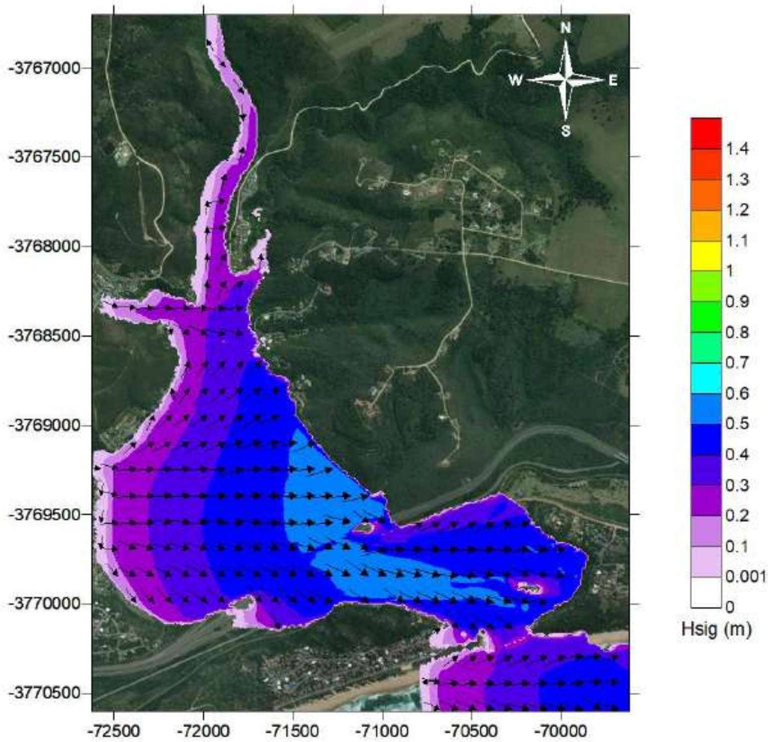


Figure 6.2-4: Contour map showing the significant wave height with peak wave direction vectors for Scenario 8 for Groot Brak River with W'ly wind

6.3. Calculation of wave runup caused by short waves

Wave runup is the extreme levels reached by oscillating waves on a slope, which is a function of wave height, wave period and bank slope, and could be more or less than the incident wave height. Wave runup for the wave height which is exceeded by 2% of the waves in the irregular wave train ($H_{2\%}$) was derived with empirical methods at/near representative locations. The short wave runup values were calculated on the river bank slope at/near the representative locations where the water's edges of the respective flood levels (due to tide, river flood and long waves) intersect the river bank.

Three different empirical methods, namely EM from EurOtop II (2016), TAW (2002a) and Ahrens (1981), were used to determine the wave runup $R_{u2\%}$ caused by $H_{2\%}$ for smooth slopes based on the significant wave height Hs and peak wave periods Tp simulated by SWAN. Refer to The Rock Manual (2007, pages 487 to 517) for explanations of the methods and formulae used. The basic approach for runup $R_{u2\%}$ equations is given by:

$$\frac{R_{u2\%}}{H_s} = A\xi + B$$

where A and B are fitting coefficients that relate the parameters Hs, Tp and slope α. The surf similarity parameter ξ is given by:

$$\xi = \frac{\tan\alpha}{\sqrt{\frac{2\pi}{g}\frac{Hs}{T^2}}}$$

where surf similarity ξ is either defined by Tp, Tm or Tm-1,0. Tp is the peak wave period where the maximum wave energy occurs, Tm is the mean wave period taken as 0.79Tp and Tm-1,0 is the mean energy spectrum related wave period taken as Tp/1.1. The relationships are based on a Rayleigh distribution of wave heights where Hs is the mean of the top 1/3 wave heights.

The EM (2016) method is described in the EurOtop II Manual (2016, pages 100 to 107). The EM (2016) states that this method may replace the other methods outlined in The Rock Manual. Therefore, the EM (2016) method was assumed to take precedence over the other three methods. For a design and assessment approach, a partial safety factor of one standard deviation is employed by these methods. However, in instances where the EM (2016) method was not applicable, an average of the Ahrens (1981) and TWA (2002a) methods was used.

In addition, a reduction factor of Yβ was calculated using the following equation to account for oblique wave attack at an approach angle of β:

$$Y_{\beta} = 1 - 0.0022\beta$$

Appendix E gives a summary of the simulated wave heights and periods as well as the final runup calculated from these parameters at selected locations (as described in subsequent sections). The statistical spread for the runup calculated at the selected locations for each scenario is given in Table 6.3-1.

Table 6.3-1: Statistical spread for the runup calculations at the selected locations for each scenario for Klein Brak and Groot Brak

	KLEIN BRAK				GROOT BRAK			
Scenario	**Min**	**Max**	**Median**	**Mean**	**Min**	**Max**	**Median**	**Mean**
1: Q50c open	0.00	1.05	0.14	0.24	0.06	1.27	0.25	0.34
2: Q100 c open	0.01	1.95	0.16	0.28	0.07	1.19	0.27	0.36
3: Q50c closed E'ly wind	0.01	0.89	0.12	0.16	0.01	0.58	0.18	0.19
3: Q50c closed W'ly wind	0.01	0.71	0.12	0.19	0.02	1.24	0.24	0.31
4: Q100c closed E'ly wind	0.00	0.91	0.14	0.17	0.00	0.59	0.18	0.20
4: Q100c closed W'ly wind	0.01	0.74	0.14	0.20	0.02	1.25	0.24	0.31
5: Q50f open	0.01	0.86	0.14	0.17	0.07	1.52	0.34	0.44
6: Q100f open	0.02	2.85	0.20	0.36	0.08	1.61	0.36	0.48
7: Q50f closed E'ly wind	0.00	0.87	0.13	0.17	0.02	0.62	0.19	0.22
7: Q50f closed W'ly wind	0.01	0.78	0.14	0.20	0.03	1.38	0.26	0.34
8: Q100f closed E'ly wind	0.01	0.86	0.14	0.18	0.02	0.63	0.20	0.22
8: Q100f closed W'ly wind	0.01	0.84	0.15	0.21	0.03	1.33	0.25	0.34

**c = current, f = future, Q = recurrent interval*

While the method by Allsop et al (1985) is not applicable, the other methods produce results that are generally similar. These runup values are defined as the vertical height above the still water level, i.e. the flood level from the Mike 21C model simulations. It should be noted that it is the short wave runup (not the incident short wave heights) that were added to the concurrent flood levels to obtain the final flood levels. Note that the significant wave heights yielded by SWAN account for the reduction in wave height caused by waves breaking on a shallow foreshore. Therefore, the equations for a shallow foreshore outlined in the EurOtop II Manual (2016) are not applicable.

6.4. Wave runup results for Klein Brak

A total of 88 representative locations, shown in Figures 6.4-1 and 6.4-2, were selected along the banks of the Klein Brak estuary to perform the runup analysis. The locations are evenly spaced at distances of approximately 270 m in order to facilitate accurate interpolation of the extreme floodlines. The significant wave heights, peak wave periods and runup yielded by the SWAN simulations at these locations are summarized in **Appendix E1**. Table E1-1 gives the co-ordinates and slopes for the different locations while Figure 6.4-3 shows the runup calculated at each location for the different scenarios.

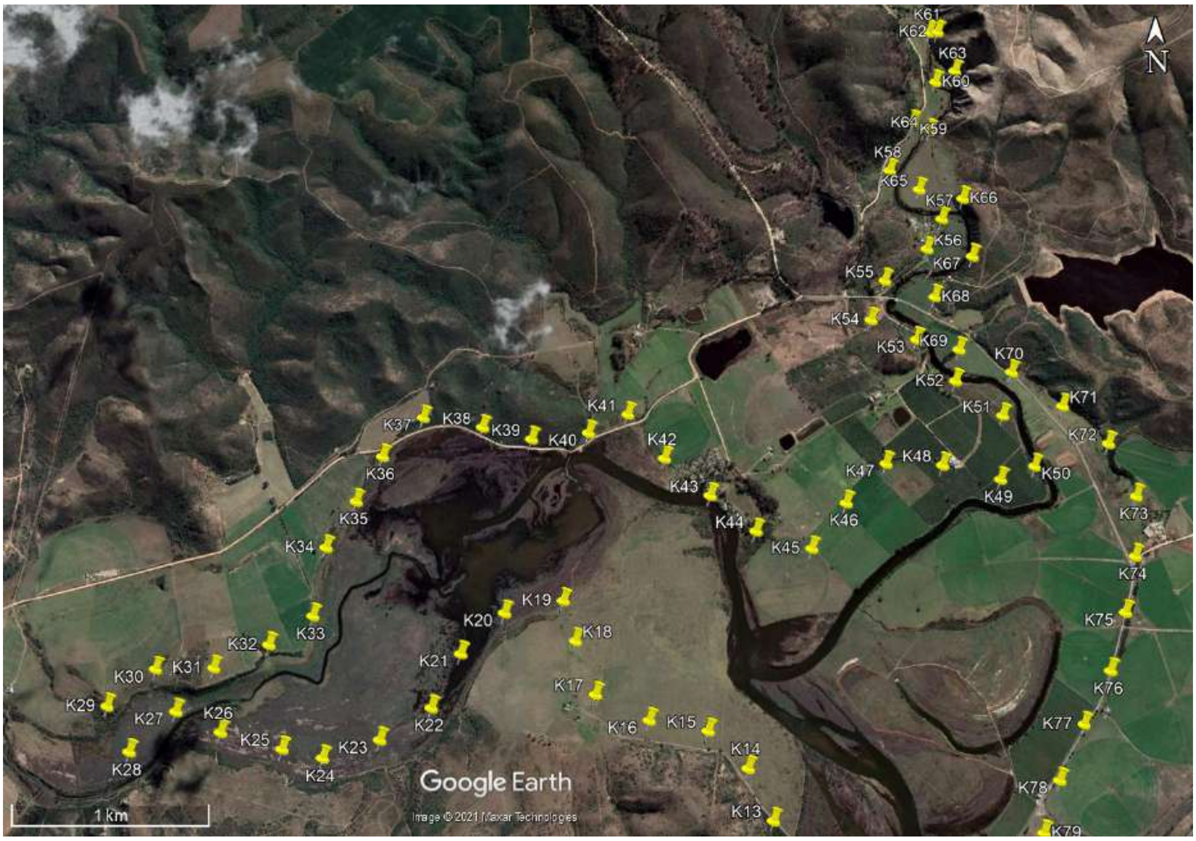


Figure 6.4-1: Representative locations selected for the wave runup calculations along the upper reaches of the Klein Brak River estuary

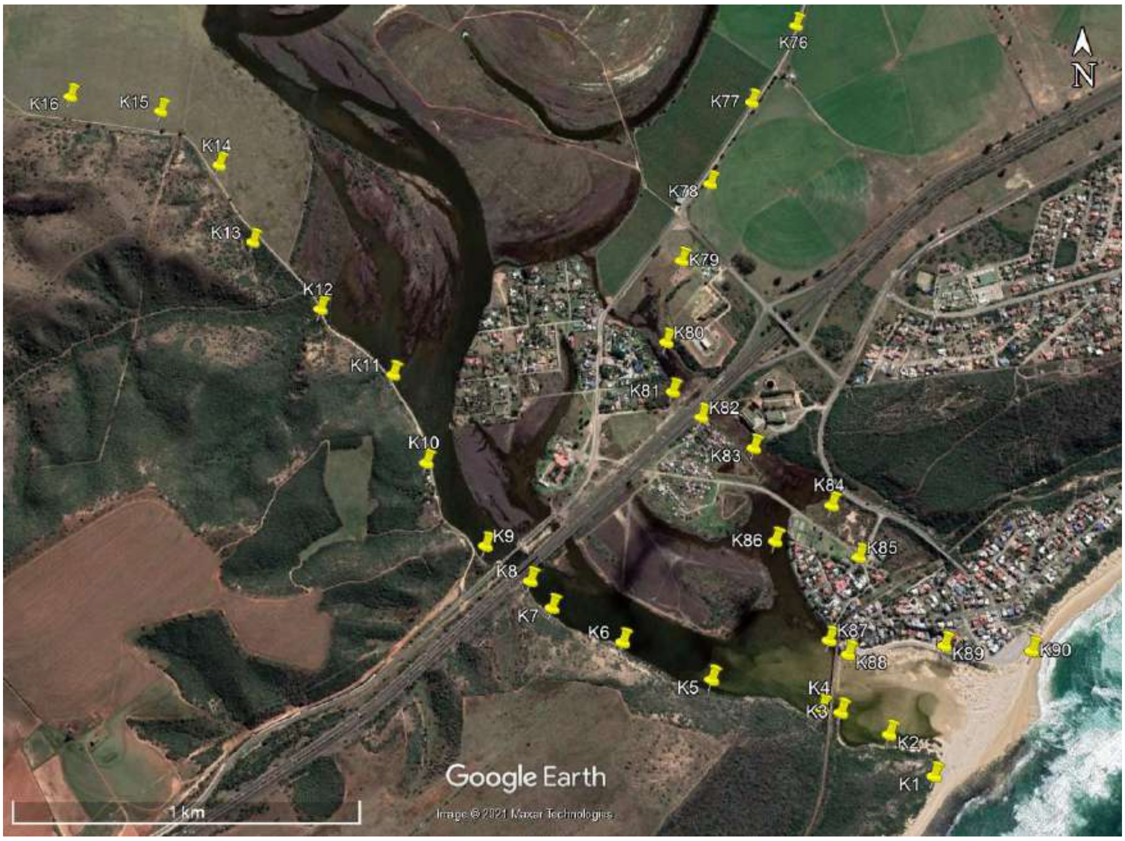


Figure 6.4-2: Representative locations selected for the wave runup calculations along the lower reaches of the Klein Brak River estuary

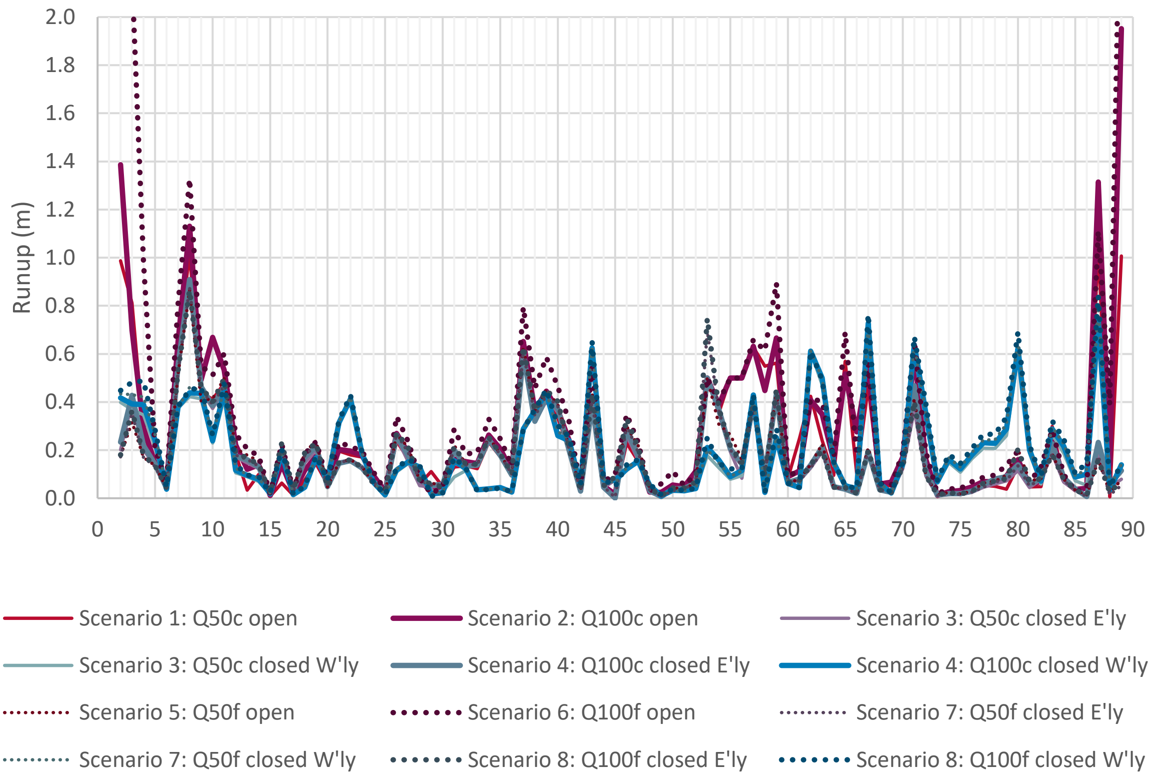


Figure 6.4-3: Runup calculated at the representative locations in the Klein Brak River estuary

Concurrent with the findings of the simulated wave heights, the open mouth conditions results in the worst case runup values while the W'ly winds produces larger runup values than E'ly winds for the closed mouth conditions. The locations closer to the opening of the mouth have higher runup values while those further inland are sheltered against waves. The left tributary has slightly higher runup due to steeper slopes. The tabulated runup values are within the anticipated range of 0.2 m. The differences between 50- and 100- year scenarios, as well as between current and future scenarios, are generally marginal (approximately 0.05 m).

6.5. Wave runup results for Groot Brak

A total of 43 representative locations, shown in Figure 6.5-1, were selected along the banks of the Klein Brak estuary to perform the runup analysis. As for Klein Brak, the locations are evenly spaced at distances of approximately 270 m to facilitate interpolation of the extreme floodlines. The significant wave heights, peak wave periods and runup yielded by the SWAN simulations at these locations are summarized in **Appendix E2**. Table E2-1 gives the co-ordinates and slopes for the different locations while Figure 6.5-3 shows the runup calculated at each location for the different scenarios.

Concurrent with the findings of the simulated wave heights as well as the runup values calculated for Klein Brak, the open mouth conditions results in the worst case runup values (approximately 0.15 m higher) while the W'ly winds produces larger runup values than E'ly winds for the closed mouth conditions. As validated by the figures with the wave heights and wave direction vectors, the left bank experiences lesser runup during E'ly winds while the right bank has lesser runup during W'ly winds. While the open mouth conditions may result in higher short wave heights and runup values, much higher water levels were simulated for the closed mouth conditions in Section 5.

The locations closer to the opening of the mouth have higher runup values while those further inland are sheltered against waves. Compared to Klein Brak, Groot Brak is subjected to slightly higher runup values which are within the anticipated range of 0.3 m. The differences between 50- and 100- year scenarios are negligible while the difference between the current and future scenarios are also marginal (approximately 0.05 m).

It should be noted that the 5 locations on the Groot Brak Island (points 39 to 43) were found to be submerged (due to the combined contribution of tide, river flood and long waves). The additional contribution of short wave runup to the maximum water level is therefore obtained by adding the short wave height (assumed to be the 2% short wave runup on a vertical wall) to the combined contribution of tide, river flood and long waves - assuming that a building at the location with vertical walls penetrates above the respective maximum water levels at the referred 5 locations. The subsequent worst-case "runup" to be expected at the island is in the order of 0.6 to 0.8 m.

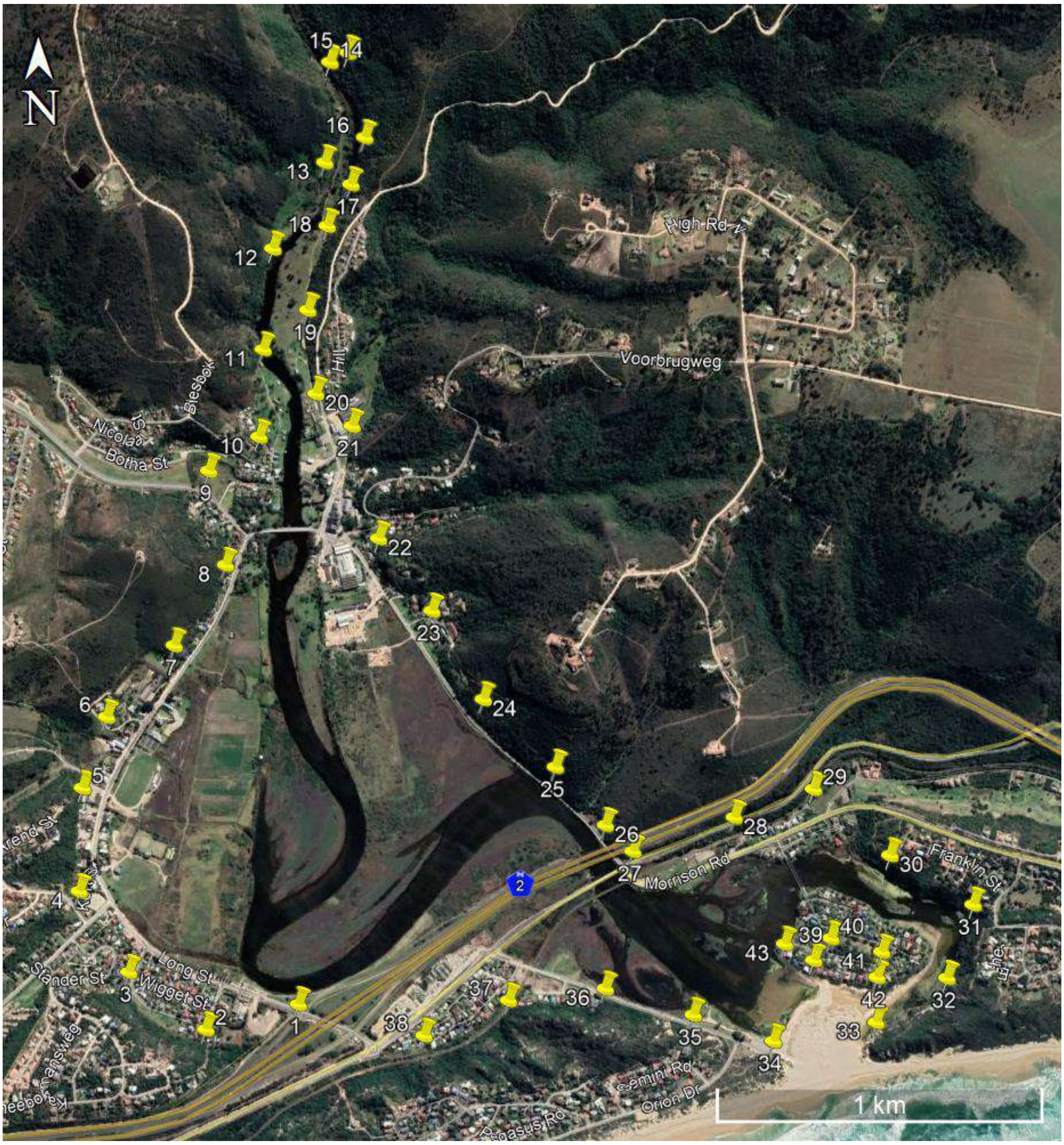


Figure 6.5-1: Representative locations selected for the wave runup calculations at Groot Brak

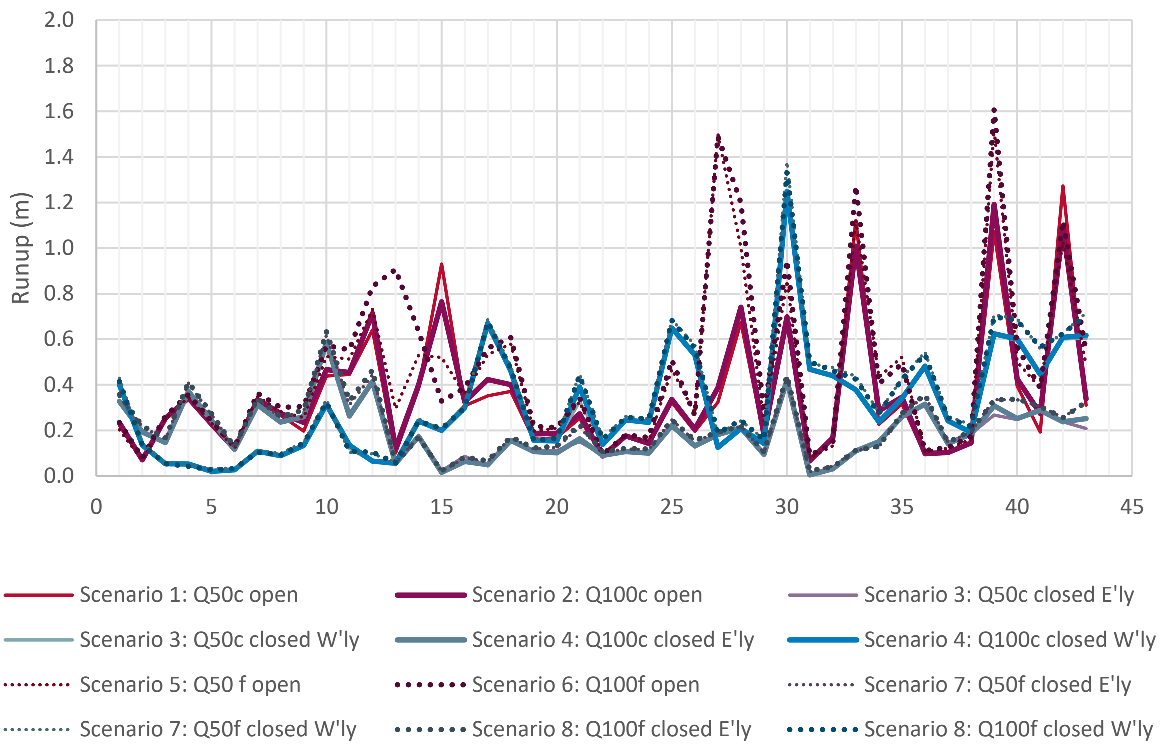


Figure 6.5-2: Runup calculated at the representative locations in the Groot Brak River estuary

7. Combined flood levels, long waves and short wave runup

7.1. Proposed floodlines

This section combines the Mike 21C hydrodynamic model simulated flood levels (caused by the flood in the river) with the wave runup SWAN simulations and calculations. The floodlines are proposed for the worst-case scenarios. The final floodlines for the 50- and 100-year floods, for the current and future scenarios will be provided as AUTOCAD Drawings in **Appendix I** as drawn by Bigen Africa Services (Pty) Ltd.

Based on the results at both Klein Brak and Groot Brak, the closed mouth initial conditions obtained conservatively higher flood levels than those for the open mouth in the lower estuaries. At Groot Brak, the floodlines for 50- and 100-year flood events are near identical (±0.1 m difference) while the future scenario floodlines are typically situated 0.9 m higher than those for the current scenarios. At Klein Brak, the floodline scenarios are separated by an elevation of approximately 0.35 m while the 50-year future and 100-year current floodlines are almost identical.

It is typically recommended that the floor levels of existing dwellings should be above the maximum floodlines i.e. Scenario 8. However, from the floodlines it is evident that extensive human settlements do not meet this criteria and will be inundated during the current 50-year flood. While mitigation measures were beyond the scope of the study, these findings are of importance to the disaster risk management for local and district levels, as well as the Klein Brak and Groot Brak estuary management plans. Officials should cooperate with the South African Weather Service to implement early warning systems.

Furthermore, it is recommended that the floodlines for Scenario 8 (100-year flood, future scenario) is enforced to the alterations/extensions of existing infrastructure as well as the development of any new infrastructure. Any other legislation stipulated by local and national authorities for the development of infrastructure near estuaries should also still be adhered to. These extreme floodlines should be reflected by the Coastal Management Lines and Estuarine Functional Zone to ensure that no further development or inappropriate development takes place in these flood prone areas.

7.2. Extreme flood levels for Klein Brak

Appendix E1 indicates the extreme flood levels (above the current mean sea level) for all the different scenarios which were calculated by superimposing the floods in the river with the wave runup at the different locations identified in Figures 6.4-1 and 6.4-2. Subsequently, the maximum flood levels were identified for the 50- and 100-year floods for the current and future scenarios. Note that the interpolation between points was smoothed. The maximum flood levels are presented in Table 7.2-1 and Figure 7.2-1. These flood levels were established for a closed mouth initial condition with W'ly winds which obtained conservatively higher flood levels than those for the open mouth in the Klein Brak estuary. Flood levels are in the order of 5 masl near the mouth but dramatically increase with the topography between points 50 and 73 along the left tributary.

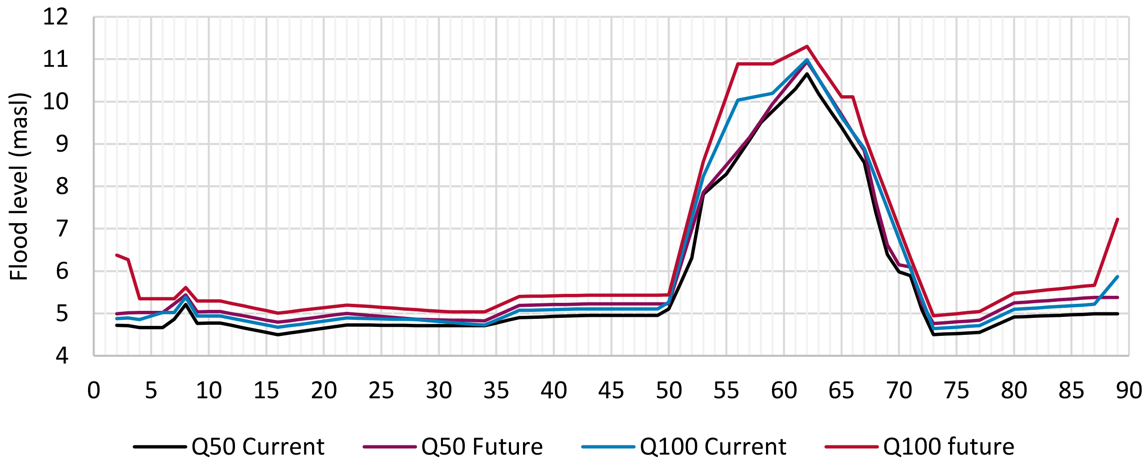


Figure 7.2-1: Final extreme flood levels at the representative locations in the Klein Brak River estuary

Table 7.2-1: Extreme flood levels for the 50- and 100-year floods for the current and future scenarios at the Klein Brak River estuary

Location	50-year flood current (masl)	100-year flood current (masl)	50-year flood future (masl)	100-year flood future (masl)	Location	50-year flood current (masl)	100-year flood current (masl)	50-year flood future (masl)	100-year flood future (masl)
2	4.72	4.88	4.99	6.38	**46**	4.96	5.11	5.23	5.43
3	4.71	4.89	5.01	6.27	**47**	4.96	5.11	5.23	5.43
4	4.66	4.86	5.02	5.35	**48**	4.96	5.11	5.23	5.43
5	4.66	4.94	5.02	5.35	**49**	4.96	5.11	5.23	5.43
6	4.66	5.02	5.02	5.35	**50**	5.10	5.26	5.23	5.44
7	4.86	5.02	5.23	5.35	**51**	5.69	6.25	6.10	6.49
8	5.21	5.38	5.44	5.61	**52**	6.31	7.25	6.98	7.53
9	4.77	4.94	5.04	5.29	**53**	7.81	8.24	7.86	8.58
10	4.77	4.94	5.04	5.29	**54**	8.05	8.84	8.18	9.35
11	4.77	4.94	5.05	5.29	**55**	8.29	9.43	8.50	10.12
12	4.72	4.88	4.99	5.23	**56**	8.69	10.03	8.82	10.89
13	4.66	4.83	4.94	5.18	**57**	9.09	10.09	9.15	10.89
14	4.61	4.78	4.89	5.12	**58**	9.51	10.14	9.55	10.89
15	4.55	4.72	4.84	5.06	**59**	9.77	10.19	9.94	10.89
16	4.50	4.67	4.79	5.01	**60**	10.04	10.46	10.28	11.03
17	4.54	4.71	4.83	5.04	**61**	10.30	10.72	10.61	11.16
18	4.57	4.74	4.86	5.07	**62**	10.65	10.99	10.94	11.30
19	4.61	4.78	4.90	5.10	**63**	10.19	10.54	10.54	10.89
20	4.65	4.82	4.93	5.13	**64**	9.79	10.09	10.11	10.50
21	4.69	4.86	4.96	5.17	**65**	9.39	9.64	9.69	10.11
22	4.73	4.89	5.00	5.20	**66**	8.97	9.27	9.26	10.11
23	4.73	4.89	4.98	5.18	**67**	8.56	8.89	8.84	9.20
24	4.72	4.88	4.95	5.16	**68**	7.38	8.19	7.63	8.48
25	4.72	4.87	4.93	5.14	**69**	6.39	7.48	6.62	7.76
26	4.72	4.87	4.91	5.12	**70**	5.98	6.77	6.15	7.04
27	4.72	4.86	4.88	5.11	**71**	5.89	6.06	6.09	6.31
28	4.71	4.85	4.86	5.09	**72**	5.08	5.35	5.23	5.63
29	4.71	4.83	4.85	5.07	**73**	4.50	4.64	4.76	4.94
30	4.71	4.81	4.85	5.05	**74**	4.51	4.66	4.78	4.97
31	4.71	4.79	4.84	5.03	**75**	4.52	4.68	4.80	4.99
32	4.71	4.77	4.84	5.03	**76**	4.54	4.70	4.82	5.02
33	4.71	4.74	4.83	5.03	**77**	4.55	4.71	4.84	5.04
34	4.71	4.72	4.83	5.03	**78**	4.67	4.84	4.98	5.19
35	4.77	4.84	4.95	5.16	**79**	4.79	4.97	5.11	5.33
36	4.84	4.96	5.07	5.28	**80**	4.91	5.09	5.25	5.47
37	4.90	5.07	5.19	5.40	**81**	4.92	5.11	5.27	5.50
38	4.91	5.08	5.19	5.41	**82**	4.93	5.13	5.29	5.53
39	4.92	5.08	5.20	5.41	**83**	4.95	5.15	5.30	5.56
40	4.93	5.09	5.21	5.41	**84**	4.96	5.16	5.32	5.58
41	4.94	5.10	5.21	5.42	**85**	4.97	5.18	5.34	5.61
42	4.95	5.10	5.22	5.42	**86**	4.98	5.20	5.36	5.64
43	4.96	5.11	5.23	5.43	**87**	4.99	5.22	5.38	5.67
44	4.96	5.11	5.23	5.43	**88**	4.99	5.54	5.38	6.45
45	4.96	5.11	5.23	5.43	**89**	4.99	5.87	5.38	7.23

7.3. Extreme flood levels for Groot Brak

Appendix E2 indicates the extreme flood levels (above the current mean sea level) for all the different scenarios which were calculated by superimposing the floods in the river with the wave runup at the different locations identified in Figure 6.5-1. Subsequently, the maximum flood levels were identified for the 50- and 100-year floods for the current and future scenarios. Note that the interpolation between points was smoothed. The maximum flood levels are presented in Table 7.3-1 and Figure 7.3-1. As for Klein Brak, these flood levels were established for a closed mouth initial condition with W'ly winds which obtained conservatively higher flood levels than those for the open mouth in the Groot Brak estuary. Flood levels are in the order of 6 to 7 masl near the mouth but increases with the topography between points 10 and 20 where the channel narrows upstream of the Stasie Road bridge.

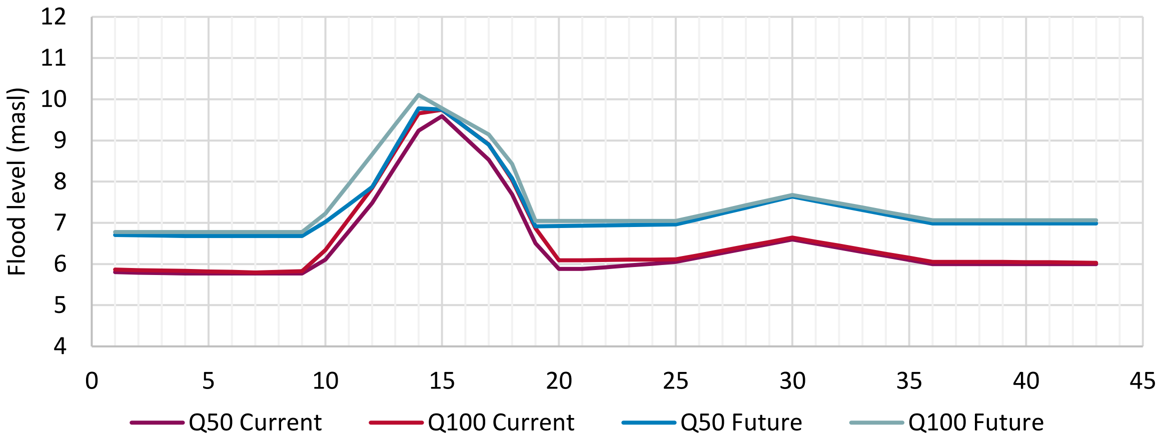


Figure 7.3-1: Final extreme flood levels at the representative locations in the Groot Brak River estuary

Table 7.3-1: Extreme flood levels for the 50- and 100-year floods for the current and future scenarios at the Groot Brak River estuary

Location	50-year flood current (masl)	100-year flood current (masl)	50-year flood future (masl)	100-year flood future (masl)
1	5.80	5.86	6.70	6.78
2	5.79	5.85	6.69	6.78
3	5.78	5.84	6.69	6.78
4	5.77	5.84	6.68	6.78
5	5.77	5.82	6.68	6.78
6	5.77	5.81	6.68	6.78
7	5.77	5.79	6.68	6.78
8	5.77	5.81	6.68	6.78
9	5.77	5.83	6.68	6.78
10	6.10	6.34	7.02	7.22
11	6.79	7.09	7.45	7.94
12	7.48	7.84	7.87	8.66
13	8.36	8.75	8.82	9.38
14	9.23	9.66	9.78	10.10
15	9.59	9.74	9.75	9.78
16	9.06	9.32	9.33	9.46
17	8.53	8.90	8.90	9.15
18	7.69	8.04	8.08	8.43
19	6.50	6.87	6.91	7.05
20	5.88	6.09	6.92	7.05
21	5.88	6.09	6.93	7.05
22	5.92	6.10	6.94	7.05
23	5.96	6.10	6.94	7.05
24	6.01	6.11	6.95	7.05
25	6.05	6.11	6.96	7.05
26	6.16	6.22	7.10	7.17
27	6.27	6.32	7.23	7.30
28	6.38	6.43	7.37	7.42
29	6.48	6.54	7.50	7.55
30	6.59	6.64	7.64	7.68
31	6.49	6.54	7.53	7.58
32	6.39	6.45	7.42	7.47
33	6.30	6.35	7.31	7.37
34	6.20	6.25	7.20	7.27
35	6.10	6.15	7.09	7.16
36	6.00	6.05	6.98	7.06
37	6.00	6.05	6.98	7.06
38	6.00	6.05	6.98	7.06
39	6.00	6.05	6.98	7.06
40	6.00	6.05	6.98	7.06
41	6.00	6.04	6.99	7.06
42	6.00	6.03	6.99	7.06
43	6.00	6.03	6.99	7.06

The maximum flood levels at the Groot Brak Island at the 5 locations (points 39 to 45) were also calculated even though the island will be submerged and the provision of floodlines for the island is technically not possible. The situation for the residential development on the island is critical in terms of flooding risk with dangerous current and future water depths of up to 4 m and 5 m respectively on the outer periphery of the island where the ground level is 2 masl. Table 7.3-2 shows the simulated maximum water levels and flow depths at these locations on the island relative to natural ground levels and human development in Figure 7.3-2. The maximum water levels were obtained from superimposing the routed river flood, the tidal levels and long waves (Section 5.4) with the short wave height H2% from SWAN (Section 6.5).

Table 7.3-2: Total water depth experienced at the island in the Groot Brak River estuary for the 50- and 100-year floods for the current and future scenarios

Point ID	39	40	41	42	43
Ground level (masl)	**2.00**	**3.50**	**5.50**	**3.00**	**2.00**
50-year flood current (m)	4.00	2.50	0.50	3.00	4.00
100-year flood current (m)	4.05	2.55	0.54	3.03	4.03
50-year flood future (m)	4.98	3.48	1.49	3.99	4.99
100-year flood future (m)	5.06	3.56	1.56	4.06	5.06

Figure 7.3-2: Final extreme flood levels at the representative locations in the Groot Brak River estuary

8. Conclusions and recommendations

The key objective of this study was to investigate the flood flow patterns and sediment dynamics in the Klein Brak River and Grot Brak River estuaries, for initially closed mouth and open mouth conditions, and for the current development and future scenarios, to determine the 50- and 100-year floodlines. The extreme flood levels were obtained from superimposing routed river floods, tidal levels and long waves with runup caused by swell and wind waves. The methodology included the following tasks:

- A hydrological flood analysis was done to determine the flood hydrographs for different return intervals. Extensive data records of historical floods observed by the Department of Water and Sanitation (DWS) were used to perform a probabilitic analysis. The results compared well with deterministic and empirical methods at Klein Brak and with a previous DWS study at Groot Brak. Climate change impacts were also considered.
- Hydrodynamic modelling simulated the flow patterns and fluvial morphology of the estuaries by routing the 50- and 100-year recurrence interval flood hydrographs through them. At the estuary mouth, open and closed initial mouth conditions were assessed. The model was also extended into the ocean with a tidal open boundary which included long waves associated with swell waves.
- Deep sea MET-Ocean data was analysed and transferred from deep sea by means of a SWAN wave model to quantify wave penetration through an open mouth into the estuary. The SWAN model was used to simulate the transferring of swell waves from the offshore wave model boundary concurrent with locally wind generated waves over the modelled area and its penetration into the estuary for selected storm events. Wave runup was also calculated at several representative locations.
- Floodlines were established for the worst-case 50- and 100-year floods (current and future scenarios) by taking the flood levels from the hydrodynamic modelling as well as the wave runup into consideration. AUTOCAD floodline drawings will be attached in **Appendix I**. Based on the results at both Klein Brak and Groot Brak, the closed mouth initial conditions obtained conservatively higher flood levels than those for the open mouth in the lower estuaries. At Groot Brak, the floodlines for 50- and 100-year flood events are near identical while the future scenario floodlines are higher than those for the current scenarios. At Klein Brak, the floodline scenarios are almost evenly distributed except for the 50-year future and 100-year current floodlines which are almost identical.

It is typically recommended that the floor levels of existing dwellings should be above the maximum floodlines i.e. Scenario 8. However, from the floodlines it is evident that extensive human settlements do not meet this criteria and will be inundated during the current 50-year flood. Disaster risk management officials should cooperate with the South African Weather Service to implement early warning systems.

Furthermore, it is recommended that the floodlines for Scenario 8 (100-year flood, future scenario) is enforced to the alterations/extensions of existing infrastructure as well as the development of any new infrastructure. Any other legislation stipulated by local and national authorities for the development of infrastructure near estuaries should also still be adhered to.

It should be noted that the island in the Groot Brak River estuary will be submerged. The situation for the residential development on the island is critical in terms of flooding risk with dangerous current and future water depths of up to 4 m and 5 m respectively on the outer periphery of the island where the ground level is 2 masl.

9. References

BICKERTON, I.B., HEYDORN, A. and GRINDLEY, J.R. (1983). *Estuaries of the Cape: Part II: Synopses of available information on individual systems.* Council for Scientific and Industrial Research.

Booysen, Z (2017). Berm Height at Temporarily Open/Closed Estuaries in South Africa: Analysis and Predictive Methods. *Masters Thesis, Stellenbosch University* Department of Civil Engineering, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa.

Botes W A M, Russel K S, Huizinga P. Resonance in South African Harbours. ICCE 1982.

Caldwell, P. C., M. A. Merrfield, P. R. Thompson (2015), Sea level measured by tide gauges from global oceans — the Joint Archive for Sea Level holdings (NCEI Accession 0019568), Version 5.5, NOAA National Centers for Environmental Information, Dataset, doi:10.7289/V5V40S7W.

CIRIA (2007). The Rock Manual. http://www.kennisbank-waterbouw.nl/DesignCodes /rockmanual/

Compiled by: CSIR, P O box 320, Stellenbosch, 7599, *In association with:* Nelson Mandela Metropolitan University, Anchor Environmental Consultants, Department of Agriculture, Forestry and Fisheries, Piet Huizinga (private consultant).

DEA (2014). Climate Change Adaptation: Perspectives for Disaster Risk Reduction and Management in South Africa. Provisional modelling of drought, flood and sea level rise impacts and a description of adaptation responses. Report no 3 for the long term adaptation scenarios research flagship program (LTAS).

DEA&DP (2018). Mouth Management Plan for the Groot Brak Estuary. Compiled by the CSIR.

DWS (2012). Wolwedans Dam Flood Frequency Analysis: Estimation of Flood Peaks for Required Probabilities. Report number: K200-R002-2012.10. SA Department of Water and Sanitation.

DWS (2013). Underwater survey of the lower Groot Brak estuary.

DWS (Department of Water and Sanitation) (2015), WP 10543, Report No. RDM/WMA16/04/CON/0713A. Reserve Determination Studies for Selected Surface Water, Groundwater, Estuaries and Wetlands in the Breede-Gouritz Water management Area. Project Technical Report 7 (Volume 1): Estuary RDM Report – Rapid Assessment: Klein Brak Estuary. Report No. RDM/WMA16/04/CON/0713A. Pretoria, South Africa.

ECMWF Data centre. http://www.ecmwf.int/en/research/climate-reanalysis/browse-reanalysis-datasets

GEBCO 30 arc-second global grid of elevations, GEBCO_2014 Grid **(**2014). http://www.gebco.net/data_and_products/gridded_bathymetry_data/gebco_30_second_grid/

Geophys. Res. Lett., 44, doi:10.1002/2016GL072488. (2017).

IPCC Intergovernmental Panel on Climate Change (2013). The Physical Science Basis. Working Group I. Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http://ipcc.ch/report/ar5/

LYNERS (2017). Topographical survey of the parking area.

Mentaschi, L., M. I. Vousdoukas, E. Voukouvalas, A. Dosio, and L. Feyen (2017). Global changes of extreme coastal wave energy fluxes triggered by intensified teleconnection patterns,

Rossouw M, Terblanche L and Moes J (2014). General Characteristics of Long Waves around the South African Coast.

Stellenbosch University Department of Civil Engineering, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa.

Stuart D C A (2013) Characterizing long wave agitation in the port of Ngqura using a Boussinesq wave model. Master thesis, University of Stellenbosch.

University of Hawaii, Seal Level Centre (UHSLC). Recorded tidal data at http://uhslc.soest.hawaii.edu/

Viljoen (2017). Groot Brak Island – Measures for flood defense. Masters Thesis, Stellenbosch University.

Wang L W et al (2014). Changes in global ocean wave heights as projected using multi-model CMIP5 simulations. Climate Research Division, Science and Technology Branch, Environment Canada, Toronto, Ontario, Canada.

WW3, an open source wave model developed by the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Prediction (NCEP). http://polar.ncep.noaa.gov/waves/wavewatch/

WW3 NOAA data centre: The Pacific Islands Ocean Observing System (PacIOOS), funded through the National Oceanic and Atmospheric Administration (NOAA); a Regional Association within the U.S. Integrated Ocean Observing System (IOOS). PacIOOS is coordinated by the University of Hawaii School of Ocean and Earth Science and Technology (SOEST).

APPENDIX A: MET-OCEAN DATA

KLEIN BRAK AND GROOT BRAK RIVER ESTUARY – BATHYMETRIC, WAVE, WIND, TIDAL AND BAROMETRIC DATA AND SEA LEVEL RISE PROJECTIONS

A1 INTRODUCTION

This appendix presents the ocean related data and the results of its analysis to serve as boundary conditions for the numerical modelling of flood elevations in the Groot Brak Estuary. For the modelling of inter alia wave penetration into the Groot Brak estuary via the Groot Brak River mouth and consequent wave runup on the estuary shores, all relevant met-ocean information is presented. This includes offshore bathymetric data of the sea bed off the Mossel Bay embayment which was obtained from GEBCO (General Bathymetric Chart of the Oceans) and a SA Navy nautical chart excerpt for inshore bathymetrical data. Hind cast wave and wind data (ERA5) were obtained from ECMWF (European Centre for Medium-Range Weather Forecasts) at a location on the southern boundary of the bathymetric data (34.75°S; 22.5°E) for the 41-year period 1979 - 2019. The ERA5 re-analysed hindcast data is the most recent available and is a combination of global numerical modelling and observations. SA Navy recorded tidal data (research quality) at Mossel Bay harbour (nearest recording location) was obtained from UHSLC (University of Hawaii Sea Level Centre). The latest information on sea level rise by the IPCC (Inter-governmental Panel on Climate Change) is also presented. Existing information on long bound waves on the South African coast is also included. This appendix is concluded with a summary of the most relevant information derived from the raw met-ocean data.

Figure A1-1: Location for which ocean data was obtained and the area for which seabed topography was obtained. Wave and wind data at 34.75°S; 22.5°E.

A2 BATHYMETRIC DATA OF SEABED

The GEBCO topographical data at a 30' (approx. 500m) grid spacing was obtained and a contour plot was generated with this data and shown in Figure A2-1 below.

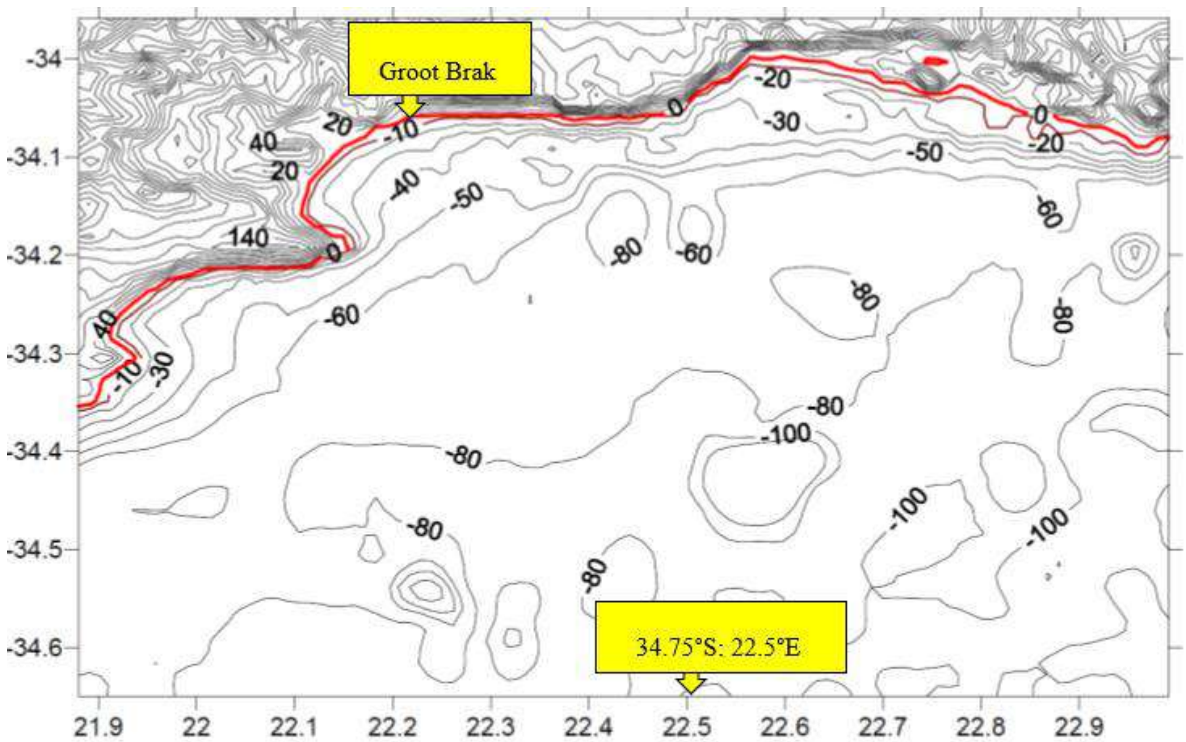


Figure A2-1: Seabed and land contour map generated from GEBCO data (latitude and longitude are shown in decimals of degrees)

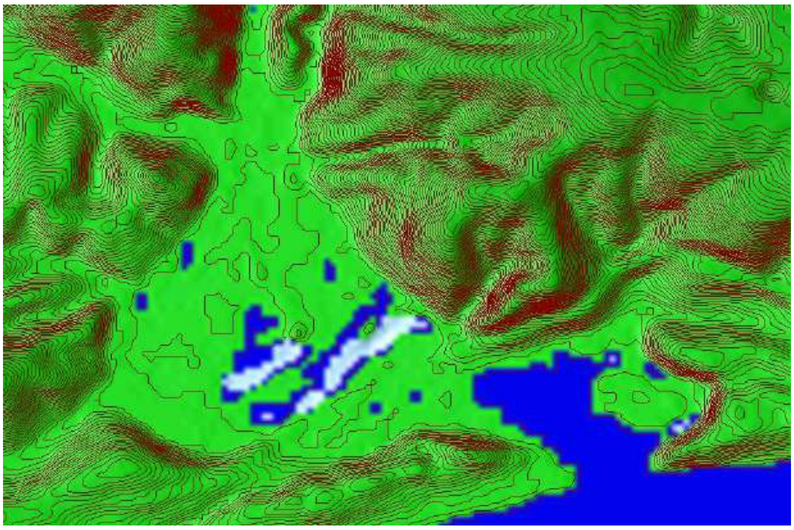


Figure A2-2: Approximate land topography (2m contour intervals) in area of Groot Brak Estuary (30 m spaced SRTM elevation data from https://www.eorc.jaxa.jp/ALOS/en/aw3d30/data/index.htm)

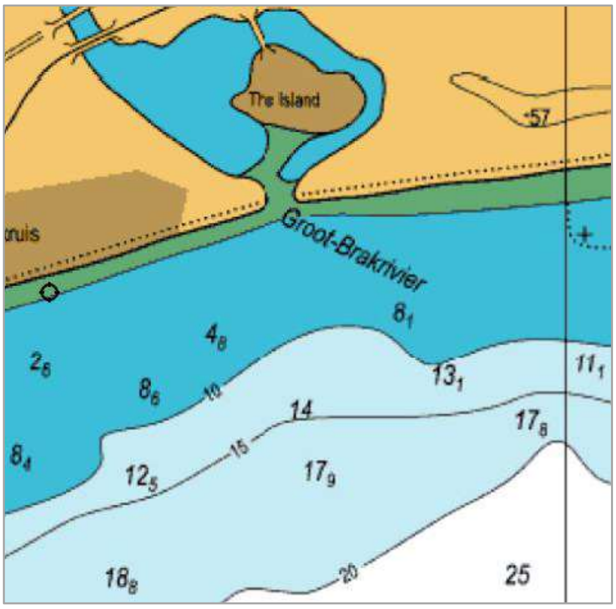


Figure A2-3: Bathymetry (m to Chart Datum) in the area offshore of the Groot Brak River mouth from SA Navy Hydrographer

A3 WAVE CONDITIONS

WAVE HEIGHT CONDITIONS

The latest re-analysed hindcast wave data (ERA5) of ECMWF at 34.75°S; 22.5°E at 3 hourly intervals for the period 1979 to 2019 was used to do statistical analyses on wave height (Hs). The results of this analyses are presented in the following formats:

- Time plot in Figure A3a-1
- Wave roses (occurrence and magnitude) in Figure A3a-2
- Occurrence per direction and height in Table A3a-1
- Exceedance plot in Figure A3a-3
- Extreme wave heights for all direction in Figure A3a-4 and Table A3a-2
- Extreme wave heights for the SE'ly sector only in Figure A3a-5 and Table A3a-3

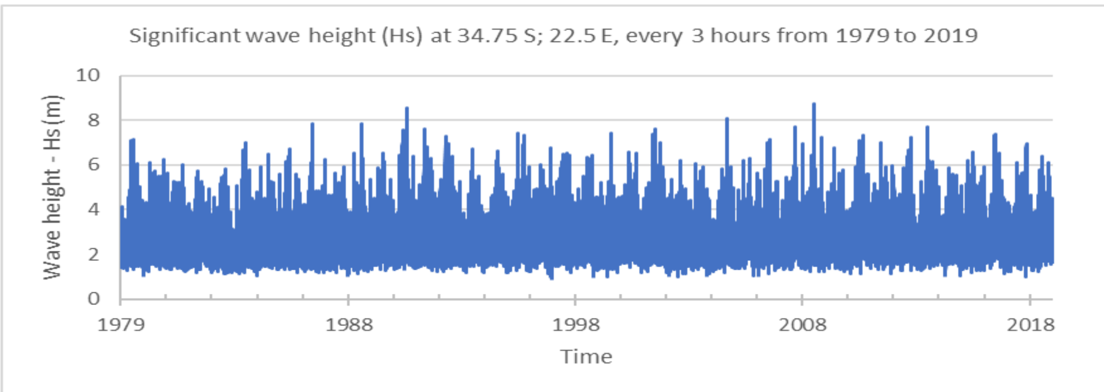


Figure A3a-1: Time plot of Hs at 34.75°S; 22.5E for period 1979 to 2019

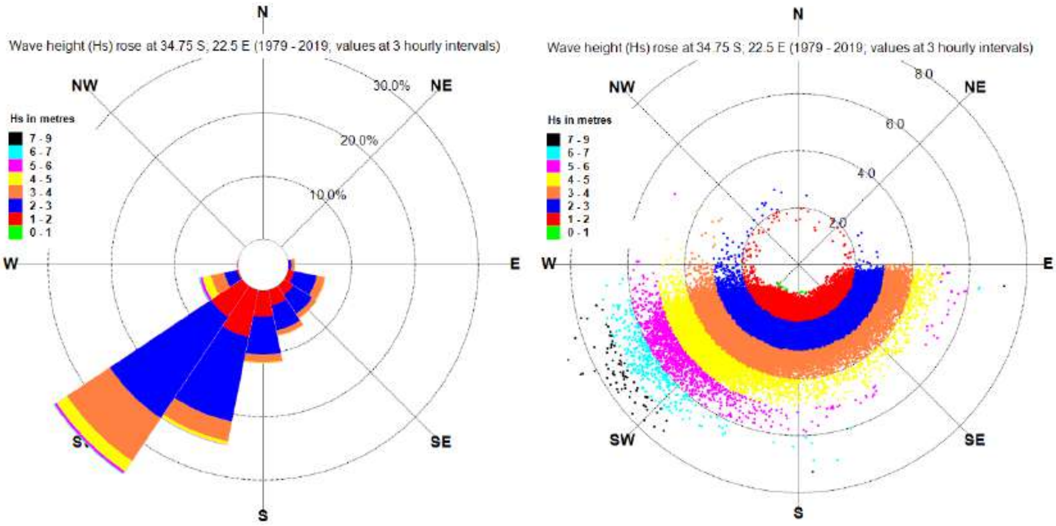


Figure A3a-2: Wave roses; occurrence per direction (left) and individual Hs values per direction (right)

Table A3a-1: Percentage occurrence of wave height versus direction for all data (1979 – 2019)

Direction from	Wave height (Hs in m)								Total
	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 9	
N		0.003	0.001						0.0
NNE		0.003							0.0
NE		0.003	0.001						0.0
ESE		0.007	0.003						0.0
SE		0.054	0.459	0.448	0.080	0.008	0.002	0.001	1.1
ESE		1.008	3.675	1.272	0.113	0.009			6.1
SE		1.790	3.560	0.801	0.069				6.2
SSE	0.001	2.518	4.063	0.809	0.085	0.013	0.001		7.5
S	0.003	4.165	6.043	1.189	0.172	0.018	0.005	0.001	11.6
SSW	0.003	7.622	13.634	3.159	0.548	0.095	0.009		25.1
SW	0.005	5.944	19.214	8.105	1.958	0.435	0.115	0.021	35.8
WSW		0.258	2.040	2.149	1.304	0.474	0.139	0.039	6.4
W		0.019	0.069	0.073	0.042	0.019	0.003		0.2
WNW		0.012	0.008	0.007	0.001	0.001			0.0
NW		0.003	0.003						0.0
NNW		0.008	0.006						0.0
Total	0.0	23.4	52.8	18.0	4.4	1.1	0.27	0.06	100.0

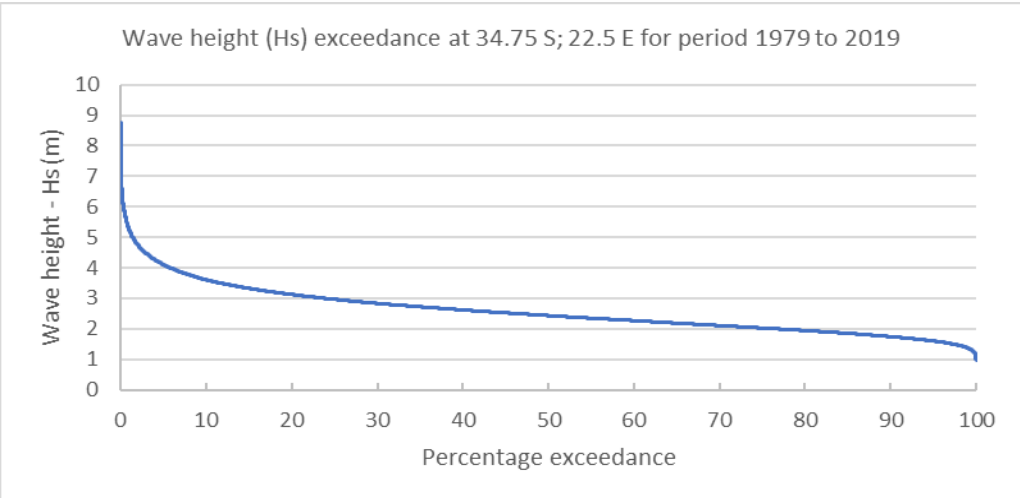


Figure A3a-3: Wave height percentage exceedance plot

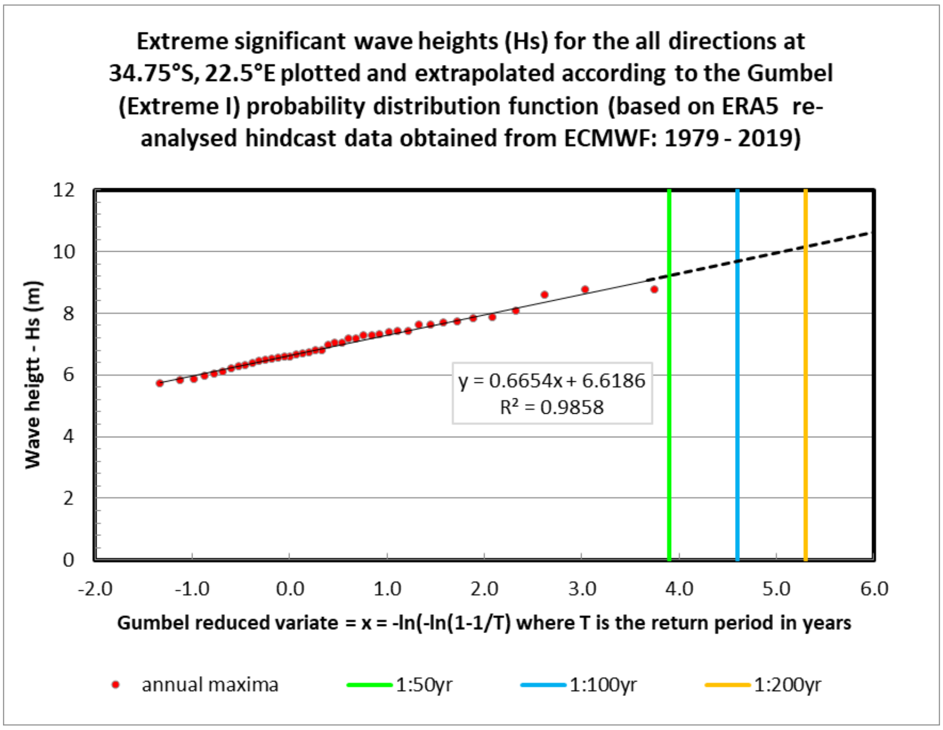


Figure A3a-4: Extreme wave heights for all directions

Table A3a-2: Summary of extreme wave heights for all directions

Return Period	Wave height (Hs)
(years)	(m)
200	10.1
100	9.7
50	9.2
20	8.6
10	8.1
5	7.6
2	6.9

Table A3a-3: Summary of extreme wave heights for the SE'ly sector only

Return Period	Wave height (Hs)
(years)	(m)
200	8.1
100	7.6
50	7.2
20	6.5
10	6.1
5	5.6
2	4.8

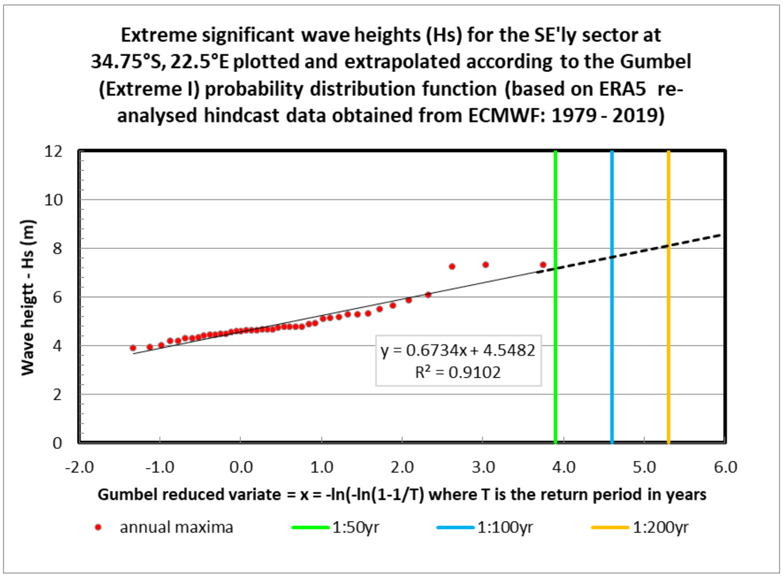


Figure A3a-5: Extreme wave heights for the SE'ly sector only

WAVE PERIOD CONDITIONS

ECMWF *peak* wave period data at 34.75°S; 22.5°E at 3 hourly intervals for the period 1979 to 2019 is presented in the following formats:

- Wave period roses (occurrence and magnitude) in Figure A3b-1
- Occurrence per direction and period in Table A3b-1
- Exceedance plots in Figure A3b-2
- Wave period vs wave height plot for all directions in Figure A3b-3
- Wave period vs wave height plot for the SE'ly sector in Figure A3b-4

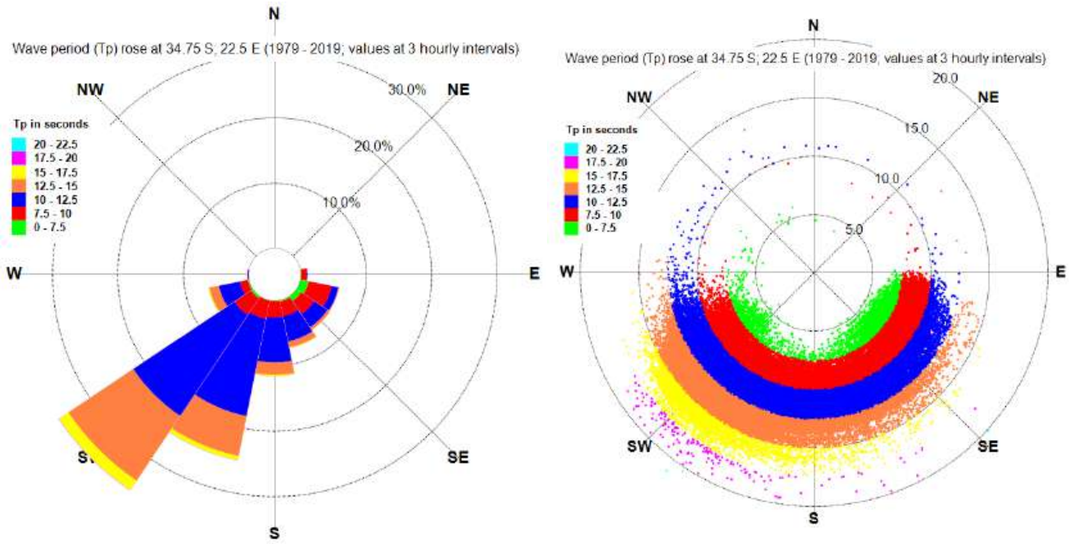


Figure A3b-1: Peak wave period roses; occurrence vs wave direction (left) and individual periods vs direction (right)

Table A3b-1: Percentage occurrence of mean wave period versus direction for all directions

Direction	Wave period - Tp (s)							Total
from	0 - 7.5	7.5 - 10	10 - 12.5	12.5 - 15	15 - 17.5	17.5 - 20	20 - 22.5	
N	0.001		0.003					0.0
NNE	0.001	0.001	0.001					0.0
NE		0.003	0.001					0.0
ESE		0.005	0.003	0.002				0.0
SE	0.124	0.828	0.097	0.003				1.1
ESE	1.310	3.605	1.059	0.100	0.003			6.1
SE	0.873	2.462	2.431	0.427	0.025	0.001	0.001	6.2
SSE	0.230	2.272	3.962	0.940	0.078	0.009		7.5
S	0.074	2.507	6.904	1.888	0.212	0.011		11.6
SSW	0.090	2.850	15.163	6.215	0.705	0.047	0.001	25.1
SW	0.348	3.103	18.576	11.927	1.768	0.074	0.001	35.8
WSW	0.230	1.242	3.279	1.467	0.180	0.004		6.4
W	0.032	0.043	0.121	0.028	0.002			0.2
WNW	0.008	0.002	0.018	0.001				0.0
NW	0.001		0.006					0.0
NNW	0.005	0.002	0.006	0.001				0.0
Total	3.3	18.9	51.6	23.0	3.0	0.1	0.00	100.0

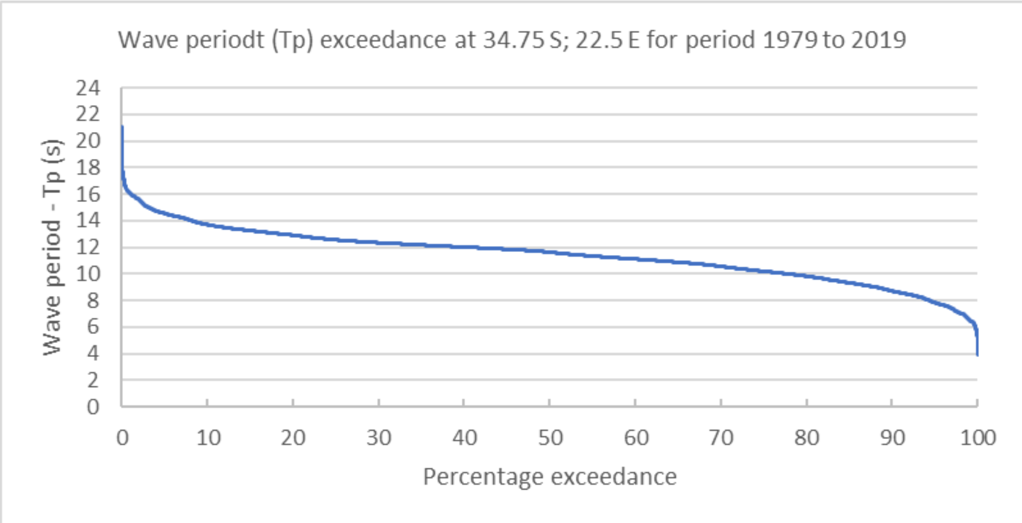


Figure A3b-2: Wave period exceedance plot for all directions

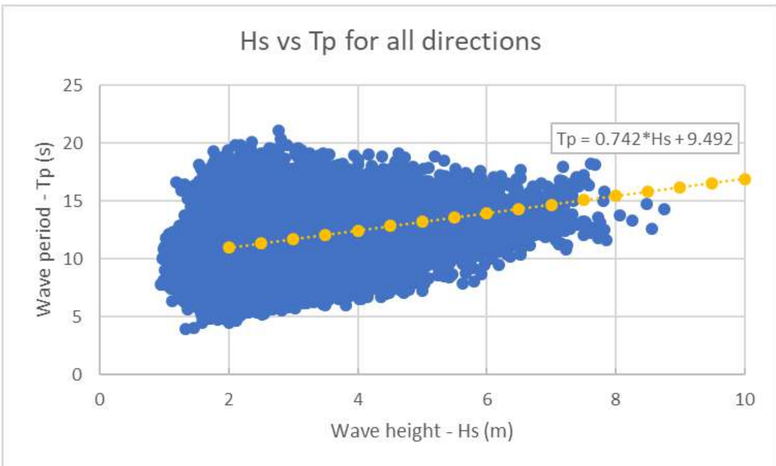


Figure A3b-3: Mean wave period vs wave height plot for all directions

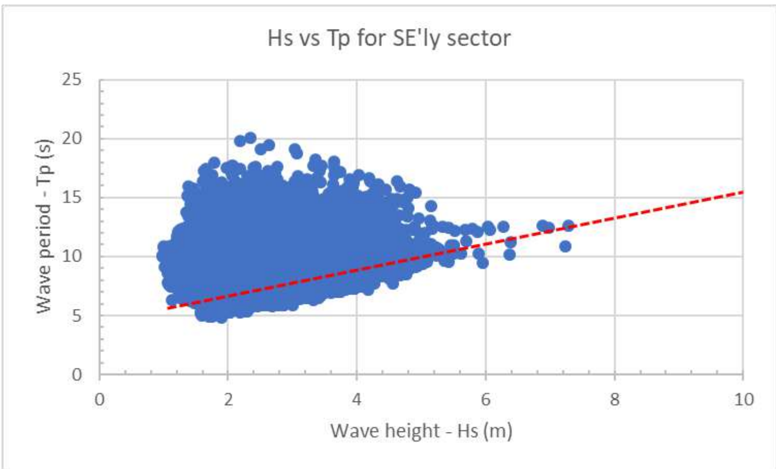


Figure A3b-4: Mean wave period vs wave height plot for SE'ly sector only

WAVE ENERGY SPECTRAL CONDITIONS

ECMWF wave energy spectral data (2D) at -35.5°S; 21.0°E of the storm of 31 August to 1 September 2008 was used to obtain typical storm wave spectral characteristics on the coastal area under investigation. The following information are presented:

A dimensionless energy spectrum compared to the corresponding Pierson- Moskowitz spectrum (of same energy and peak frequency) for the determination of the gamma value (spectral peak enhancement factor) of the 2008 storm (Figure A3c-1).

A spectral spreading plot of the August 2008 storm to obtain an indication of the directional spreading (both sides of the central direction) versus period as shown in Figure A32-2.

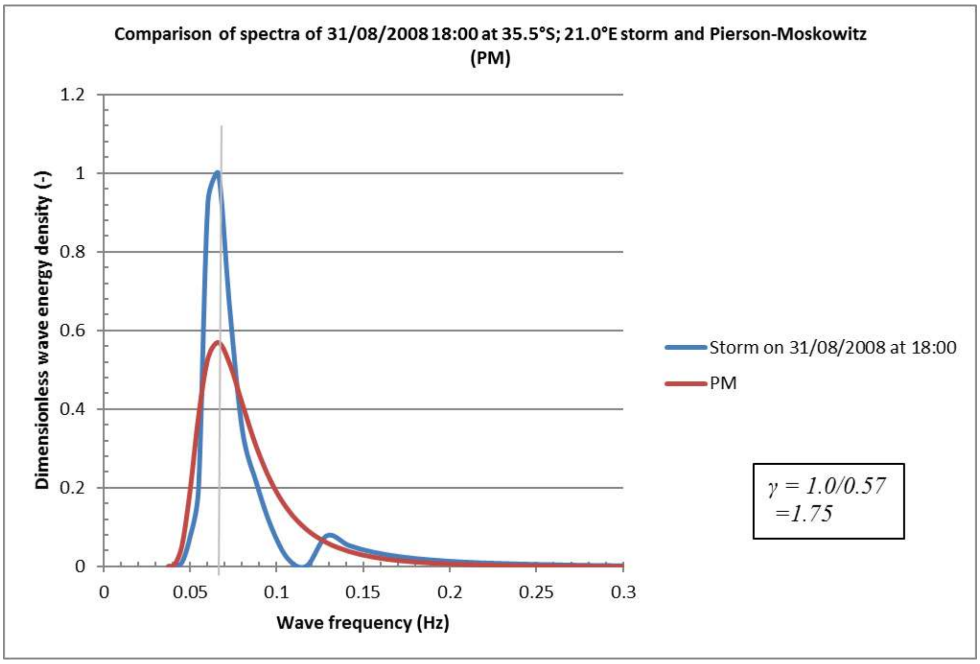


Figure A3c-1: A dimensionless energy spectrum compared to the corresponding Pierson- Moskowitz spectrum (of same energy and peak frequency) for determining the gamma value of the 2008 storm

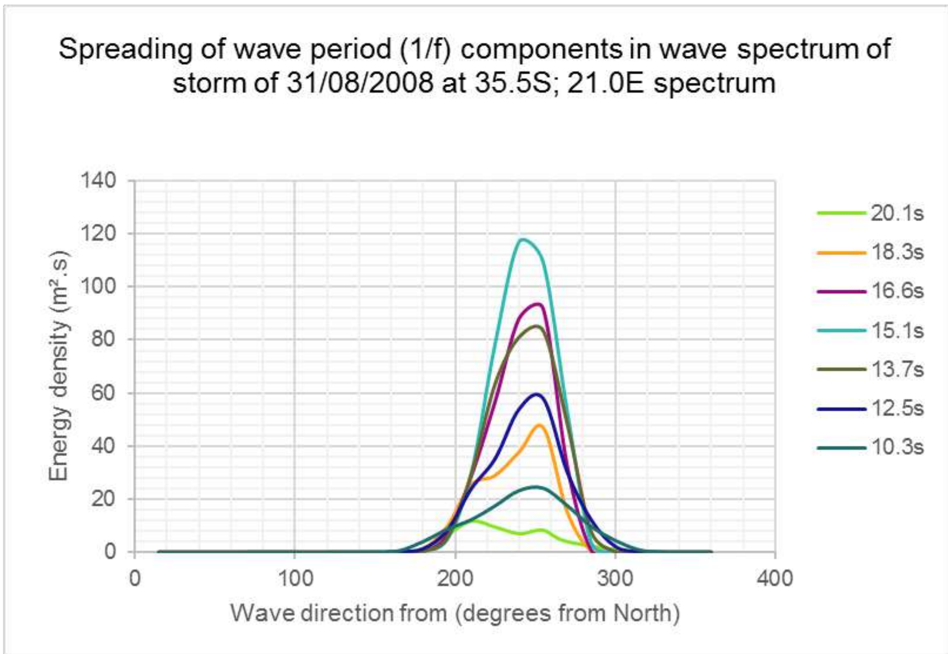


Figure A3c-2: A spectral directional spreading plot of the August 2008 storm to obtain an indication of the directional spreading (both sides of the central direction) versus period. [A directional spreading of 30° both sides of the central direction was assumed for this study]

A4 WIND CONDITIONS

ECMWF mean hourly wind velocity data at 10 m above sea level at -34.75°S; 22.5°E at 3 hourly intervals for the period 1979 to 2019 is presented in the following formats:

- Wind velocity time plot in Figure A4-1
- Wind roses (occurrence and magnitude) in Figure A4-2
- Occurrence per direction of wind velocities in Table A4-1
- Exceedance plot in Figure A4-3
- Extreme velocities for all direction in Figure A4-4 and Table A4-2
- Extreme wind velocities for the SE'ly sector only in Figure A4-5 and Table A4-3

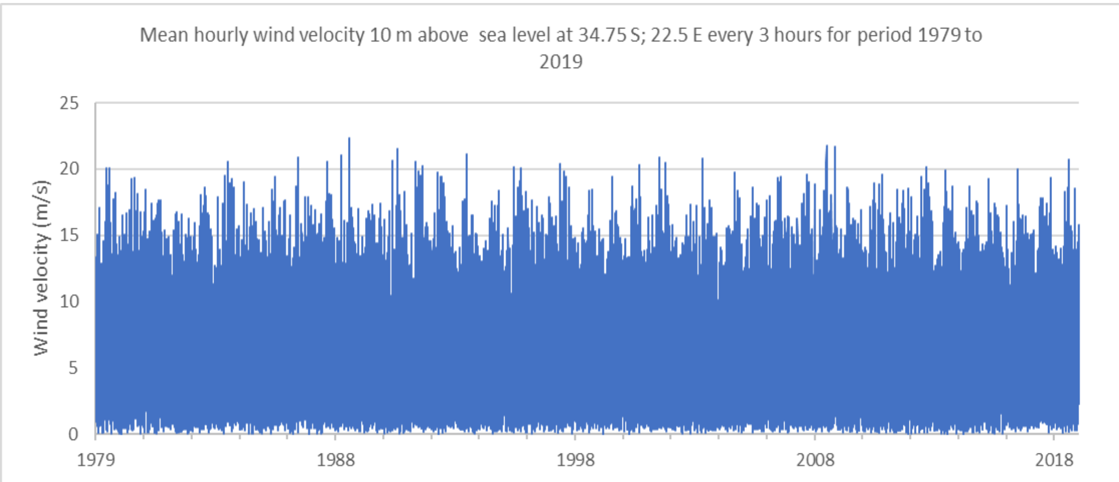


Figure A4-1: Wind velocity time plot

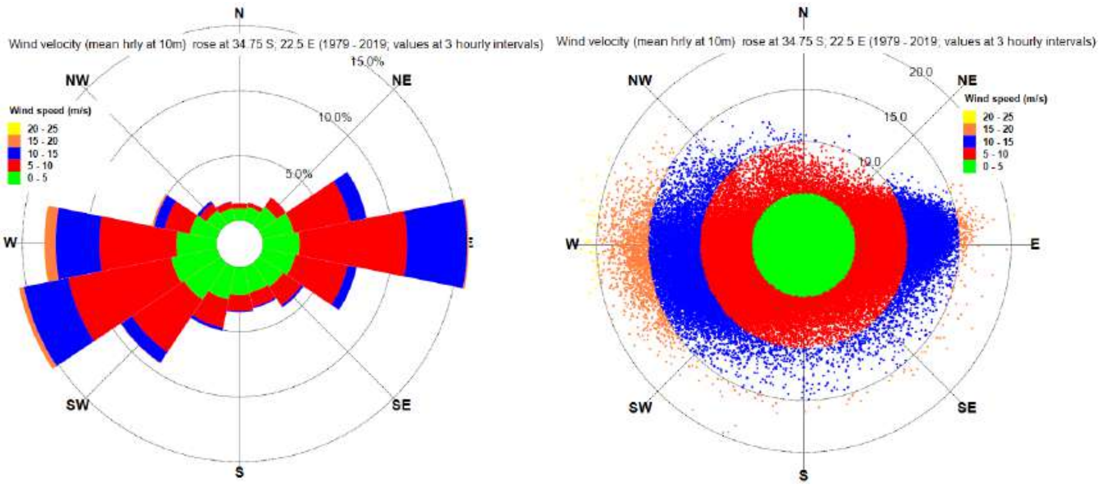


Figure A4-2: Wind roses; occurrence vs wind direction (left) and individual wind velocities vs direction (right)

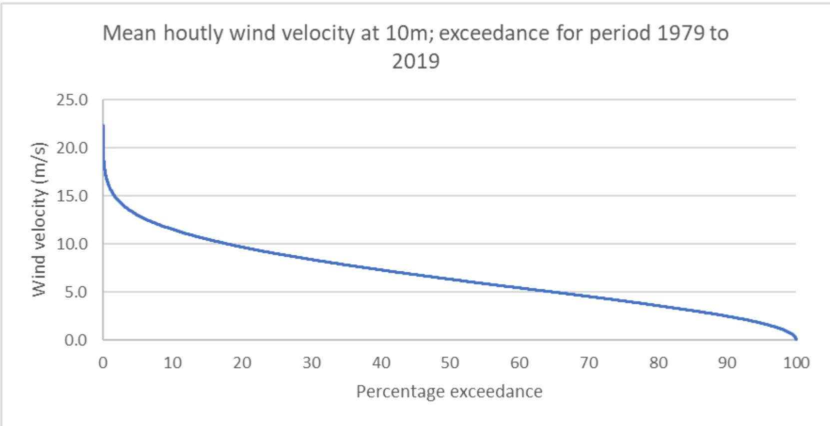


Figure A4-3: Exceedance of wind velocities plot

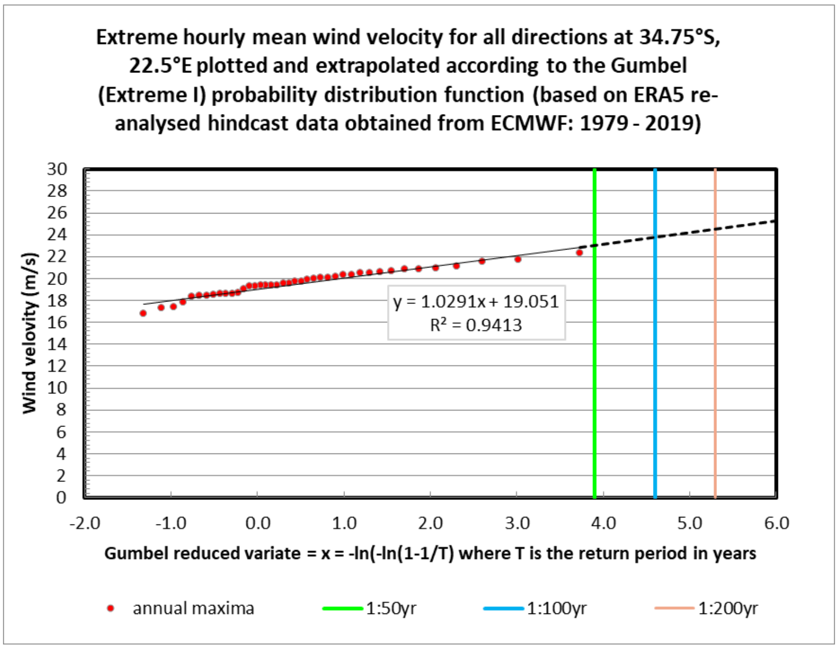


Figure A4-4: Extreme wind velocities for all directions

Table A4-1: Occurrence per direction of wind velocities

Direction from	Hourly mean wind velocity (m/s) 0 - 5	5 - 10	10 - 15	15 - 20	20 - 25	Total
N	0.931	0.402	0.013			1.3
NNE	1.119	0.339	0.003			1.5
NE	1.631	0.889	0.008			2.5
ESE	2.463	4.459	1.274	0.018		8.2
SE	2.816	8.310	4.629	0.126	0.002	15.9
ESE	2.578	4.124	0.715	0.014		7.4
SE	2.235	1.702	0.195	0.011		4.1
SSE	2.052	1.129	0.121	0.006		3.3
S	2.184	1.221	0.104	0.005		3.5
SSW	2.600	2.224	0.247	0.014		5.1
SW	3.402	4.854	1.011	0.037		9.3
WSW	3.624	8.091	3.482	0.378	0.002	15.6
W	3.113	5.947	3.386	0.841	0.023	13.3
WNW	2.140	1.997	0.823	0.152	0.006	5.1
NW	1.303	0.669	0.236	0.007		2.2
NNW	1.003	0.529	0.033			1.6
Total	35.2	46.9	16.3	1.6	0.0	100.0

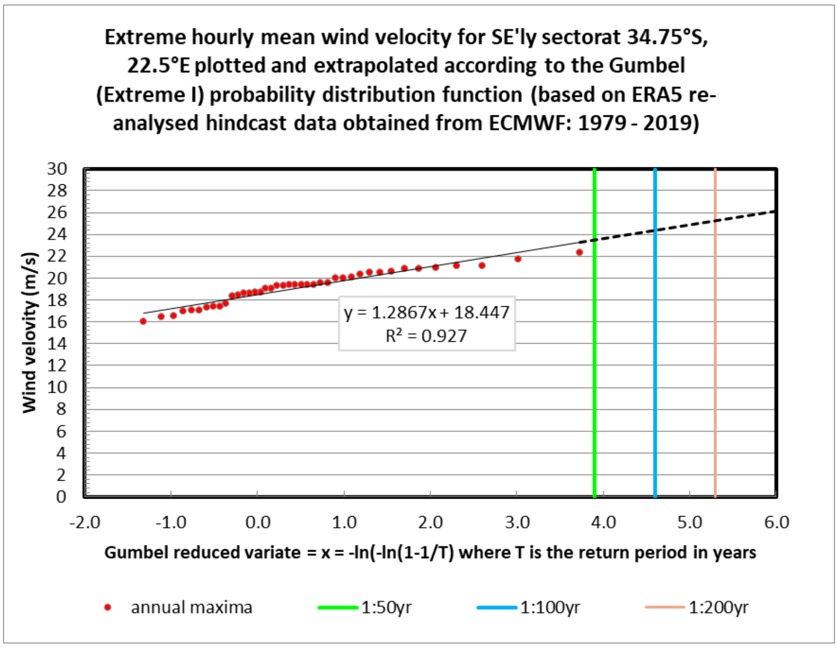


Figure A4-5: Extreme wind velocities for the SE'ly sector only

Table A4-2: Summary of extreme velocities for all direction

Return Period	Wind velocity (all directions)
(years)	(m/s)
200	24.5
100	23.8
50	23.1
20	22.1
10	21.4
5	20.6
2	19.4

Table A4-3: Summary of extreme velocities for SE'ly sector only

Return Period	Wind velocity (SE'ly sector)
(years)	(m/s)
200	25.3
100	24.4
50	23.5
20	22.3
10	21.3
5	20.4
2	18.9

A5 TIDAL CONDITIONS

The standard tidal levels relative to Chart Datum (CD) AND Land Levelling Datum (MSL) for Mossel Bay which is the closest harbour where tides are recorded by the SA Navy (SAN) is presented in Table A5-1 below. MSL is 0.933m above CD for Mossel Bay tidal data.

Table A5-1: Standard tidal levels at Mossel Bay

Tidal levels relative to Chart Datum (CD) in m						
LAT	MLWS	MLWN	ML	MHWN	MHWS	HAT
0	0.26	0.88	1.17	1.46	2.10	2.44
Tidal levels relative to Land Levelling Datum (MSL) in m						
(MSL is 0.933m above CD at Mossel Bay)						
-0.933	-0.673	-0.053	0.237	0.527	1.167	1.507

SA Naval tidal data recorded in Mossel Bay harbour was obtained from UHSLC (University of Hawaii Sea Level Centre) for the period 1964 to 2016.The analysed tidal data is presented in the following formats:

- One hourly recorded tidal level time plot in Figure A5-1
- Tidal exceedance plot in Figure A5-2
- Annual recorded tidal maxima and minima in Figure A5-3
- Extreme tidal levels in Figure A5-4
- Summary of extreme tidal levels in Table A5-2

[Note: On 28 October 2019 an exceptional high water level was observed in the study area (in Knysna estuary). This event was investigated and reported on in detail in Appendix Aa of this appendix to establish if the observed water level during this event falls inside the expected statistical population of the annual maxima recorded since the 1960's].

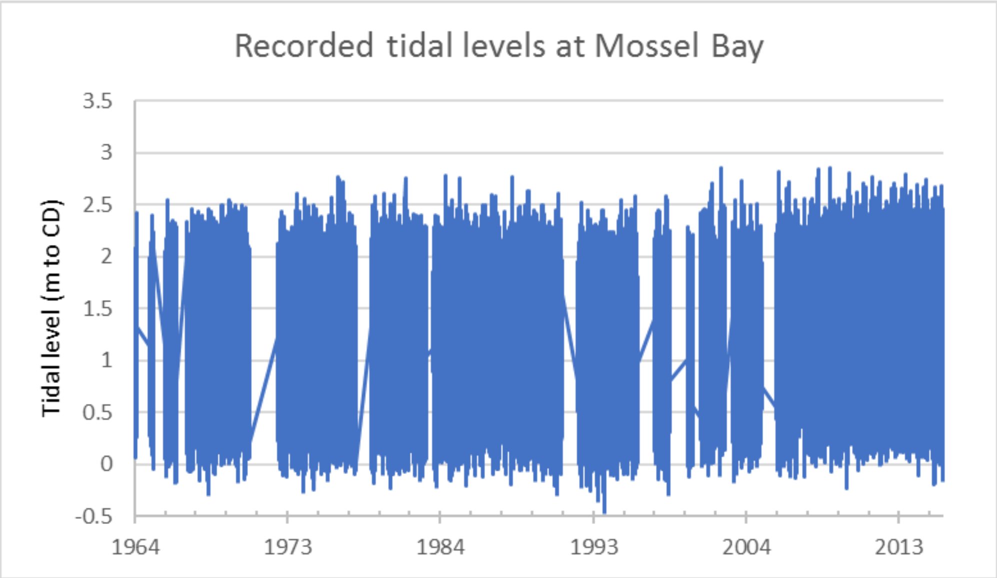


Figure A5-1: One hourly recorded tidal levels time plot Mossel Bay (1964 – 2016)

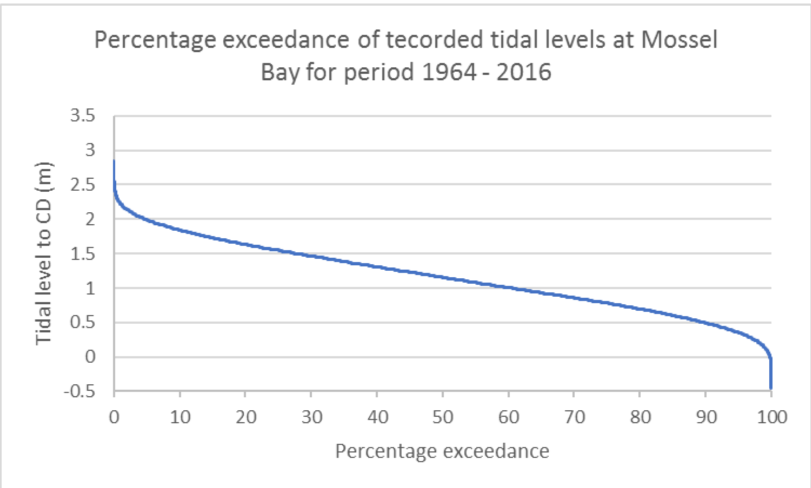


Figure A5-2: Percentage exceedance of recorded tidal levels at Mossel Bay

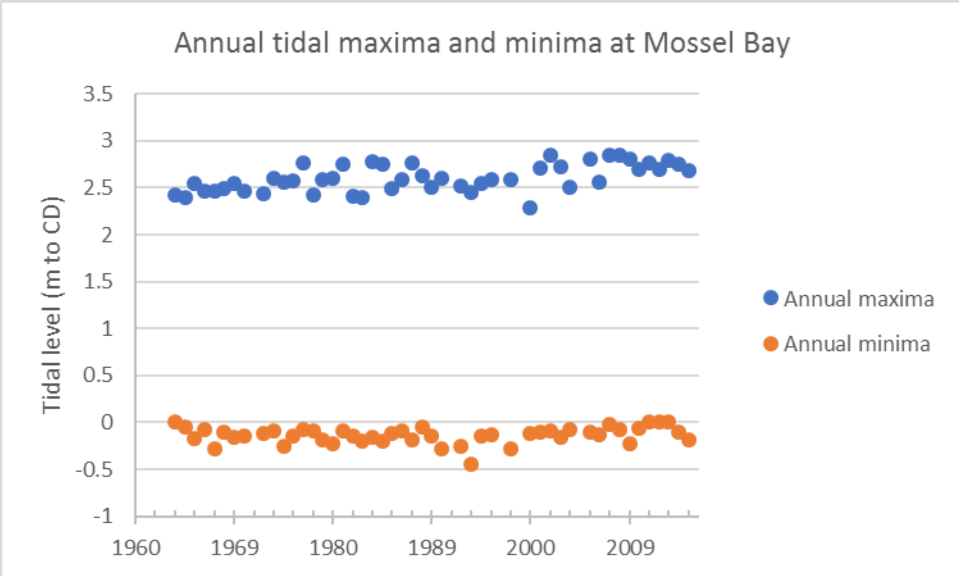


Figure A5-3: Annual recorded tidal maxima and minima at Mossel Bay

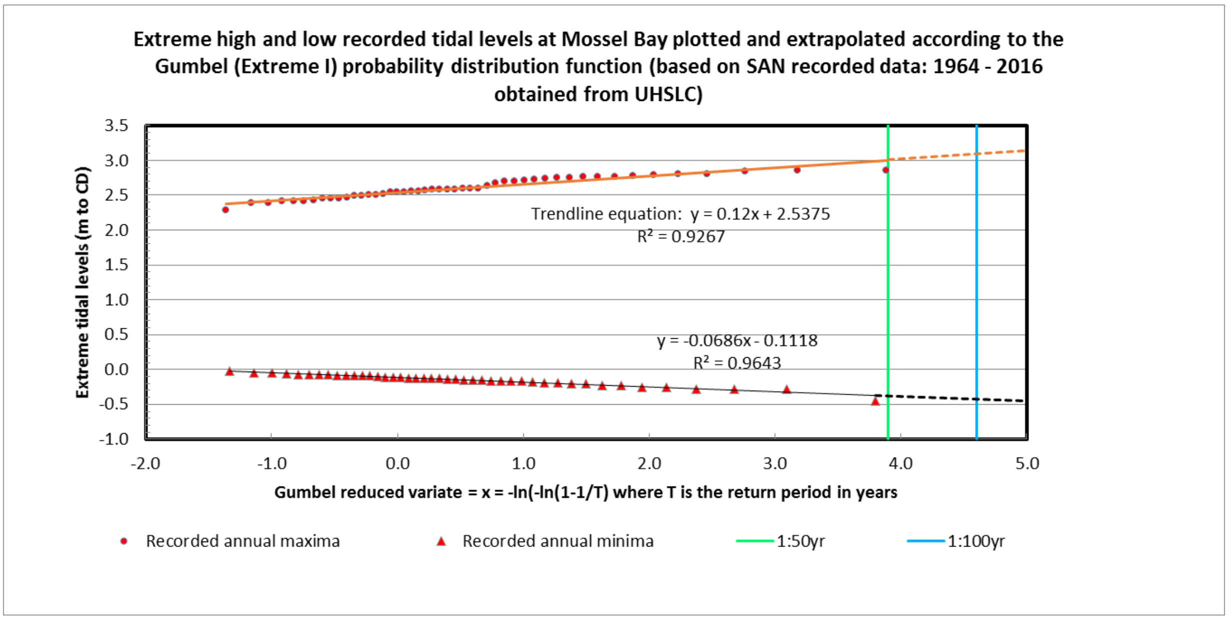


Figure A5-4: Extreme maxima and minima tidal levels at Mossel Bay

Table A5-2: Summary of extreme tidal levels at Mossel Bay

Return Period	Maximum tidal levels		Minimum tidal levels	
(years)	(m to CD)	(m to MSL)	(m to CD)	(m to MSL)
200	3.17	2.24	-0.48	-1.41
100	3.09	2.16	-0.43	-1.36
50	3.01	2.07	-0.38	-1.31
20	2.89	1.96	-0.32	-1.25

A6 BAROMETRIC PRESSURE CONDITIONS

ECMWF barometric pressure at sea level at -34.75°S; 20.75°E at 6 hourly intervals for the period 1979 to 2016 is presented in the following formats:

- Barometric pressure time plot in Figure A6-1
- Exceedance plot in Figure A6-2
- Extreme barometric pressures in Figure A6-3
- Summary of extreme barometric pressures in Table A6-1

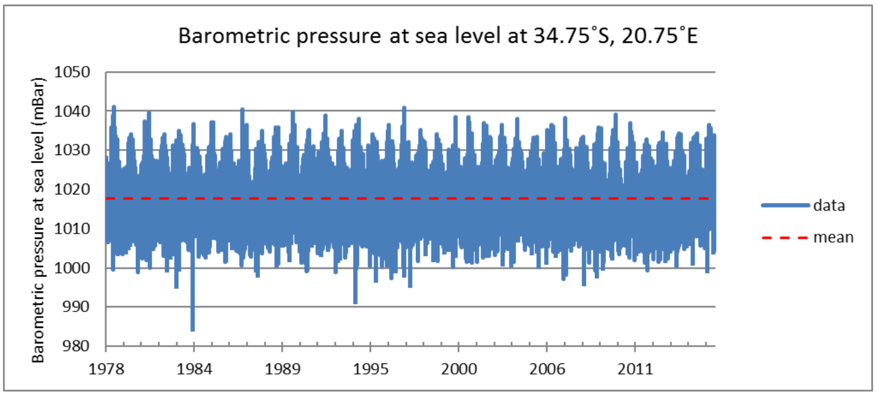


Figure A6-1: Barometric pressure time plot

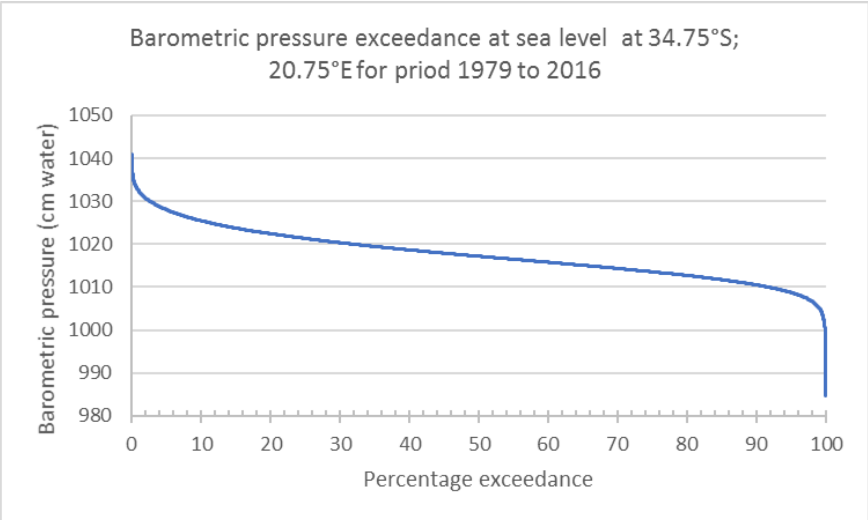


Figure A6-2: Percentage exceedance plot of barometric pressure

Table A6-1: Summary of extreme maximum and minimum barometric pressures

Return Period	Barometric pressure (cm water) [Mean pressure = 1017.57 cm water]			
(years)	Low	High	Low below mean	High above mean
100	987.96	1044.43	-29.61	26.86
50	989.92	1043.07	-27.65	25.50
20	992.54	1041.27	-25.03	23.70

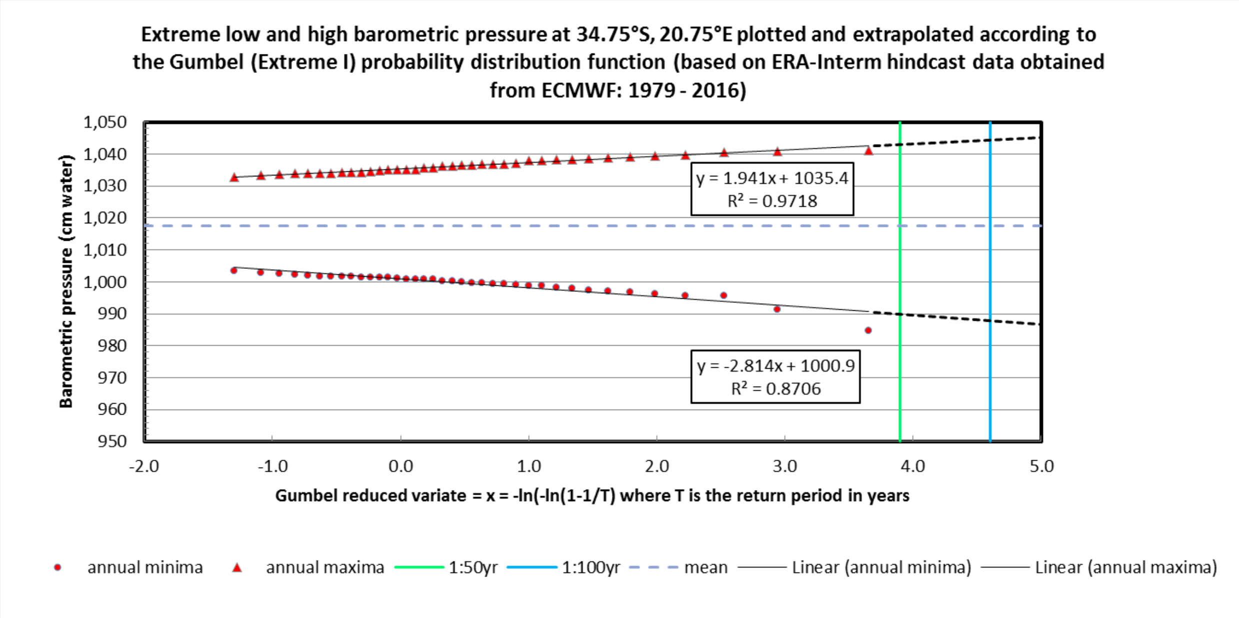


Figure A6-3: Extreme maximum and minimum barometric pressures

A7 SEA LEVEL RISE DUE TO CLIMATE CHANGE AND ITS INFLUENCE ON WAVE AND WIND CONDITIONS

SEA LEVEL RISE (SLR)

The International Panel for Climate Change (IPCC) has issued five Assessment Reports (AR) since its establishment in 1988 in the flowing years (refer also to http://wg1.ipcc.ch/AR6/AR6.html from which Box A7-1 is an excerpt):

- AR1 issued in 1990
- AR2 issued in 1995
- AR3 issued in 2001
- AR4 issued in 2007
- AR5 issued in 2013/14

The sixth Assessment Report (AR6) is scheduled to be issued in April 2021.

Box A7-1: Excerpt from IPCC history highlights

IPCC Factsheet: Timeline – highlights of IPCC history

1988 - The United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) establish the Intergovernmental Panel on Climate Change.
- The United Nations General Assembly endorses the action of UNEP and the WMO in setting up the IPCC.

1990 - The IPCC publishes its First Assessment Report (Working Group I – *Climate Change: The IPCC Scientific Assessment*; Working Group II – *Climate Change: The IPCC Impacts Assessment*; Working Group III – *Climate Change: The IPCC Response Strategies*).
- The UN General Assembly notes the report findings and decides to initiate negotiations for a framework convention on climate change.

1992 - The IPCC publishes Supplementary Reports (Working Group I – *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment*; Working Group II – *Climate Change 1992: The Supplementary Report to the IPCC Impacts Assessment*; Climate Change: *The IPCC 1990 and 1992 Assessments*).
- The United Nations Framework Convention on Climate Change (UNFCCC) opens for signature at the UN Conference on Environment and Development in Rio de Janeiro.

1995 - The IPCC publishes its Second Assessment Report (Working Group I – *Climate Change 1995: The Science of Climate Change*; Working Group II – *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*; Working Group III – *Climate Change 1995: Economic and Social Dimensions of Climate Change*; *IPCC Second Assessment: Climate Change 1995* (includes Synthesis Report)).

1996 - The IPCC issues the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*.

1997 - The UNFCCC's Kyoto Protocol is adopted. It comes into force in 2005.

1998 - The IPCC sets up the Task Force on National Greenhouse Gas Inventories (TFI) to oversee the National Greenhouse Gas Inventories Programme. Since 1999 the Task Force has been supported by the Government of Japan.

2000 - The IPCC issues the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*.

2001 - The IPCC publishes its Third Assessment Report (Working Group I – *Climate Change 2001: The Scientific Basis*; Working Group II – *Climate Change 2001: Impacts, Adaptation, and Vulnerability*; Working Group III – *Climate Change 2001: Mitigation*; *Climate Change 2001: Synthesis Report*).

2003 - The IPCC issues the *Good Practice Guidance for Land Use, Land-Use Change and Forestry*.

2006 - The IPCC issues the *2006 Guidelines for National Greenhouse Gas Inventories*.

2007 - The IPCC publishes its Fourth Assessment Report (AR4) (Working Group I – *Climate Change 2007: The Physical Science Basis*; Working Group II – *Climate Change 2007: Impacts, Adaptation and Vulnerability*; Working Group III – *Climate Change 2007: Mitigation of Climate Change*; *Climate Change 2007: Synthesis Report*).
- The IPCC shares the Nobel Peace Prize which is awarded for its "efforts to build up and disseminate greater knowledge of man-made climate change, and to lay the foundations for the measures that are needed to counteract such change".

2009 - The IPCC approves the outlines of the three Working Group contributions to the Fifth Assessment Report (AR5), due to be finalized in 2013 and 2014.

2010 - The three Working Groups complete the selection of the 831 authors for the AR5 and work on the assessment starts.
- The IPCC starts a review of its processes and procedures, completed in 2012, based on recommendations from the InterAcademy Council.

2011 - The IPCC approves the *Special Report on Renewable Energy Sources and Climate Change Mitigation* (SRREN), prepared by Working Group III.
- The IPCC approves the *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX), prepared by Working Group II and Working Group I.

2013 - The IPCC approves *Climate Change 2013: The Physical Science Basis*, the Working Group I contribution to AR5.
- The IPCC approves two Methodology Reports: the *2013 Supplement to 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (Wetlands Supplement) and the *2013 Revised Supplementary Methods and Good Practice Guidelines Arising from the Kyoto Protocol* (KP Supplement).

2014 - The IPCC approves *Climate Change 2014: Impacts Adaptation and Vulnerability* and *Climate Change 2014: Mitigation of Climate Change*, the Working Group II and Working Group III contributions to AR5. The Fifth Assessment Report was completed in November 2014 with the *Synthesis Report*.

Figure A7-1 and Figure A7-2 present AR5 projections of global mean sea level rise for 2100 for the two extreme scenarios, i.e. RCP2.6 and RSP8.5 with their corresponding projection ranges.

These projections are presented in more detail in Box A7-2. Based on information presented in Box A7-2 and Figure A7-2, sea level rise projections for the South African south coast has been estimated and are shown in Table A7-1.

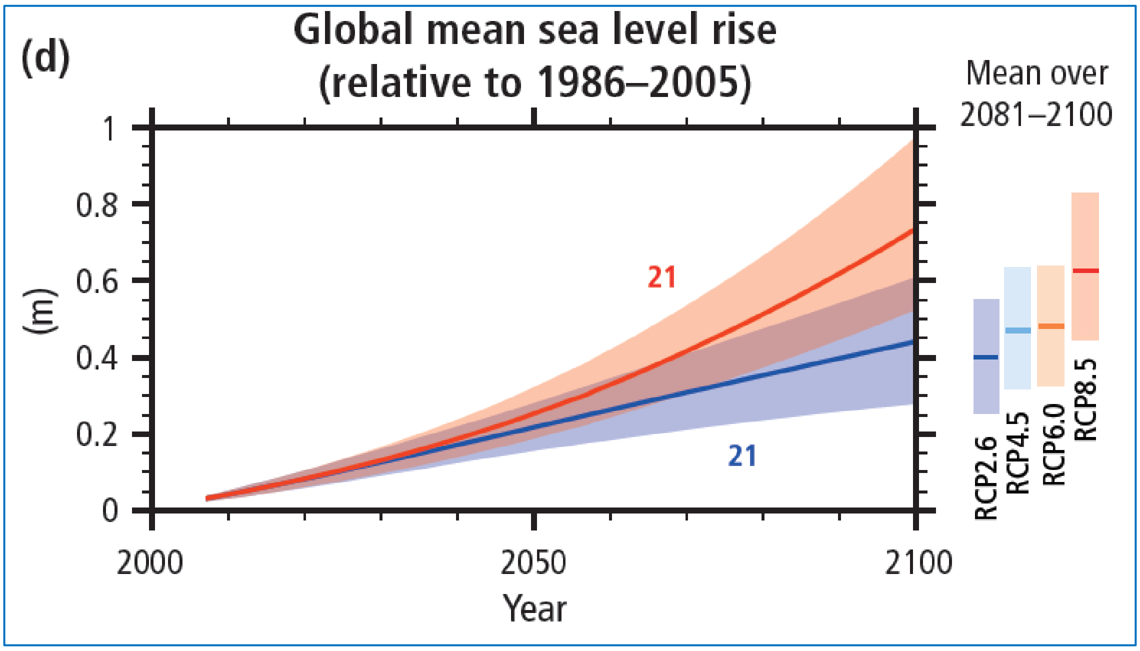


Figure A7-1: Excerpt from latest IPCC assessment report (Figure 2.1d of the Fifth Assessment Report (AR5) of the IPCC)

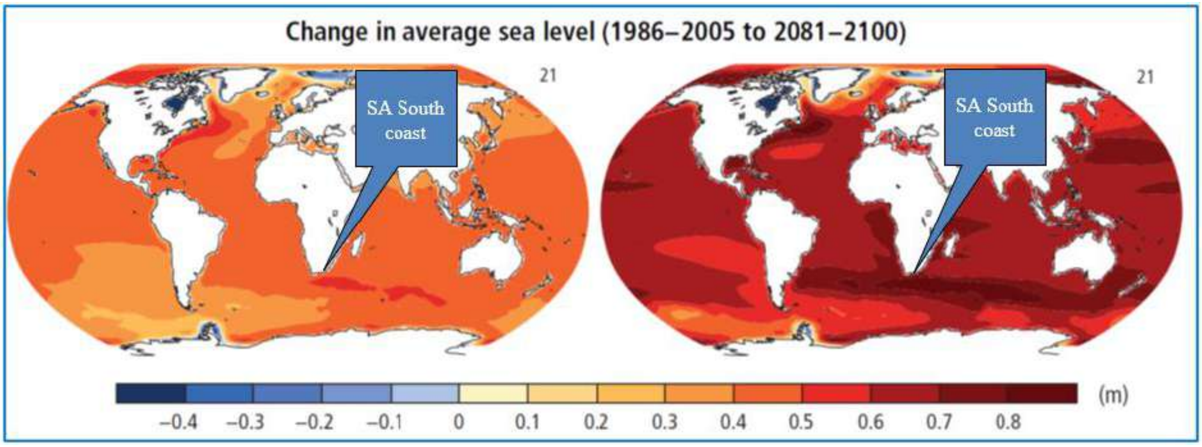


Figure A7-2: Excerpt from latest IPCC assessment report (Figure 2.2d of the Fifth Assessment Report (AR5) of the IPCC). Projections are for the 2081–2100 period under the RCP2.6 (left) and RCP8.5 (right) scenarios

Box A7-2: Excerpt from latest IPCC assessment report (Table 2.1 of the Fifth Assessment Report (AR5) of the IPCC). The sea level rise projections are based on the 5 – 95% projection ranges of 21 CMIP5 climate models

Table 2.1 | Projected change in global mean surface temperature and global mean sea level rise for the mid- and late 21st century, relative to the 1986–2005 period. *{WGI Table SPM.2, 12.4.1, 13.5.1, Table 12.2, Table 13.5}*

		2046–2065		2081–2100	
	Scenario	Mean	*Likely* range [c]	Mean	*Likely* range [c]
Global Mean Surface Temperature Change (°C) [a]	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
	Scenario	Mean	*Likely* range [d]	Mean	*Likely* range [d]
Global Mean Sea Level Rise (m) [b]	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

Table A7-1: Estimation of projections of sea level rise for the South African south coast by the author based on information presented in Box A7-2 and Figure A7-2.

	2046 - 2065				2081 - 2100			
Scenario	Mean	Likely range			Mean	Likely range		
RCP2.6	0.28	0.20	to	0.37	0.46	0.30	to	0.64
RCP4.5	0.30	0.22	to	0.38	0.54	0.37	to	0.73
RCP6.0	0.29	0.21	to	0.37	0.56	0.38	to	0.73
RCP8.5	0.35	0.25	to	0.44	0.73	0.52	to	0.95

CHANGE IN WIND CONDITIONS DUE TO CLIMATE CHANGE

The projected change in wind conditions due to climate change is presented as an excerpt from IPCC AR5 (2013) in Box A7-3 below. According to the information on projected change in wind velocity in Box A7-3 it is evident that projected change in wind velocity (both for the daily averaged and 99th percentile of the daily averaged velocities) is very small on the SA South coast. However, the projected change in wind velocity in the southern ocean close to the polar zone shows an increase of about 10% for daily averaged and 5% for the 99th percentile of the daily averaged velocities – this is probably due to the shifting of the pathways of the southern extra-tropical cyclones further south to the polar area and probable increase in wind velocity there.

Based on the above information the projected local wind velocities for the Breede River Estuary study (Section A4) were not adjusted.

Box A7-3: Excerpt from latest IPCC AR5 showing projected change in daily average (upper diagrams) and 99th percentile (lower diagrams) 10m wind velocities.

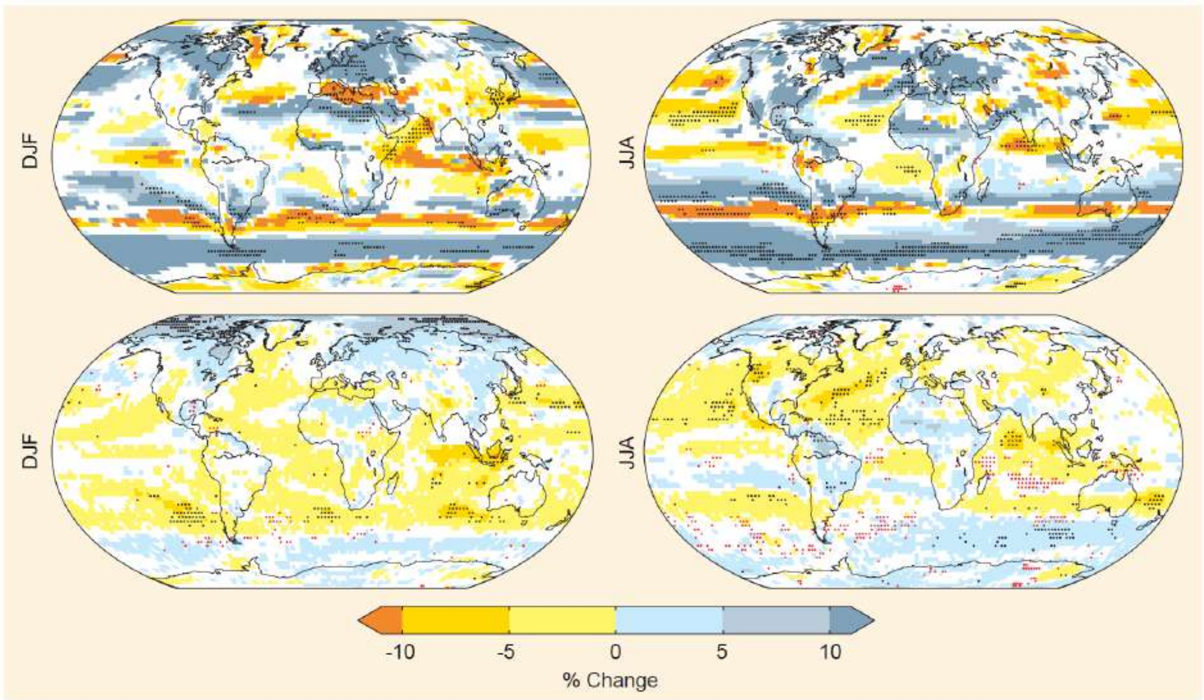


Figure 3-8 | Averaged changes from a 19-member ensemble of CMIP3 GCMs in the mean of the daily averaged 10-m wind speeds (top) and 99th percentile of the daily averaged 10-m wind speeds (bottom) for the period 2081-2100 relative to 1981-2000 (% change) for December to February (left) and June to August (right) plotted only where more than 66% of the models agree on the sign of the change. Black stippling indicates areas where more than 90% of the models agree on the sign of the change. Red stippling indicates areas where more than 66% of models agree on a small change between ±2%. Adapted from McInnes et al. (2011); for more details see Appendix 3.A.

CHANGE IN WAVE CONDITIONS DUE TO CLIMATE CHANGE

The projected change in wave conditions (including wave height, wave period and wave direction) due to climate change is presented as an excerpt from IPCC AR5 (2013) in Box A7-4 below. The diagrams in Box A7-4 indicate very small change in the projected annual mean significant wave height (SWH) on the SA South coast – an increase of about 1%. The change in projected mean wave period is very small on the SA South coast. And the change in projected wave direction more from the south (a change of about 5° anticlockwise).

The IPCC AR5 report concluded inter alia with the following statement regarding change in wave conditions:

> "Despite the existence of downscaling studies for some regions such as the eastern North Sea, there is overall *low confidence* in wave height projections because of the small number of studies, the lack of consistency of the wind projections between models, and limitations in their ability to simulate extreme winds. However, the strong linkages between wave height and winds and storminess means that it is *likely* that future negative or positive changes in SWH will reflect future changes in these parameters." *(Excerpt from IPCC AR5 Section 3.5.4 Changes in Climate Extremes and their Impacts on the Natural Physical Environment).*

Subsequent to the publishing of IPCC AR5 (2013), Wang et al (2014) of the Climate Research Division, Science and Technology Branch, Environment Canada, published their work on projected wave height change due to climate change. This study made statistical projections of changes in ocean wave heights using sea level pressure (SLP) information from 20 CMIP5 (Coupled Model Inter-comparison Project Phase 5) global climate models for the 21st century and an excerpt from this publication is presented in Box A7-5 below.

Box A7-4: Excerpt from latest IPCC AR5 showing projected change in wave height, wave period and wave direction.

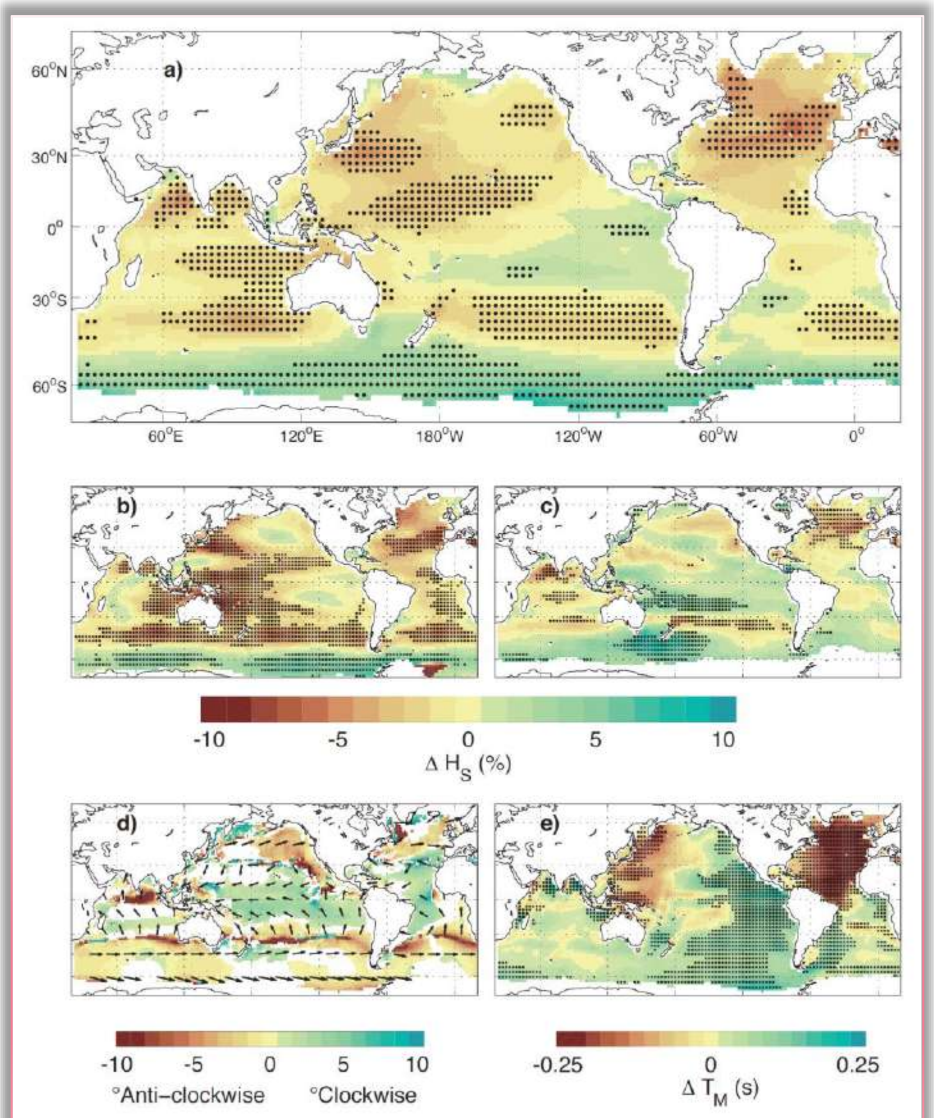


Figure 13.26 | Projected changes in wind–wave conditions (~2075–2100 compared with ~1980–2009) derived from the Coordinated Ocean Wave Climate Projection (COWCLIP) Project (Hemer et al., 2013). (a) Percentage difference in annual mean significant wave height. (b) Percentage difference in means of January to March significant wave height. (c) Percentage difference in means of July to September significant wave height. Hashed regions indicate projected change is greater than the 5-member ensemble standard deviation. (d) As for (a), but displaying absolute changes in mean wave direction, with positive values representing projected clockwise rotation relative to displayed vectors, and colours shown only where ensemble members agree on sign of change. (e) As for (a), but displaying absolute changes in mean wave period. The symbol ~ is used to indicate that the reference periods differ slightly for the various model studies considered.

Box A7-5: Excerpt from Wang L W et al (2014) showing projected change in wave height (SWH or Hs); change in return periods (waiting times) in upper diagrams and change in 1:10 year Hs in the lower diagrams.

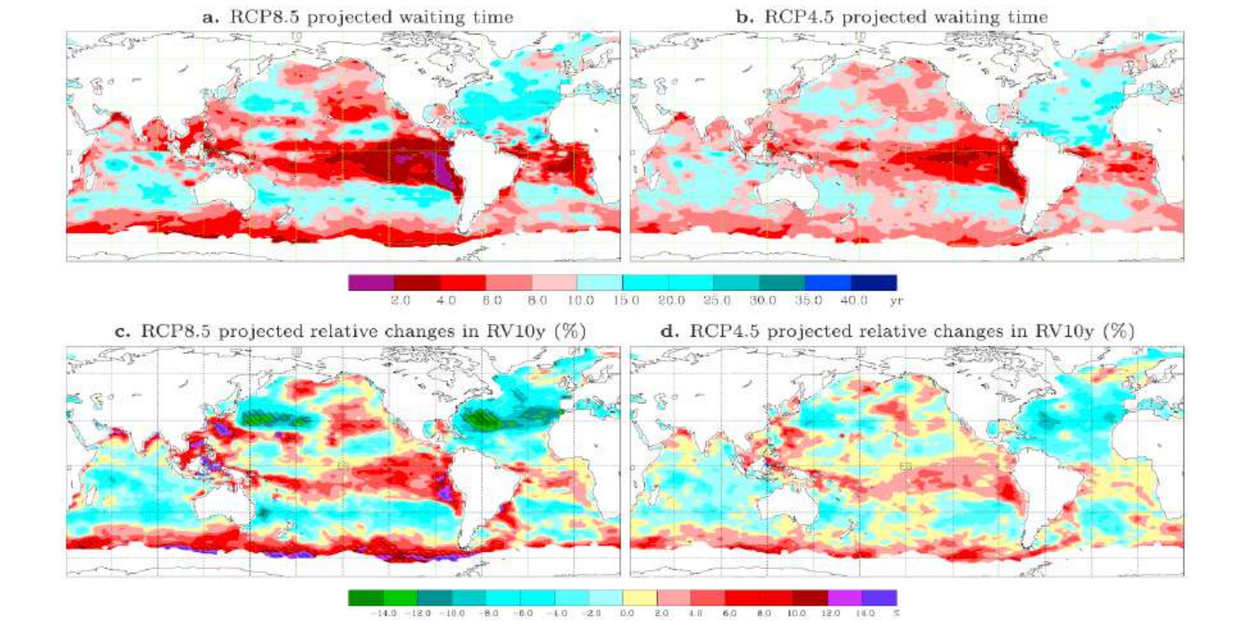


Figure 3. (a and b) The 20-model ensemble mean of projected waiting time of the present-day (1970–1999) one in 10 year extreme H_s for the period 2070–2099, for RCP8.5 and RCP4.5 scenarios. The unit is year. (c and d) The 20-model ensemble mean projected changes in the one in 10 year extreme H_s (RV10y) for the period 2070–2099, expressed in percentage of the present-day one in 10 year extreme H_s. Hatchings indicate areas where the multimodel ensemble mean exceeds the intermodel standard deviation.

From the information in Box A7-5 (Wang et al, 2014) above it can be stated that the projected 1:10 year although the significant wave height is projected to increase over large portions of the globe (including the southern ocean area close to Antarctica) the projected change close to the SA South coast is very small.

Box A7-6: Excerpt from Mentaschi L et al (2017) showing the 1:100-year wave energy flux (WEF) based on historic data ((a), the projected changes in the 1:100-years WEF for 2050 (b) and for 2100 (c).

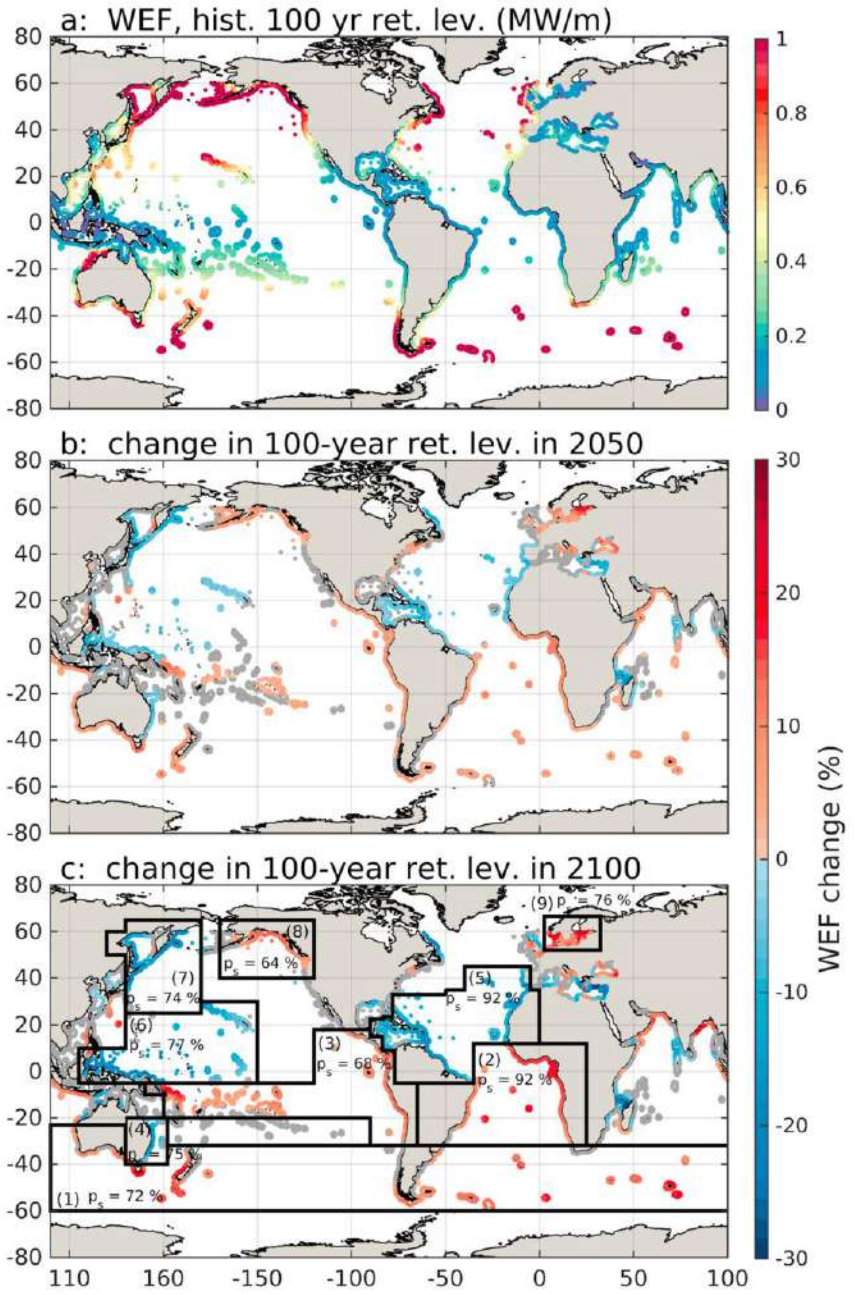


Figure 1. Ensemble projection of WEF along the global coastline: (a) baseline 100 year return level, ensemble relative change of the 100 year WEF for the year (b) 2050, and (c) 2100. The gray dots correspond to locations where no significant change was projected. In Figure 1c the areas of significant change are reported together with the percentage p_s of points where the increase is significant. The considered areas are the (1) southern temperate zone, (2) southern Atlantic, (3) subequatorial-tropical eastern Pacific, (4) eastern Australia, (5) northern tropical Atlantic, (6) north-western tropical Pacific, (7) north-western Pacific, (8) north-eastern Pacific, and (9) Baltic Sea.

From the information in Box A7-6 (Mentaschi et al, 2017) above, [which agrees with the predictions of Wang et al (2014) in Box A7-5], it can be stated that the projected 1:100-year wave energy flux (WEF) shows for the SA South coast a slight increase for 2050 (in the order of 2-3%) and no change for 2100.

Based on the above presented information on projected change of wave height conditions for the period 2070 – 2099, it was decided not to adjust the projected wave conditions presented in Section A3 for this period.

A8 LONG WAVES ASSOCIATED WITH STORM WAVES (BOUND WAVES)

Bound waves are associated with wave grouping of the larger waves in a wave train of normal storm waves as illustrated in Figure A8-1, which is and excerpt from a paper by Rossouw et al (2014). The wave grouping is the result of superposition of short waves of nearly the same wave period with resulting harmonic waves. These long waves contribute to wave runup on beaches and since their periods are relatively long (approximately 90s to 180s) they cause a temporary higher still water level in the surf zone (referred to as surf beat) causing short waves at this higher still water level to reach higher runup levels.

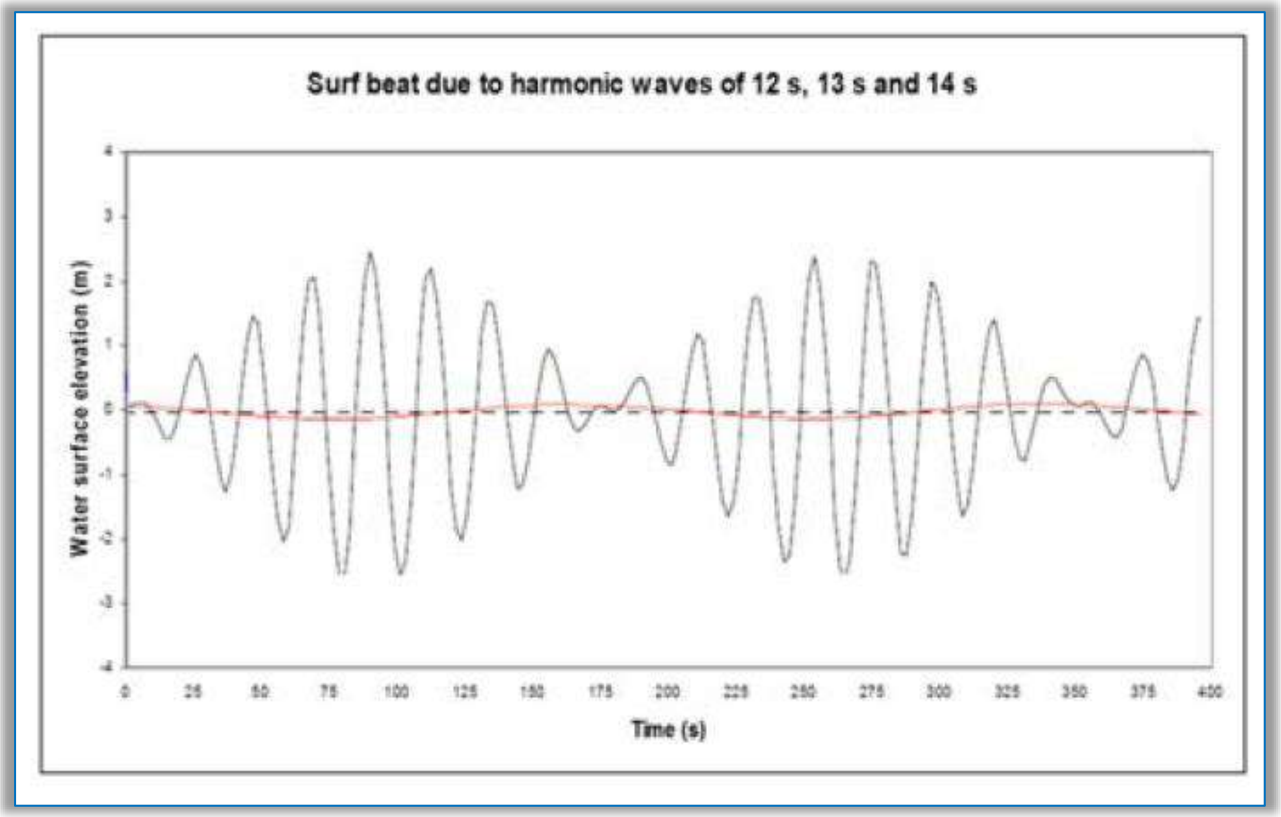


Figure A8-1: Excerpt from paper by Rossouw et al (2014) demonstrating the relation between wave grouping in short storm waves (red) and bound long waves (black)

Information on magnitude of the heights of these long waves on the SA coastline has been reported by Botes et al (1982) - see Box A8-1, Stuart (2013) – see Box A8-2 and Rossouw et al (2014) – see Box A8-3.

Box A8-1: Excerpt from paper by Botes et al (1982) indicating a relation between long wave height (HL) and short wave height (Hs) as well as the periods of the long waves of about 90s (blue line) and 180s (red line).

The height of short-period and long-period waves for 1981 were plotted and the following correlation was determined:

$HS_2 = 0,43 + 5,44\ HL$ (Figure 4)
$(R^2 = 0,77)$

The 95% confidence limits are:

$HS = 0,51 + 5,73\ HL$
$HS = 0,36 + 5,15\ HL$

where HS = short period wave height (m) (1 to 30 s)
HL = long period wave height (m) (50 to 110 s).

An exponential fit is even more realistic as the long wave heights will not increase indefinitely (Figure 5).

$HS = 0,75\ e^{3,03\ HL}$

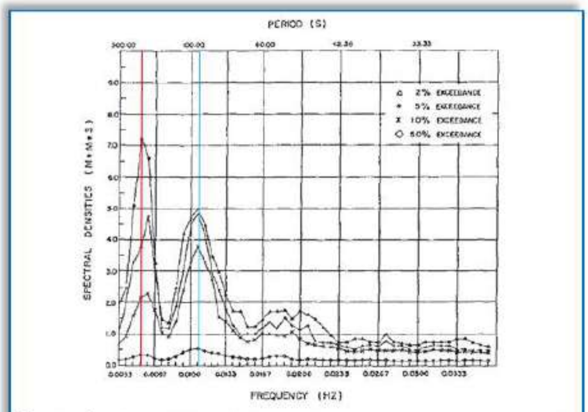
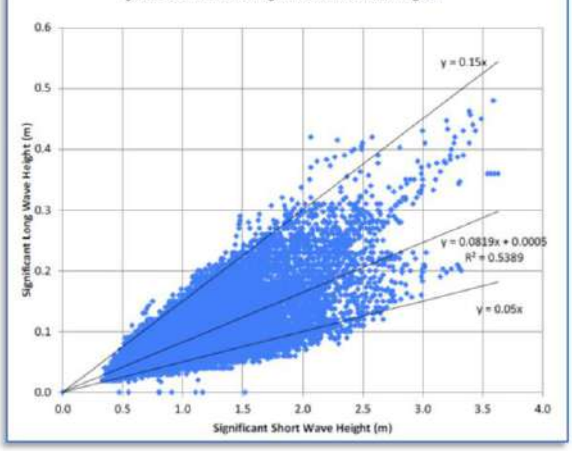
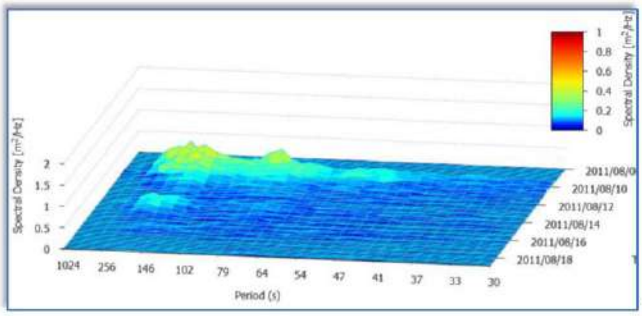


Figure 6 Spectral density exceedances for September 1981 at the entrance of the harbour

Box A8-2: Excerpt from thesis by Stuart (2013) indicating relations between long wave height and short wave height as well as the periods of the long waves where wave energy density peaks at about 90s and 180s.

Figure 7-3: Correlation of long wave with short wave heights.





Box A8-3: Excerpt from paper by Rossouw et al (2014) indicating relations between long wave height and short wave height as well as the period ranges of the long waves

Table 1: Summary on long waves

Location: Saldanha Bay (Port of Saldanha)
A reliable data set was obtained for the period May 2001 to November 2005. This data set is presently being used to calibrate the numerical long wave model for ship motion studies. $Hmo^{50\%}$ = 0.07 m; $Hmo1^{\%}$ = 0.20 m Tp range: 25 to 340 s (25 to 130 s)*
Location: Table Bay (Port of Cape Town)
Based on limited information on long waves from reports, the data collected in the main basin (Duncan Dock) showed a range of heights between 8 cm and 15 cm. Long waves were defined for the range of 50 s to 200 s. More data are required inside and outside the port, since long waves are present in Table Bay [1].
Location: Algoa Bay (Port of Ngqura)
Extensive studies have recently been conducted by the CSIR on the long wave climate at this port. Wave data have also been collected for about 12 years outside the port in Algoa Bay for Transnet. $Hmo^{50\%}$ = 0.07 m; $Hmo1^{\%}$ = 0.25 m Tp range: 25 to 300 s (25 to 125 s)*
Location: Port of Durban
A measurement exercise of five months has recently been undertaken inside the harbour as part of a harbour development project. Outside the port, the following information was obtained: $Hmo^{50\%}$ = 0.09 m; $Hmo1^{\%}$ = 0.19 m Tp range: 25 to 300 s (25 to 100 s)* These measurements were taken during May to October, the period when the waves are generally larger. The statistics can therefore not be directly compared to those of Saldanha Bay and Algoa Bay. The long waves inside the Port of Durban appears to be quite small (<0.1m). The geometry of the port and a large sand bank or mud-flat inside the harbour are probably reasons for the dampening of the long waves.
Location: Port of Richards Bay
Although the electronic data are not available, statistics were obtained from reports on long wave records collected inside the port over a period of one year (1993). The port is located inside a natural estuary, which probably provides some dampening of long wave energy. $Hmo^{50\%}$ = 0.02 m; $Hmo1^{\%}$ = 0.08 m Tp range: 150 to 350 s (250 to 350 s)* The long waves are generally small. The prevailing wave periods are generally outside the vessel response range.

** Dominant peak period range*

Table A8-1: Estimation of long wave heights for the South African south coast by the author based on information presented in Boxes A8-1 and A8-2.

Return Period	Short waves		Wave heights of long waves from all directions	
	Hs from all directions	Hs from SE'ly sector only	Botes et al (1982)	Stuart (2013)
(years)	(m)	(m)	(m)	(m)
200	10.1	8.1	0.86	0.83
100	9.7	7.6	0.84	0.79
50	9.2	7.2	0.83	0.76
20	8.6	6.5	0.80	0.70
10	8.1	6.1	0.79	0.67
5	7.6	5.6	0.77	0.62
2	6.9	4.8	0.73	0.56

A9 SUMMARY OF OCEAN CONDITIONS

From the ocean data presented in this appendix a summary of the data most relevant to the projects in the Mossel Bay embayment is listed below:

- *Bathymetric* data of the ocean floor obtained from GEBCO is available at a grid spacing of approximately 500m x 500 m for the offshore seabed - refer Figure A2-1. An excerpt from a SA Navy Nautical chart indicates more detailed seabed depths in the nearshore area – refer Figure A2-3.
- *Wave* data (including wave height, wave period and direction) obtained from ECMWF (ERA5 hindcast data) for the period 1979 to 2019 was analysed and indicated a dominance from the SW'ly sector but also waves from the SE'ly sector which is the critical direction for wave penetration into Groot Brak River estuary (refer Figure A3a-2). A summary of the extreme wave heights is presented in Table A3a-2 for all directions and in Table A3a-3 for the SE'ly sector and repeated in the table below. A summary of the *peak* wave periods associated with wave heights are presented in Figure A3b-3 for all directions and in Figure A3b-4 for the SE'ly sector and summarised in the table below.
- The effect of climate change on extreme wave heights and local wind velocities on the SA South coast was considered (refer Section A7b & c). However, due to the small projected changes for the SA South coast, no adjustments to both extreme wind velocities and wave parameters were done.
- *Wave* data on wave directional energy density spectra (2D spectra) was also obtained from ECMWF hindcast data. From this data, a typical wave energy density spectrum vs frequency for the severe storm of 31 Aug/1Sept 2008 was obtained to define a typical gamma value (peak energy enhancement factor) of 1.75 for the energy density spectrum of a storm (refer Figure A3c-1). Also, the directional spreading per frequency of approximately 30° both sides of the central direction of the latter storm was obtained (refer Figure A3c-2).

Extreme wave heights (Hs) with associated peak wave periods (Tp)				
Return period	Hs from all directions	Wave period from all directions	Hs from SE'ly sector	Wave period from SE'ly sector
(years)	(m)	(s)	(m)	(s)
200	10.1	17.0	8.1	13.0
100	9.7	16.5	7.6	12.5
50	9.2	16.0	7.2	12.0
20	8.6	15.5	6.5	12.0

- *Wind* data (including wind direction and hourly mean wind velocity at 10m above sea level for the same period as for the wave data) from ECMWF hindcast data was analysed and indicated a dominance from the W'ly and E'ly sectors (i.e. alongshore winds – up coast and down coast). Winds from the SE'ly sector is the critical direction for wave penetration of locally generated waves into Groot Brak River estuary (refer Figure A4-2). A summary of the extreme wind velocities is presented in Table A4-2 for all directions and in Table A4-3 for the SE'ly sector and repeated in the table below. Regarding influence of climate change on wind conditions, refer to paragraph ii above.

Return Period	Wind velocity (all directions)	Wind velocity (SE'ly sector)
(years)	(m/s)	(m/s)
200	24.5	25.3
100	23.8	24.4
50	23.1	23.5
20	22.1	22.3

- *Tidal* standard levels (predicted tides due to astronomical forces only) as published in the Tide Tables by the Hydrographer of the SA Navy are presented in Table A5-1 and repeated below.

Tidal levels relative to Chart Datum (CD) in m						
LAT	MLWS	MLWN	ML	MHWN	MHWS	HAT
0	0.26	0.88	1.17	1.46	2.10	2.44
Tidal levels relative to Land Levelling Datum (MSL) in m						
(MSL is 0.933m above CD at Mossel Bay)						
-0.933	-0.673	-0.053	0.237	0.527	1.167	1.507

- *Tidal* data *recorded* by the SA Navy at Mossel Bay harbour was obtained from UHSLC for the period 1964 to 2016. The data was analysed and extreme high and low tidal levels were derived as presented in Table A5-2 and repeated below.

Return Period	Maximum tidal levels		Minimum tidal levels	
(years)	(m to CD)	(m to MSL)	(m to CD)	(m to MSL)
200	3.17	2.24	-0.48	-1.41
100	3.09	2.16	-0.43	-1.36
50	3.01	2.07	-0.38	-1.31
20	2.89	1.96	-0.32	-1.25

The derived extreme tidal levels were based on *recorded* levels and therefore include local effects such as barometric pressure and wind set-up. The analysed barometric pressure should therefore not be added to the derived extreme tidal levels but should only serve the purpose of indicating how much barometric pressure can affect the tidal level.

- *Barometric pressure* data was also obtained from ECMWF for the same period as for the wave and wind data. Extreme maximum and minimum pressures were derived as presented in Table A6-1 and repeated below. Comparing the extreme tidal levels based on recorded tidal levels under (vi) above and the predicted extreme astronomical tidal level (HAT and LAT) under (v) above with the extreme barometric pressures below and above the mean, it is evident that the effect of barometric pressure is included in the recorded tide.

Return Period	Barometric pressure (cm water) [Mean pressure = 1017.57 cm water]			
(years)	Low	High	Low below mean	High above mean
100	987.96	1044.43	-29.61	26.86
50	989.92	1043.07	-27.65	25.50
20	992.54	1041.27	-25.03	23.70

- *Sea level rise* (SLR) as projected for 2065 and 2100 in the IPCC's latest assessment report of 2014 (AR5) was used to estimate SLR for the SA south coast by the author as presented in Table A7-1 and repeated below. Based on the worst emission scenario (RCP8.5) it is assumed for this study that the sea level rise will be 0.5 m by 2065 and 1.0 m by 2100.

	2046 - 2065				2081 - 2100			
Scenario	Mean	Likely range			Mean	Likely range		
RCP2.6	0.28	0.20	to	0.37	0.46	0.30	to	0.64
RCP4.5	0.30	0.22	to	0.38	0.54	0.37	to	0.73
RCP6.0	0.29	0.21	to	0.37	0.56	0.38	to	0.73
RCP8.5	0.35	0.25	to	0.44	0.73	0.52	to	0.95

- Long waves due to the presence of groups of large short waves in a storm was also addressed since these long waves contribute to wave runup on beaches and since their periods are relatively long (approximately 90s to 180s) they cause a temporary higher still water level in the surf zone (referred to as surf beat) causing short waves at this higher still water level to reach higher runup levels. Based on the relation between short and long wave heights in the literature, extreme long wave heights were estimated and presented in Table A8-1 and repeated below.

Return Period	Short waves		Wave heights of long waves from all directions	
	Hs from all directions	Hs from SE'ly sector only	Botes et al (1982)	Stuart (2013)
(years)	(m)	(m)	(m)	(m)
200	10.1	8.1	0.86	0.83
100	9.7	7.6	0.84	0.79
50	9.2	7.2	0.83	0.76
20	8.6	6.5	0.80	0.70

APPENDIX AA: EXTREME TIDES IN KNYSNA – 28 OCTOBER 2019

AA1 INTRODUCTION

Knysna experienced exceptional high water levels in the estuary on 28 October 2019 – so much so that the local newspaper (Knysna-Plett Harold) reported it in their weekly issue of 31 October 2019 and by amateur photographer, Sailing Pluto, on you-tube (https://www.youtube.com/watch?v=sbt2ArdmJso). A few photographs during Spring high water taken by Nichelle Swanepoel during the event are shown below. The newspaper reported that "according to the local SA National Parks marine ecologist Kyle Smith, high tide occurred just after 16:00 on 28 October, and the water level was estimated to have reached 2.16 m. This, along with a swell of 5 m with a wave period of 13 seconds would have pushed the water level up higher than normal". The newspaper further reported that "Sanparks Knysna manager Megan Taplin also indicated that by Monday the area had received 53 mm of rain in the preceding two weeks, which would have also contributed to the high water levels."

Figure Aa.1-1: Photograph (courtesy Nichelle Swanepoel) Waterfront Drive adjacent Knysna Quays Marina during high tide (approx. 16:00) on 28 October 2019

Figure Aa.1-2: Photograph (courtesy Nichelle Swanepoel) of Knysna Quays Marina during high tide (approx. 16:00) on 28 October 2019. Cope level of the quay walls are at +2.5 m above sea level

AA2 FACTORS INFLUENCING TIDAL LEVEL IN KNYSNA ESTUARY

The exceptional high tidal level (significantly higher than the predicted astronomical tide) observed on 28 October 2019 during highwater at 16:00 is shown in Figure Aa2-1 below with possible factors that could have contributed to the high water level

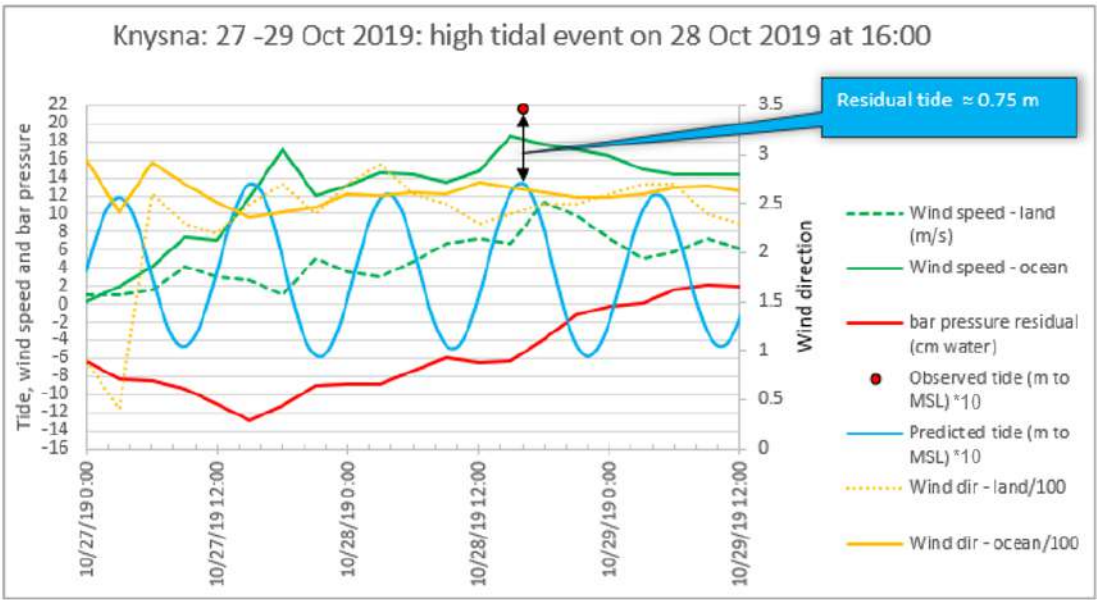


Figure Aa2-1: Factors that could have contributed to the observed exceptional high tidal level in Knysna estuary on 28 October 2019 at 16:00

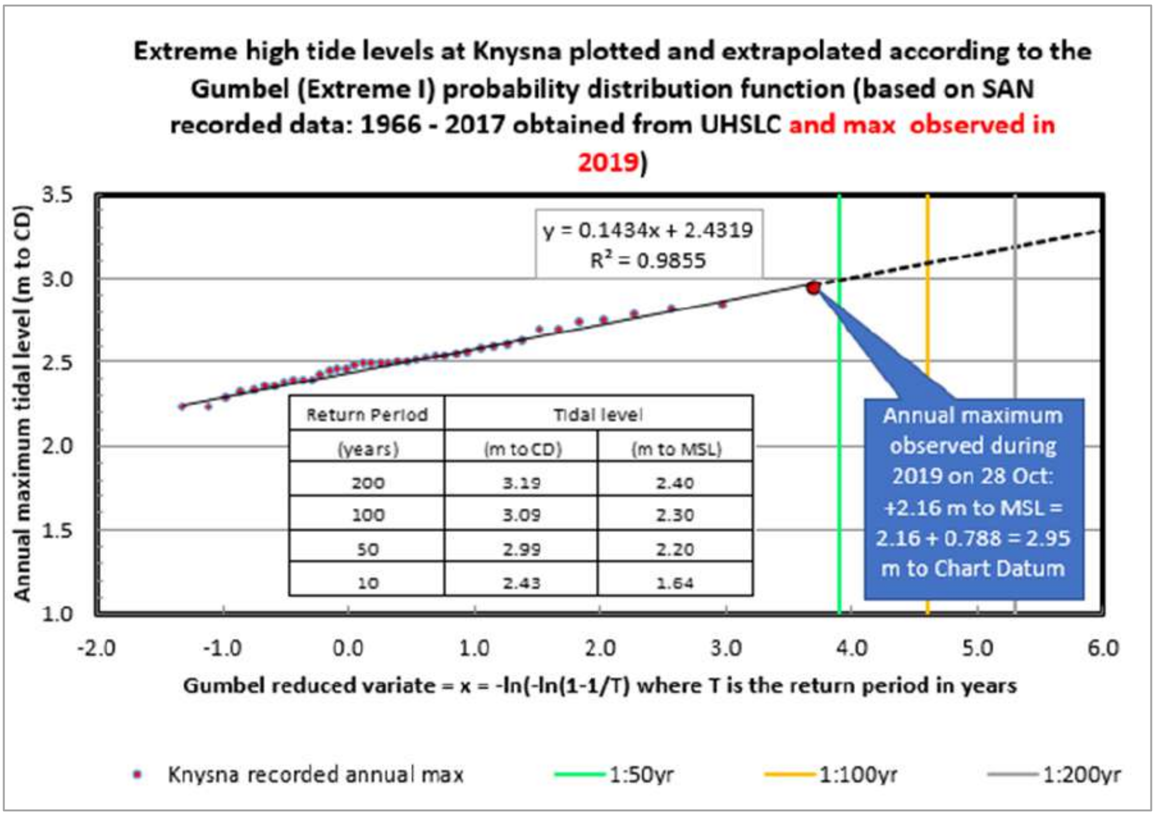
The observed water level at 16:00 was approximately 0.75 m above the predicted astronomical tide (spring tide). The factors that could have contributed to the observed high-water level (i.e. above the predicted astronomical spring tide) are:

- *Low barometric pressure (inverse barometric effect):* The maximum negative residual pressure on 27 October was -12.5 cm water which would have caused sea level to rise 12.5 cm above the astronomical tide. Although the negative residual pressure on 28 October at 16:00 was less than that on 27 October one could expect the same order of negative residual pressure on 28 October due to some delay in the inverse barometric effect.
- *Wind setup due to a strong westerly wind over the estuary:* Wind direction on the coastline in the vicinity of Knysna during the event was from the west (i.e. alongshore and not onshore) and wind setup on the coastline would have been minimal. However, wind setup at the location of the tide gauge at Sanparks (as well as at the Knysna Quays marina – refer Figure Aa2-2 below) due to the relative strong westerly wind speed towards these locations during the event is estimated (using equation of Van Rijn, 2015) in the order of 7 cm for a wind speed of 18 m/s over a fetch of about 800 m with an average water depth of say 0.75 m.
- *Flood flows from the rivers flowing into the estuary due to relative high rainfall during the two preceding weeks:* Due to relative high rainfall during the period preceding the extreme water level event, some effect due to floods entering the estuary could have been expected. The flood effect seems to have been the dominant factor since the sum of the inverse barometric effect plus the wind setup effect is about 20 cm whereas the total observed residual was 0.76m.

Figure Aa2-2: Westerly wind during the extreme water level event on 28 October 2019 at 16:00

AA3 STATISTICAL EVALUATION OF OBSERVED EXTREME WATER LEVEL

The observed water level at on 28 October 2019 at 16:00 was incorporated in the statistical analysis of the SA Navy recorded tidal levels at Knysna available for the period 1960 – 2017 from UHSLC. The results are presented in Figure Aa3_1 below and indicate that the extreme water level of 28 October 2019 falls within the expected statistical population of annual maximum recorded water levels i.e. is not an outlier.



Return Period	Tidal level	
(years)	(m to CD)	(m to MSL)
200	3.19	2.40
100	3.09	2.30
50	2.99	2.20
10	2.43	1.64

Figure Aa3-1: Statistical analysis of annual maximum recorded Knysna water levels incorporating the extreme water level observed on 28 October 2019.

AA4 CONCLUSION

It is concluded that although the extreme water level observed in Knysna estuary on 28 October 2019 at 16:00 is the maximum known recorded since 1966, it falls within the expected statistical population of annual maximum recorded water levels in Knysna estuary i.e. is not an outlier. Local Wind setup and the inverse barometric effect had an influence on the water level but the main contributor to the extreme water level above the spring astronomical tidal level is considered to be the concurrent flood from the catchment flowing into Knysna estuary due to preceding high rainfall.

APPENDIX B: FLOOD HYDROLOGY

APPENDIX B1: KLEIN BRAK ESTUARY FLOOD HYDROLOGY

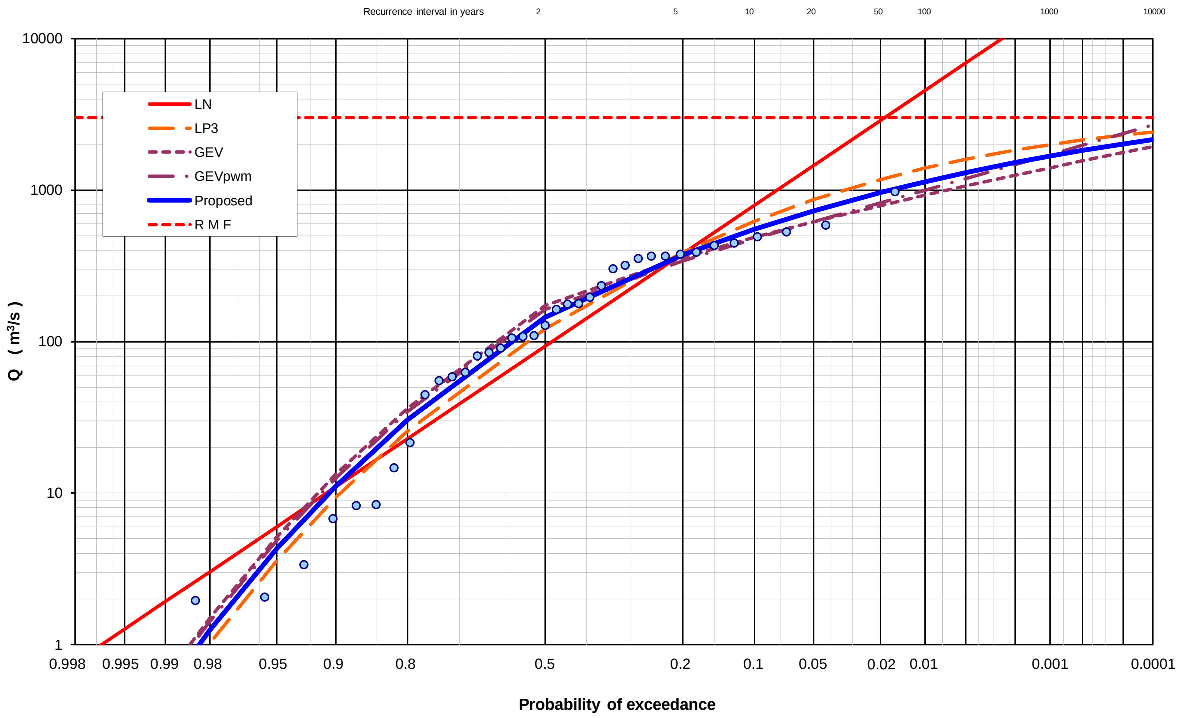


Figure B1-1: Statistical Analysis for Klein Brak River Mouth Flood Hydrology

Table B1-1: Estimated flood peak results of fitted distributions

ARI	Exceed Prob	LN Q (m^3/s)	LPIII Q (m^3/s)	GEV_{MM} Q (m^3/s)	GEV_{PWM} Q (m^3/s)	Proposed Q (m^3/s)
2	0.50	93	122	172	163	145
5	0.20	381	389	359	342	373
10	0.10	795	623	488	477	552
20	0.05	1459	865	617	620	731
50	0.02	2888	1177	790	828	964
100	0.01	4553	1397	925	1002	1137
200	0.005	6907	1600	1064	1193	1305

Table B1-2: Probabilistic properties of the flood peak record

Property	Untransformed data
Record length	37
Median	127.7
Mean	213.0
Std Deviation	215.9
Skewness	1.463

Table B1-3: Flood peak record compiled for the Klein Brak Estuary

Hydrological Year			K1H004 Brandwag (m^3/s)	K1H005 Moordkuil (m^3/s)	Compiled Record (m^3/s)
Catchment (km^2)			215	198	562
1978	/	1979	5	36	45
1979	/	1980	0	2	2
1980	/	1981	151	42	234
1981	/	1982	19	30	55
1982	/	1983	21	31	59
1983	/	1984	35	44	90
1984	/	1985	1	7	8
1985	/	1986	32	62	106
1986	/	1987	4	96	108
1987	/	1988	1	6	7
1988	/	1989	1	0	2
1989	/	1990	92	255	388
1990	/	1991	0	7	8
1991	/	1992	136	337	531
1992	/	1993	67	263	366
1993	/	1994	21	78	109
1994	/	1995	17	262	302
1995	/	1996	50	1	63
1996	/	1997	129	266	447
1997	/	1998	4	15	22
1998	/	1999	3	10	15
1999	/	2000	9	64	80
2000	/	2001	25	90	128
2001	/	2002	11	67	85
2002	/	2003	121	406	587
2003	/	2004	56	100	178
2004	/	2005	51	92	163
2005	/	2006	11	390	432
2006	/	2007	137	299	492
2007	/	2008	98	238	377
2008	/	2009	165	106	319
2009	/	2010	2	0	3
2010	/	2011	213	664	977
2011	/	2012	90	225	353
2012	/	2013	63	93	178
2013	/	2014	101	66	196
2014	/	2015	130	190	367
2015	/	2016	1	53	57
2016	/	2017	2	20	24
2017	/	2018	2	17	22

Table B1-4: Flood Peaks for Deterministic and Empirical Methods (m^3/s)

Return Period	2	5	10	20	50	100
Deterministic Methods						
Standard Design Flood	79	273	454	660	976	1247
Unit Hydrograph	206	281	360	451	601	749
Rational	139	201	269	350	478	617
Rational Alternative 2	127	227	314	408	537	649
Rational Alternative 3	154	243	323	420	592	775
Empirical Methods						
Midgley and Pitman			440	551	720	847
Kovacs (TR137)					1295	1630

Table B1-5: Rainfall stations contributing towards the Klein Brak catchment

Rainfall Station	SAWS Number	Record (years)	Altitude (m)	MAP (mm)
Pine Grove	002 8207 W	40	287	718
Ruiterbos	002 8083 W	59	1036	743
Kewertuin	002 8150 W	71	198	440
Sandhoogte	001 2303 W	72	76	576
Herbertsdale	001 1451 W	99	100	438

APPENDIX B2: GROOT BRAK ESTUARY FLOOD HYDROLOGY

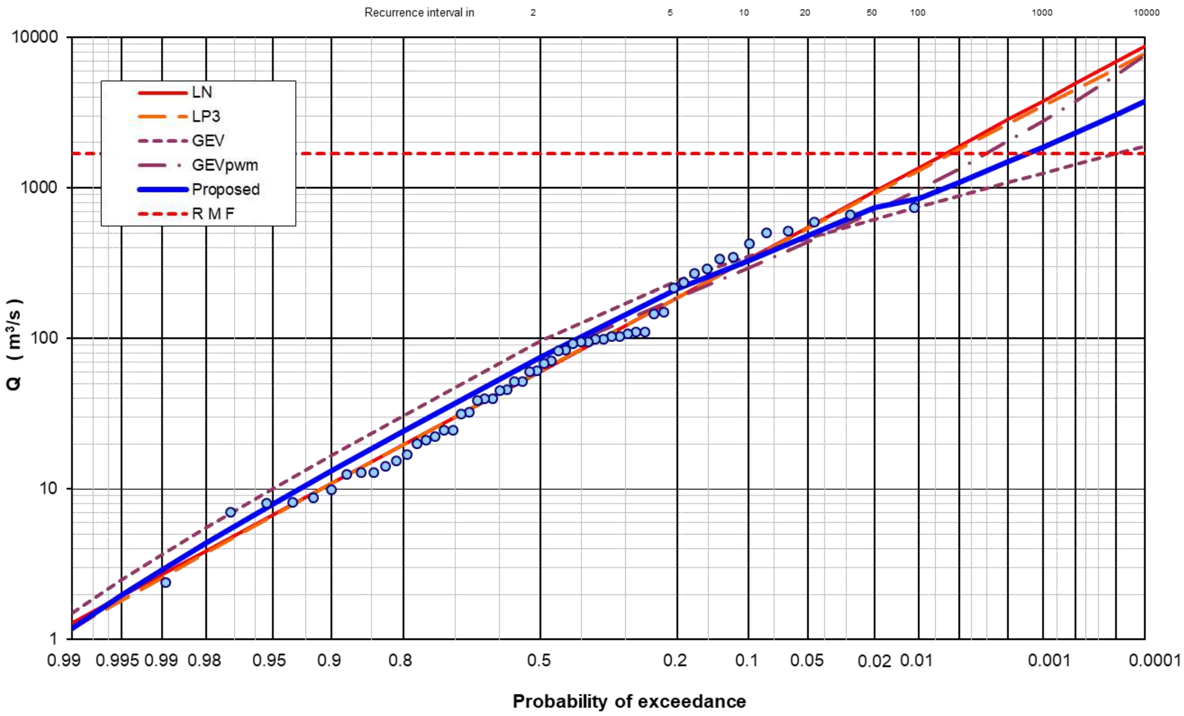


Figure B2-1. Statistical Analysis for Groot Brak River Mouth Flood Hydrology

Table B2-1: Estimated flood peak results of fitted distributions

ARI	Exceed Prob	LN Q (m^3/s)	LPIII Q (m^3/s)	GEV_{MM} Q (m^3/s)	GEV_{PWM} Q (m^3/s)	Proposed Q (m^3/s)
2	0.50	61	61	96	76	76
5	0.20	187	188	243	186	213
10	0.10	337	335	351	295	327
20	0.05	548	539	463	437	480
50	0.02	946	918	621	700	744
100	0.01	1362	1308	751	977	856
200	0.005	1902	1806	889	1349	1095

Table B2-2: Probabilistic properties of the flood peak record

Property	Untransformed data
Record length	56
Median	64.75
Mean	133.94
Std Deviation	177.428
Skewness	1.986

Table B2.3. Flood peak record compiled for the Groot Brak Estuary

Hydrological Year			K2H002 (m^3/s)	K2R002 Dam Inflow (m^3/s)	K2R002 Dam Outflow (m^3/s)	Compiled Record for the Estuary (m^3/s)
Catchment (km^2)			131	123	123	169
1961	/	1962	254			288
1962	/	1963	191			217
1963	/	1964	526			598
1964	/	1965	14			15
1965	/	1966	95			108
1966	/	1967	91			104
1967	/	1968	15			17
1968	/	1969	28			31
1969	/	1970	22			25
1970	/	1971	60			69
1971	/	1972	22			25
1972	/	1973	8			9
1973	/	1974	28			32
1974	/	1975	35			40
1975	/	1976	12			14
1976	/	1977	374			425
1977	/	1978	7			8
1978	/	1979	46			52
1979	/	1980	7			8
1980	/	1981	306			347
1981	/	1982	40			45
1982	/	1983	53			60
1983	/	1984	74			84
1984	/	1985	9			10
1985	/	1986	46			52
1986	/	1987	88			99
1987	/	1988	11			13
1988	/	1989	11			13
1989	/	1990	88			99
1990	/	1991	6	17	0	20
1991	/	1992	26	128	0	150
1992	/	1993	78	442	75	518
1993	/	1994	52	61	53	72
1994	/	1995	136	202	129	237
1995	/	1996	15	88	67	103
1996	/	1997	372	427	323	501
1997	/	1998	22	19	18	22
1998	/	1999	26	18	16	21
1999	/	2000	27	34	28	40

2000	/	2001	49	71	54	83
2001	/	2002	25	39	30	46
2002	/	2003	147	230	159	270
2003	/	2004	24	11	0	13
2004	/	2005	33	95	38	111
2005	/	2006	240	289	244	339
2006	/	2007	23	79	21	93
2007	/	2008	327	633	404	742
2008	/	2009	24	33	29	39
2009	/	2010	0	6	0	7
2010	/	2011	265	563	337	660
2011	/	2012	72	124	99	145
2012	/	2013	52	81	68	95
2013	/	2014	38	52	46	61
2014	/	2015	55	94	77	110
2015	/	2016	45	81	59	95
2016	/	2017	24	2	2	2

Flow data from the gauging station K2H002, located downstream of the Wolwedans Dam, was used for the period 1961 until 1989, prior to the construction of the dam in 1990. For this period, the flood peak for one year was above the station's Discharge Table (DT) limit of 1.52 m (44.48 m³/s), which was extended using the DWS rating curve and 6 spills from Wolwedans Dam. Half of the spills appear to have been subjected to more submergence by the sea tide and the state (open or closed) of the estuary.

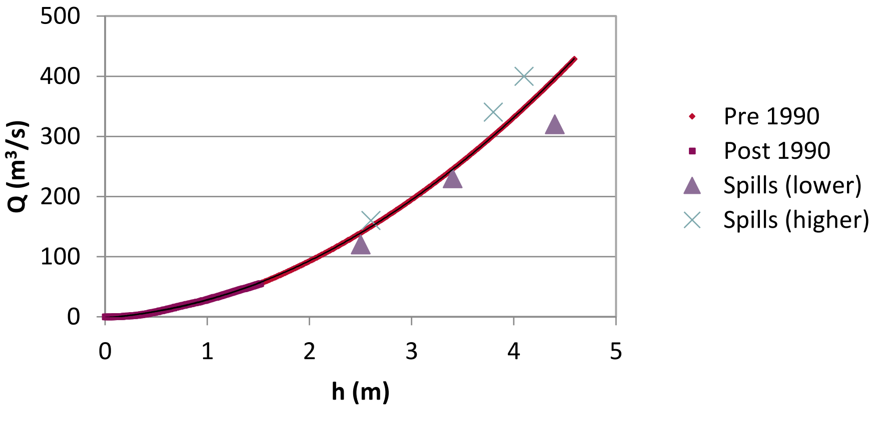
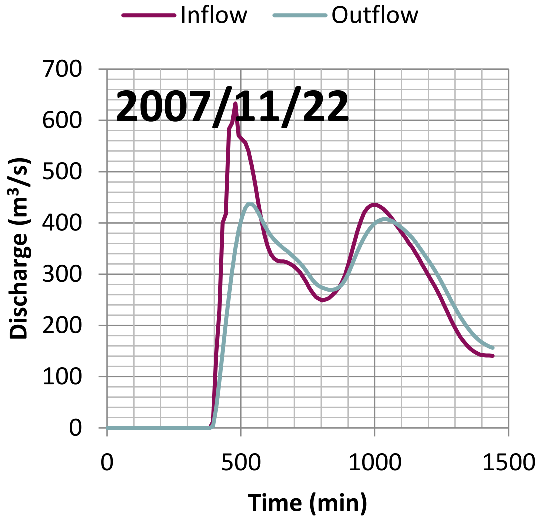
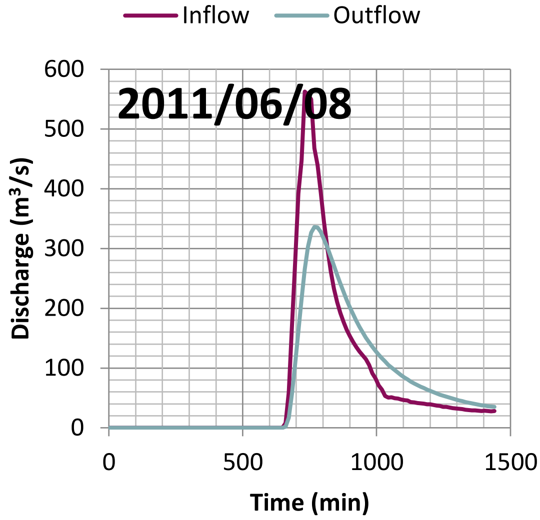


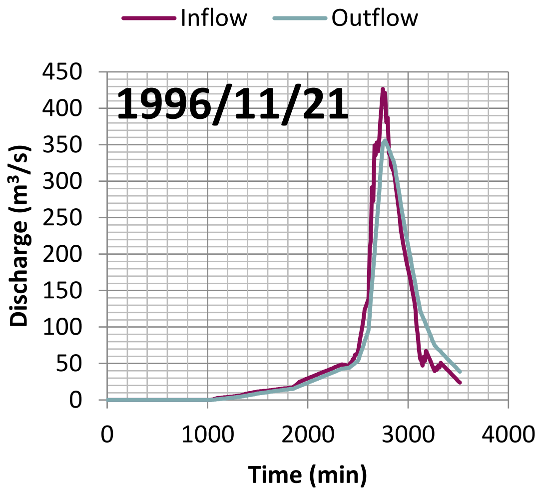
Figure B2-2. Flow-height rating curve for K2H002

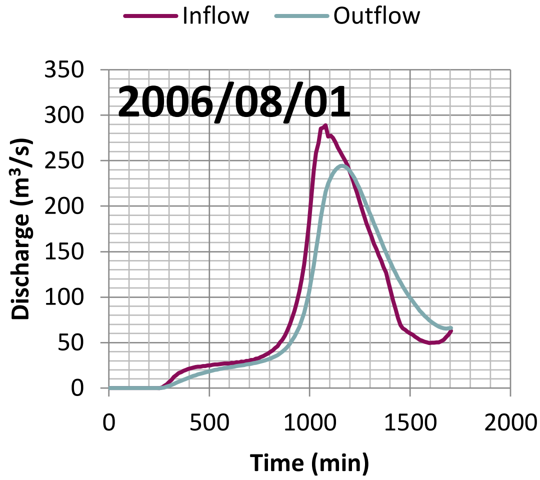
Outflow flood peaks were estimated for the Wolwedans Dam for the period 1990 to 2016 from station K2R002. To obtain a more conservative representation of the floods for the Groot Brak estuary, it was preferred to employ inflow data without the effect of the dam on flood attenuation. Level-pool-routing calculations were based on observed outflow hydrographs and the reservoir capacity of 25 million m³ at a full supply level of 98 masl. It was assumed that the dam was full such that peak inflows corresponded to the peak outflows of the same time period. This assumption was checked against a previous study by the DWS in 2012 and was adjusted for periods where the dam level was low.

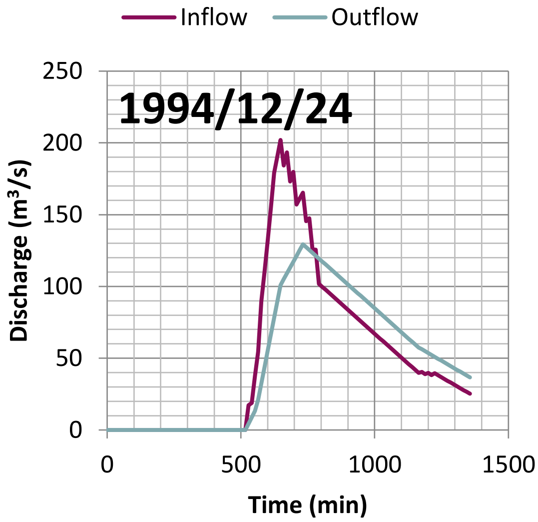
An excerpt of some of the observed outflow hydrographs and calculated inflow hydrographs at the Wolwedans Dam are given below.

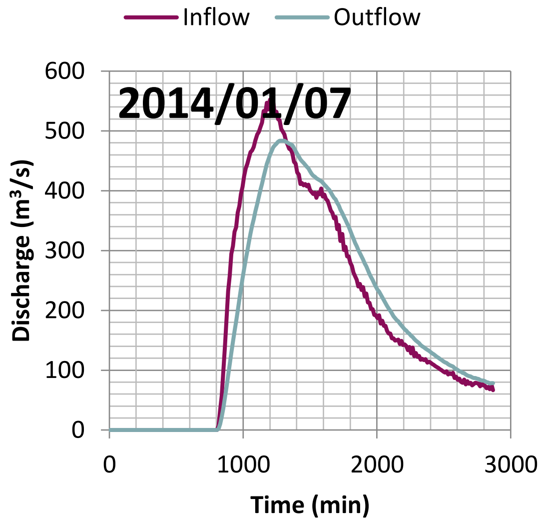












APPENDIX C: HYDRODYNAMIC MODEL RESULTS

SIMULATION RESULTS OF ROUTED FLOODS THROUGH THE ESTUARY: FLOW DEPTHS, FLOW VELOCITIES AND BED LEVEL CHANGE (EROSION AND DEPOSITION)

APPENDIX C1: HYDRODYNAMIC MODELLING OF KLEIN BRAK

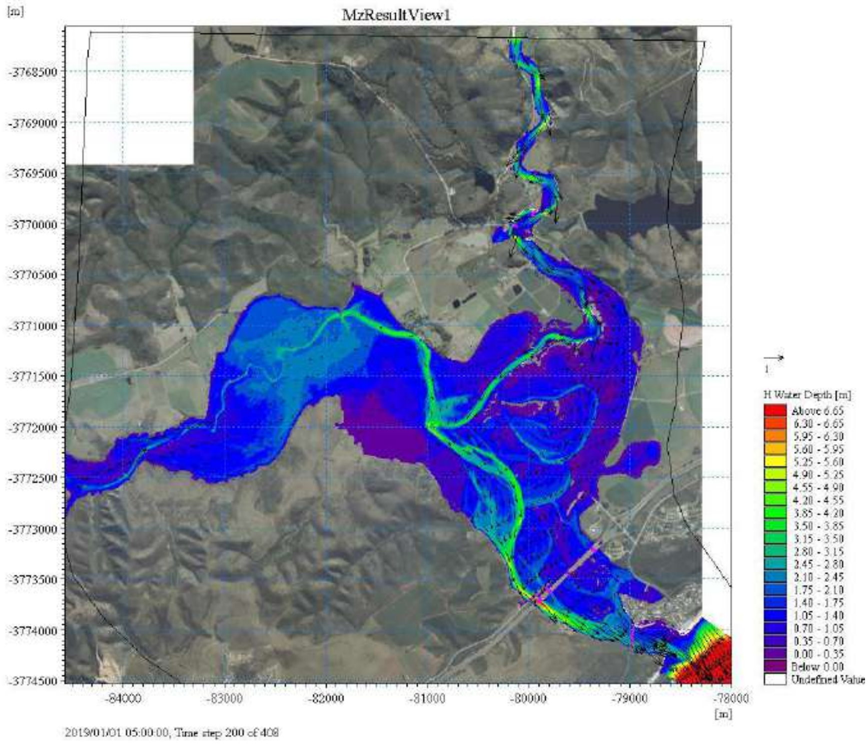


Figure C1-1: Simulated flow depths at the peak of the flood for the 50-year flood – current scenario with open mouth for Klein Brak

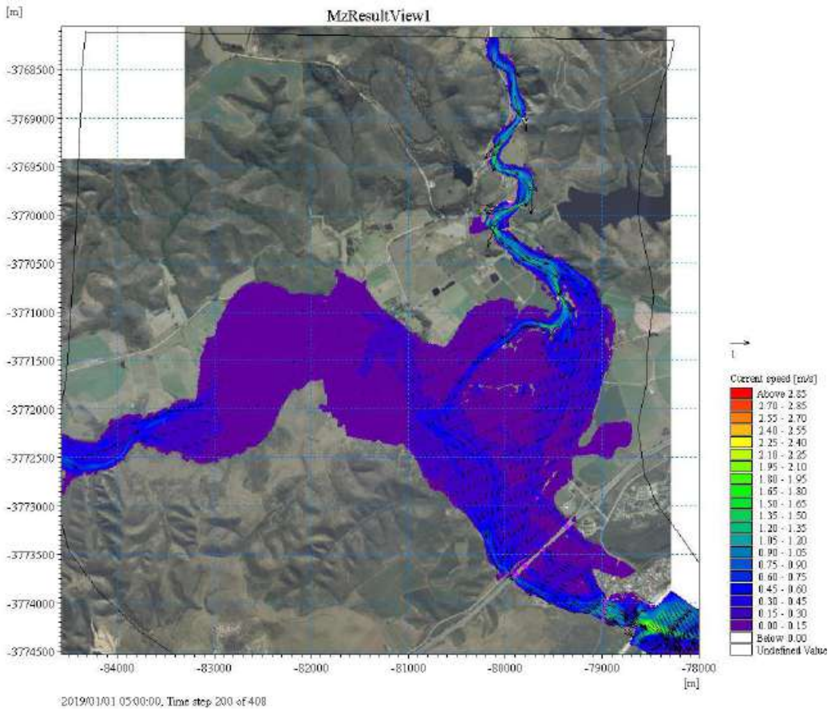


Figure C1-2: Simulated flow velocities and vectors at the peak of the flood for the 50-year flood – current scenario with open mouth for Klein Brak

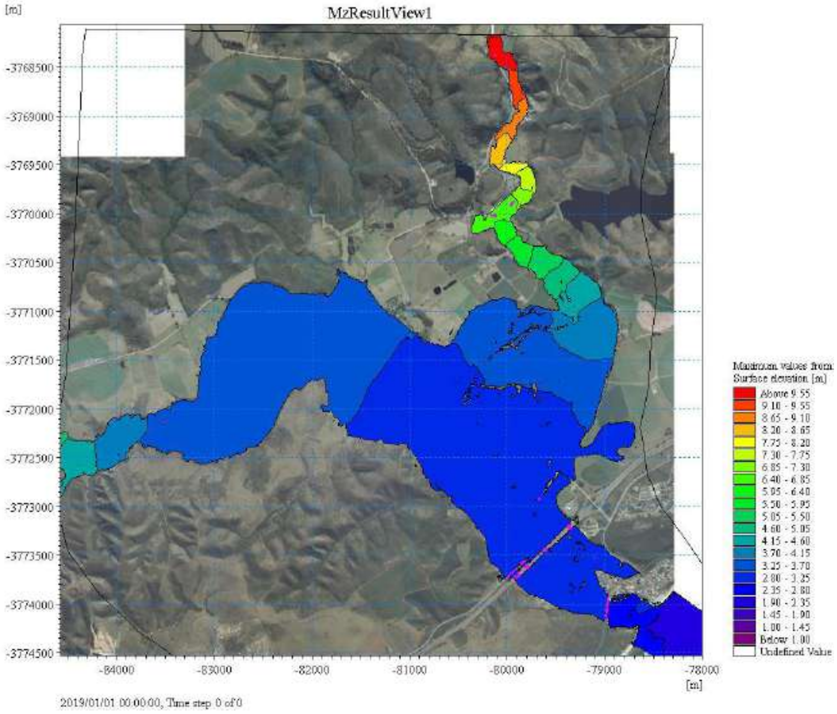


Figure C1-3: Simulated maximum flood levels for the 50-year flood – current scenario with open mouth (masl) for Klein Brak

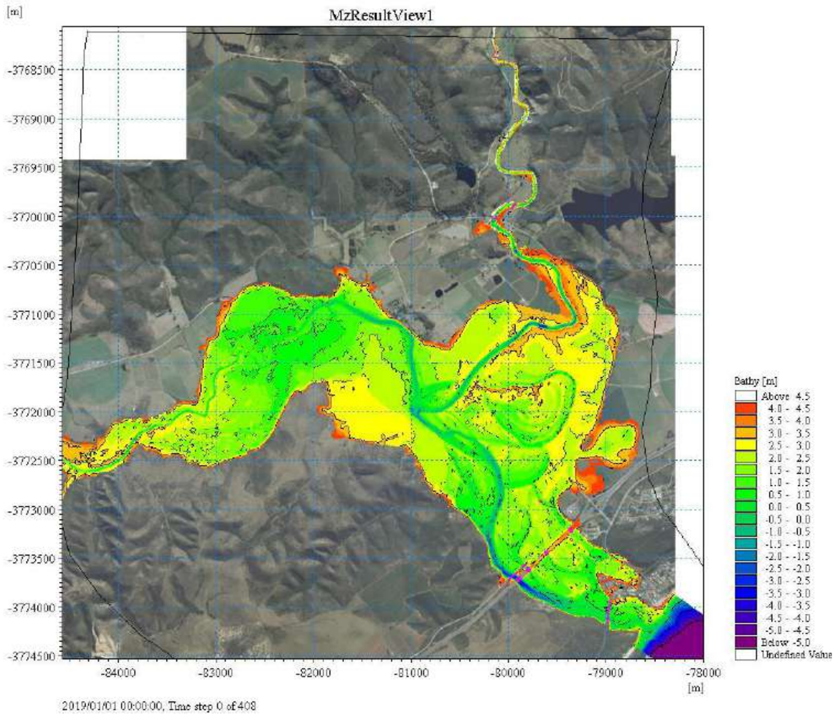


Figure C1-4: Initial bed levels – current scenario with open mouth (masl) for Klein Brak

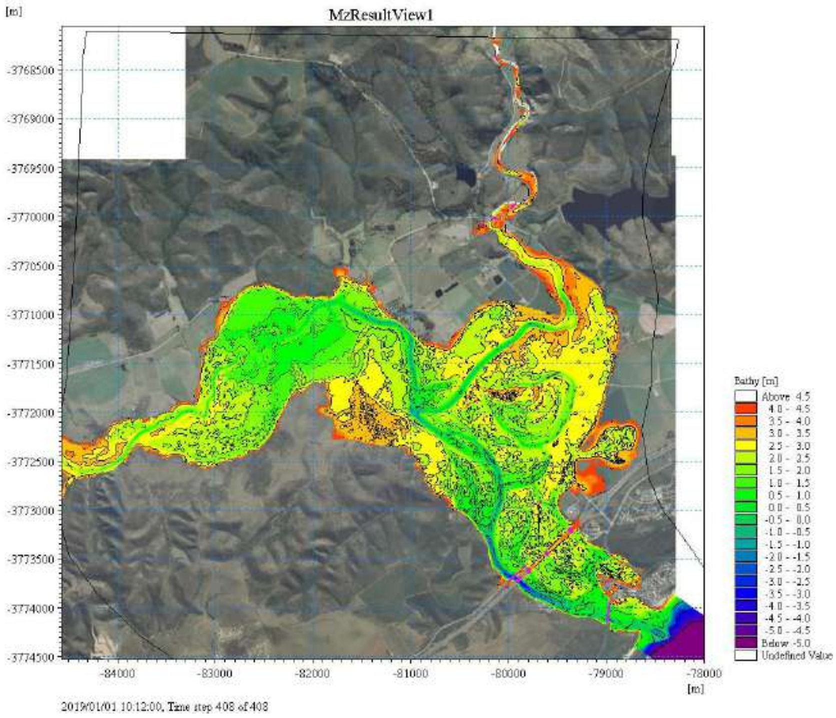


Figure C1-5: Simulated bed levels at end of the 50-year flood – current scenario with open mouth (masl) for Klein Brak

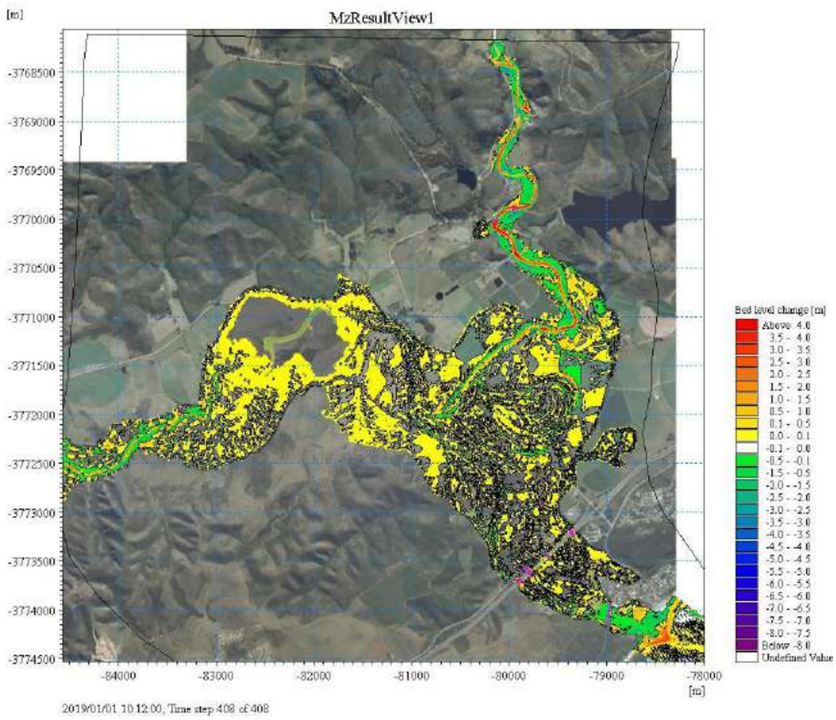


Figure C1-6: Simulated bed level (change) at end of the 50-year flood – current scenario with open mouth for Klein Brak

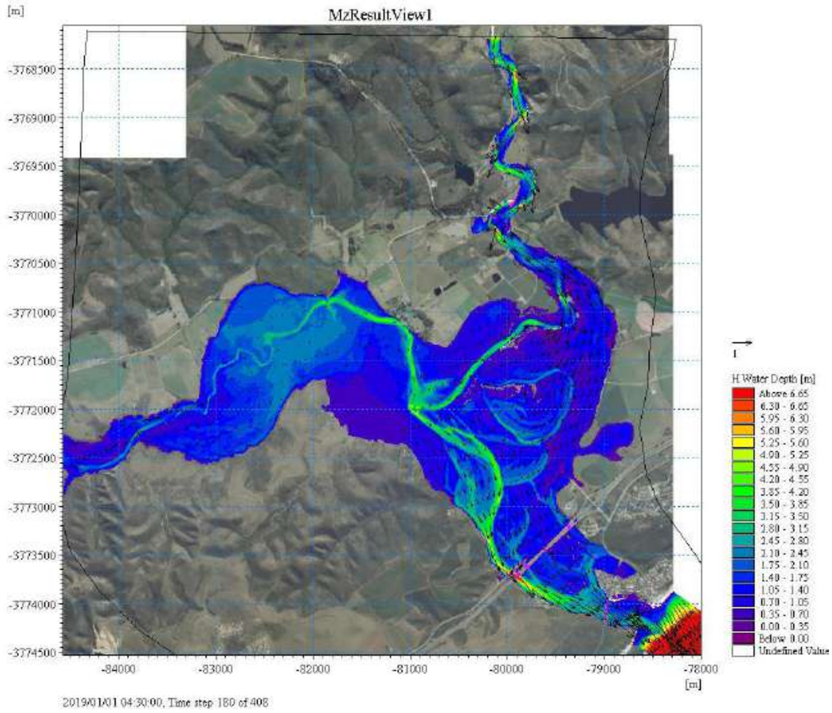


Figure C1-7: Simulated flow depths at the peak of the flood for the 100-year flood – current scenario with open mouth for Klein Brak

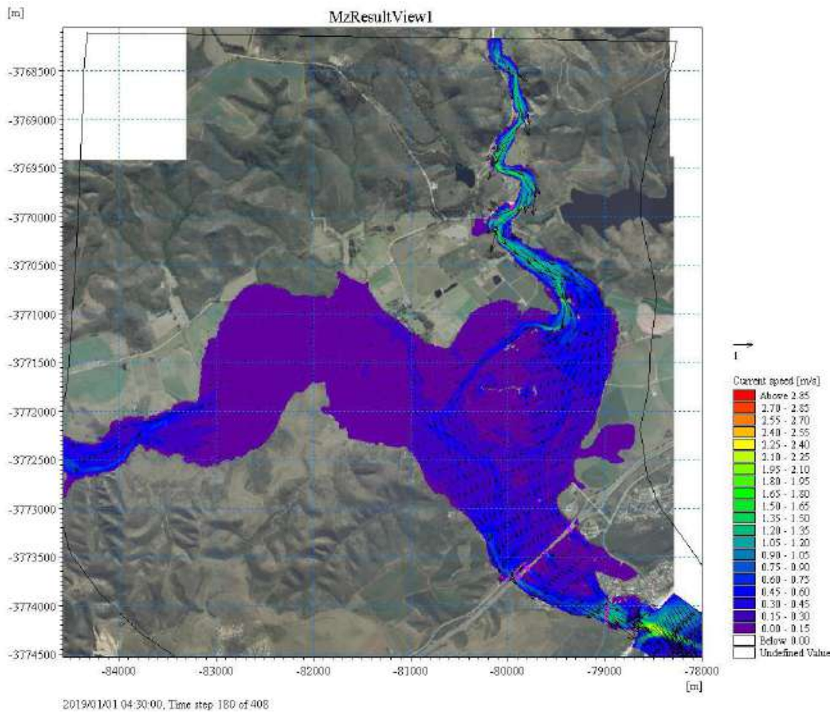


Figure C1-8: Simulated flow velocities and vectors at the peak of the flood for the 100-year flood – current scenario with open mouth for Klein Brak

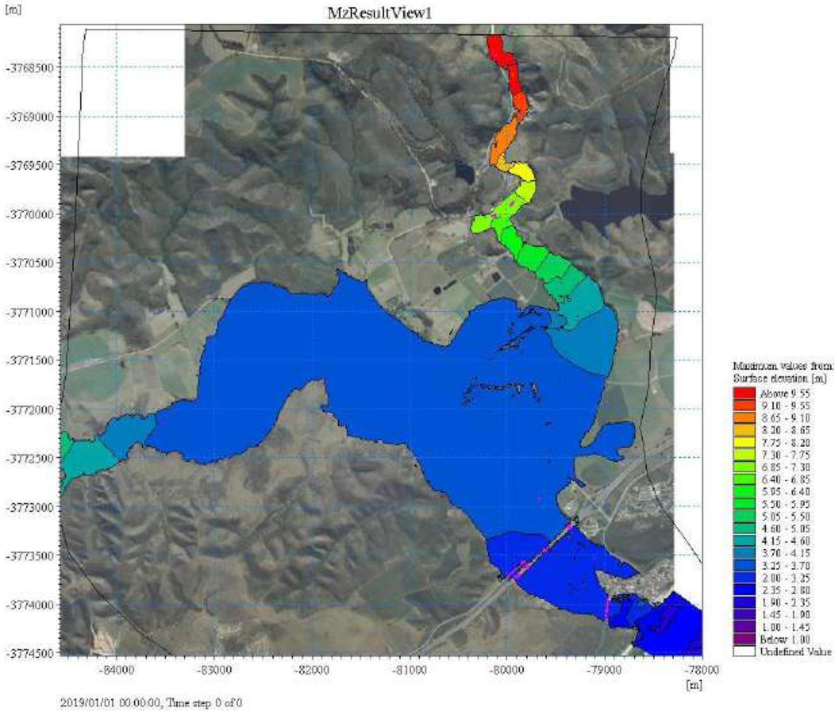


Figure C1-9: Simulated maximum flood levels for the 100-year flood – current scenario with open mouth (masl) for Klein Brak

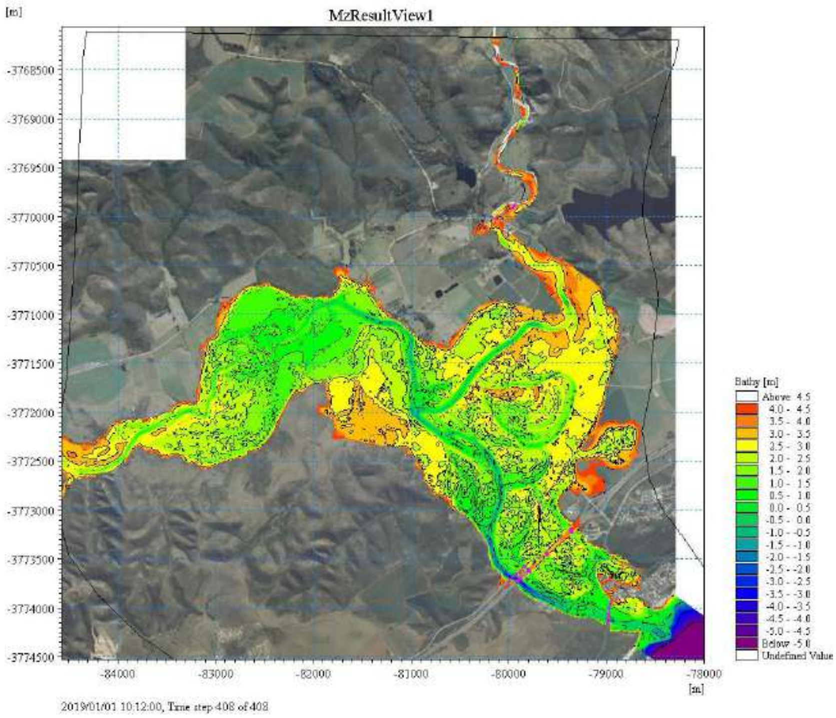


Figure C1-10: Simulated bed levels at end of the 100-year flood – current scenario with open mouth (masl) for Klein Brak

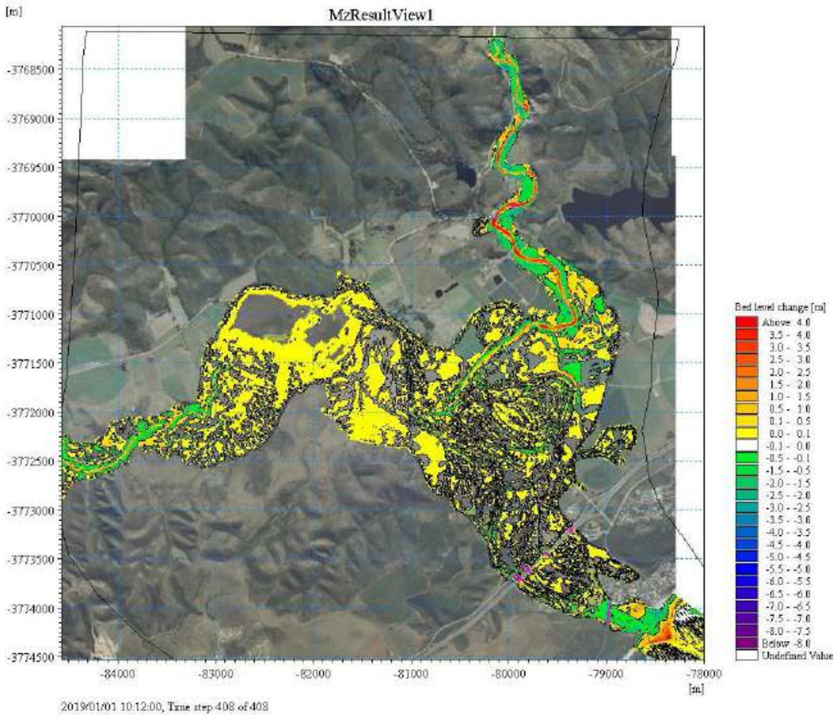


Figure C1-11: Simulated bed level (change) at end of the 100-year flood – current scenario with open mouth for Klein Brak

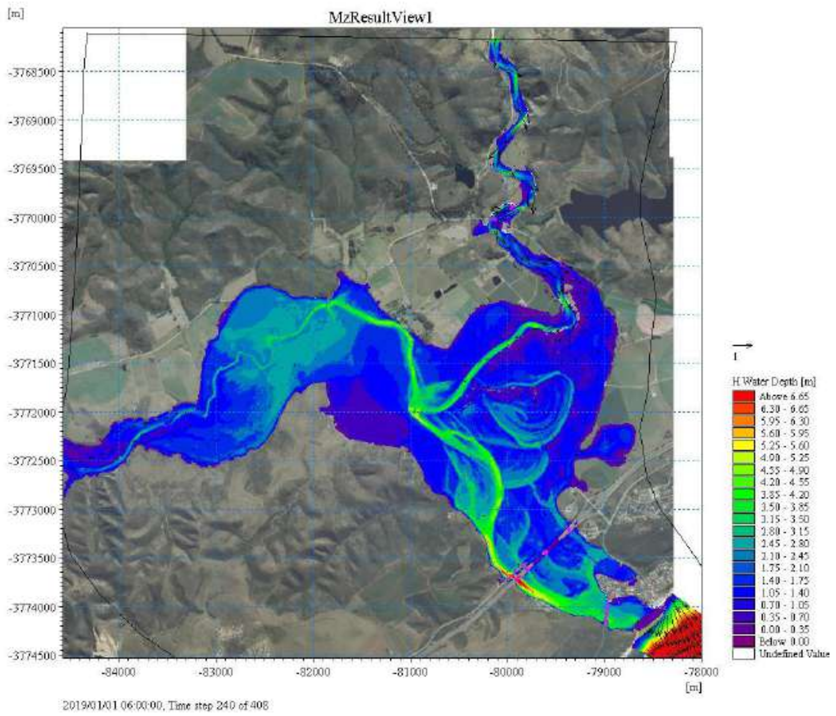


Figure C1-12: Simulated flow depths at the peak of the flood for the 50-year flood – current scenario with closed initial mouth for Klein Brak

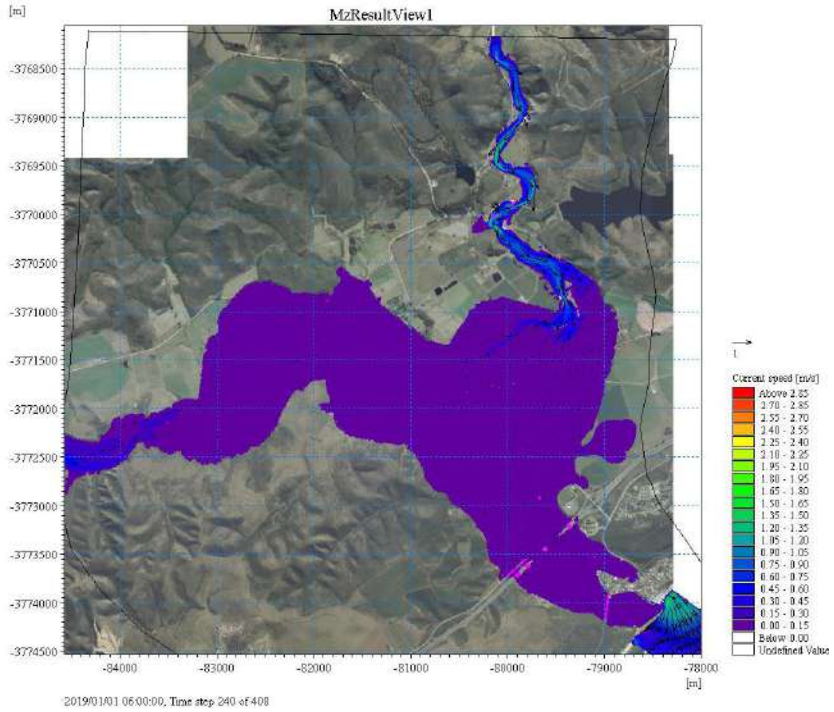


Figure C1-13: Simulated flow velocities and vectors at the peak of the flood for the 50-year flood – current scenario with closed initial mouth for Klein Brak

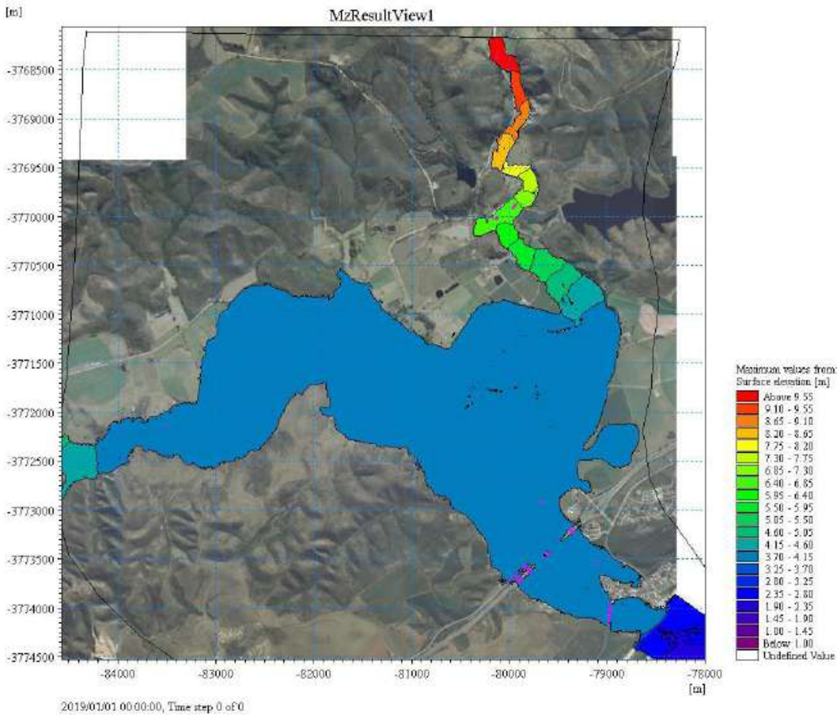


Figure C1-14: Simulated maximum flood levels for the 50-year flood – current scenario with closed initial mouth (masl) for Klein Brak

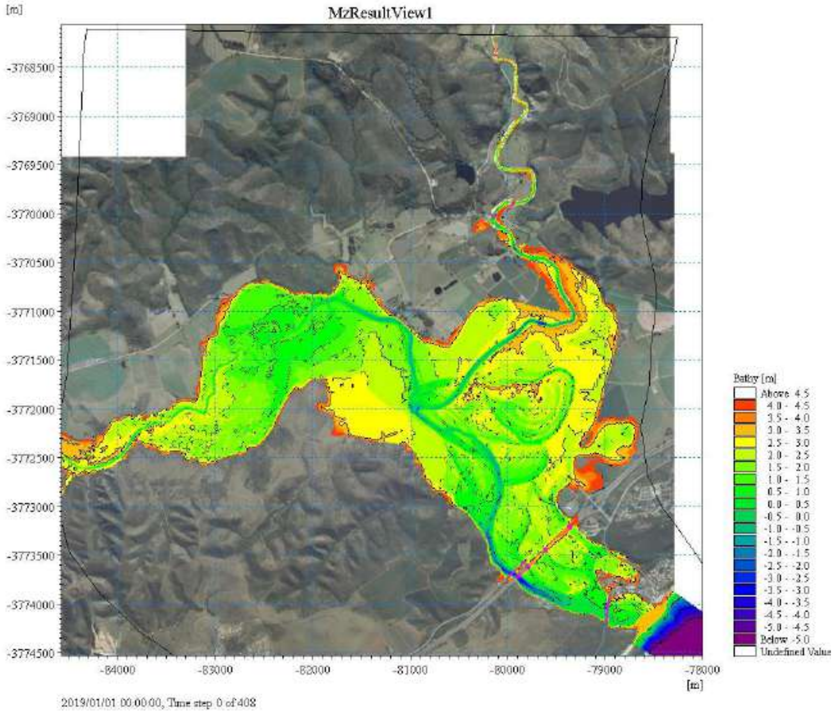


Figure C1-15: Initial bed levels – current scenario with closed initial mouth (masl) for Klein Brak

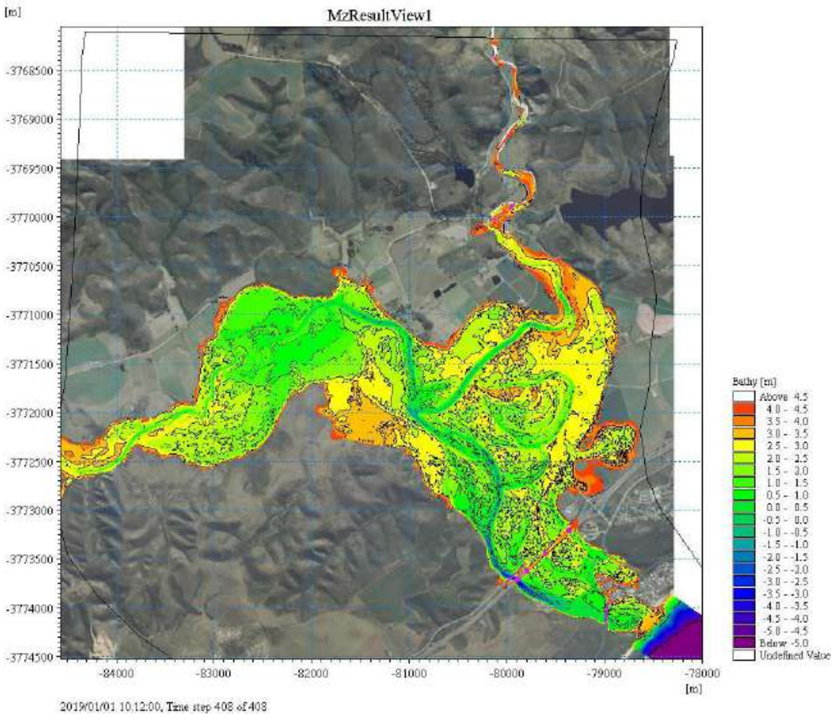


Figure C1-16: Simulated bed level at end of the 50-year flood – current scenario with closed initial mouth for Klein Brak

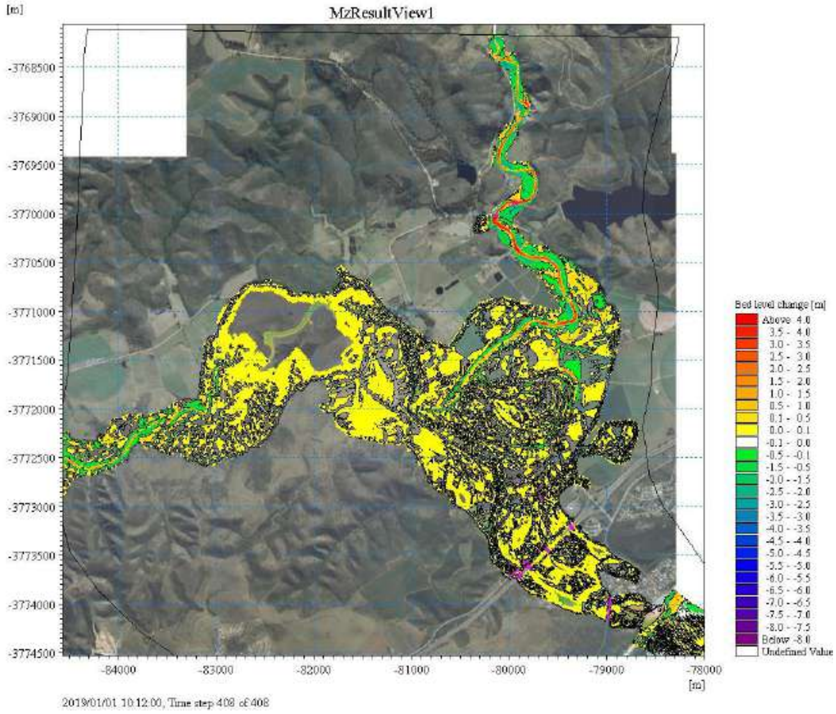


Figure C1-17: Simulated bed level (change) at end of the 50-year flood – current scenario with closed initial mouth for Klein Brak

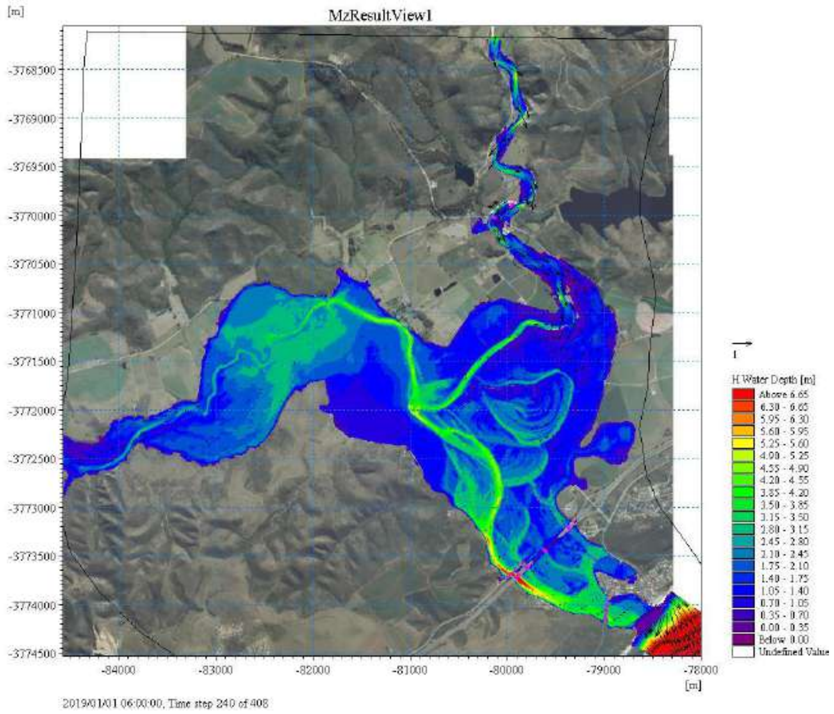


Figure C1-18: Simulated flow depths at the peak of the flood for the 100-year flood – current scenario with closed initial mouth for Klein Brak

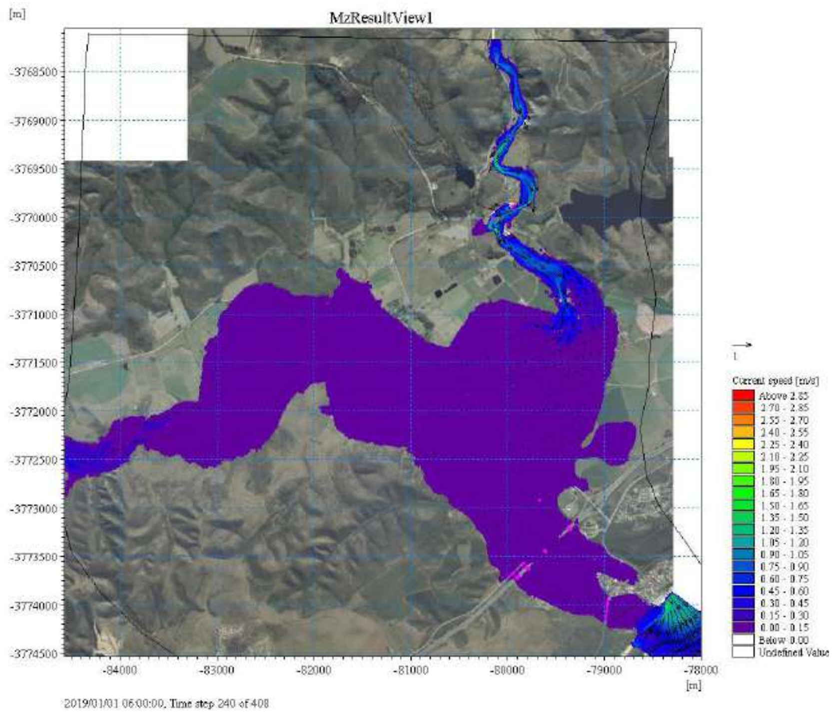


Figure C1-19: Simulated flow velocities and vectors at the peak of the flood for the 100-year flood – current scenario with closed initial mouth for Klein Brak

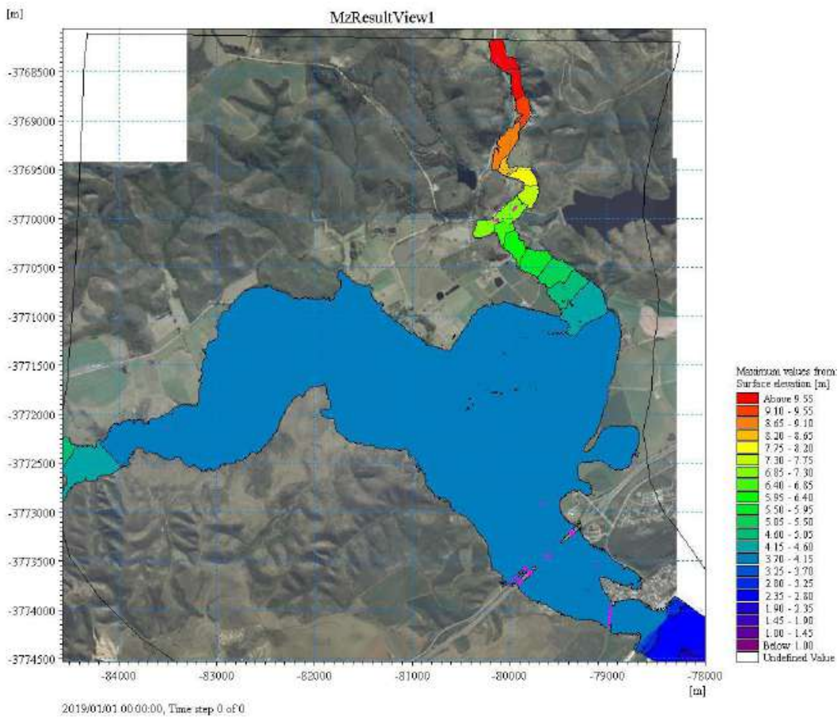


Figure C1-20: Simulated maximum flood levels for the 100-year flood – current scenario with closed initial mouth (masl) for Klein Brak

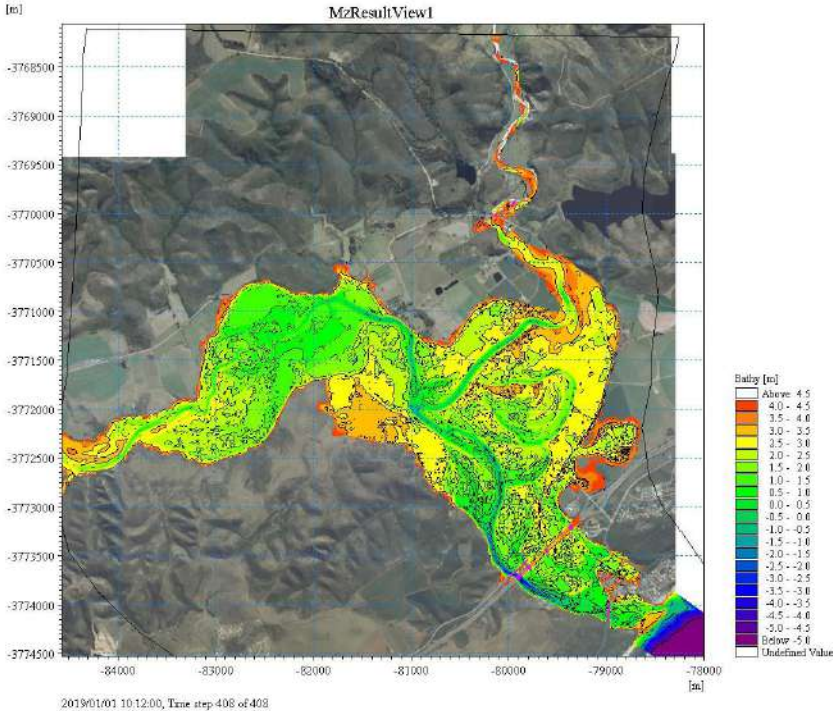


Figure C1-21: Simulated bed levels at end of the 100-year flood – current scenario with closed initial mouth (masl) for Klein Brak

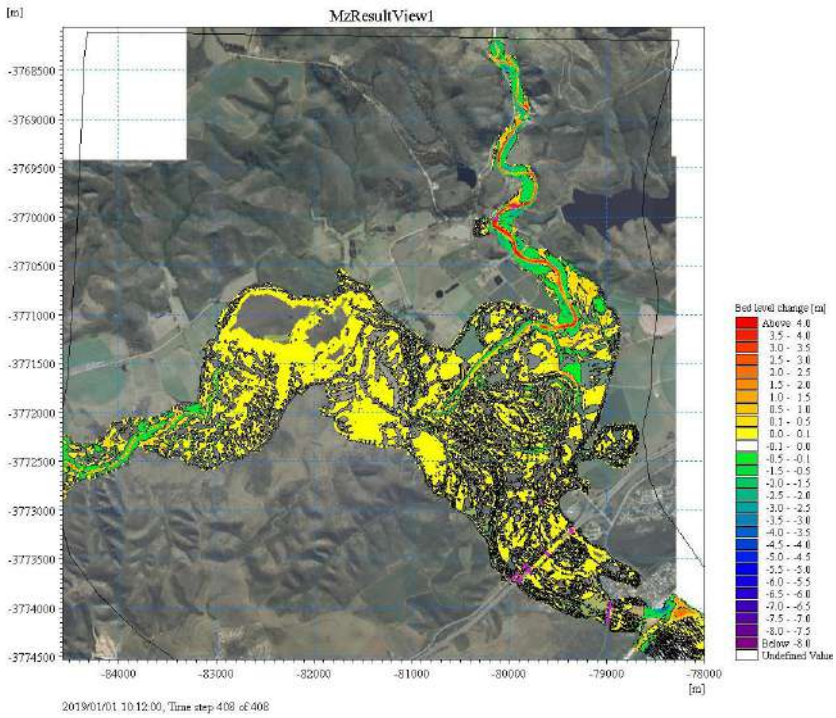


Figure C1-22: Simulated bed level (change) at end of the 100-year flood – current scenario with closed initial mouth for Klein Brak

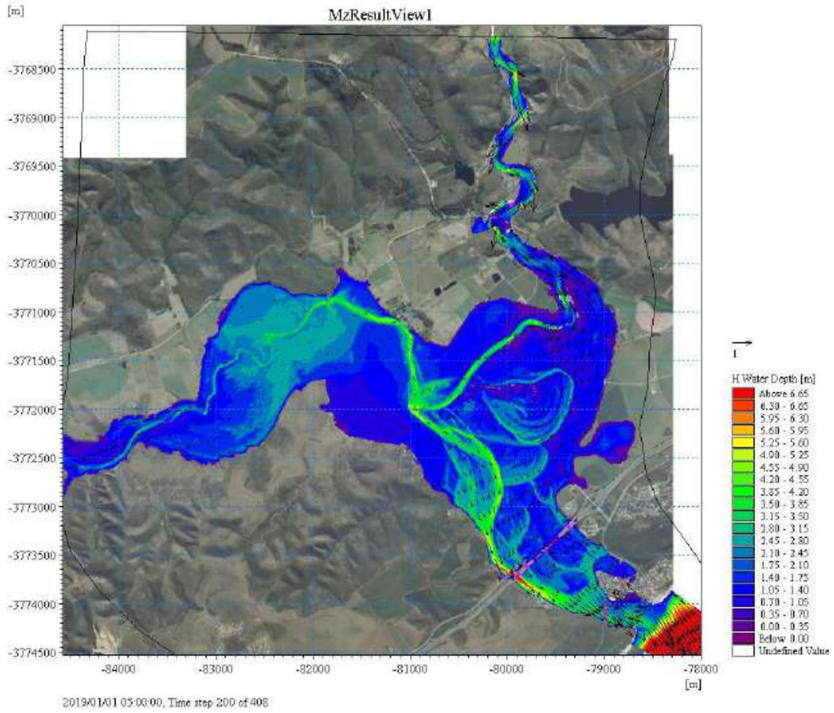


Figure C1-23: Simulated flow depths at the peak of the flood for the 50-year flood – future scenario with open mouth for Klein Brak

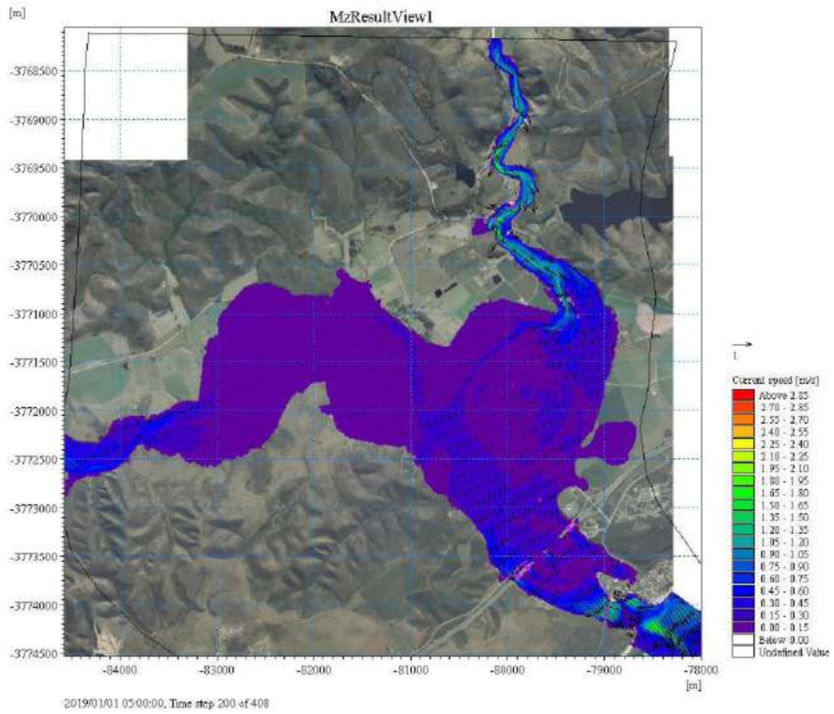


Figure C1-24: Simulated flow velocities and vectors at the peak of the flood for the 50-year flood – future scenario with open mouth for Klein Brak

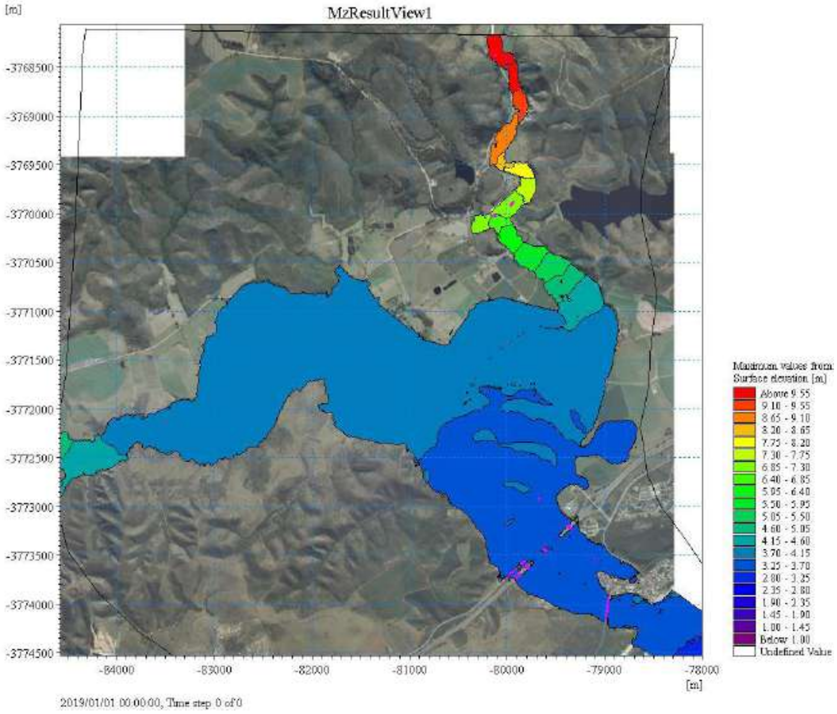


Figure C1-25: Simulated maximum flood levels for the 50-year flood – future scenario with open mouth (masl) for Klein Brak

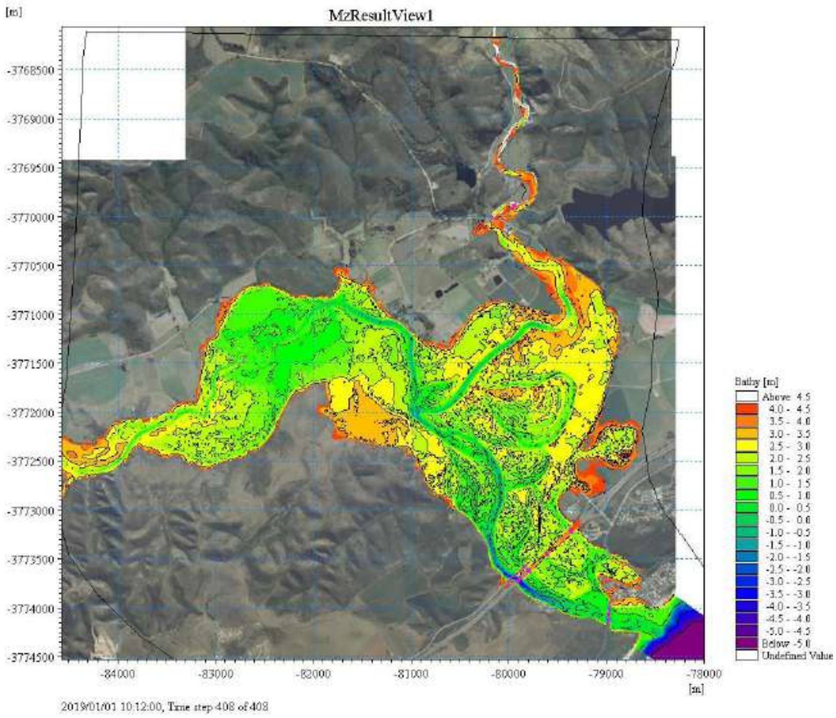


Figure C1-26: Simulated bed levels at end of the 50-year flood – future scenario with open mouth (masl) for Klein Brak

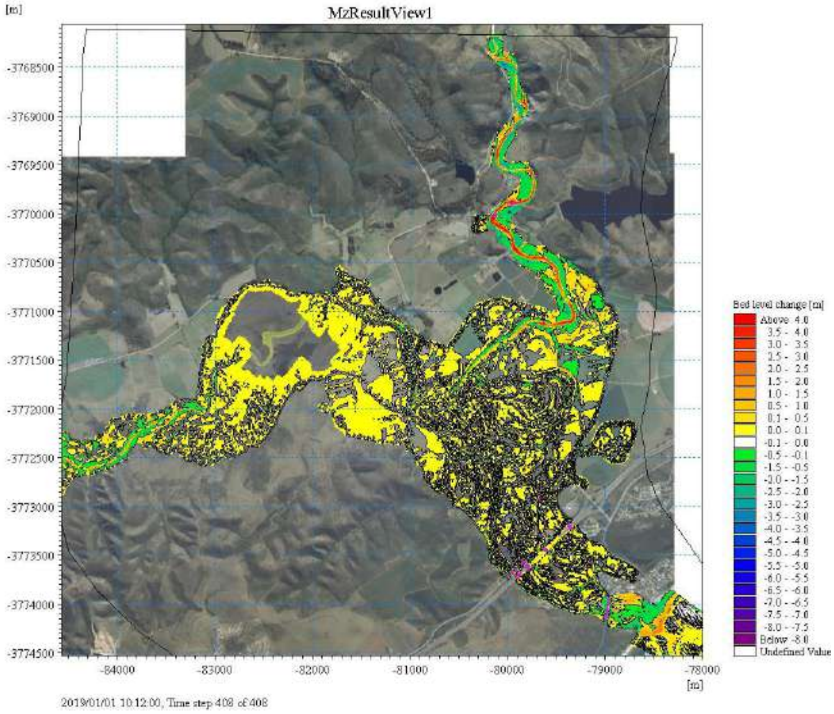


Figure C1-27: Simulated bed level (change) at end of the 50-year flood – future scenario with open mouth for Klein Brak

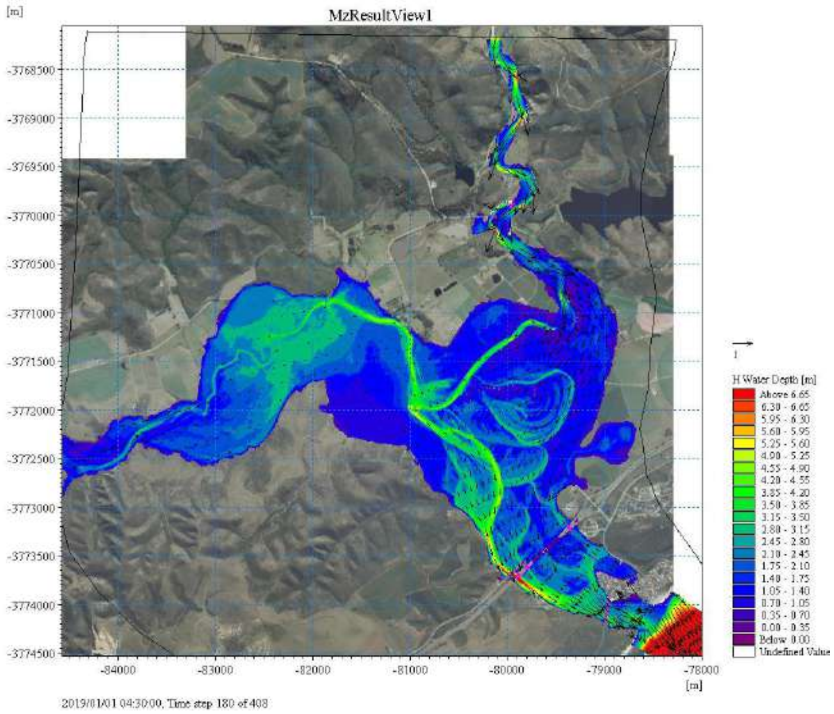


Figure C1-28: Simulated flow depths at the peak of the flood for the 100-year flood – future scenario with open mouth for Klein Brak

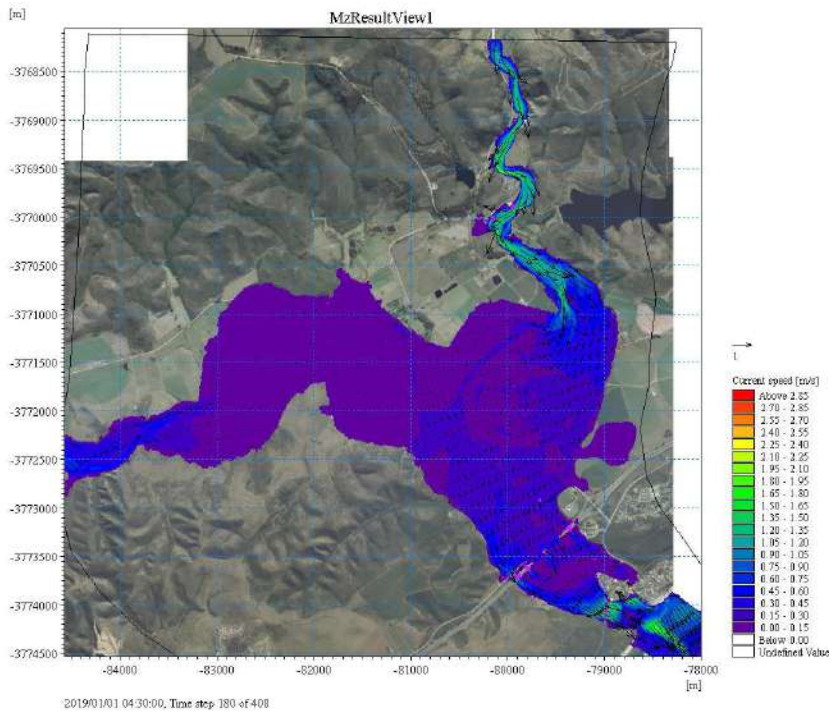


Figure C1-29: Simulated flow velocities and vectors at the peak of the flood for the 100-year flood – future scenario with open mouth for Klein Brak

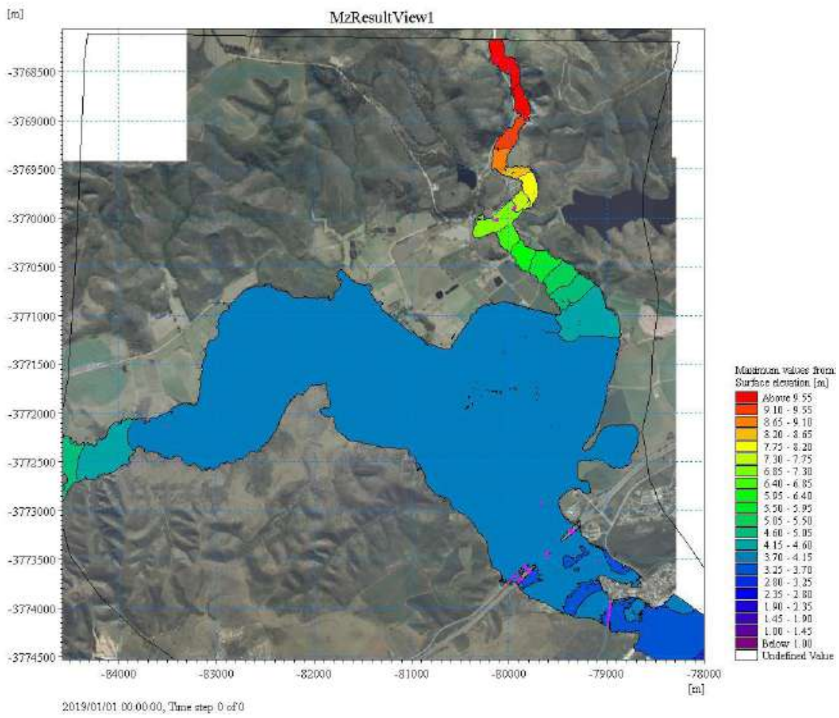


Figure C1-30: Simulated maximum flood levels for the 100-year flood – future scenario with open mouth (masl) for Klein Brak

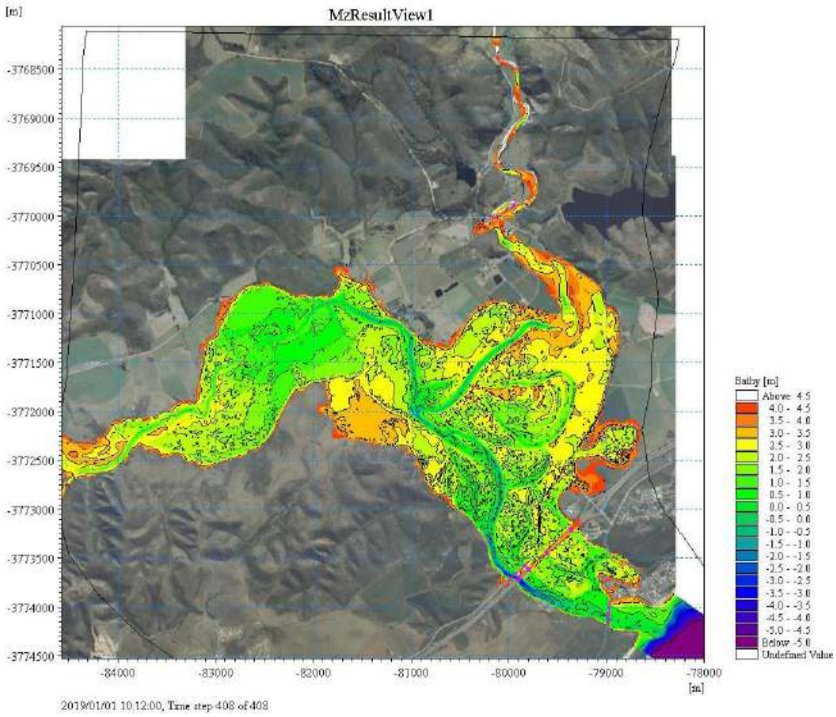


Figure C1-31: Simulated bed levels at end of the 100-year flood – future scenario with open mouth (masl) for Klein Brak

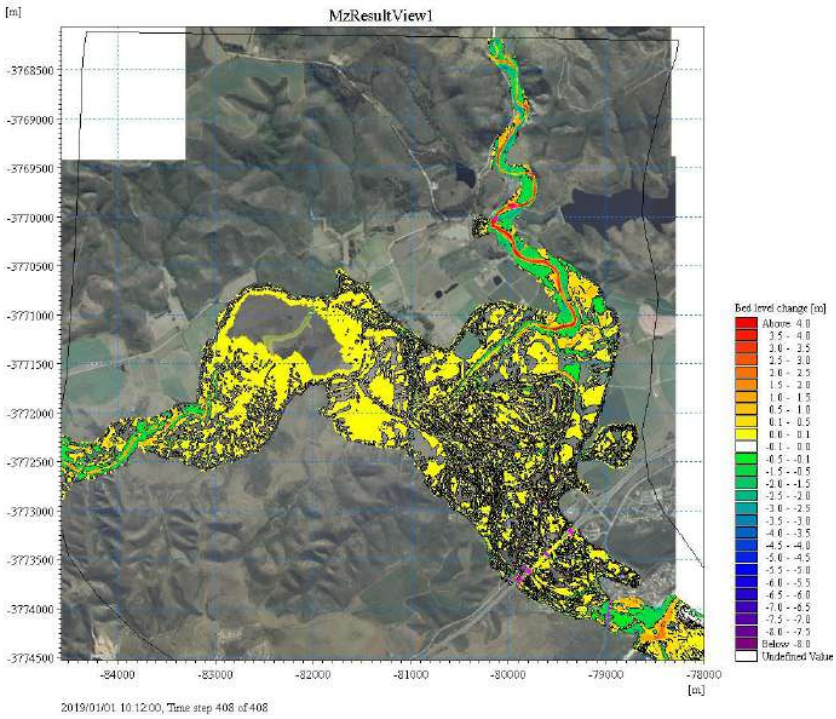


Figure C1-32: Simulated bed level (change) at end of the 100-year flood – future scenario with open mouth for Klein Brak

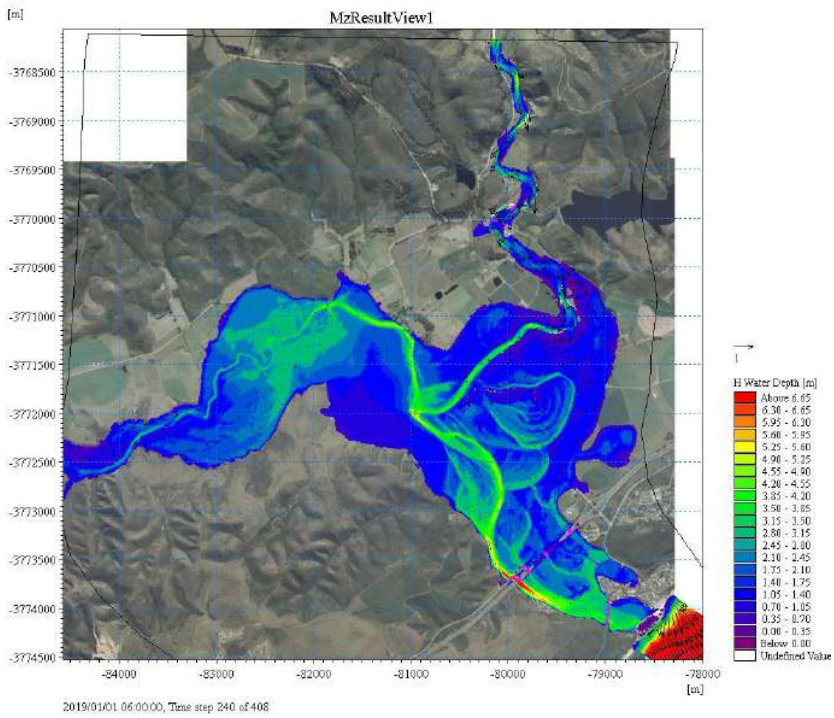


Figure C1-33: Simulated flow depths at the peak of the flood for the 50-year flood – future scenario with closed initial mouth condition for Klein Brak

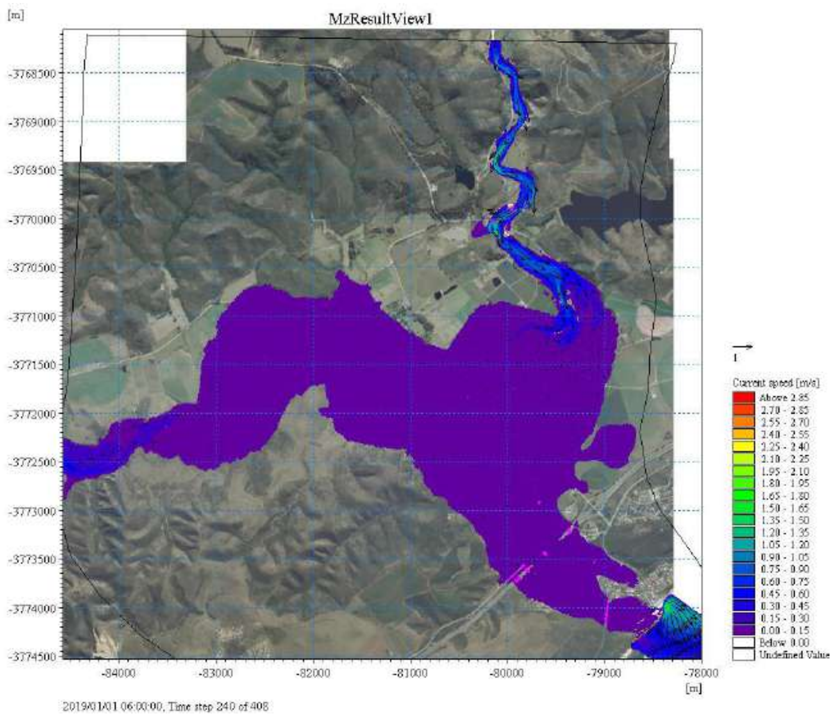


Figure C1-34: Simulated flow velocities and vectors at the peak of the flood for the 50-year flood – future scenario with closed initial mouth condition for Klein Brak

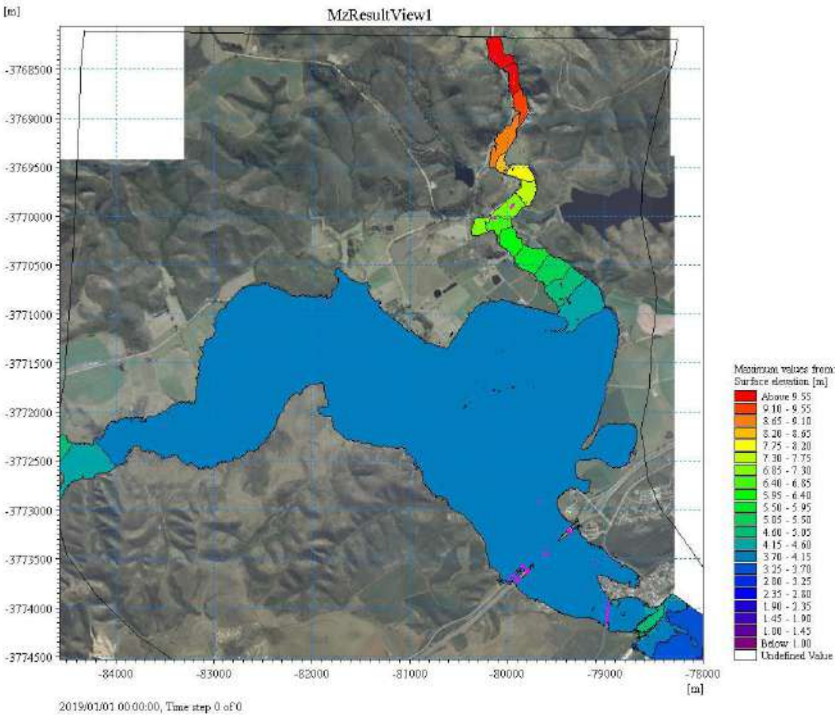


Figure C1-35: Simulated maximum flood levels for the 50-year flood – future scenario with closed initial mouth condition (masl) for Klein Brak

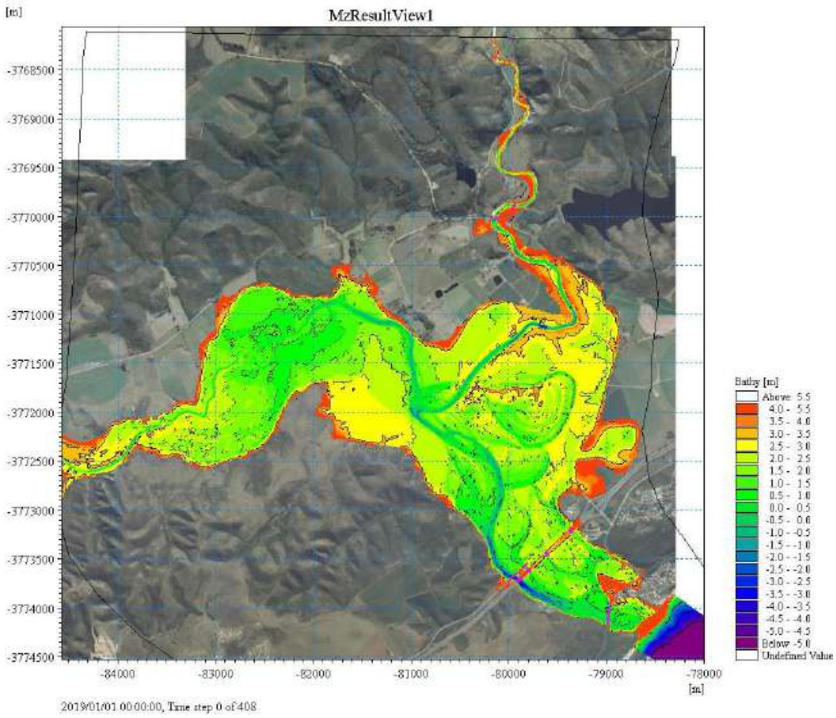


Figure C1-36: Initial bed levels – future scenario with closed initial mouth condition (masl) for Klein Brak

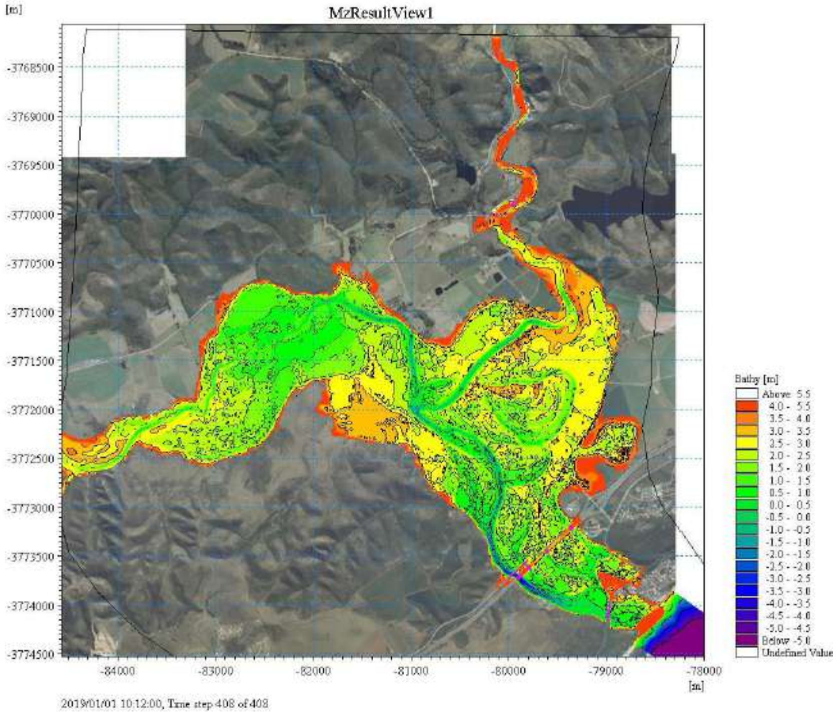


Figure C1-37: Simulated bed levels at end of the 50-year flood – future scenario with closed initial mouth condition (masl) for Klein Brak

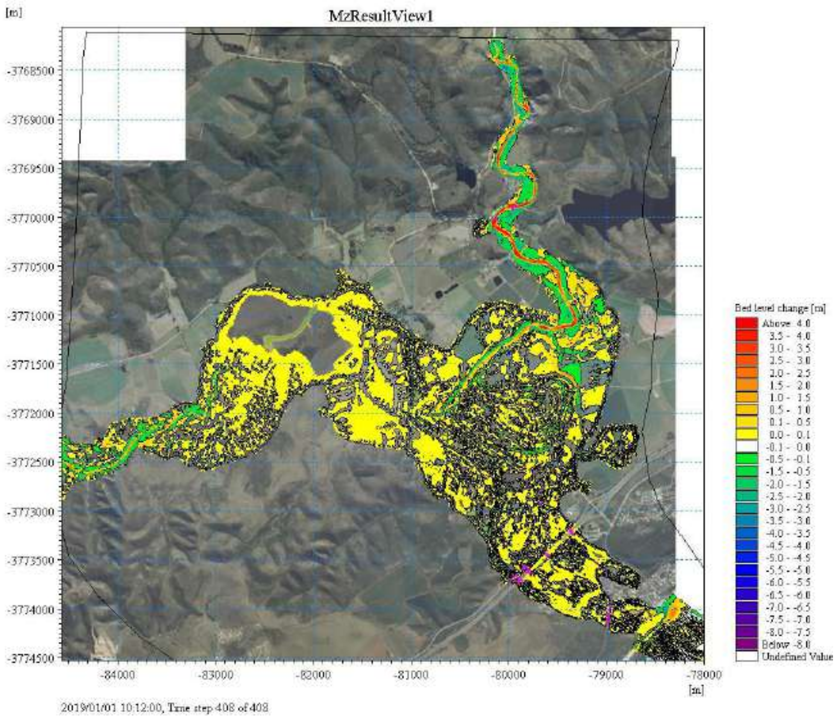


Figure C1-38: Simulated bed level (change) at end of the 50-year flood – future scenario with closed initial mouth condition for Klein Brak

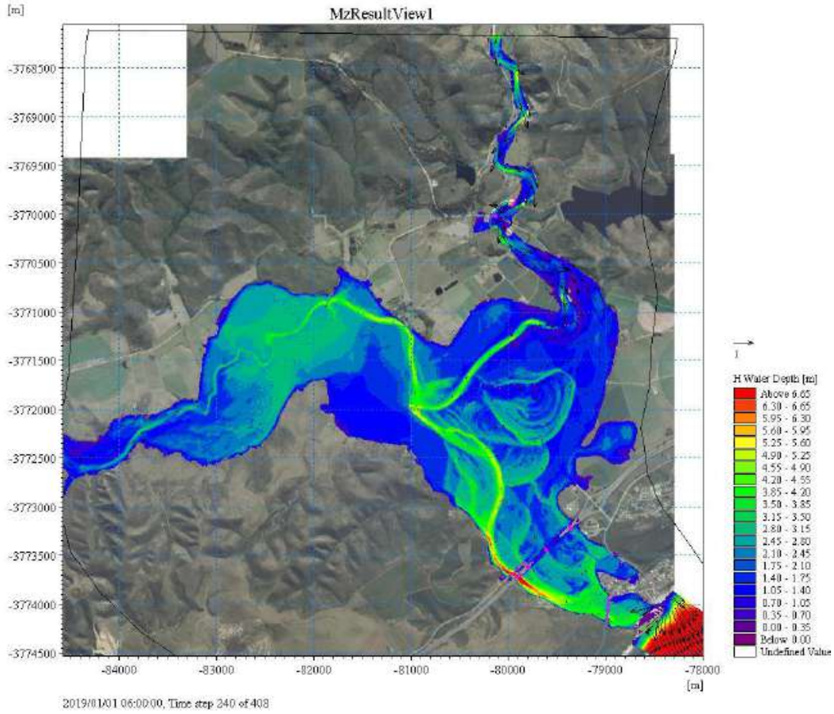


Figure C1-39: Simulated flow depths at the peak of the flood for the 100-year flood – future scenario with closed initial mouth condition for Klein Brak

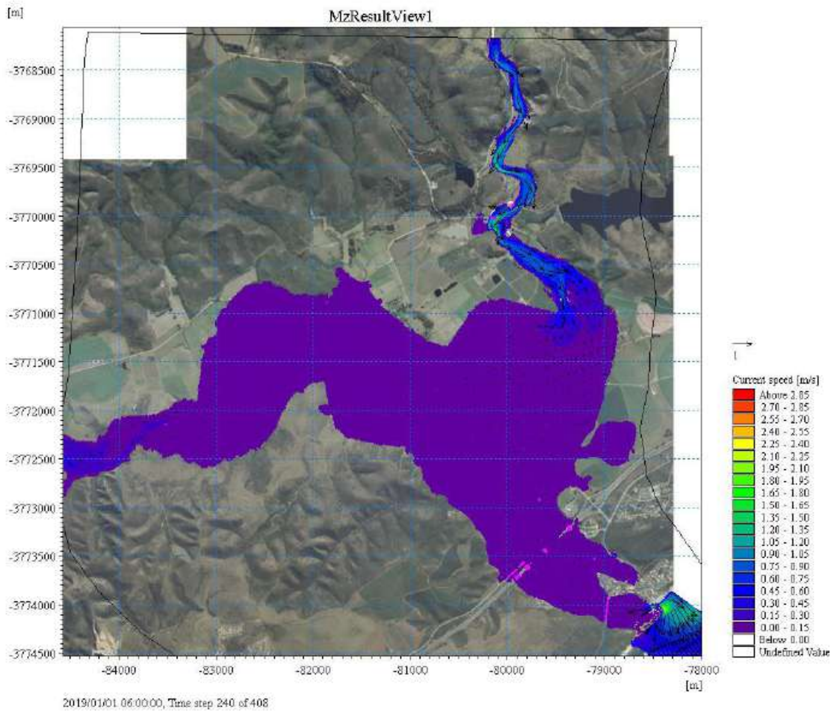


Figure C1-40: Simulated flow velocities and vectors at the peak of the flood for the 100-year flood – future scenario with closed initial mouth condition for Klein Brak

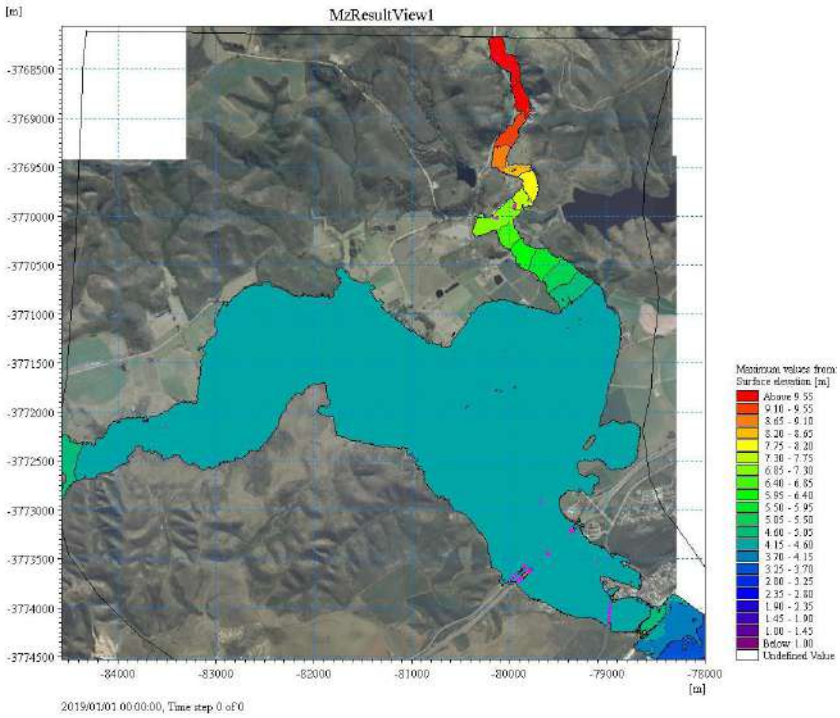


Figure C1-41: Simulated maximum flood levels for the 100-year flood – future scenario with closed initial mouth condition (masl) for Klein Brak

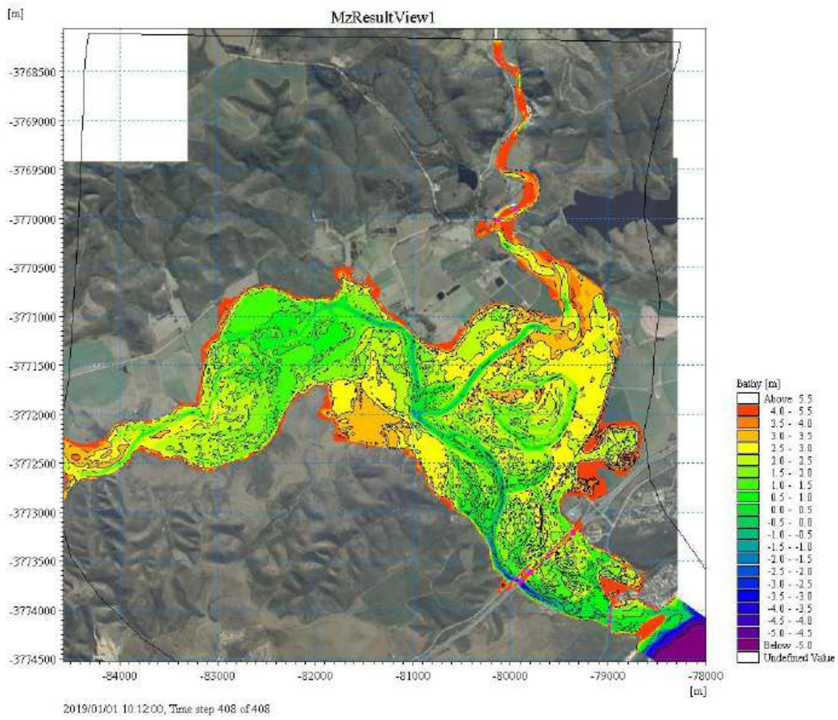


Figure C1-42: Simulated bed levels at end of the 100-year flood – future scenario with closed initial mouth condition (masl) for Klein Brak

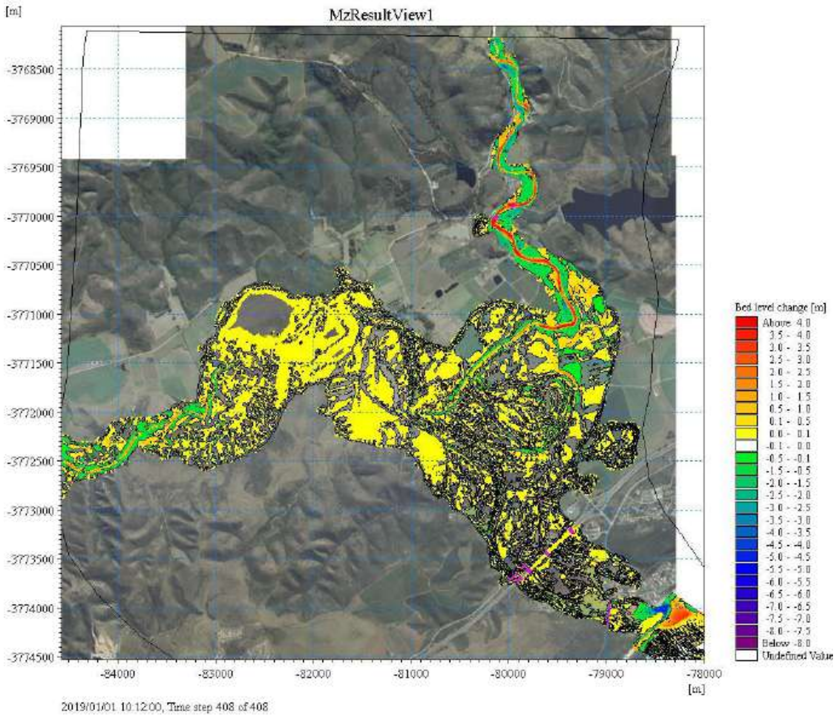


Figure C1-43: Simulated bed level (change) at end of the 100-year flood – future scenario with closed initial mouth condition for Klein Brak

APPENDIX C2: HYDRODYNAMIC MODELLING OF GROOT BRAK

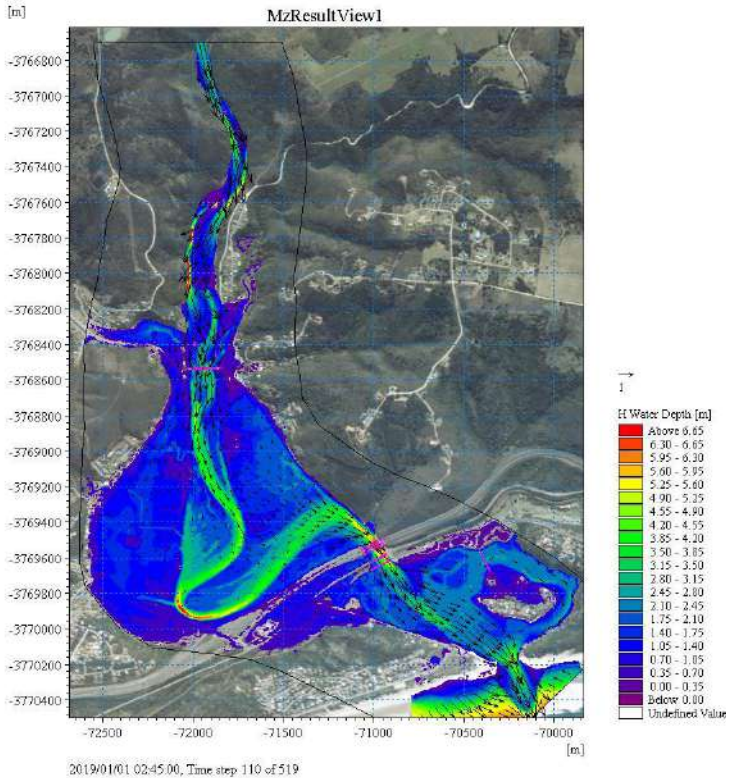


Figure C2-1: Simulated flow depths at the peak of the flood for the 50-year flood – current scenario with open mouth for Groot Brak

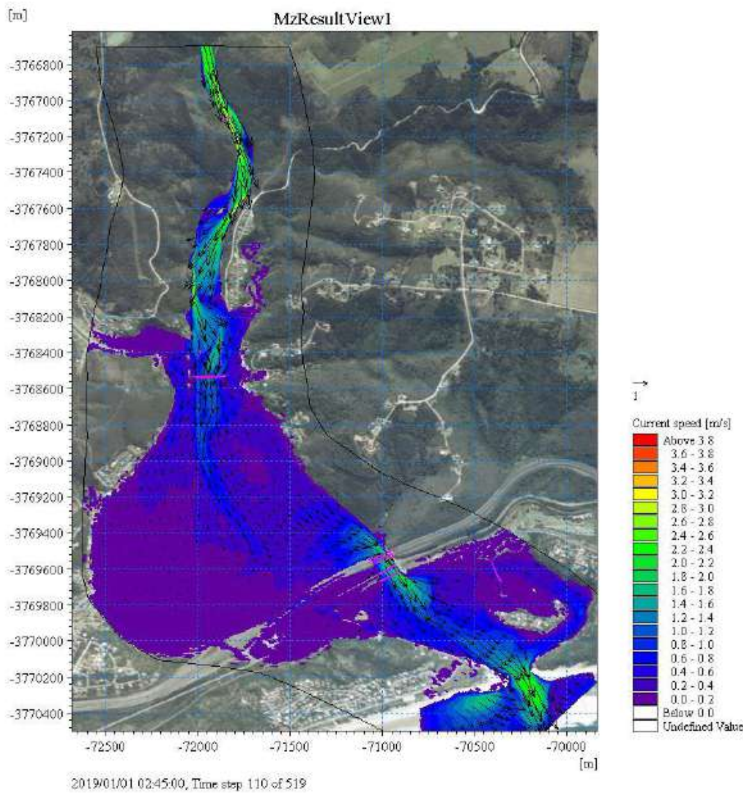


Figure C2-2: Simulated flow velocities and vectors at the peak of the flood for the 50-year flood – current scenario with open mouth for Groot Brak

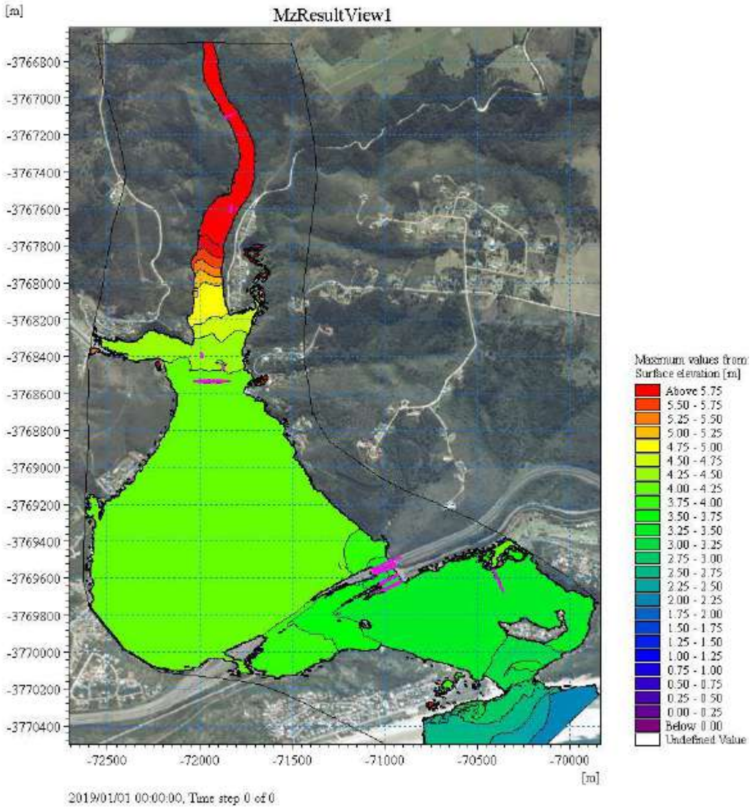


Figure C2-3: Simulated maximum flood levels for the 50-year flood – current scenario with open mouth (masl) for Groot Brak

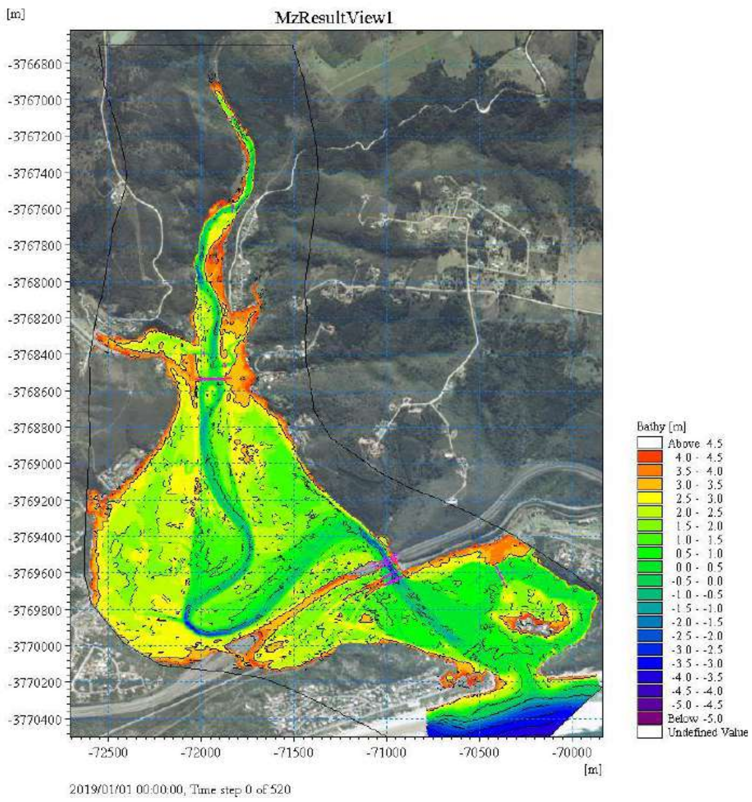


Figure C2-4: Initial bed levels – current scenario with open mouth (masl) for Groot Brak

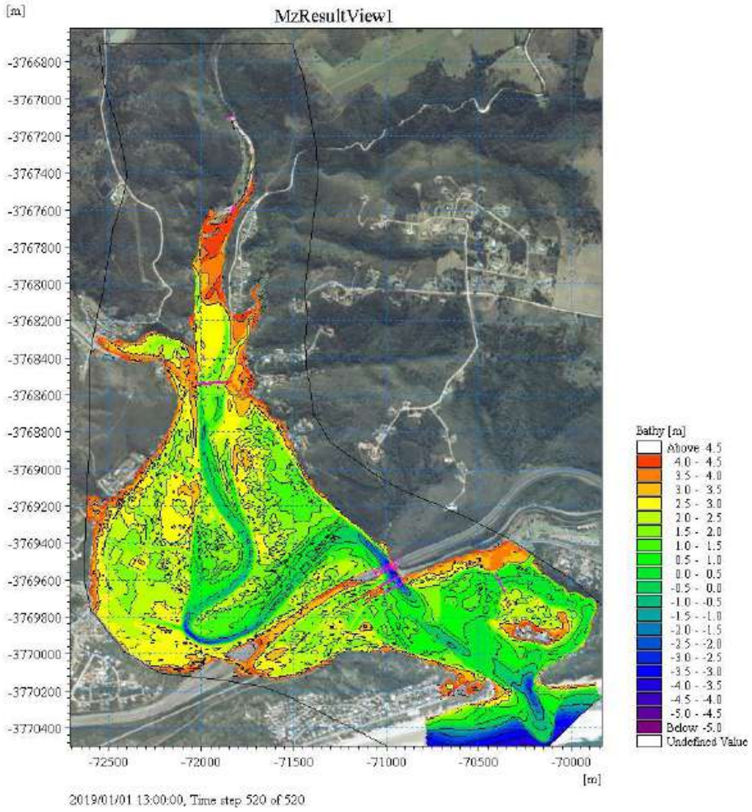


Figure C2-5: Simulated bed levels at end of the 50-year flood – current scenario with open mouth (masl) for Groot Brak

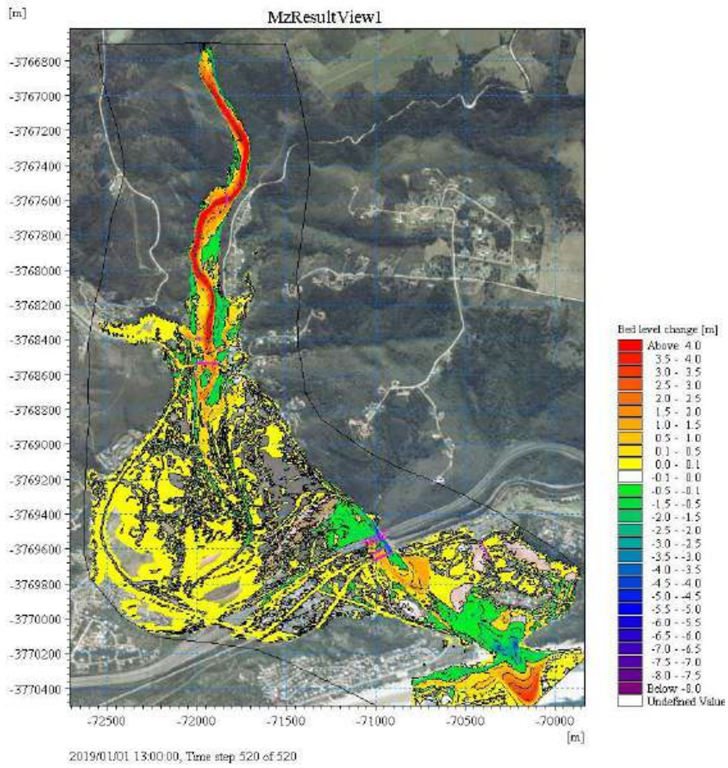


Figure C2-6: Simulated bed level (change) at end of the 50-year flood – current scenario with open mouth for Groot Brak

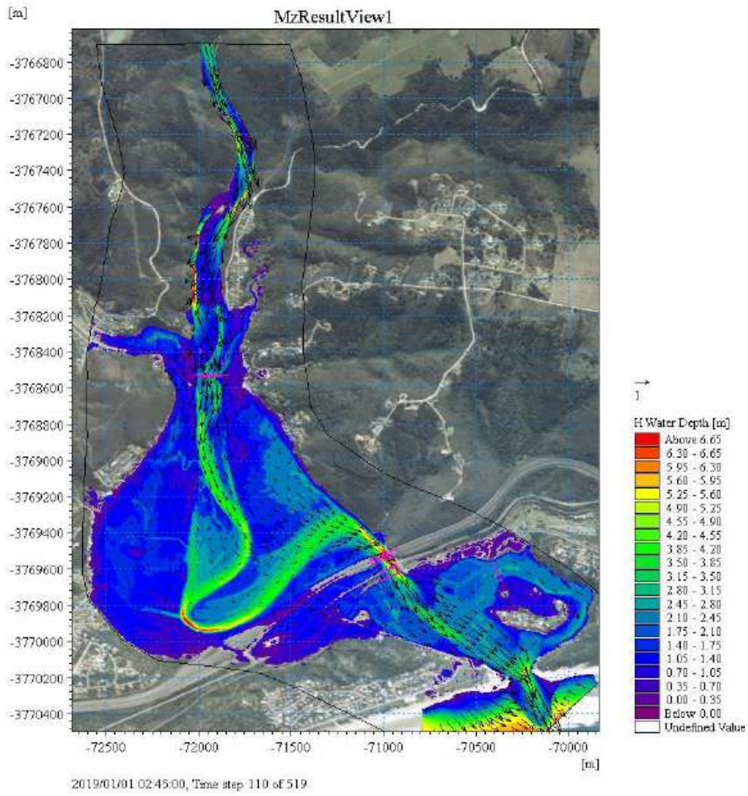


Figure C2-7: Simulated flow depths at the peak of the flood for the 100-year flood – current scenario with open mouth for Groot Brak

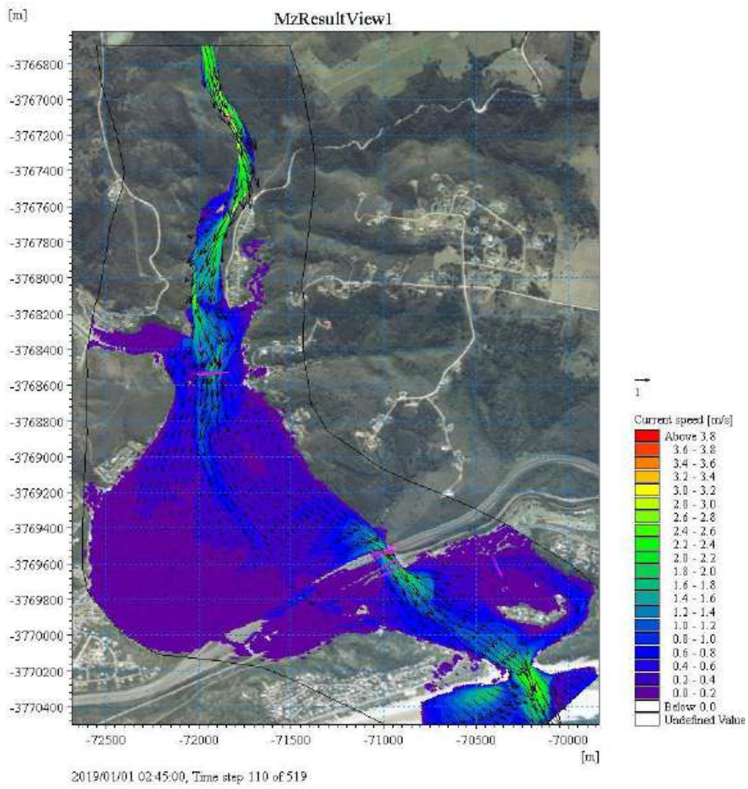


Figure C2-8: Simulated flow velocities and vectors at the peak of the flood for the 100-year flood – current scenario with open mouth for Groot Brak

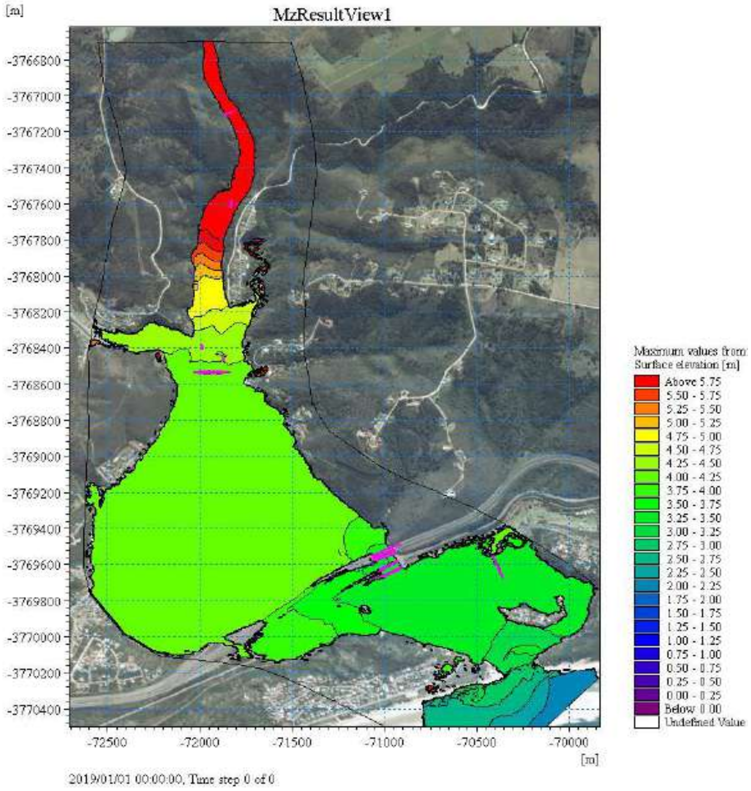


Figure C2-9: Simulated maximum flood levels for the 100-year flood – current scenario with open mouth (masl) for Groot Brak

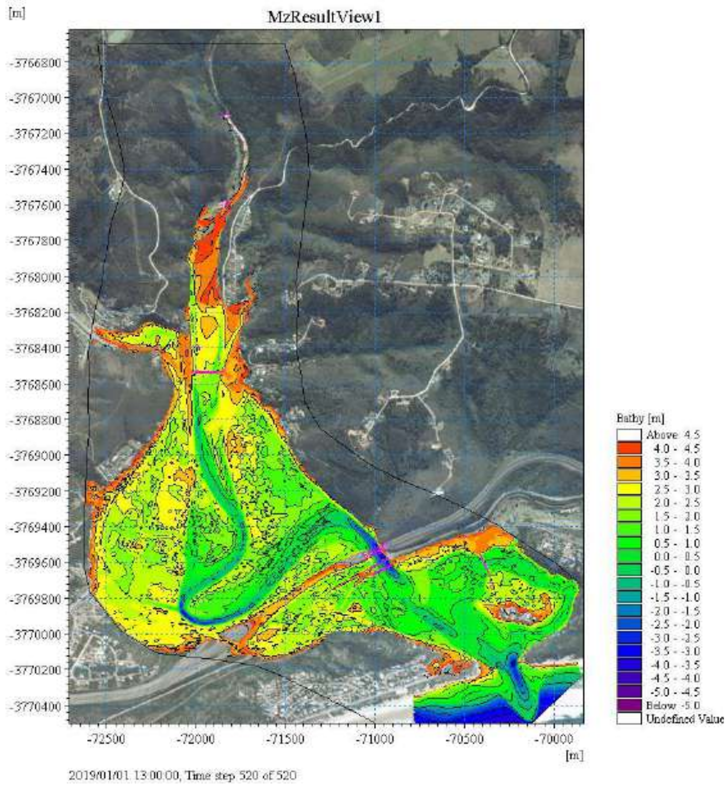


Figure C2-10: Simulated bed levels at end of the 100-year flood – current scenario with open mouth (masl) for Groot Brak

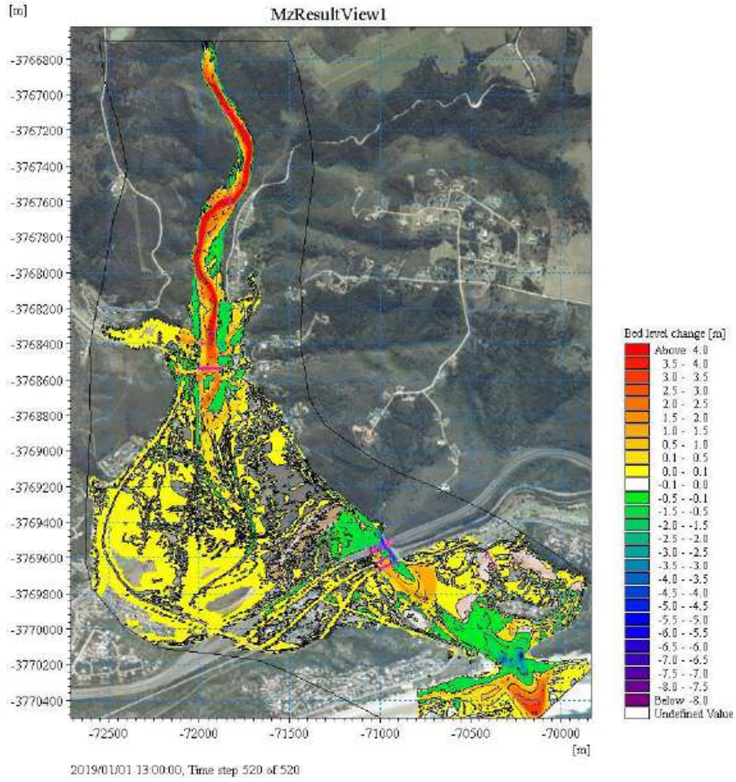


Figure C2-11: Simulated bed level (change) at end of the 100-year flood – current scenario with open mouth for Groot Brak

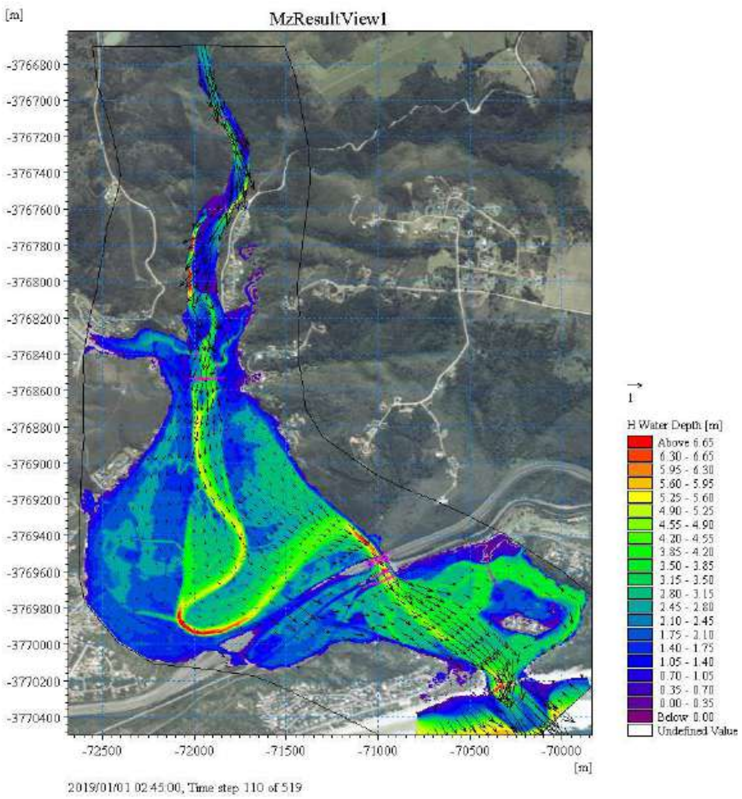


Figure C2-12: Simulated flow depths at the peak of the flood for the 50-year flood – current scenario with closed initial mouth condition for Groot Brak

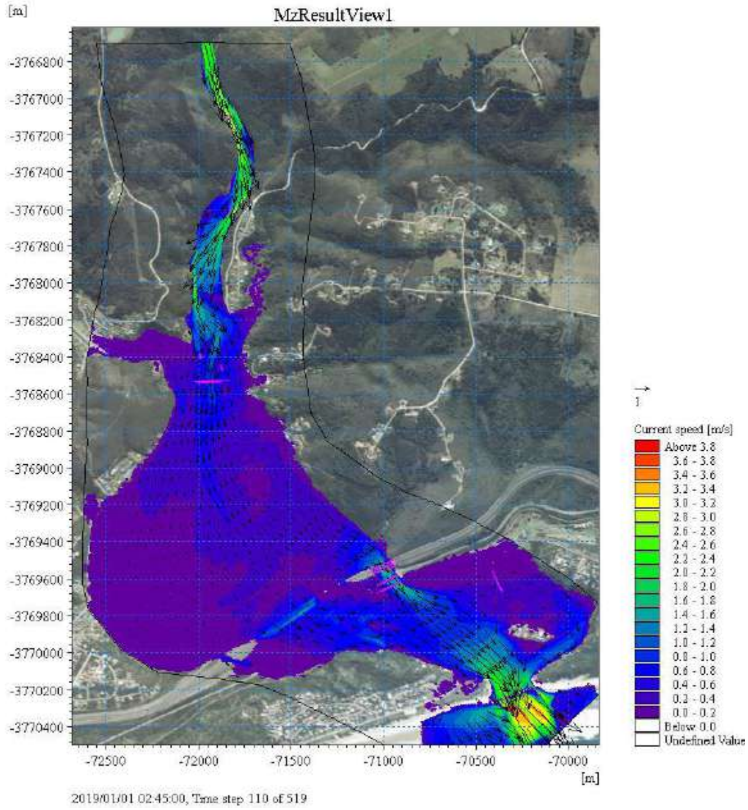


Figure C2-13: Simulated flow velocities and vectors at the peak of the flood for the 50-year flood – current scenario with closed initial mouth condition for Groot Brak

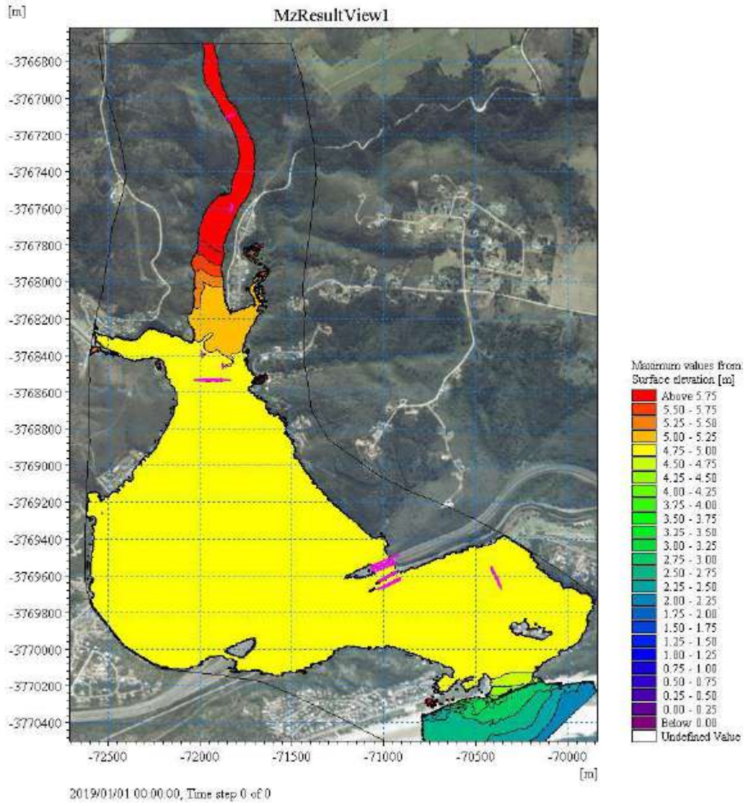


Figure C2-14: Simulated maximum flood levels for the 50-year flood – current scenario with closed initial mouth condition (masl) for Groot Brak

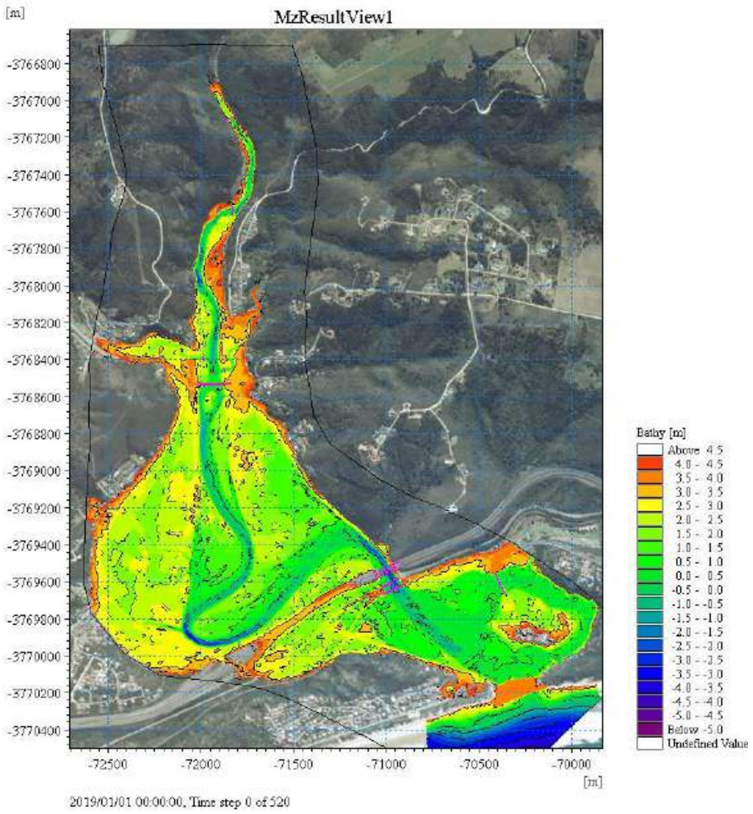


Figure C2-15: Initial bed levels – current scenario with closed initial mouth condition (masl) for Groot Brak

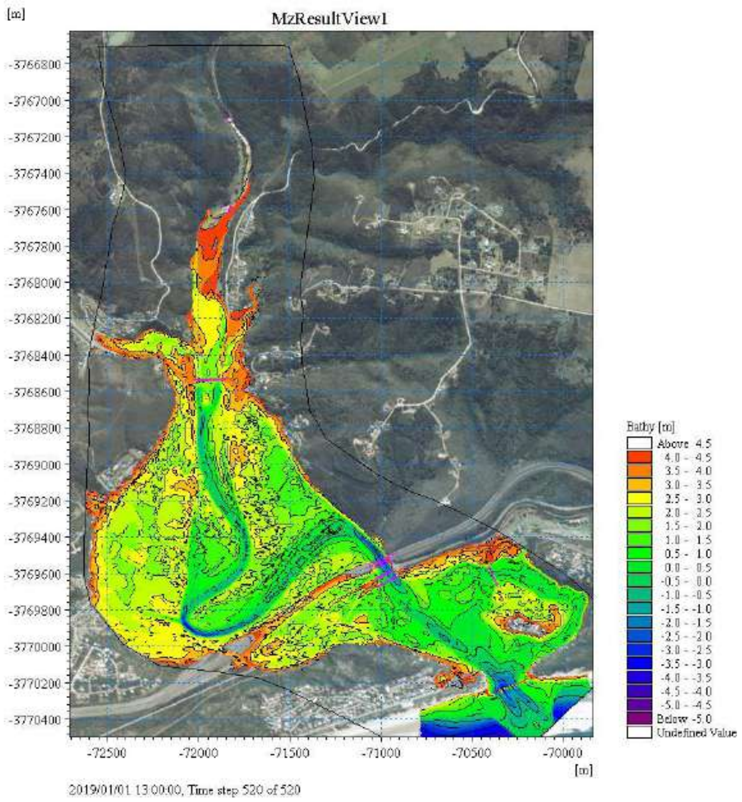


Figure C2-16: Simulated bed levels at end of the 50-year flood – current scenario with closed initial mouth condition (masl) for Groot Brak

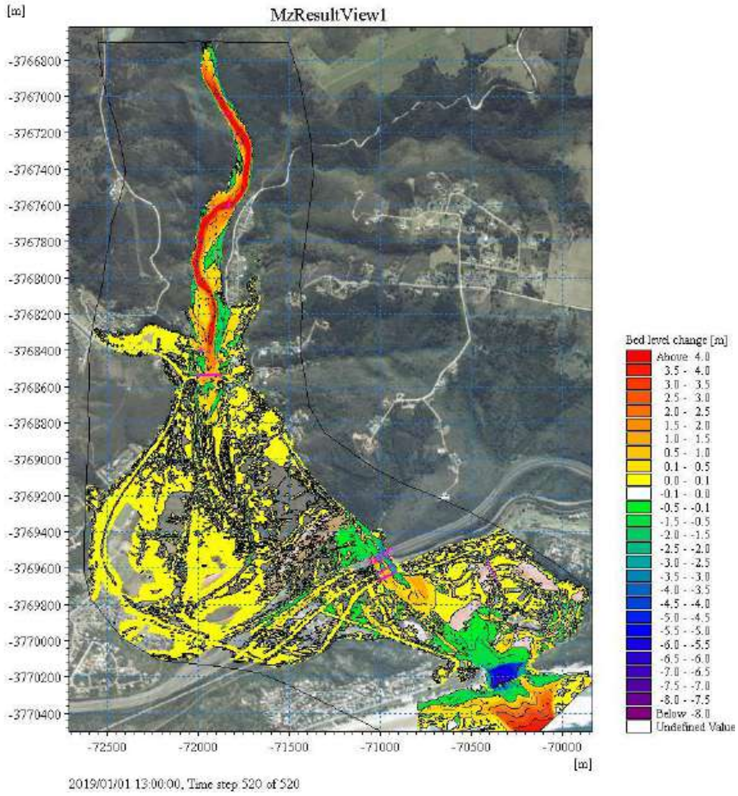


Figure C2-17: Simulated bed level (change) at end of the 50-year flood – current scenario with closed initial mouth condition for Groot Brak

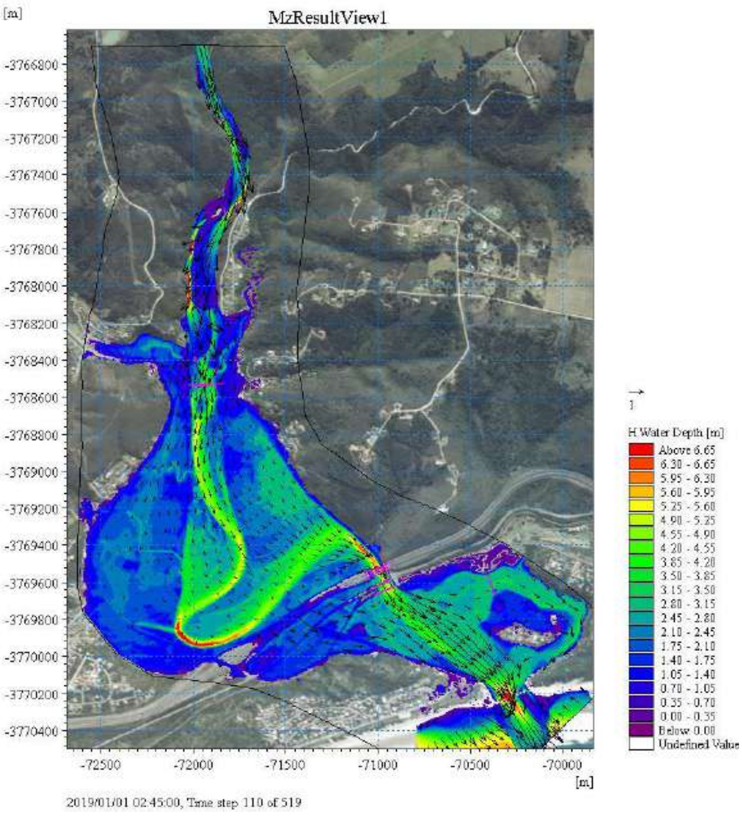


Figure C2-18: Simulated flow depths at the peak of the flood for the 100-year flood – current scenario with closed initial mouth condition for Groot Brak

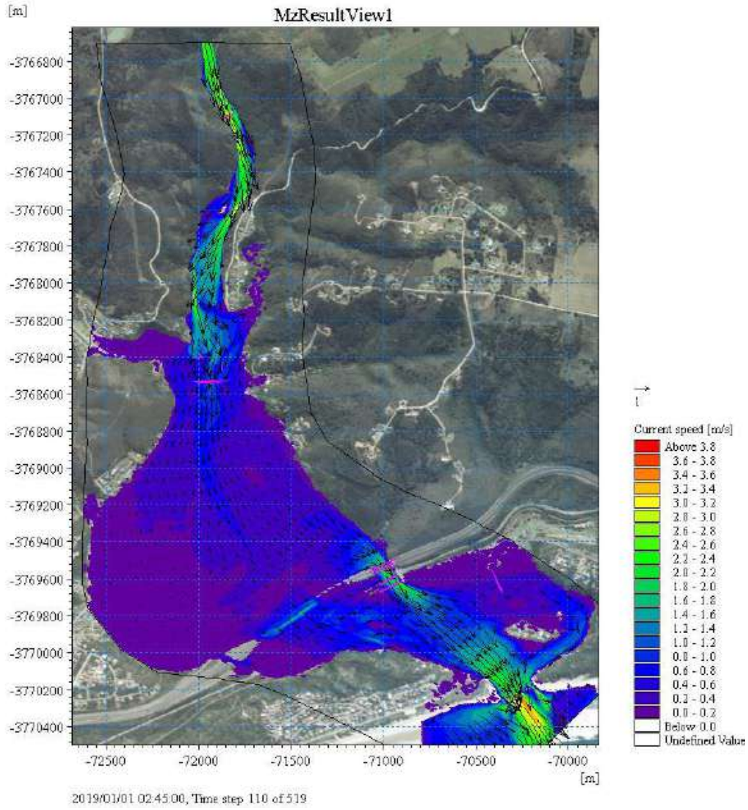


Figure C2-19: Simulated flow velocities and vectors at the peak of the flood for the 100-year flood – current scenario with closed initial mouth condition for Groot Brak

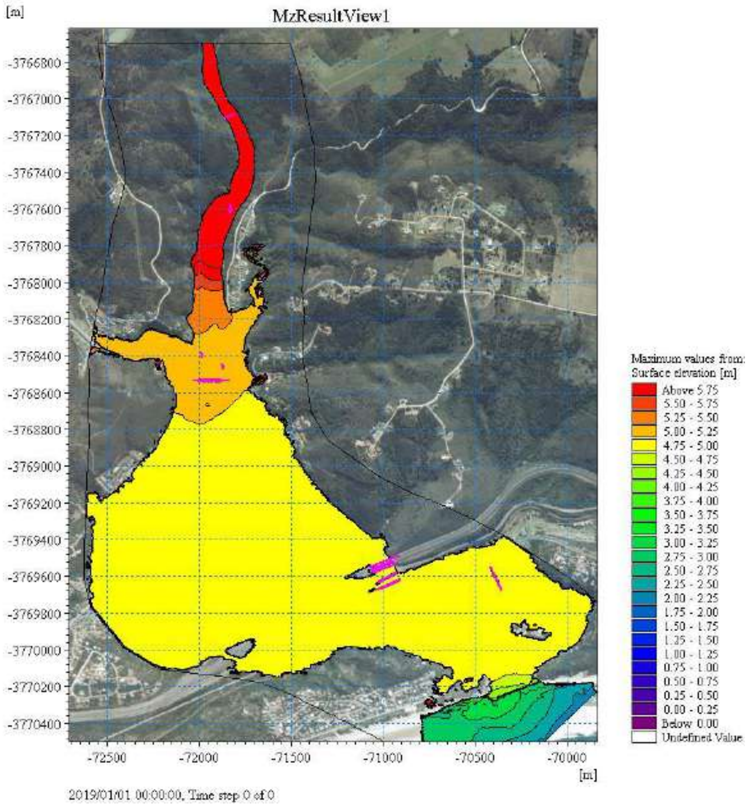


Figure C2-20: Simulated maximum flood levels for the 100-year flood – current scenario with closed initial mouth condition (masl) for Groot Brak

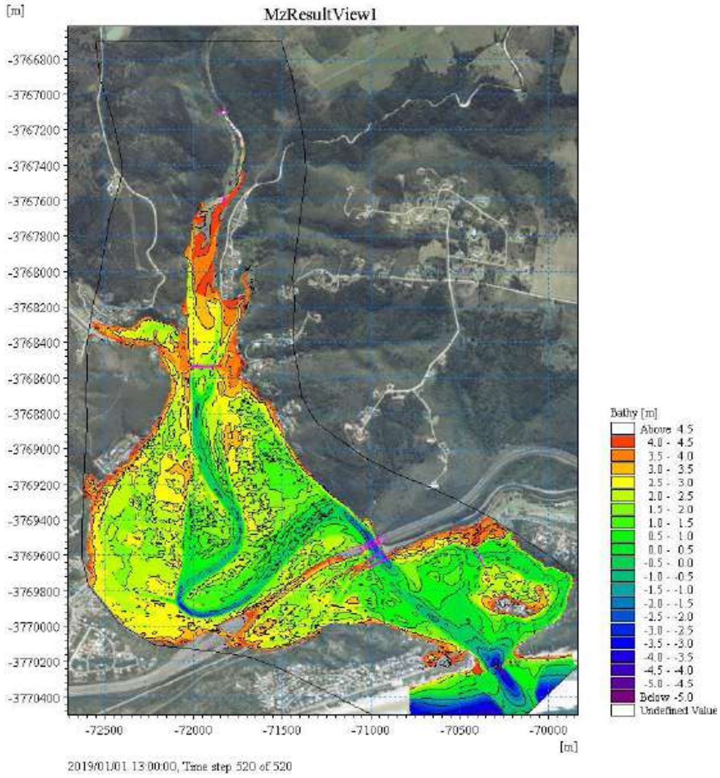


Figure C2-21: Simulated bed levels at end of the 100-year flood – current scenario with closed initial mouth condition (masl) for Groot Brak

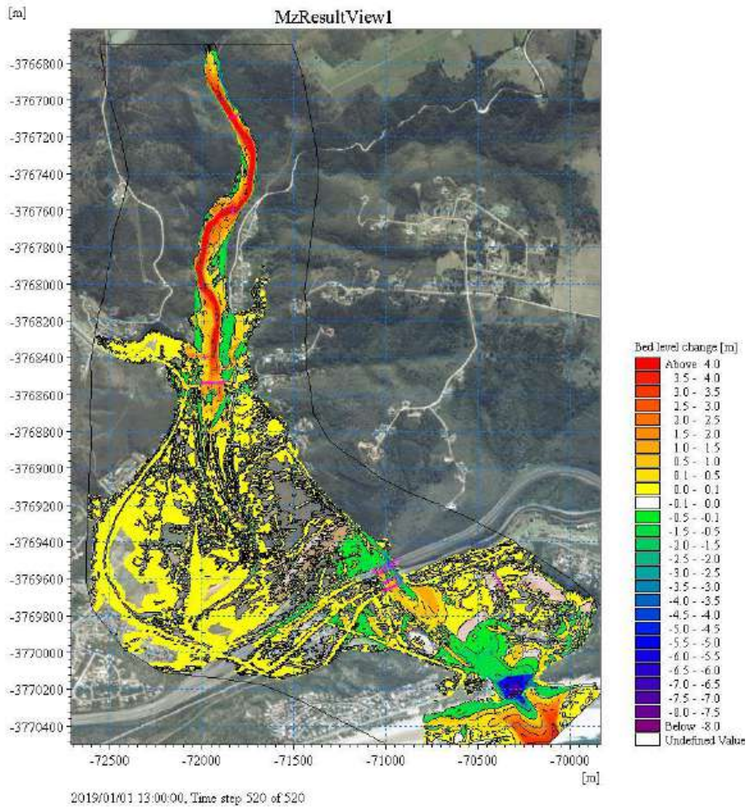


Figure C2-22: Simulated bed level (change) at end of the 100-year flood – current scenario with closed initial mouth condition for Groot Brak

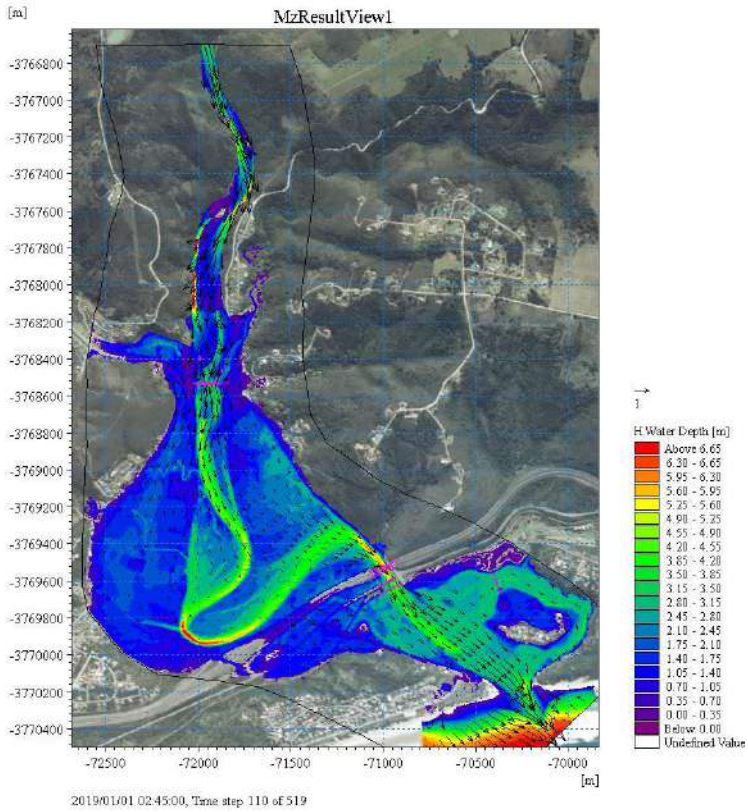


Figure C2-23: Simulated flow depths at the peak of the flood for the 50-year flood – future scenario with open mouth for Groot Brak

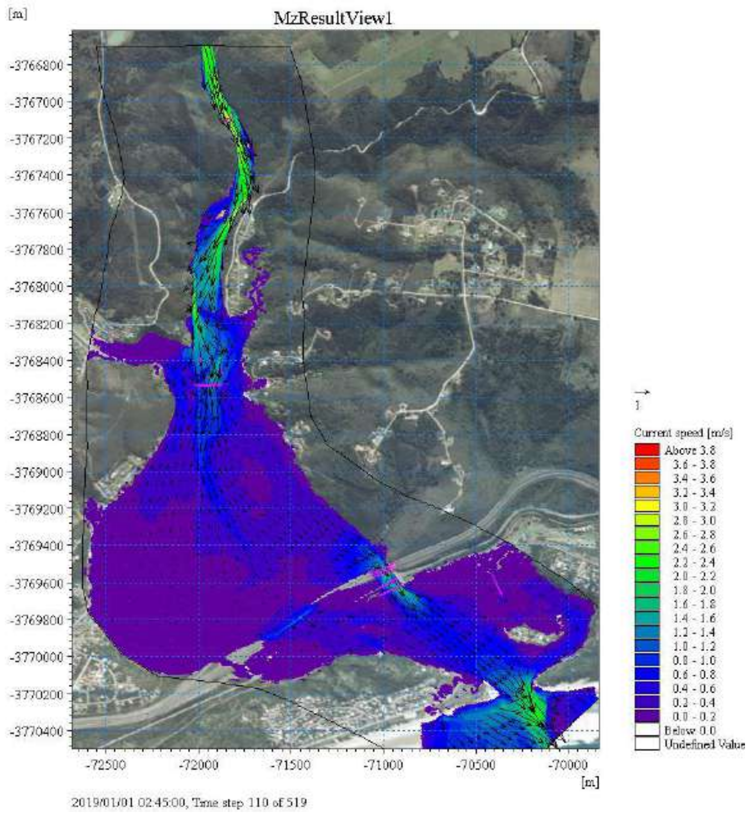


Figure C2-24: Simulated flow velocities and vectors at the peak of the flood for the 50-year flood – future scenario with open mouth for Groot Brak

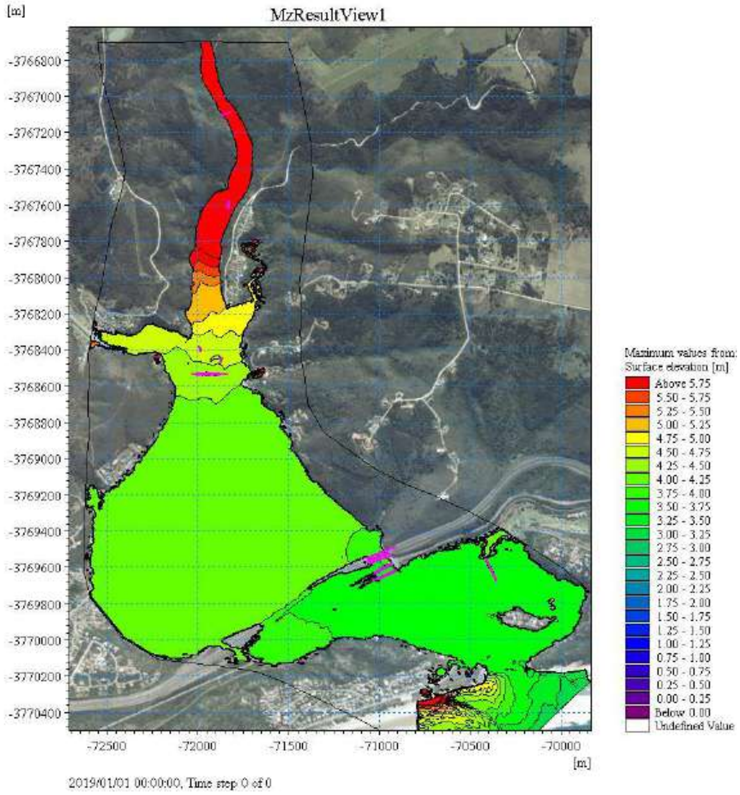


Figure C2-25: Simulated maximum flood levels for the 50-year flood – future scenario with open mouth (masl) for Groot Brak

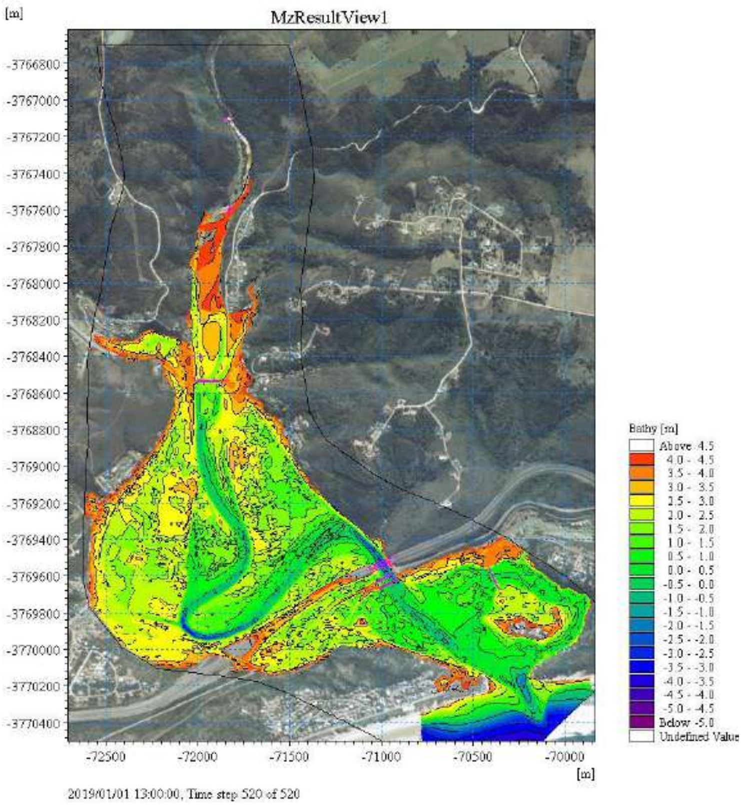


Figure C2-26: Simulated bed levels at end of the 50-year flood – future scenario with open mouth (masl) for Groot Brak

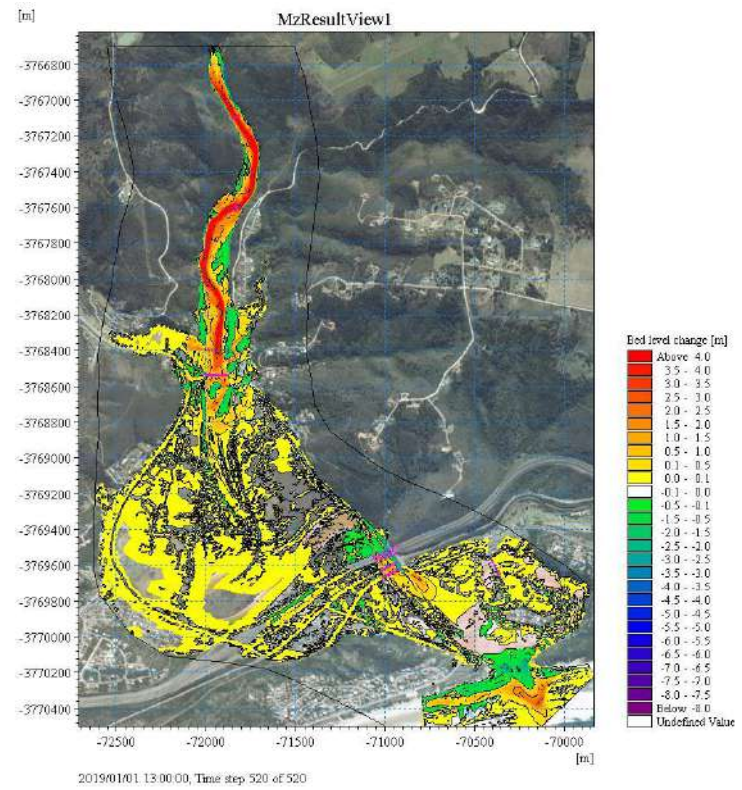


Figure C2-27: Simulated bed level (change) at end of the 50-year flood – future scenario with open mouth for Groot Brak

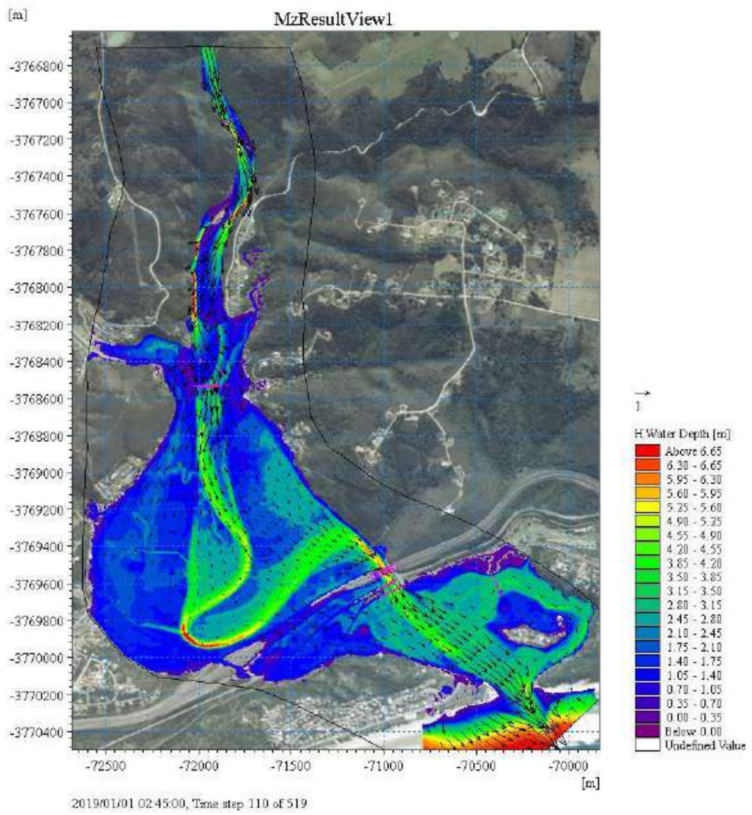


Figure C2-28: Simulated flow depths at the peak of the flood for the 100-year flood – future scenario with open mouth for Groot Brak

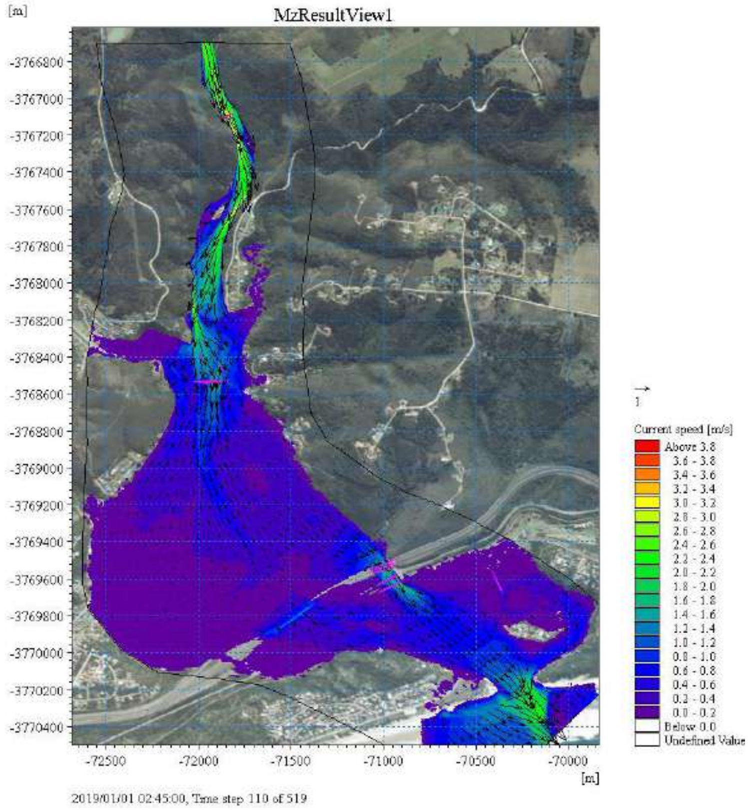


Figure C2-29: Simulated flow velocities and vectors at the peak of the flood for the 100-year flood – future scenario with open mouth for Groot Brak

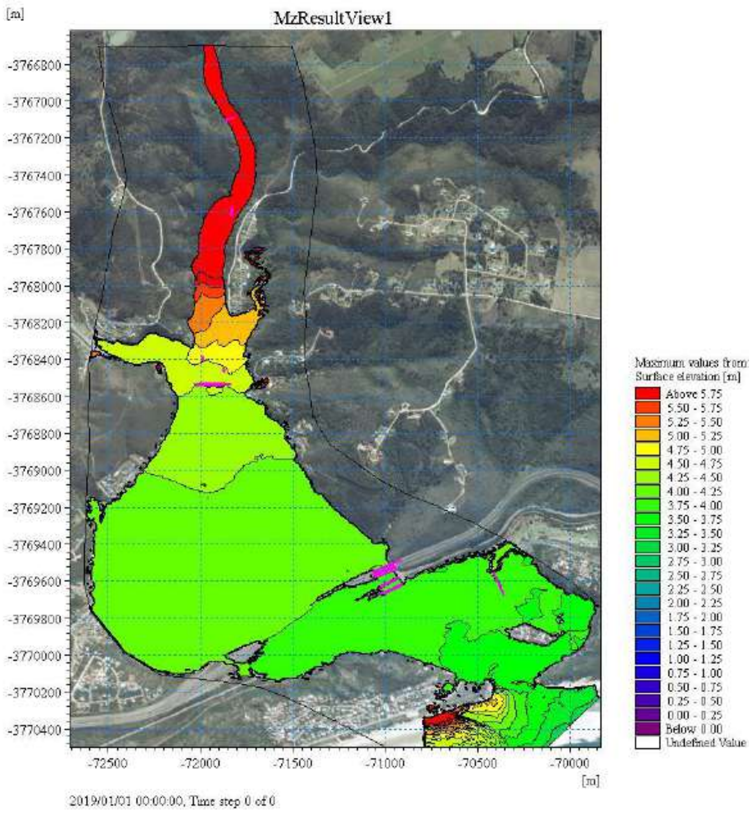


Figure C2-30: Simulated maximum flood levels for the 100-year flood – future scenario with open mouth (masl) for Groot Brak

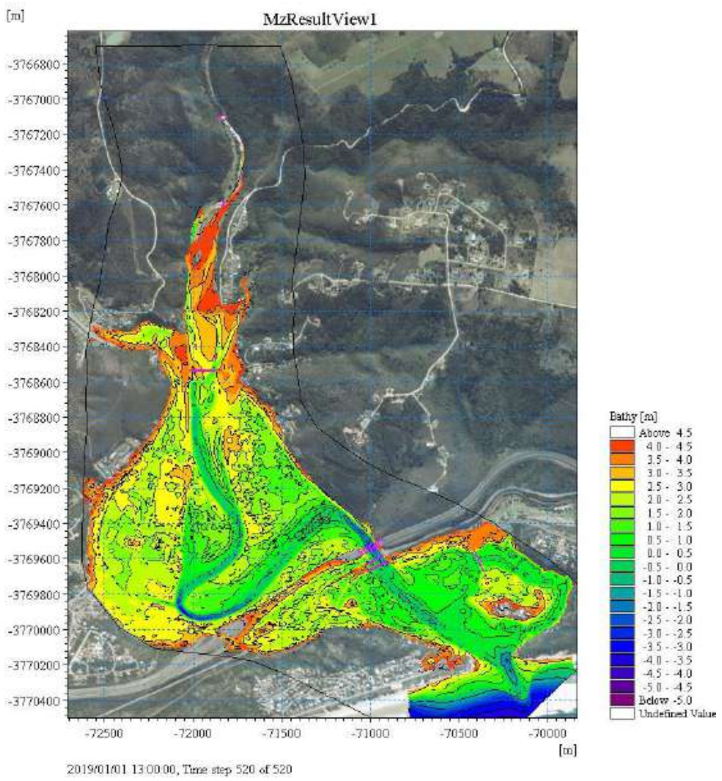


Figure C2-31: Simulated bed levels at end of the 100-year flood – future scenario with open mouth (masl) for Groot Brak

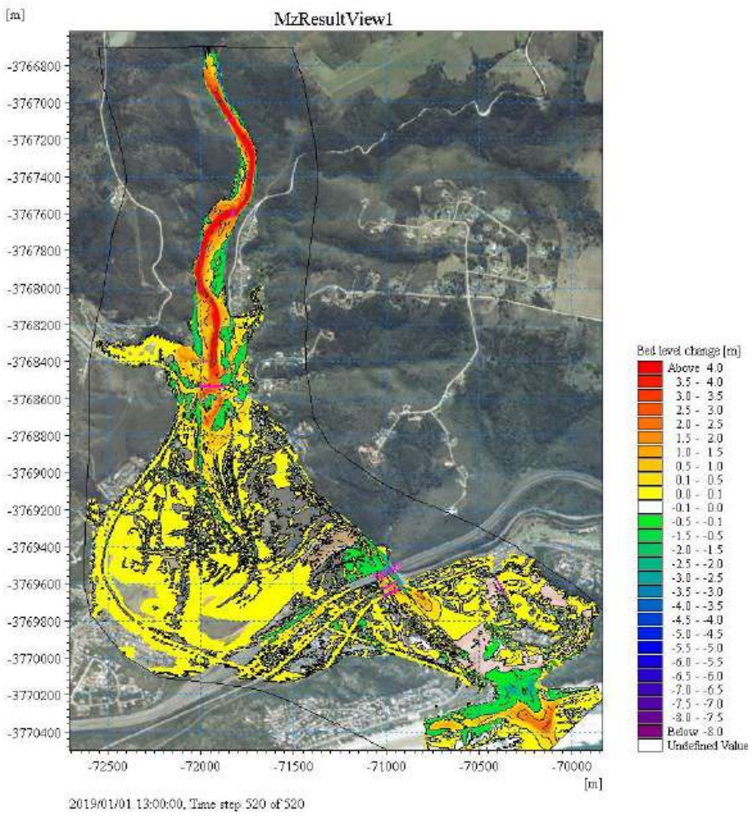


Figure C2-32: Simulated bed level (change) at end of the 100-year flood – future scenario with open mouth for Groot Brak

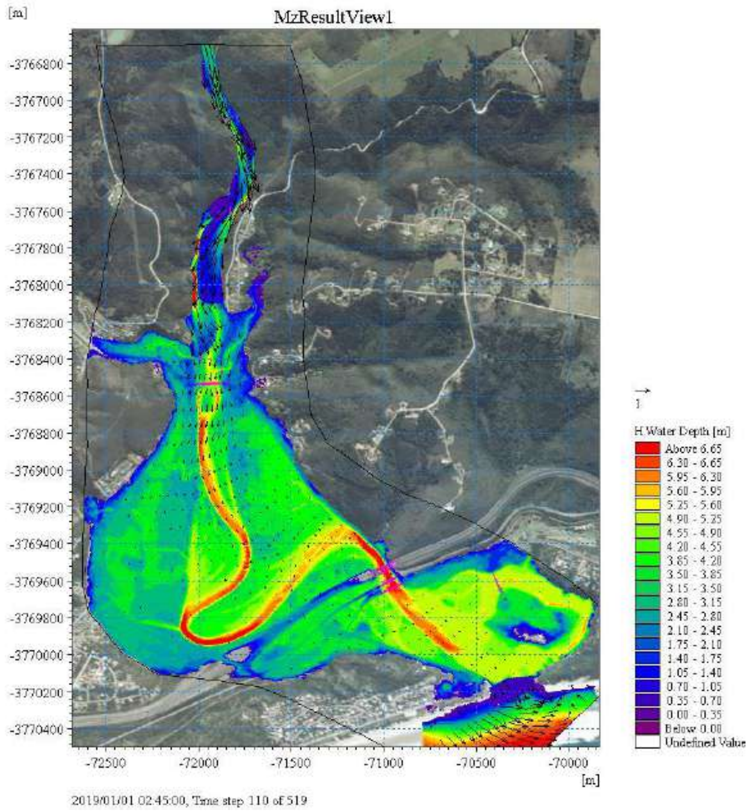


Figure C2-33: Simulated flow depths at the peak of the flood for the 50-year flood – future scenario with closed initial mouth condition for Groot Brak

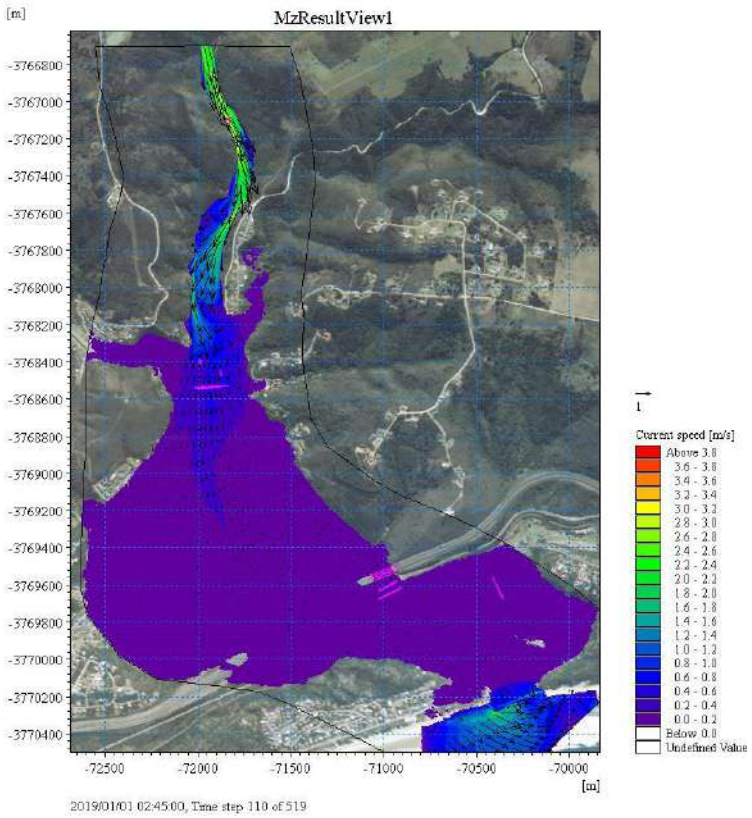


Figure C2-34: Simulated flow velocities and vectors at the peak of the flood for the 50-year flood – future scenario with closed initial mouth condition for Groot Brak

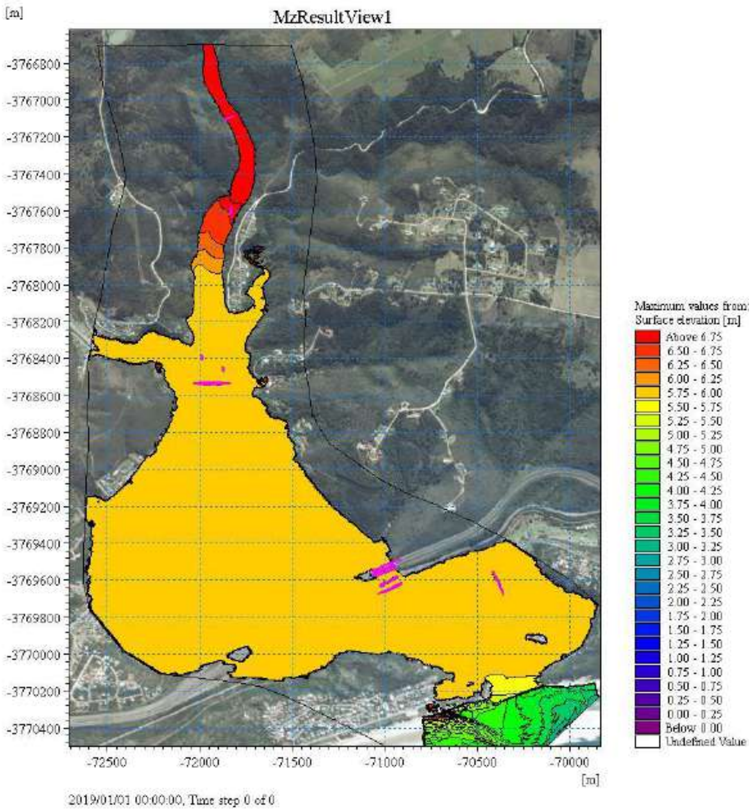


Figure C2-35: Simulated maximum flood levels for the 50-year flood – future scenario with closed initial mouth condition (masl) for Groot Brak

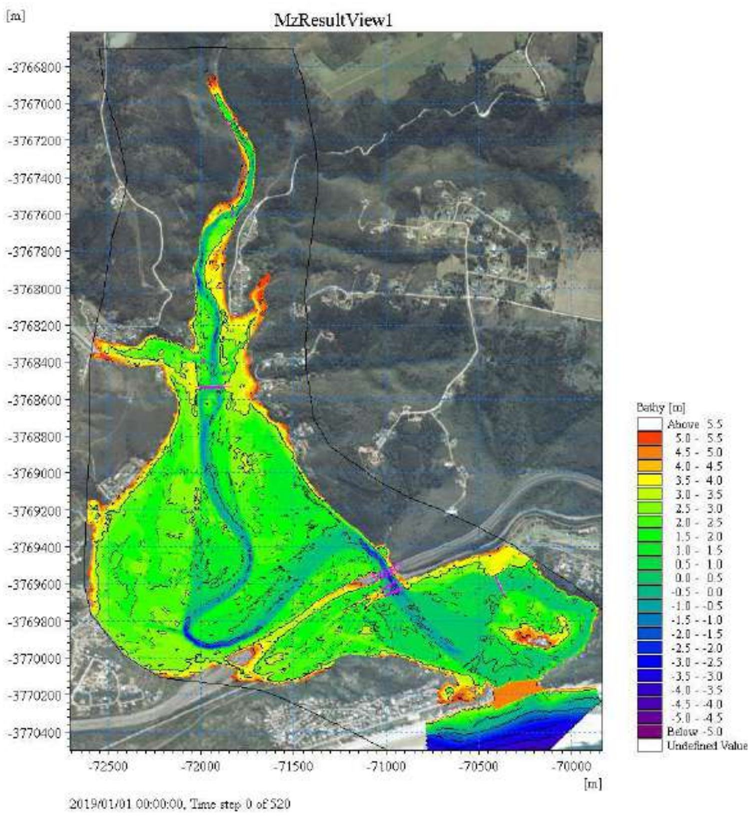


Figure C2-36: Initial bed levels – future scenario with closed initial mouth condition (masl) for Groot Brak

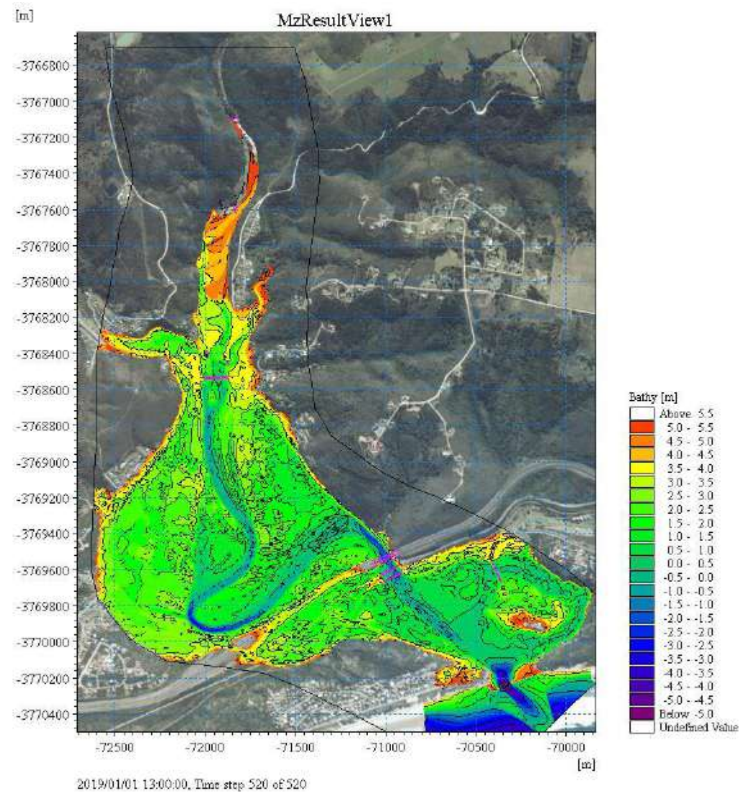


Figure C2-37: Simulated bed levels at end of the 50-year flood – future scenario with closed initial mouth condition (masl) for Groot Brak

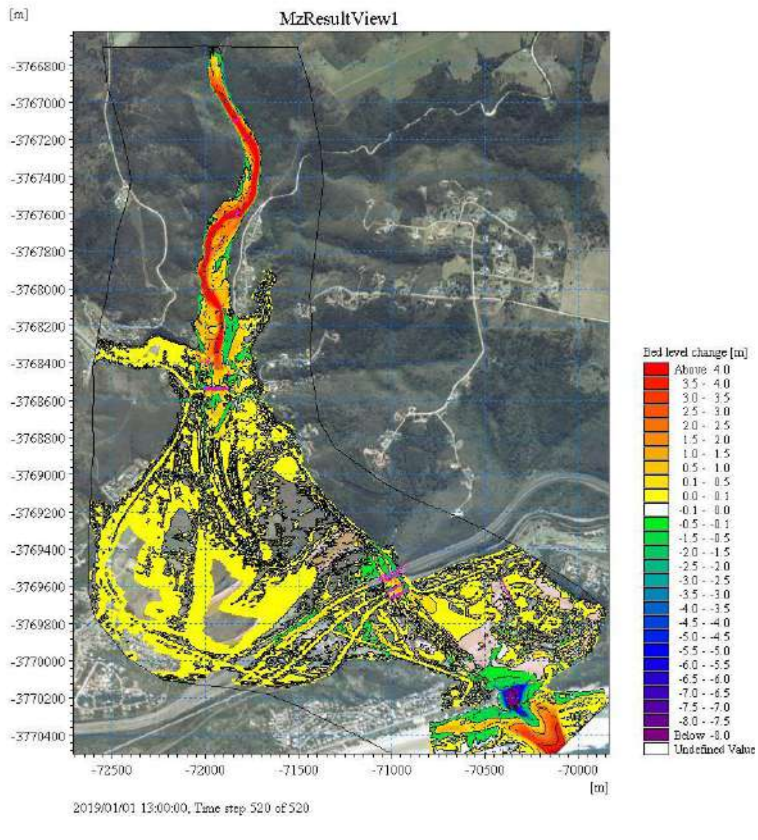


Figure C2-38: Simulated bed level (change) at end of the 50-year flood – future scenario with closed initial mouth condition for Groot Brak

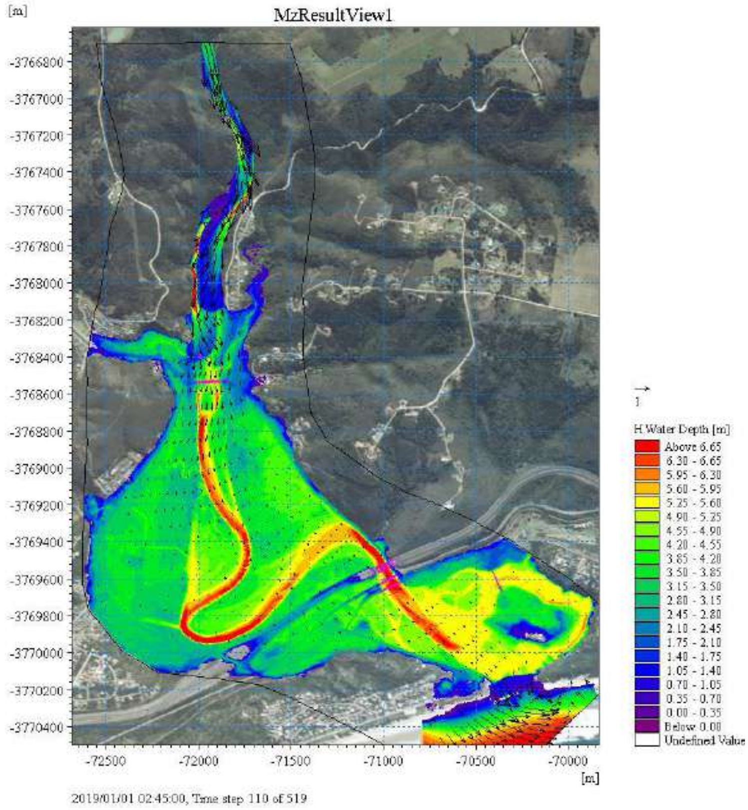


Figure C2-39: Simulated flow depths at the peak of the flood for the 100-year flood – future scenario with closed initial mouth condition for Groot Brak

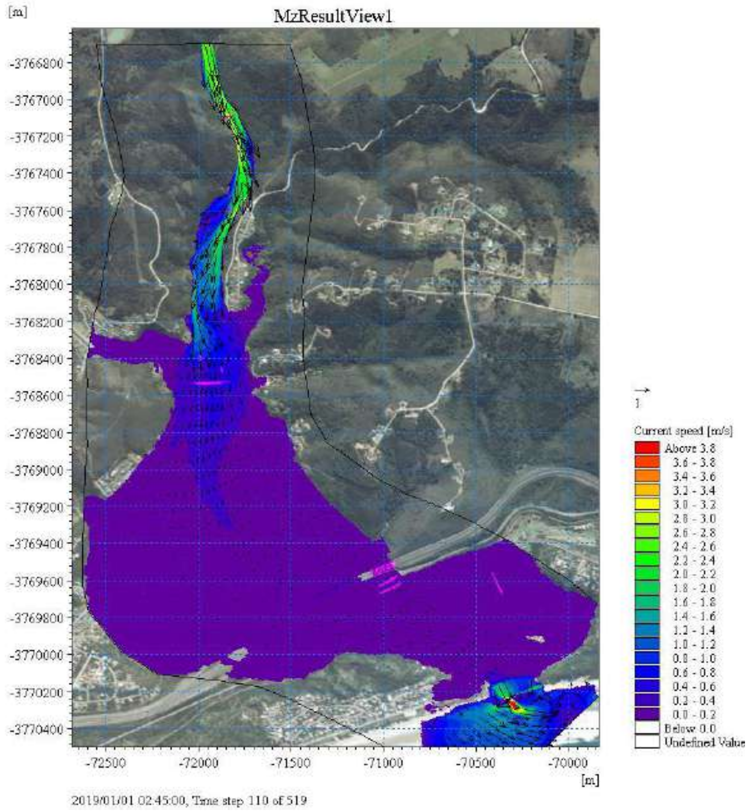


Figure C2-40: Simulated flow velocities and vectors at the peak of the flood for the 100-year flood – future scenario with closed initial mouth condition for Groot Brak

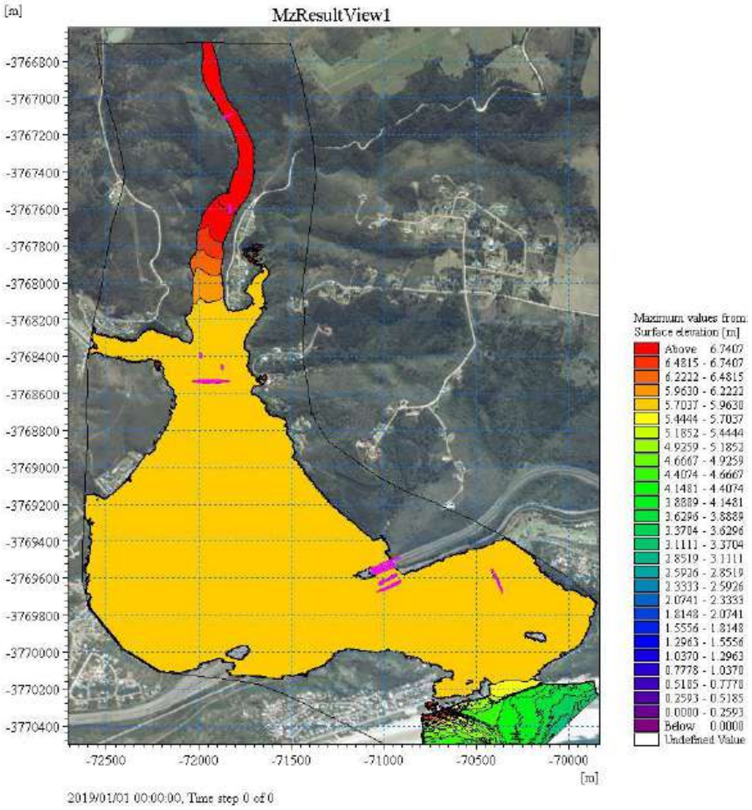


Figure C2-41: Simulated maximum flood levels for the 100-year flood – future scenario with closed initial mouth condition (masl) for Groot Brak

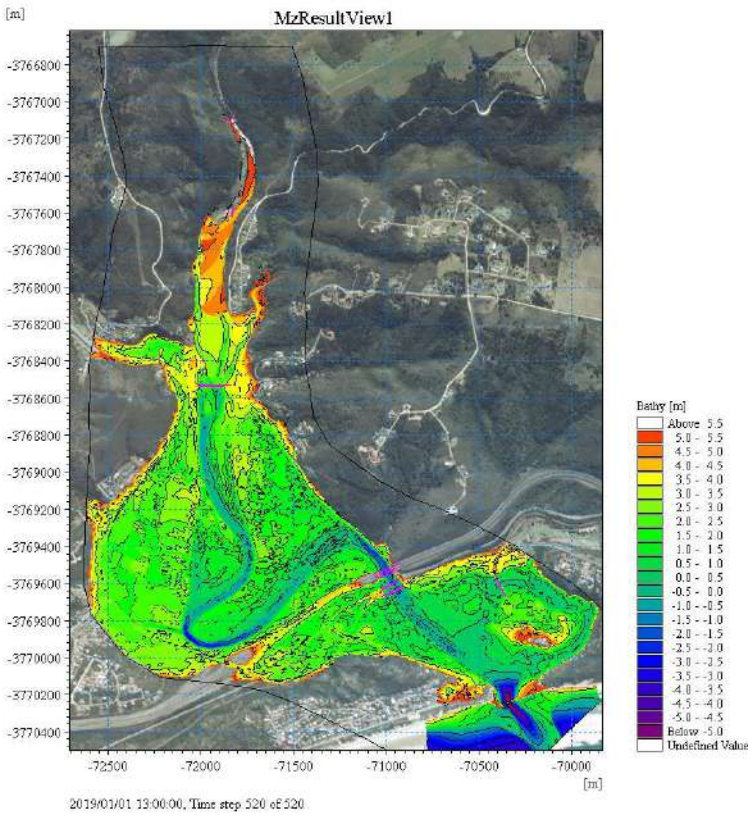


Figure C2-42: Simulated bed levels at end of the 100-year flood – future scenario with closed initial mouth condition (masl) for Groot Brak

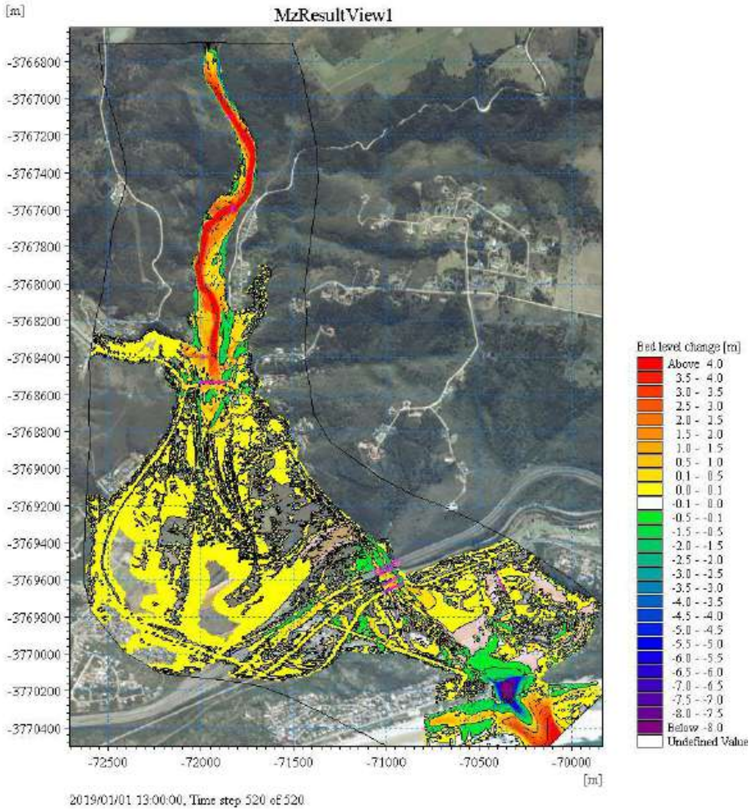


Figure C2-43: Simulated bed level (change) at end of the 100-year flood – future scenario with closed initial mouth condition for Groot Brak

APPENDIX D: SHORT WAVE HEIGHT FROM SWAN

SIMULATION RESULTS OF SHORT WAVE HEIGHTS IN ESTUARIES DURING STORM EVENTS

APPENDIX D1: SWAN MODELLING OF KLEIN BRAK

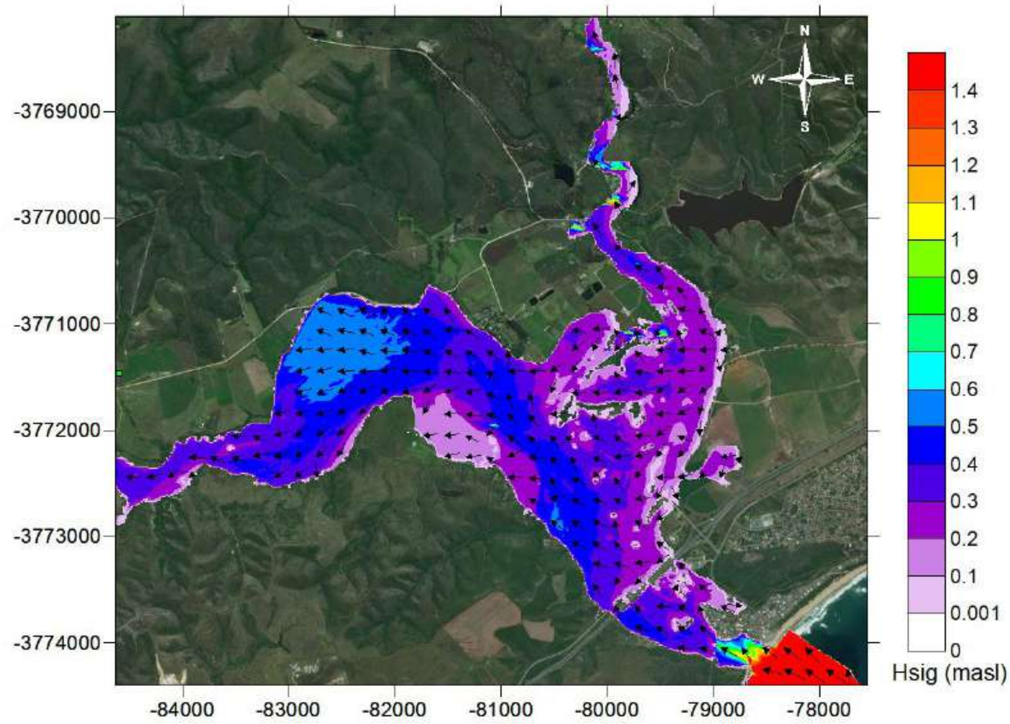


Figure D.1.1: Contour map showing the significant wave height with peak wave direction vectors for Scenario 1 for Klein Brak River

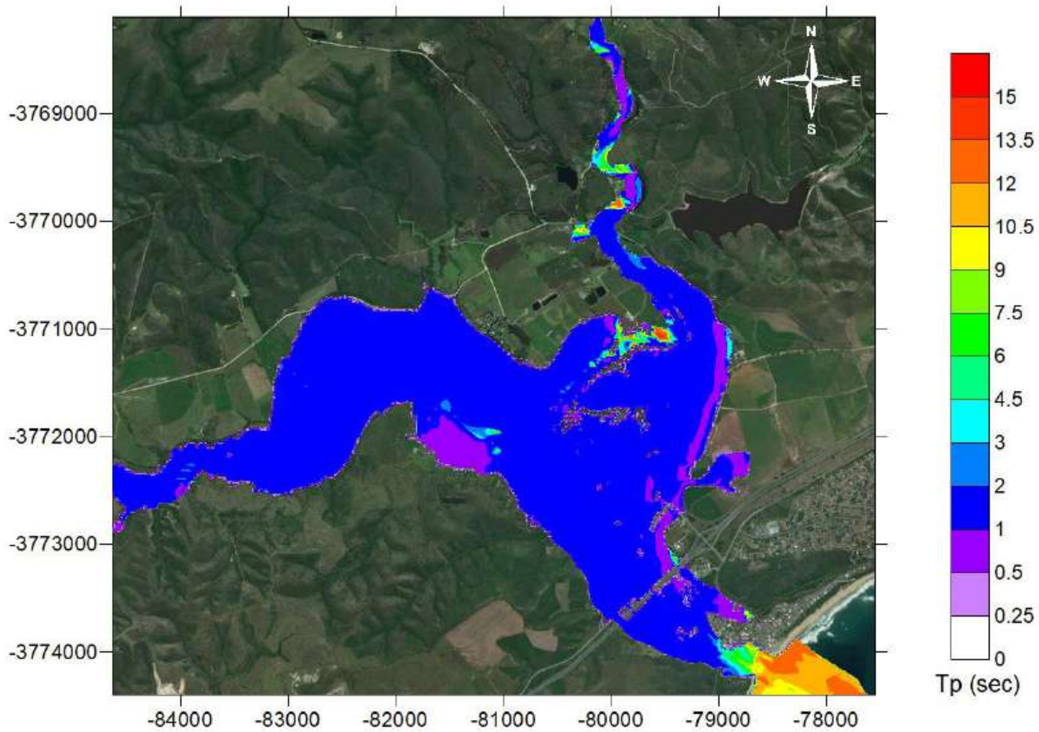


Figure D.1.2: Contour map showing the mean wave period for Scenario 1 for Klein Brak River

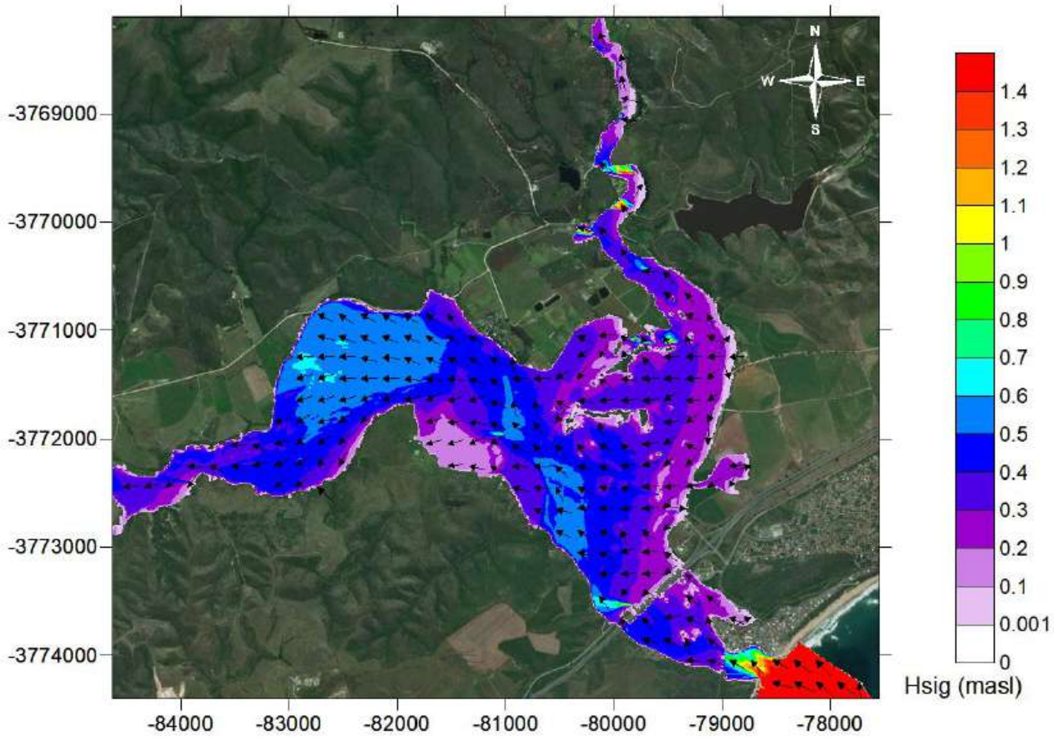


Figure D.1.3: Contour map showing the significant wave height with peak wave direction vectors for Scenario 2 for Klein Brak River

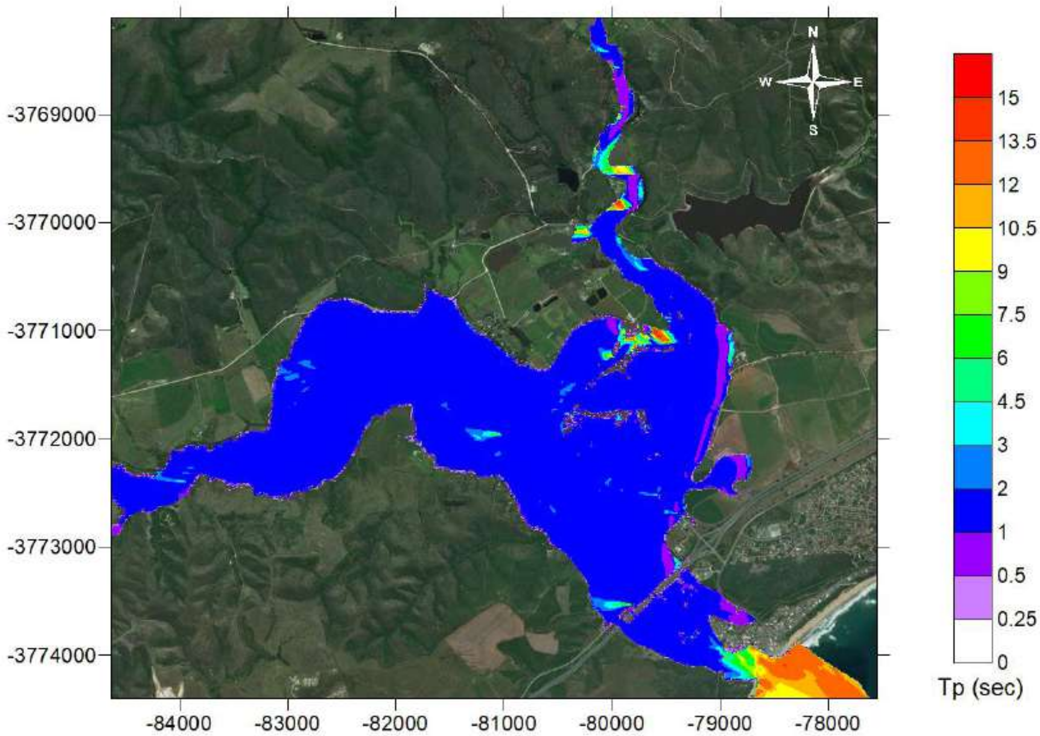


Figure D.1.4: Contour map showing the mean wave period for Scenario 2 for Klein Brak River

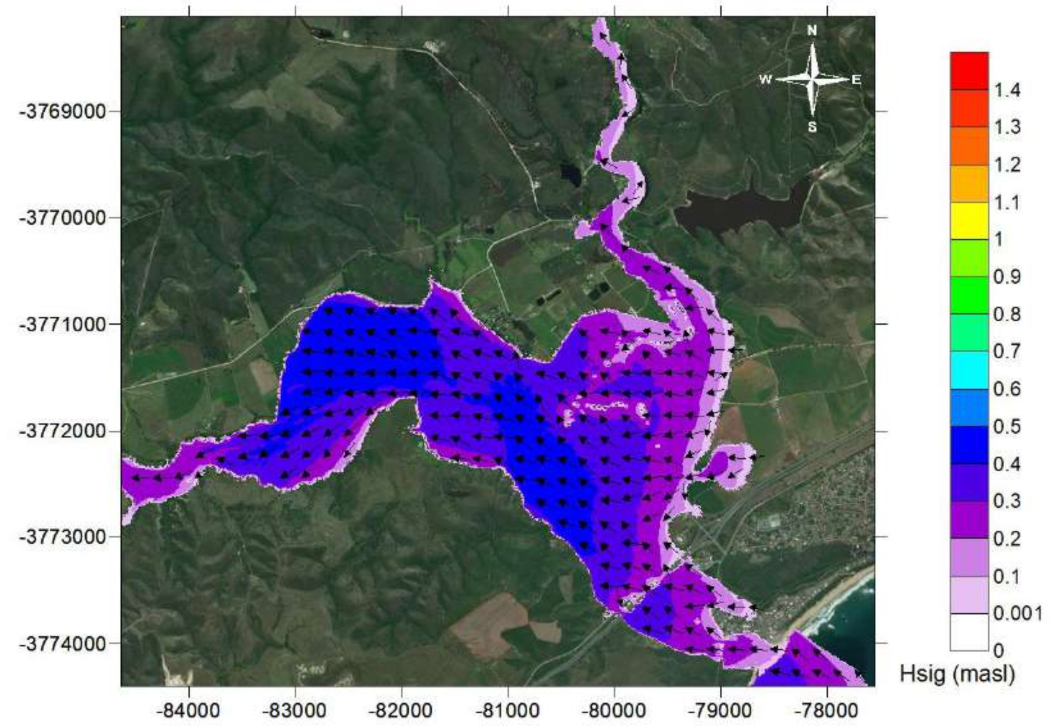


Figure D.1.5: Contour map showing the significant wave height with peak wave direction vectors for Scenario 3 for Klein Brak River with E'ly wind

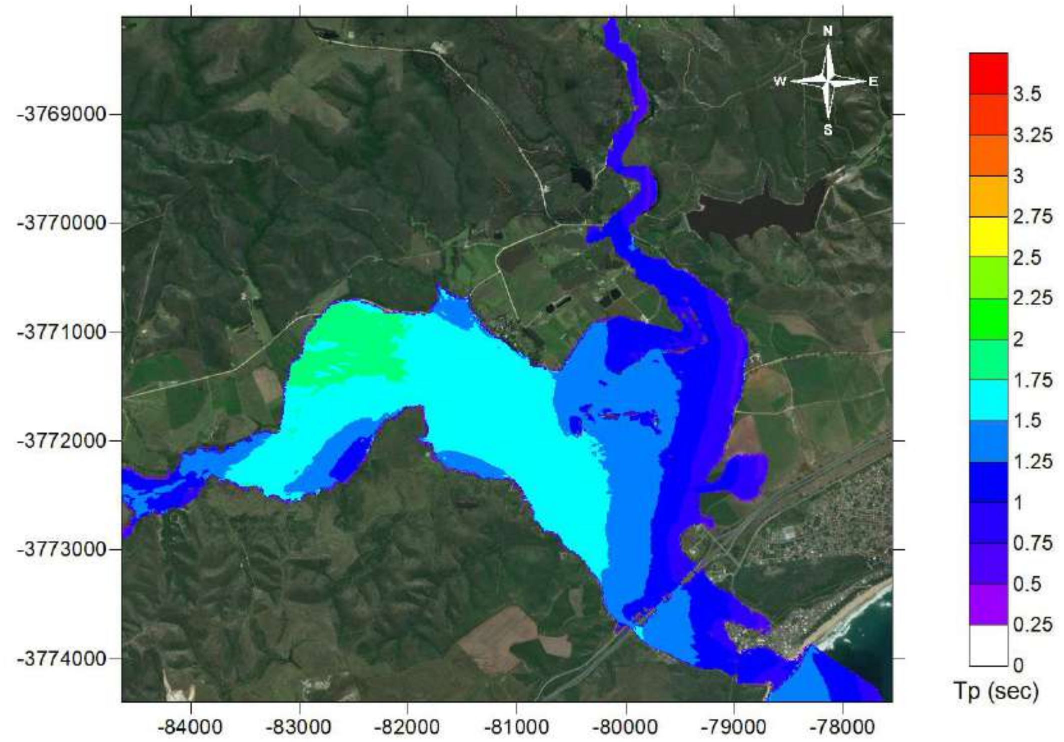


Figure D.1.6: Contour map showing the mean wave period for Scenario 3 for Klein Brak River with E'ly wind

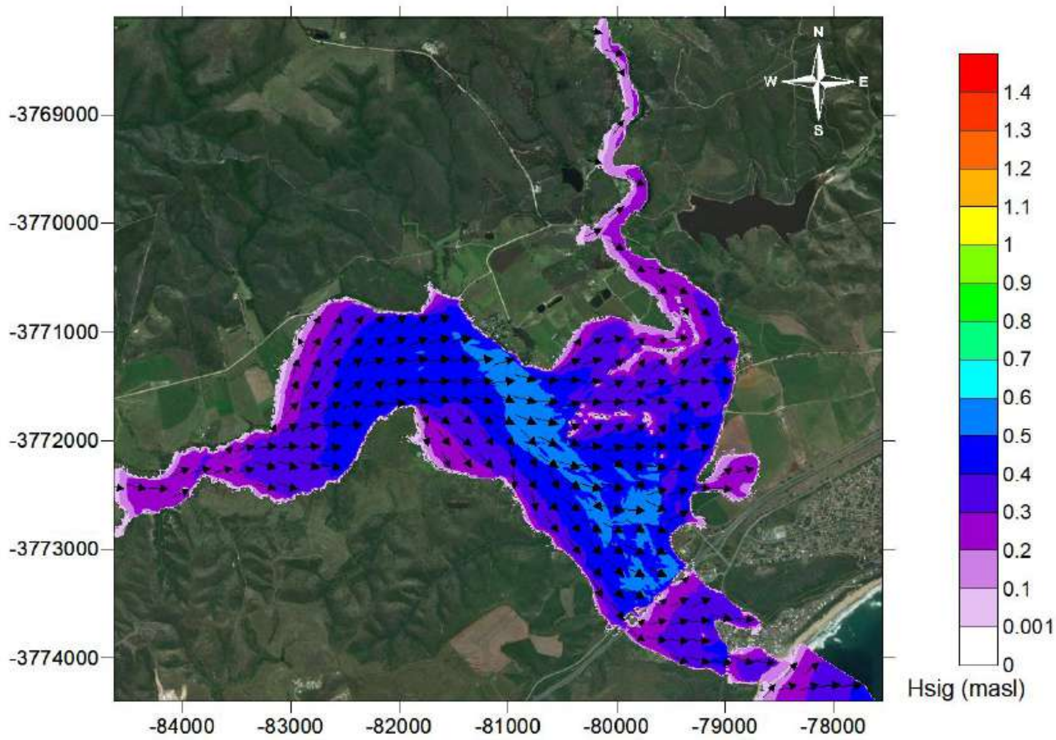


Figure D.1.7: Contour map showing the significant wave height with peak wave direction vectors for Scenario 3 for Klein Brak River with W'ly wind

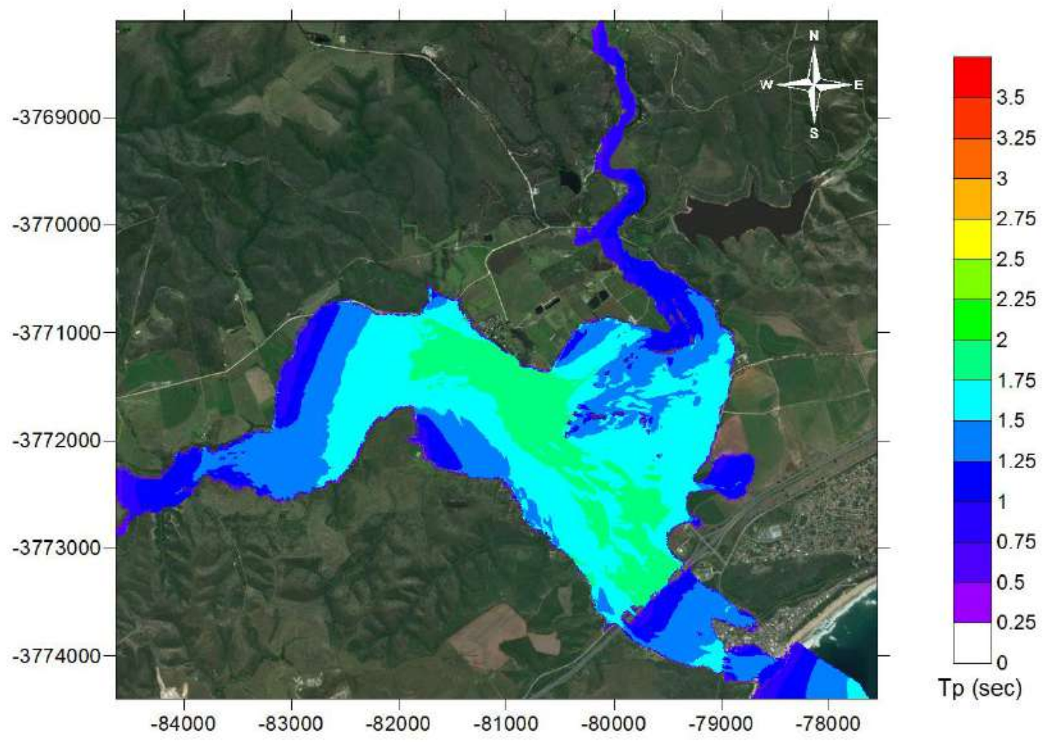


Figure D.1.8: Contour map showing the mean wave period for Scenario 3 for Klein Brak River with W'ly wind

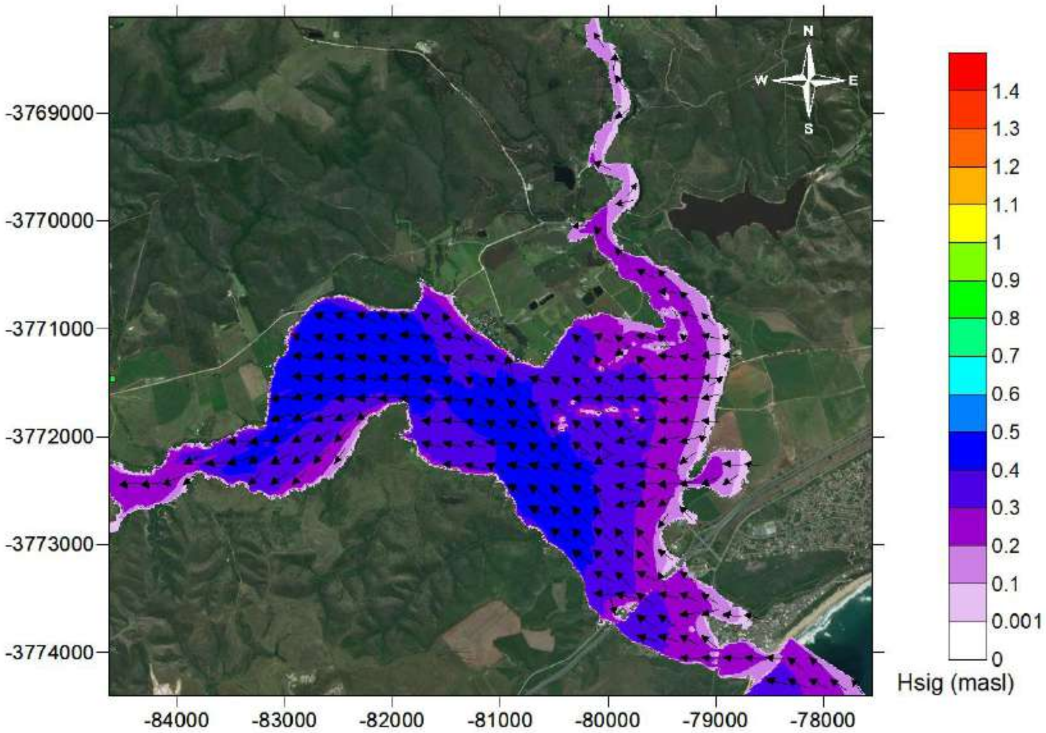


Figure D.1.9: Contour map showing the significant wave height with peak wave direction vectors for Scenario 4 for Klein Brak River with E'ly wind

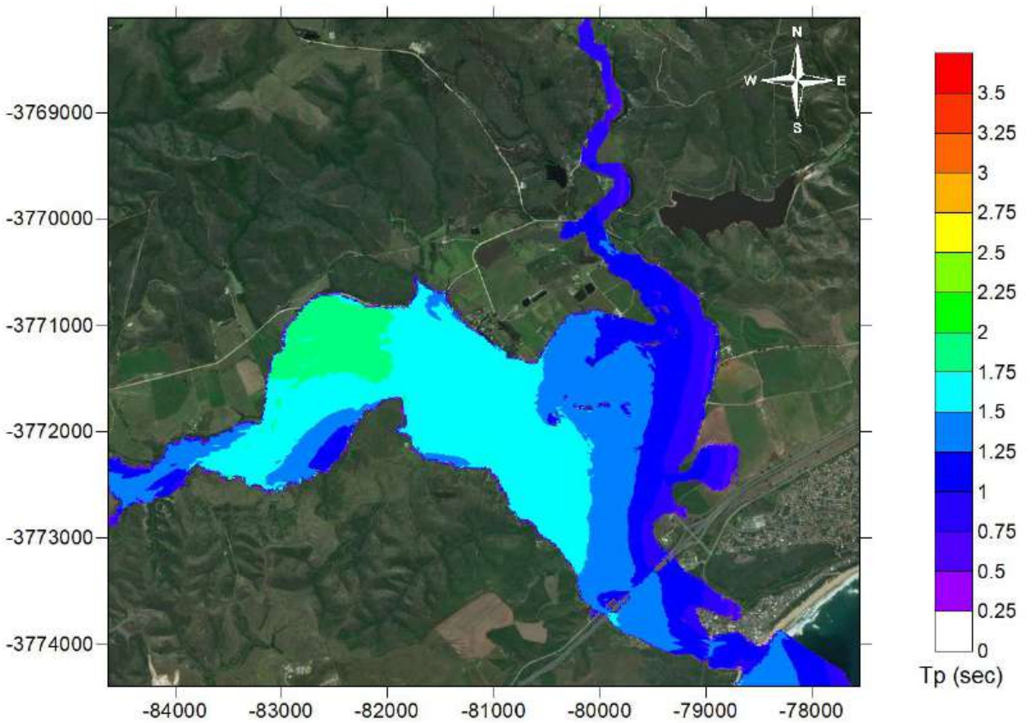


Figure D.1.10: Contour map showing the mean wave period for Scenario 4 for Klein Brak River with E'ly wind

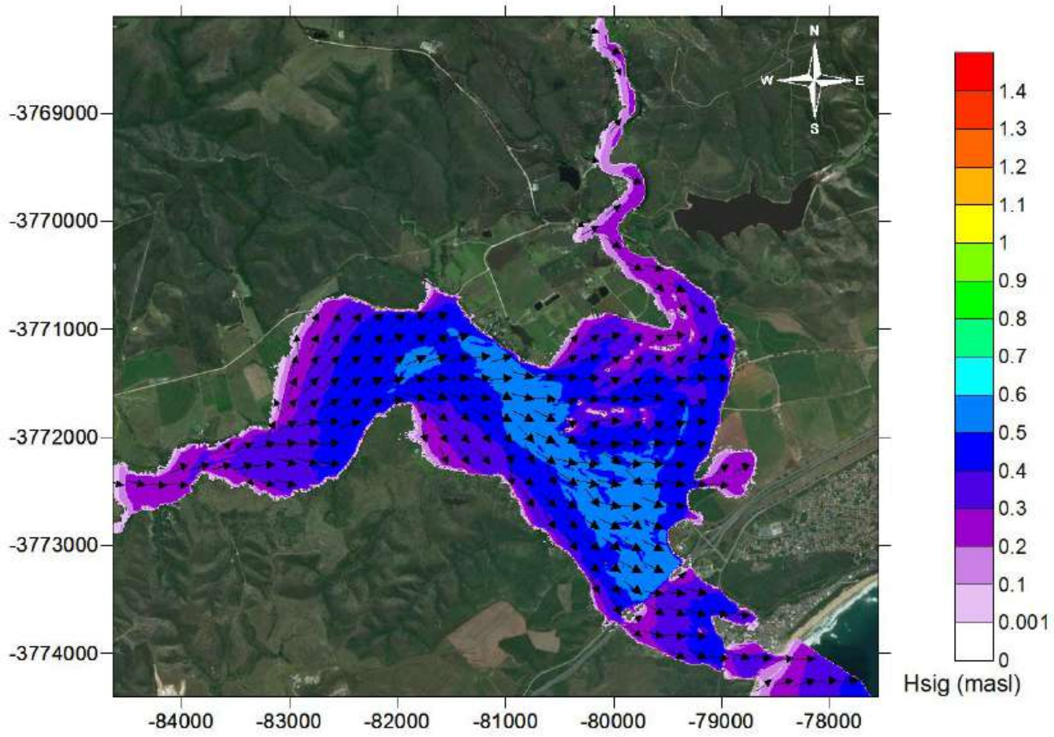


Figure D.1.11: Contour map showing the significant wave height with peak wave direction vectors for Scenario 4 for Klein Brak River with W'ly wind

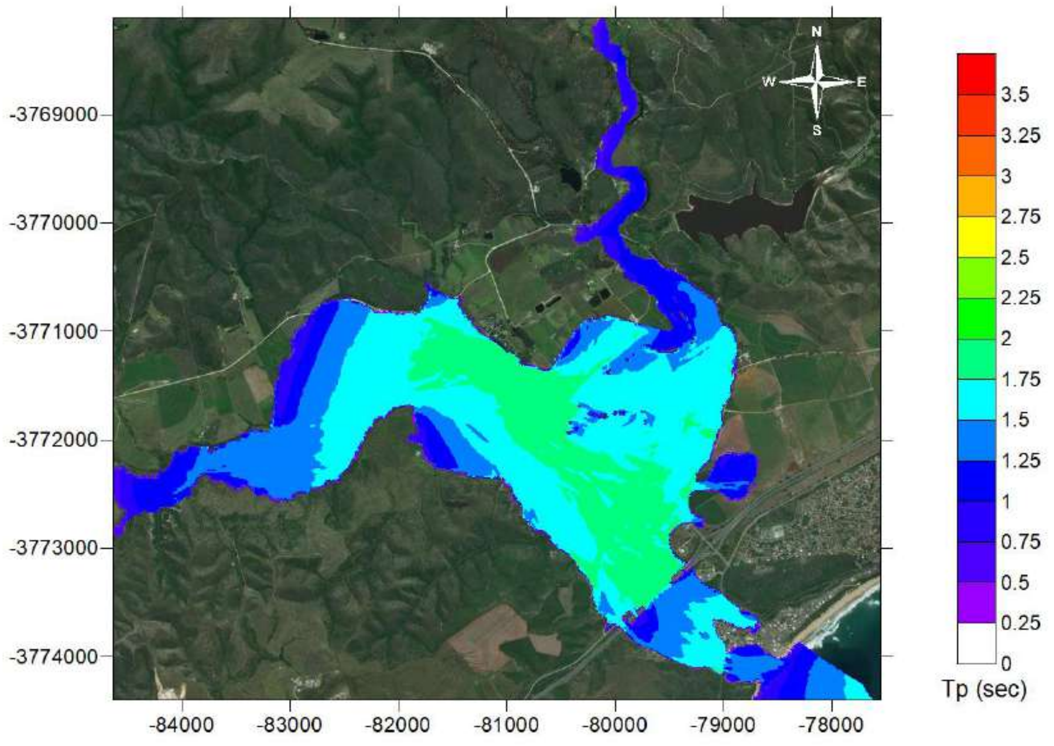


Figure D.1.12: Contour map showing the mean wave period for Scenario 4 for Klein Brak River with W'ly wind

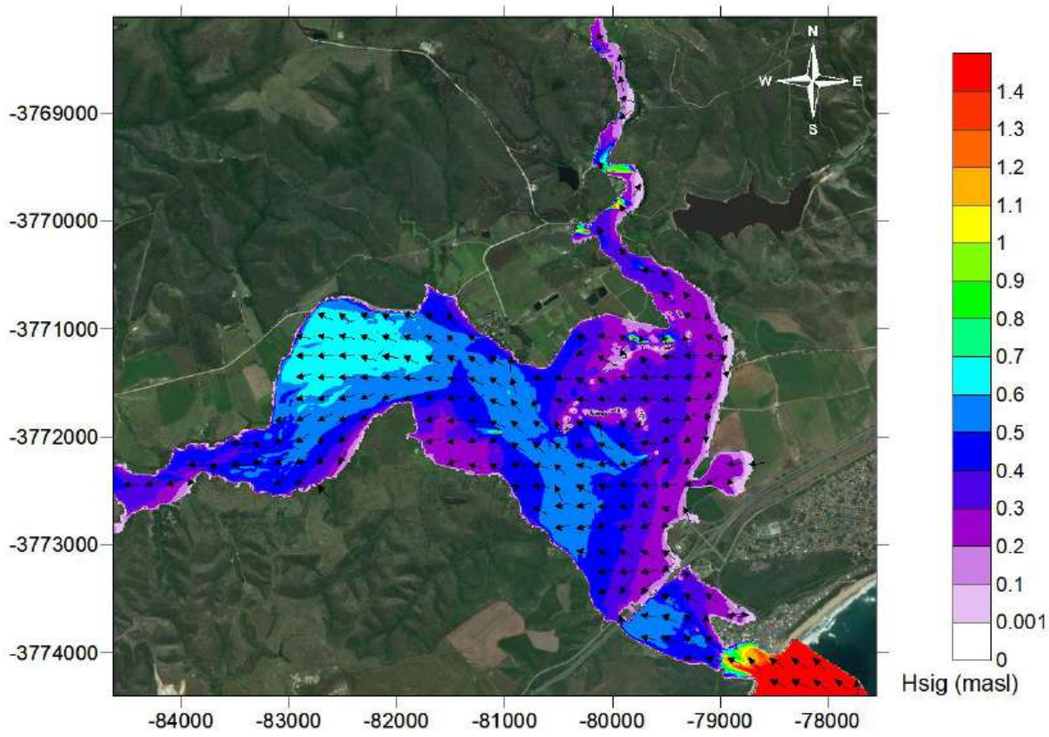


Figure D.1.13: Contour map showing the significant wave height with peak wave direction vectors for Scenario 5 for Klein Brak River

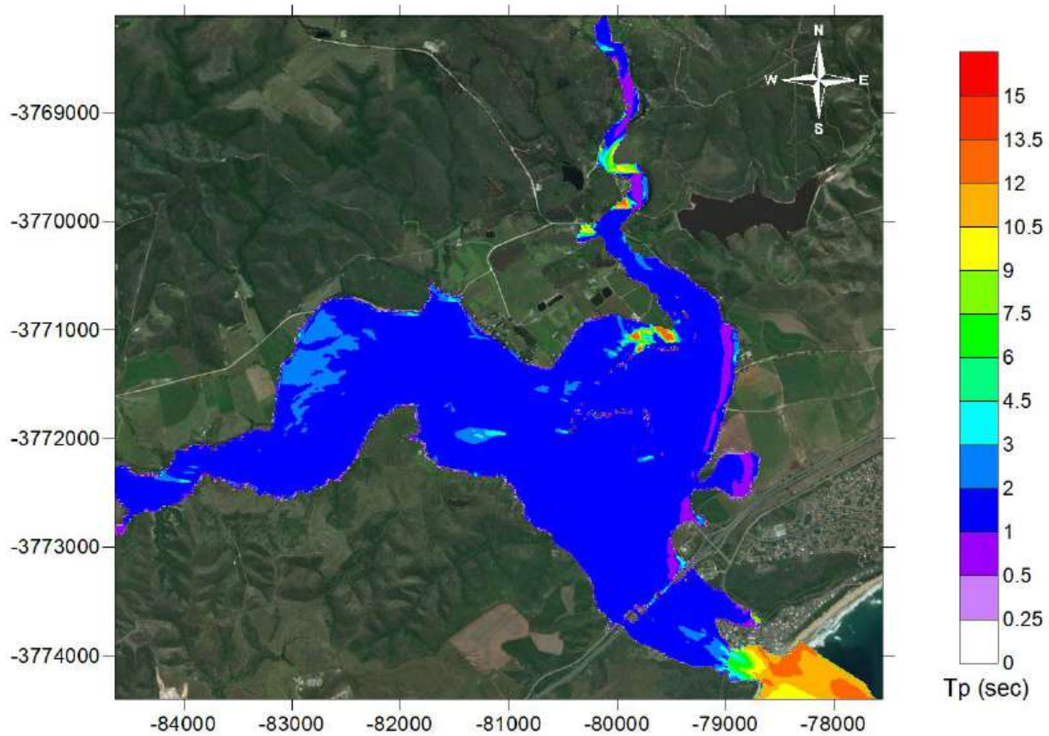


Figure D.1.14: Contour map showing the mean wave period for Scenario 5 for Klein Brak River

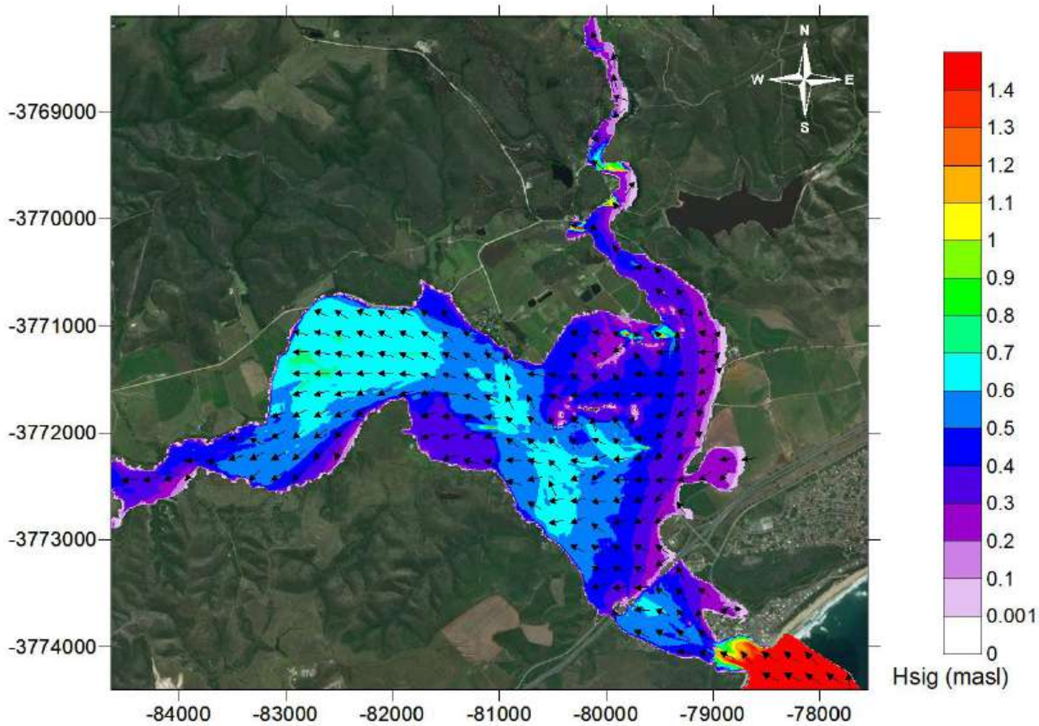


Figure D.1.15: Contour map showing the significant wave height with peak wave direction vectors for Scenario 6 for Klein Brak River

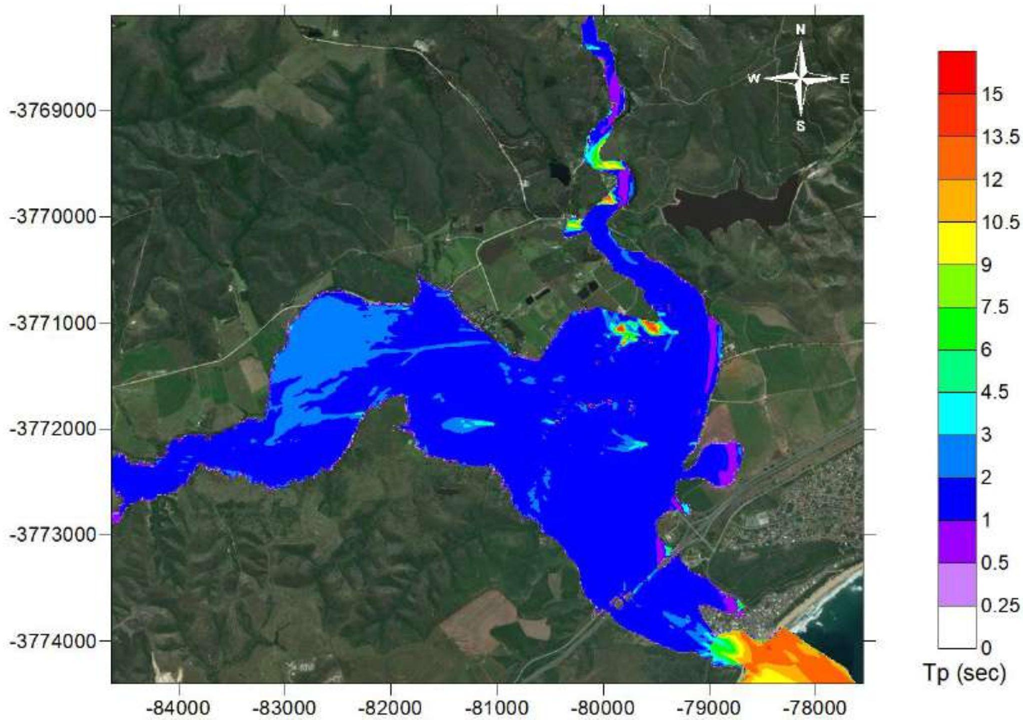


Figure D.1.16: Contour map showing the mean wave period for Scenario 6 for Klein Brak River

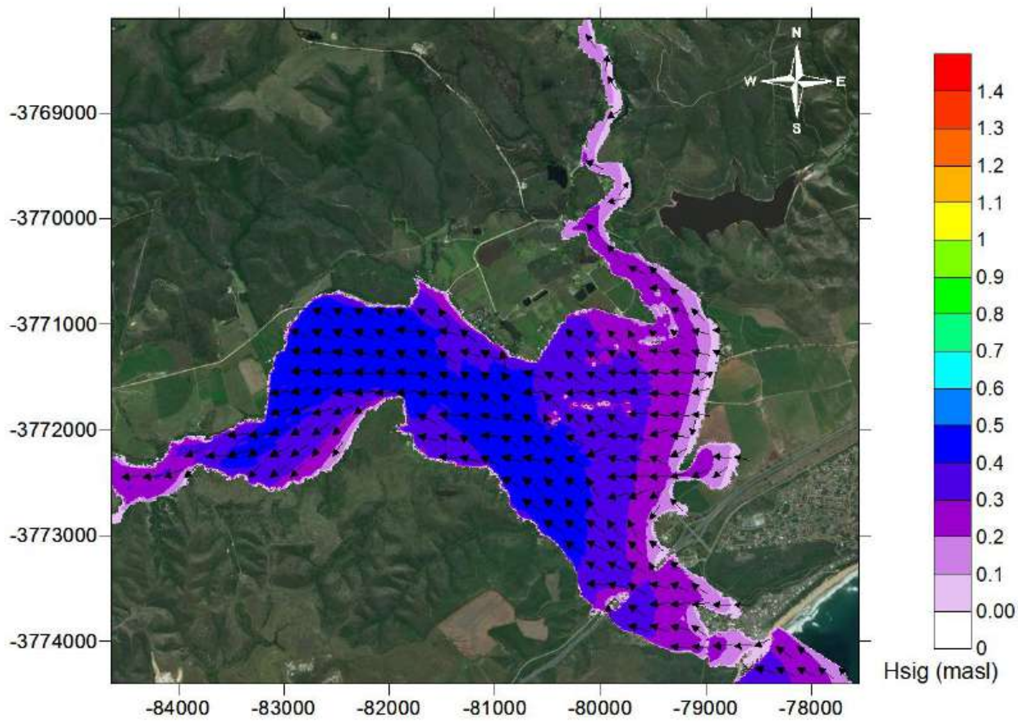


Figure D.1.17: Contour map showing the significant wave height with peak wave direction vectors for Scenario 7 for Klein Brak River with E'ly wind

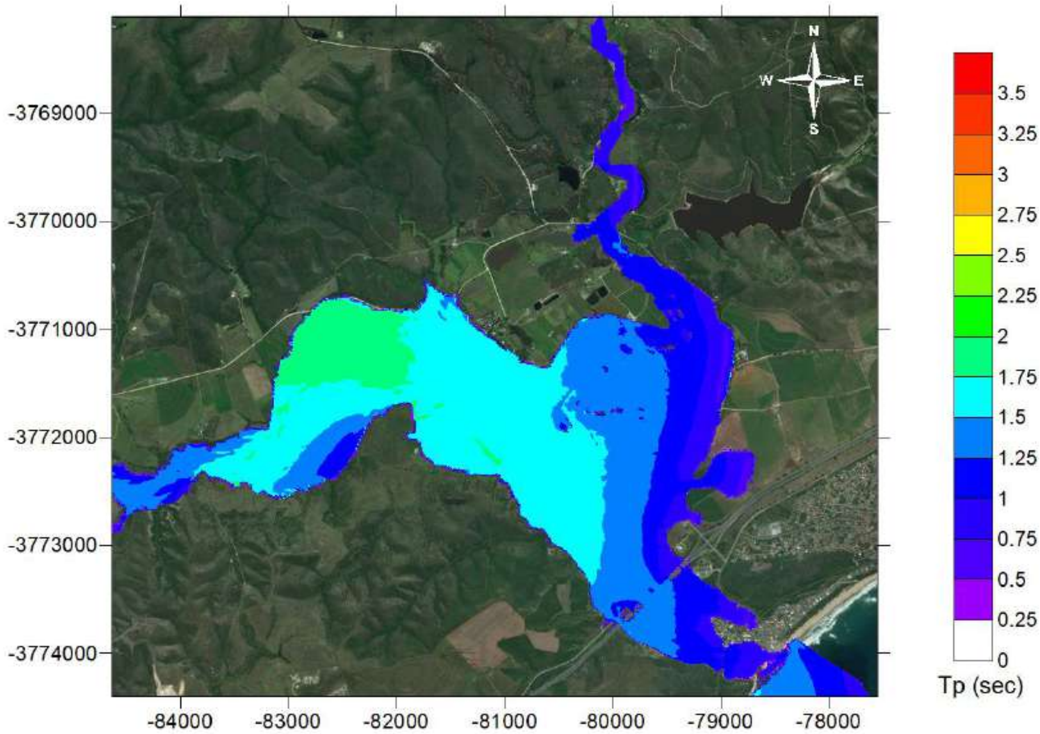


Figure D.1.18: Contour map showing the mean wave period for Scenario 7 for Klein Brak River with E'ly wind

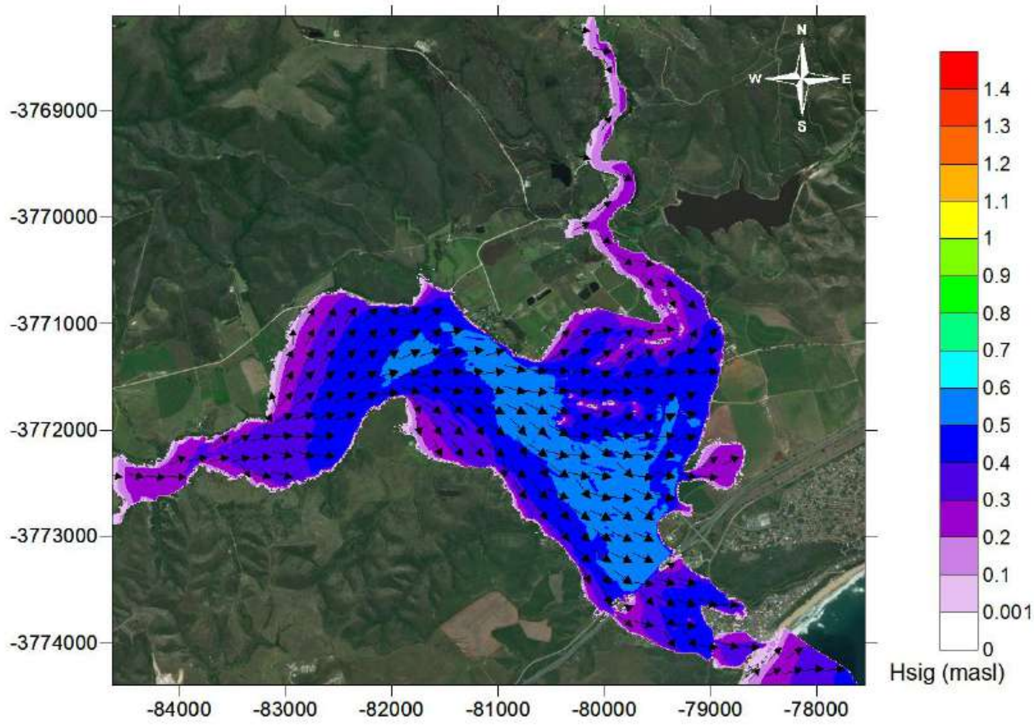


Figure D.1.19: Contour map showing the significant wave height with peak wave direction vectors for Scenario 7 for Klein Brak River with W'ly wind

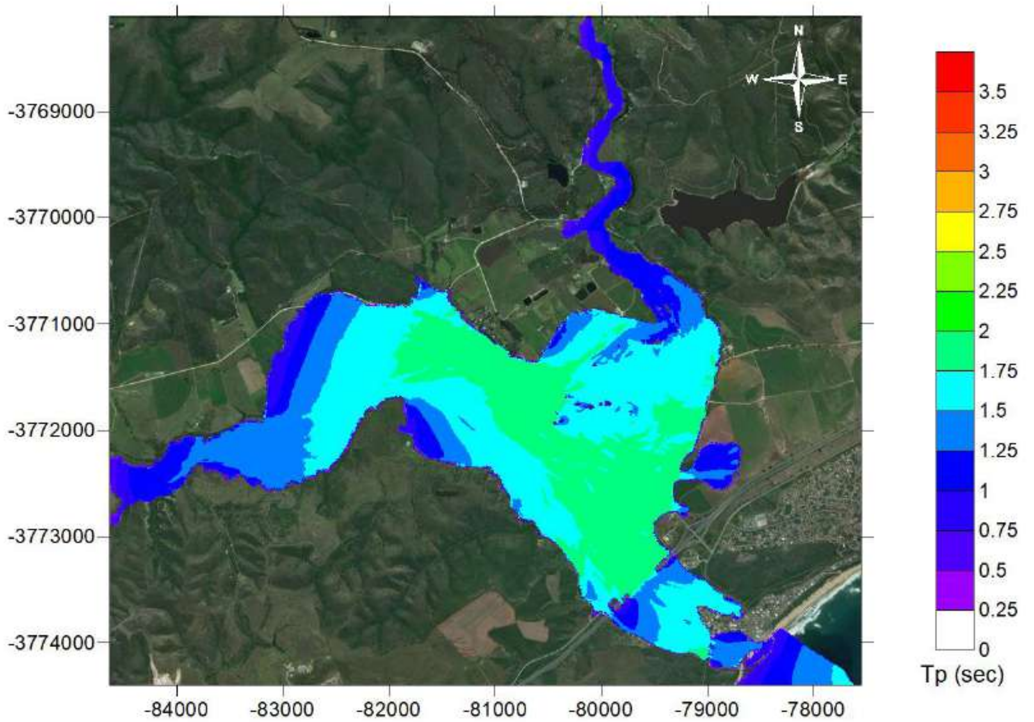


Figure D.1.20: Contour map showing the mean wave period for Scenario 7 for Klein Brak River with W'ly wind

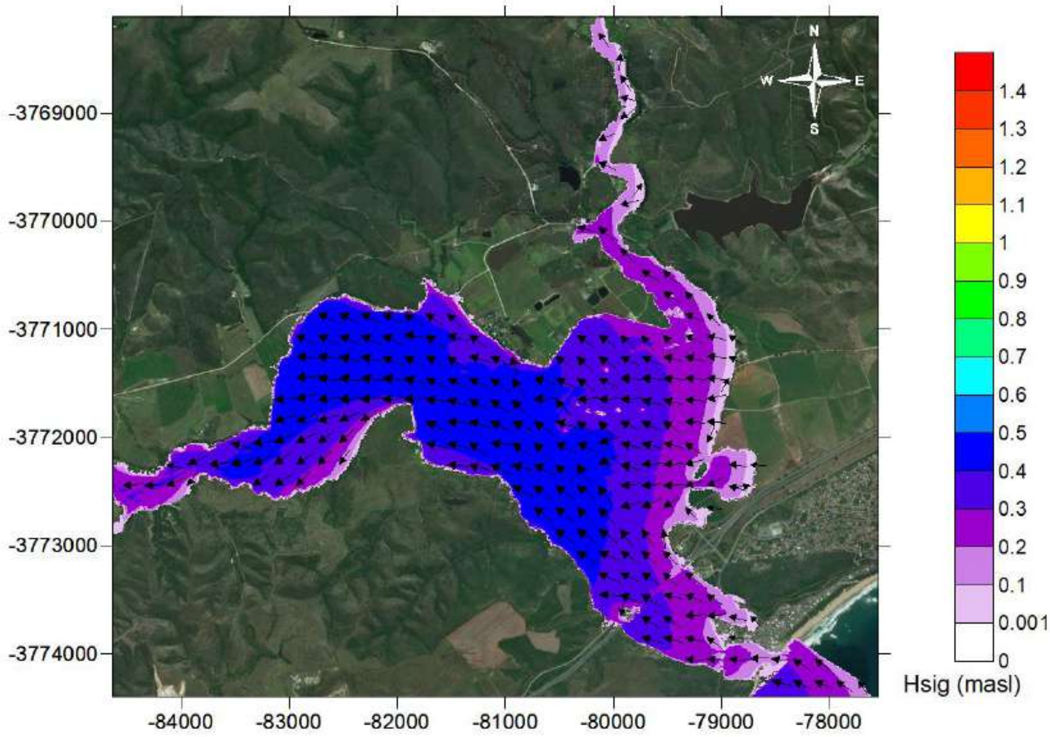


Figure D.1.21: Contour map showing the significant wave height with peak wave direction vectors for Scenario 8 for Klein Brak River with E'ly wind

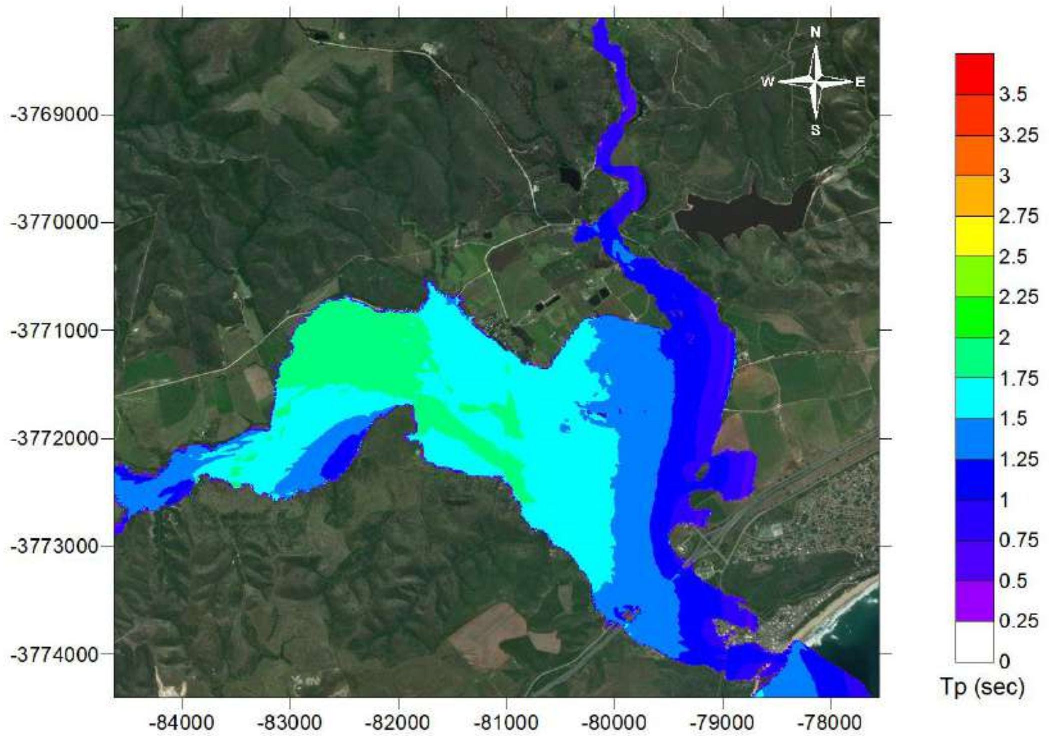


Figure D.1.22: Contour map showing the mean wave period for Scenario 8 for Klein Brak River with E'ly wind

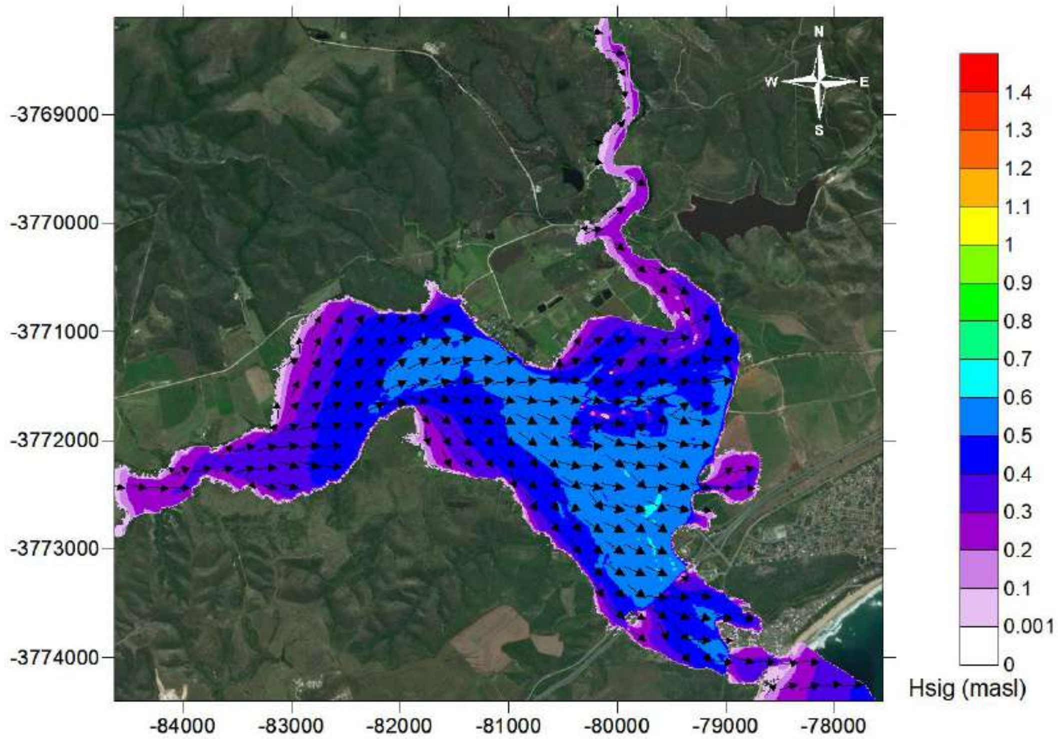


Figure D.1.23: Contour map showing the significant wave height with peak wave direction vectors for Scenario 8 for Klein Brak River with W'ly wind

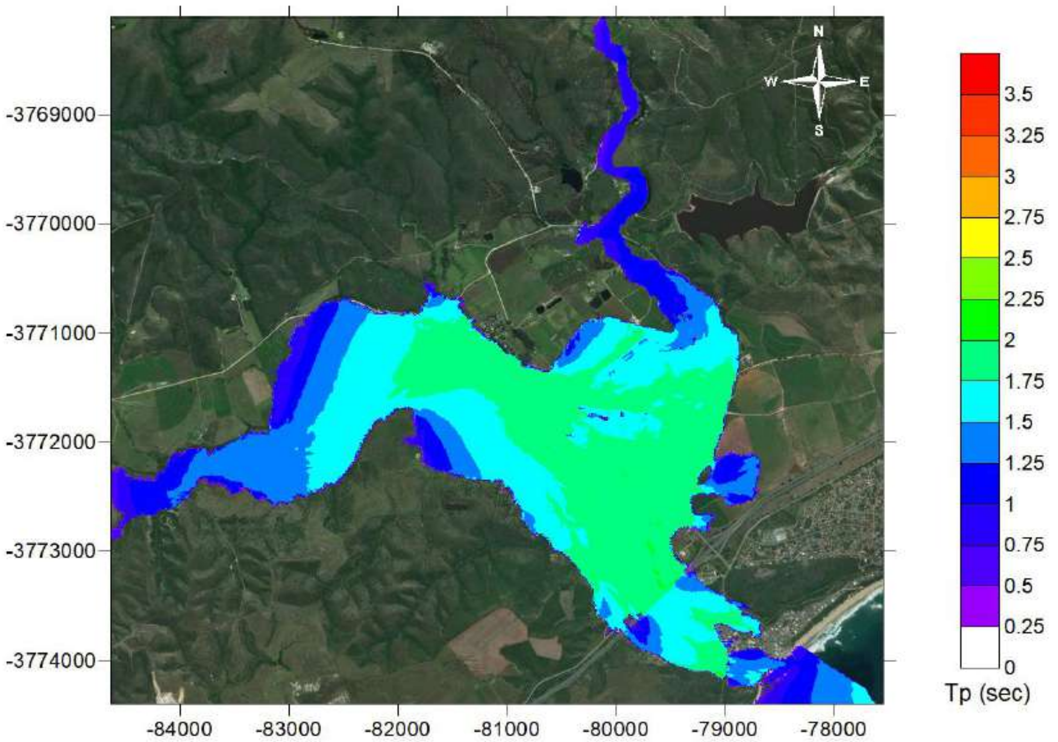


Figure D.1.24: Contour map showing the mean wave period for Scenario 8 for Klein Brak River with W'ly wind

APPENDIX D2: SWAN MODELLING OF GROOT BRAK

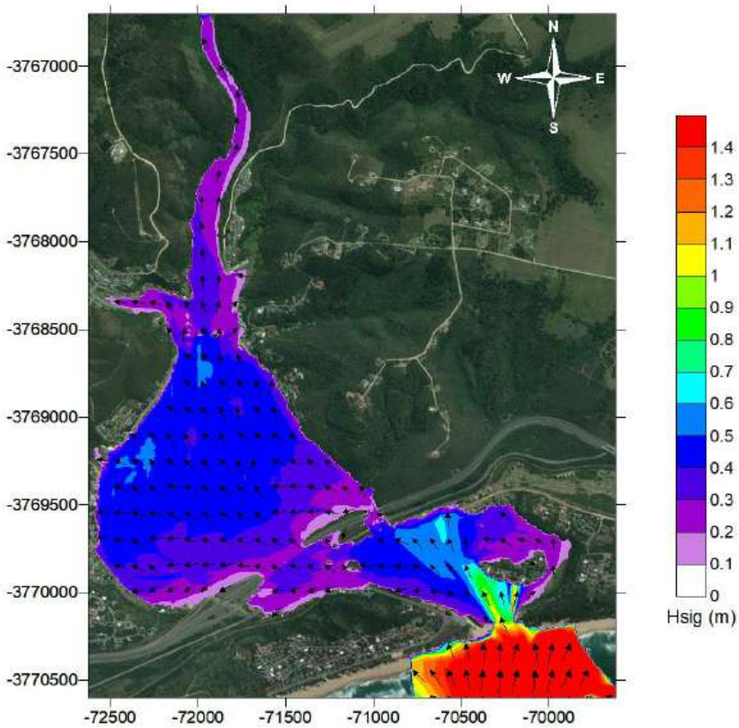


Figure D.2.1: Contour map showing the significant wave height with peak wave direction vectors for Scenario 1 for Groot Brak River

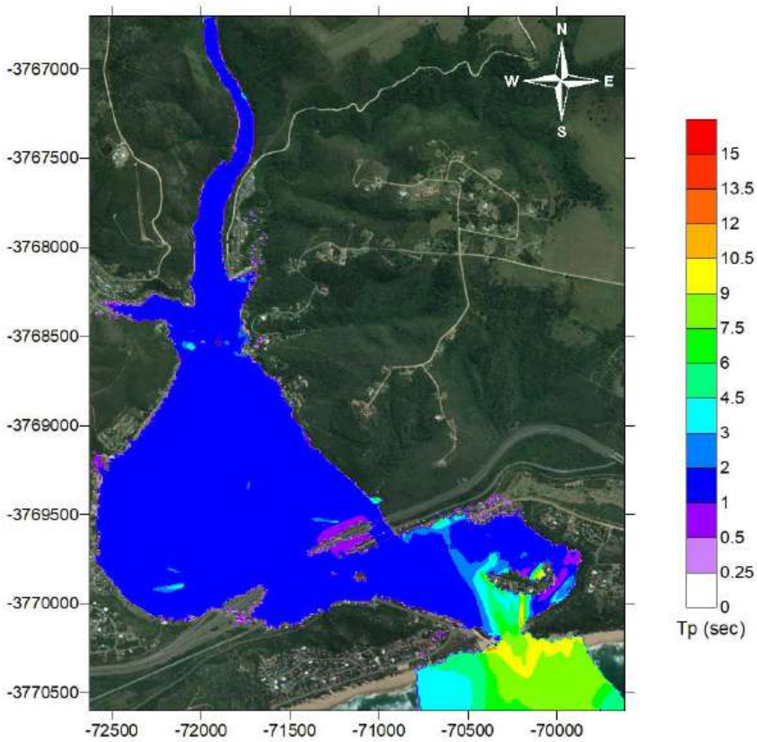


Figure D.2.2: Contour map showing the mean wave period for Scenario 1 for Groot Brak River

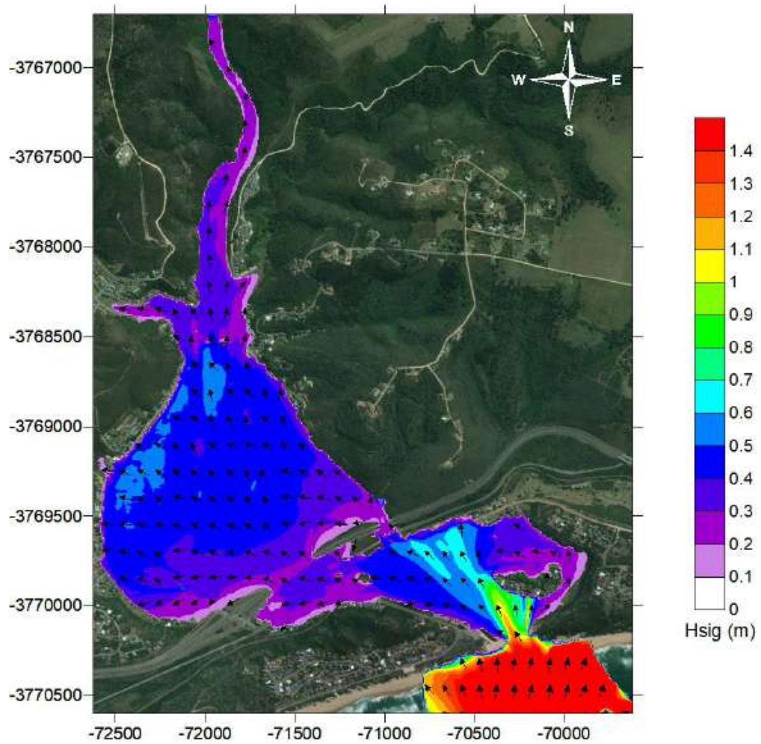


Figure D.2.3: Contour map showing the significant wave height with peak wave direction vectors for Scenario 2 for Groot Brak River

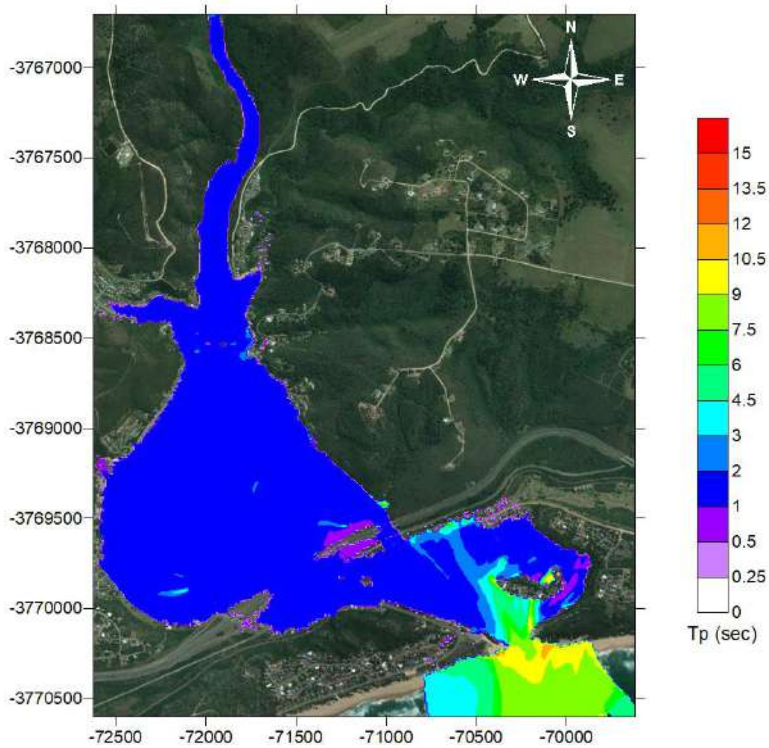


Figure D.2.4: Contour map showing the mean wave period for Scenario 2 for Groot Brak River

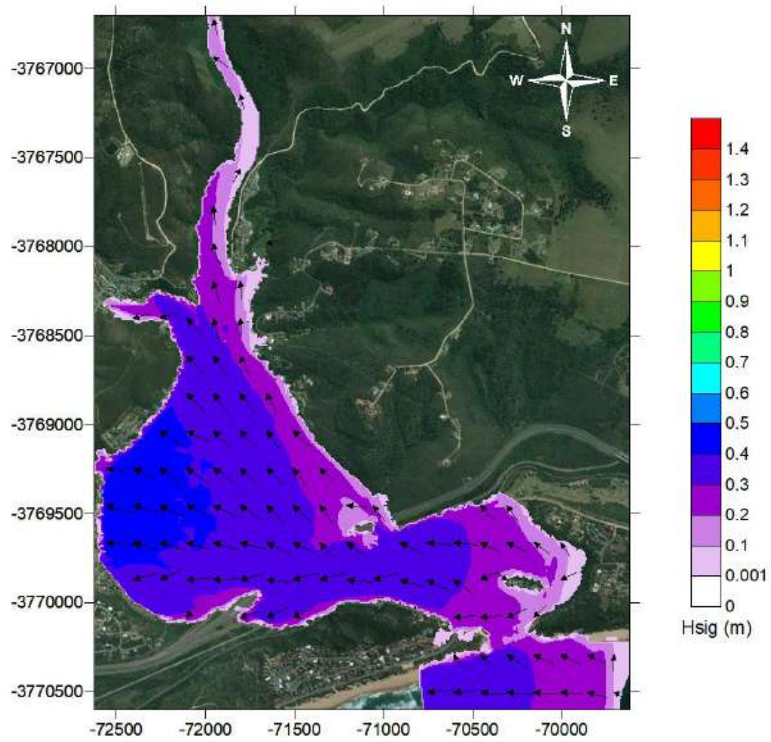


Figure D.2.5: Contour map showing the significant wave height with peak wave direction vectors for Scenario 3 for Groot Brak River with E'ly wind

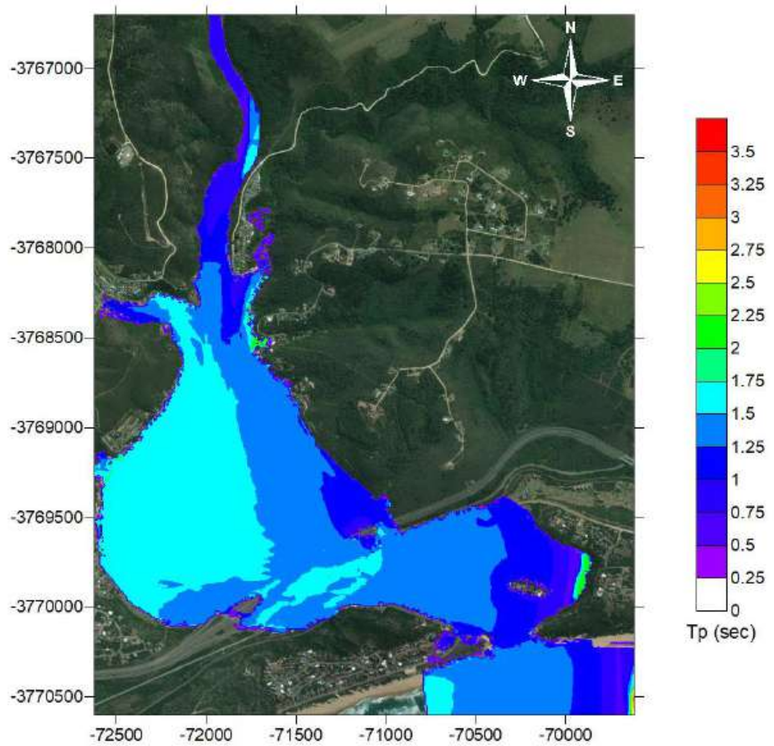


Figure D.2.6: Contour map showing the mean wave period for Scenario 3 for Groot Brak River with E'ly wind

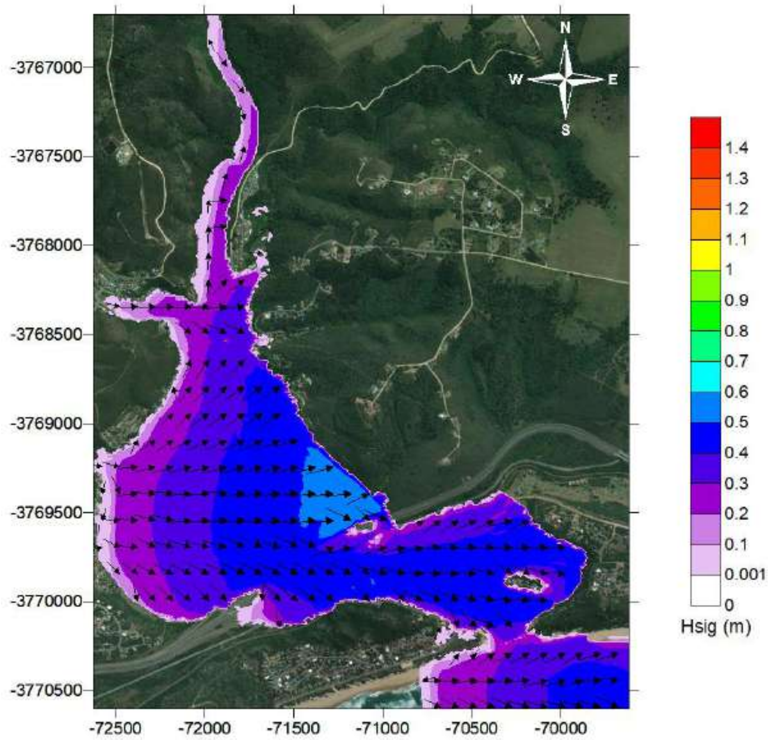


Figure D.2.7: Contour map showing the significant wave height with peak wave direction vectors for Scenario 3 for Groot Brak River with W'ly wind

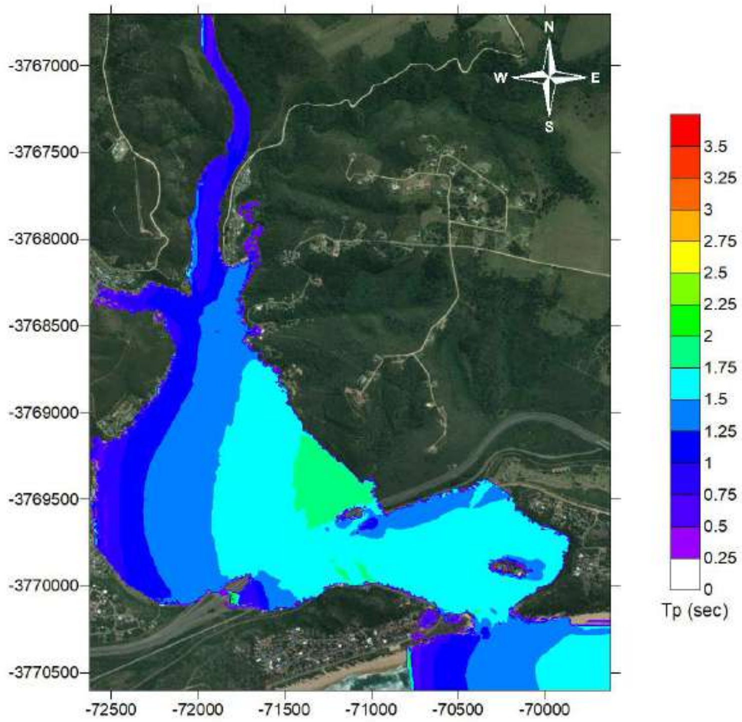


Figure D.2.8: Contour map showing the mean wave period for Scenario 3 for Groot Brak River with W'ly wind

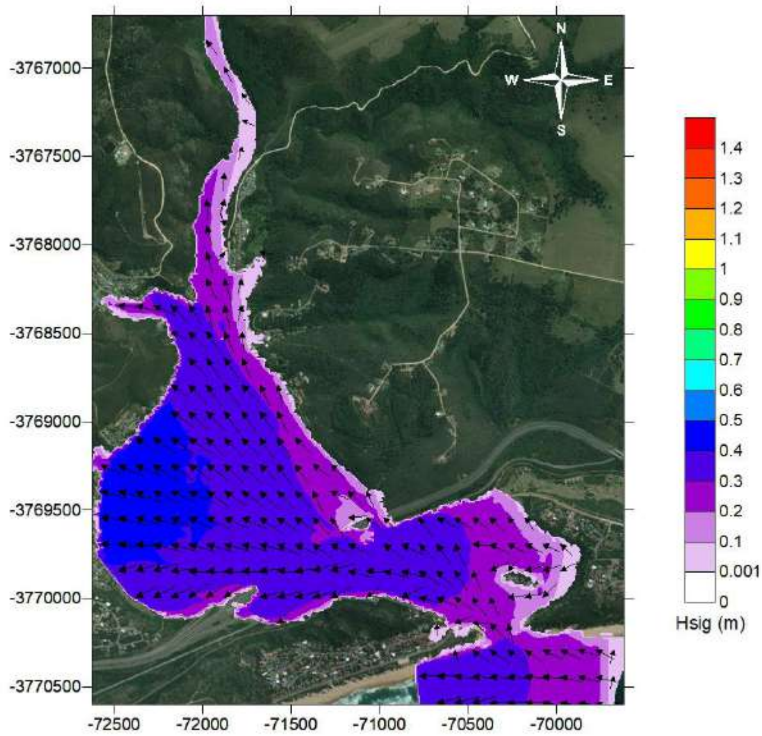


Figure D.2.9: Contour map showing the significant wave height with peak wave direction vectors for Scenario 4 for Groot Brak River with E'ly wind

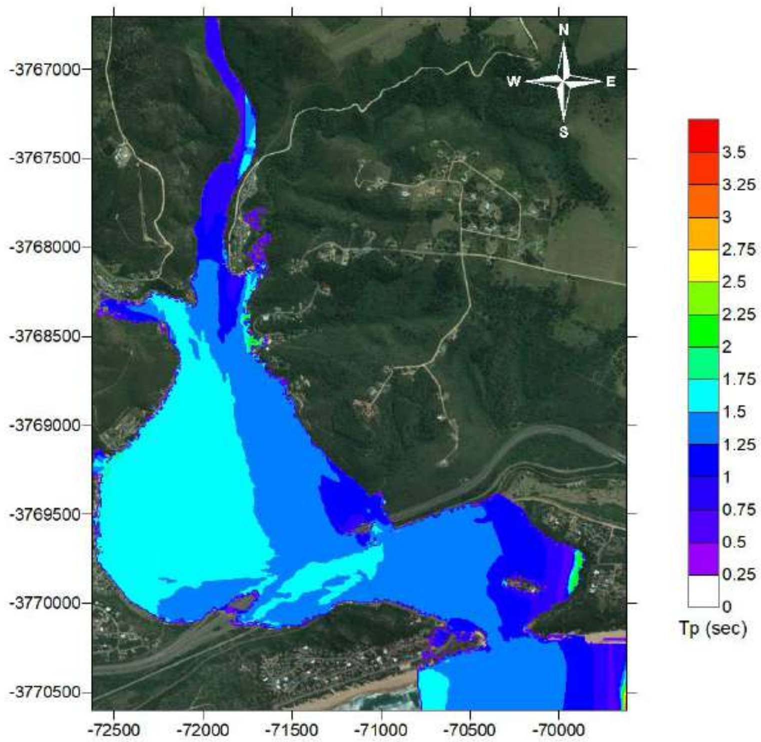


Figure D.2.10: Contour map showing the mean wave period for Scenario 4 for Groot Brak River with E'ly wind

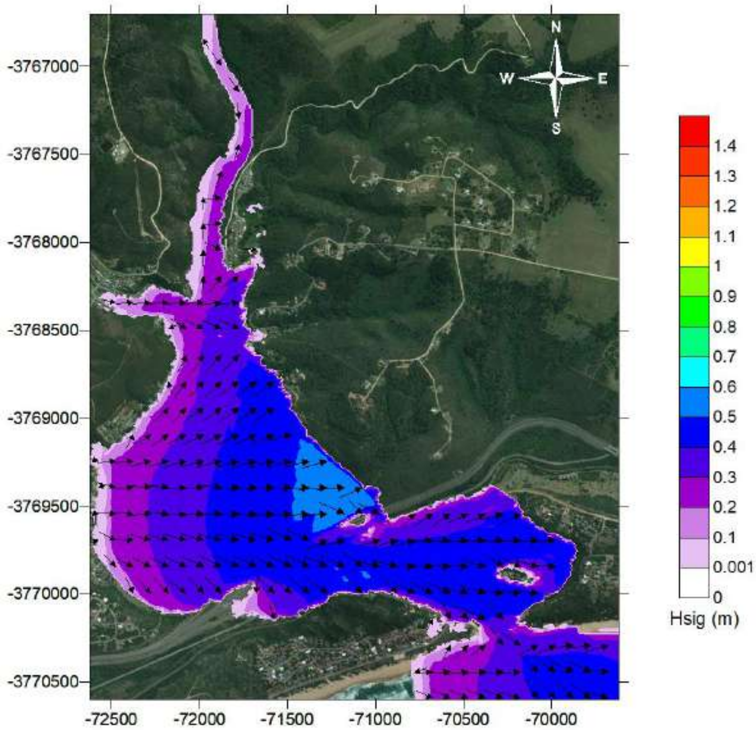


Figure D.2.11: Contour map showing the significant wave height with peak wave direction vectors for Scenario 4 for Groot Brak River with W'ly wind

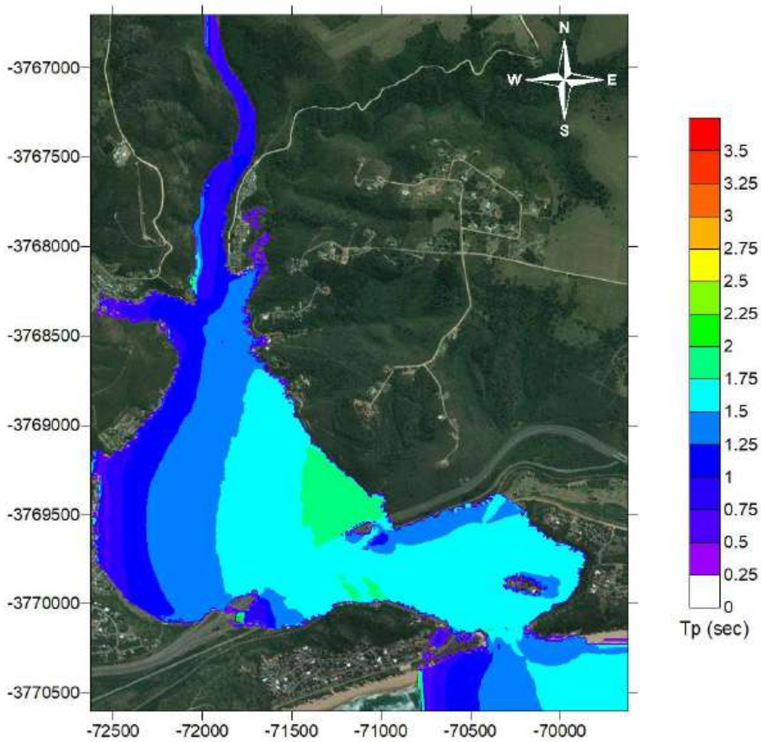


Figure D.2.12: Contour map showing the mean wave period for Scenario 4 for Groot Brak River with W'ly wind

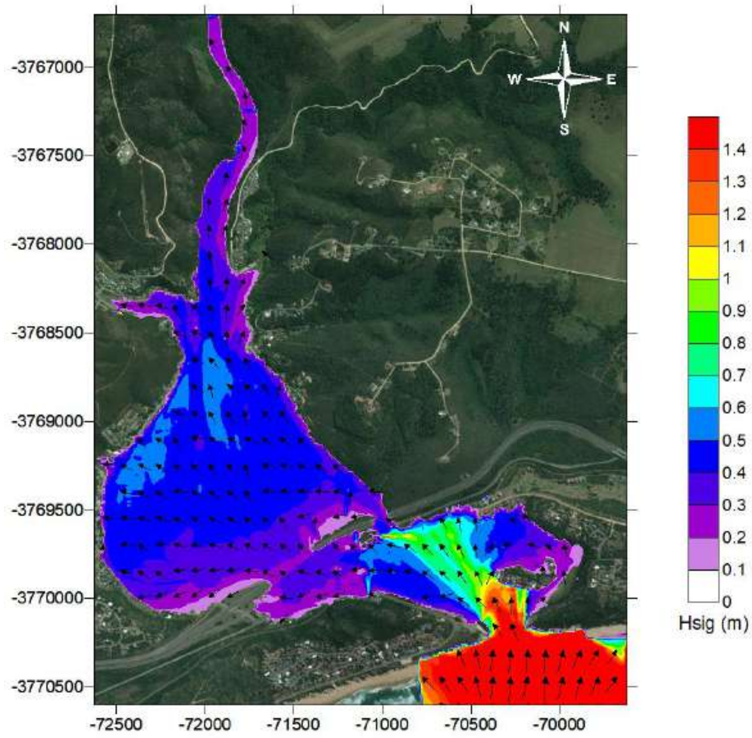


Figure D.2.13: Contour map showing the significant wave height with peak wave direction vectors for Scenario 5 for Groot Brak River

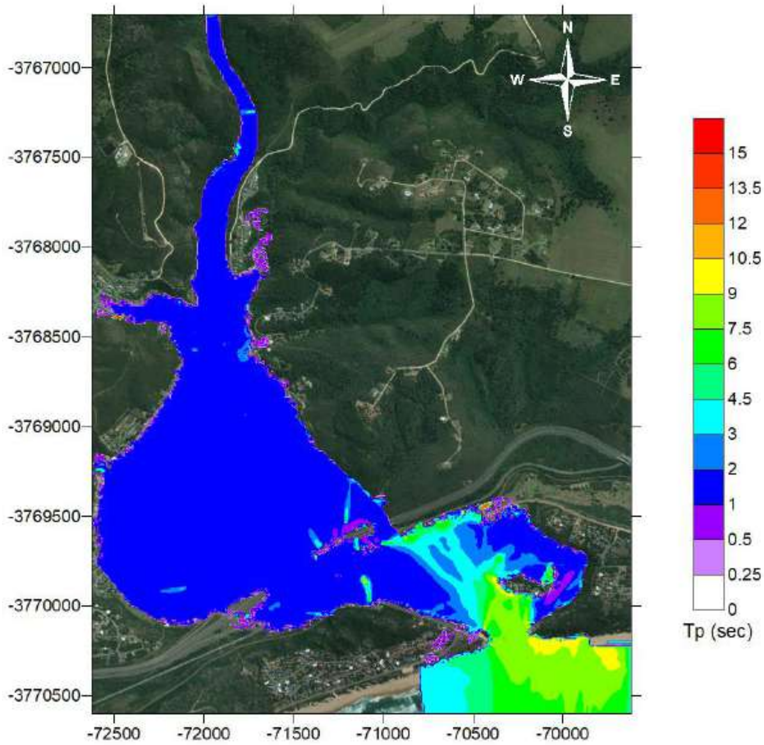


Figure D.2.14: Contour map showing the mean wave period for Scenario 5 for Groot Brak River

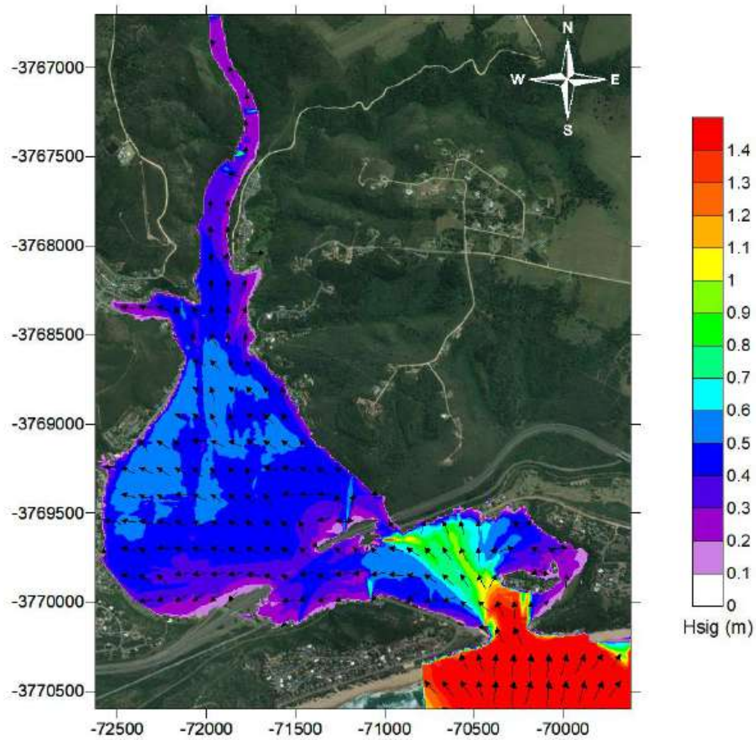


Figure D.2.15: Contour map showing the significant wave height with peak wave direction vectors for Scenario 6 for Groot Brak River

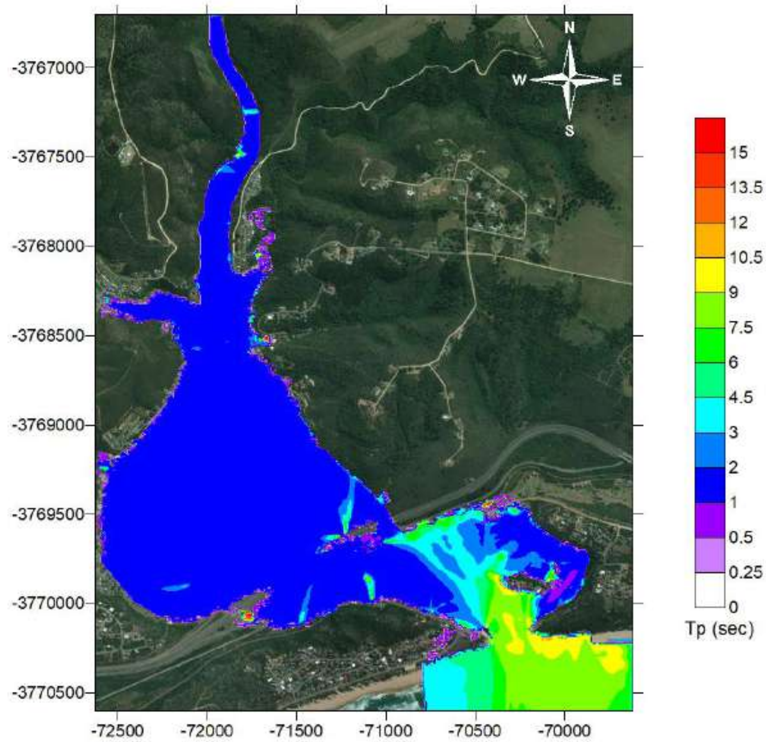


Figure D.2.16: Contour map showing the mean wave period for Scenario 6 for Groot Brak River

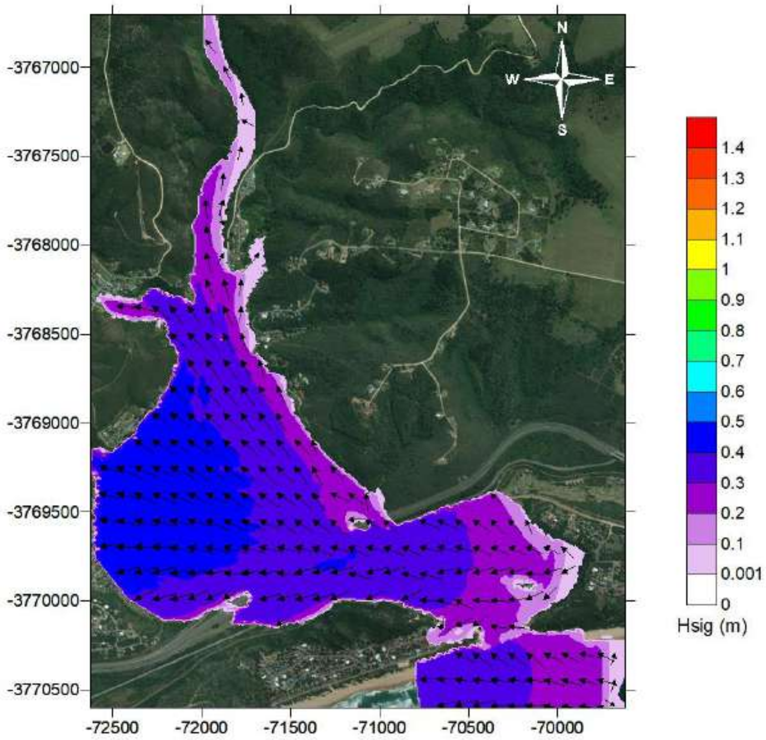


Figure D.2.17: Contour map showing the significant wave height with peak wave direction vectors for Scenario 7 for Groot Brak River with E'ly wind

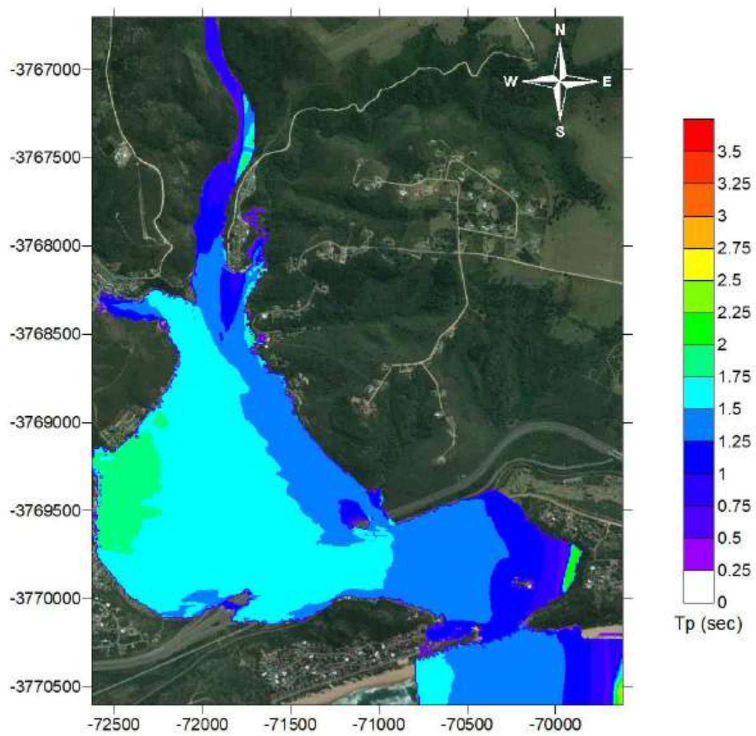


Figure D.2.18: Contour map showing the mean wave period for Scenario 7 for Groot Brak River with E'ly wind

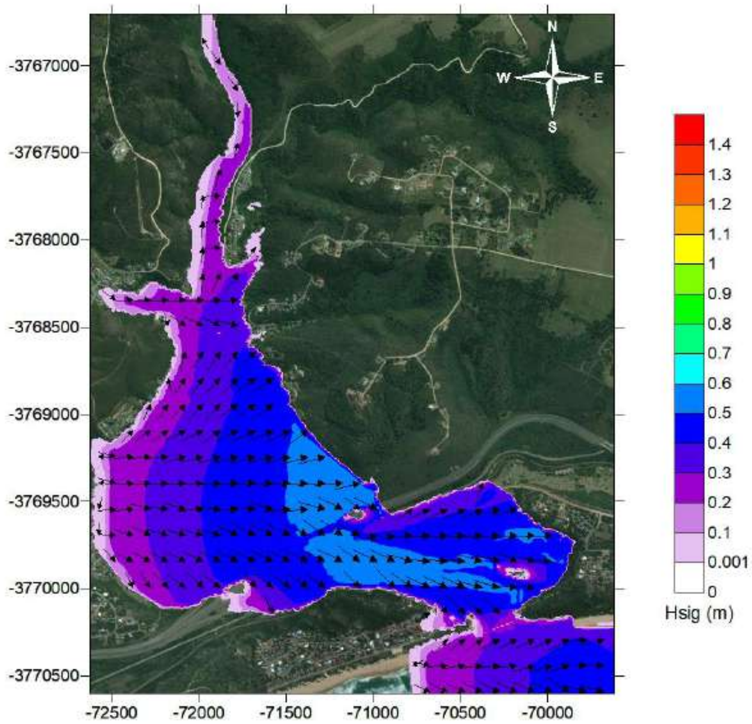


Figure D.2.19: Contour map showing the significant wave height with peak wave direction vectors for Scenario 7 for Groot Brak River with W'ly wind

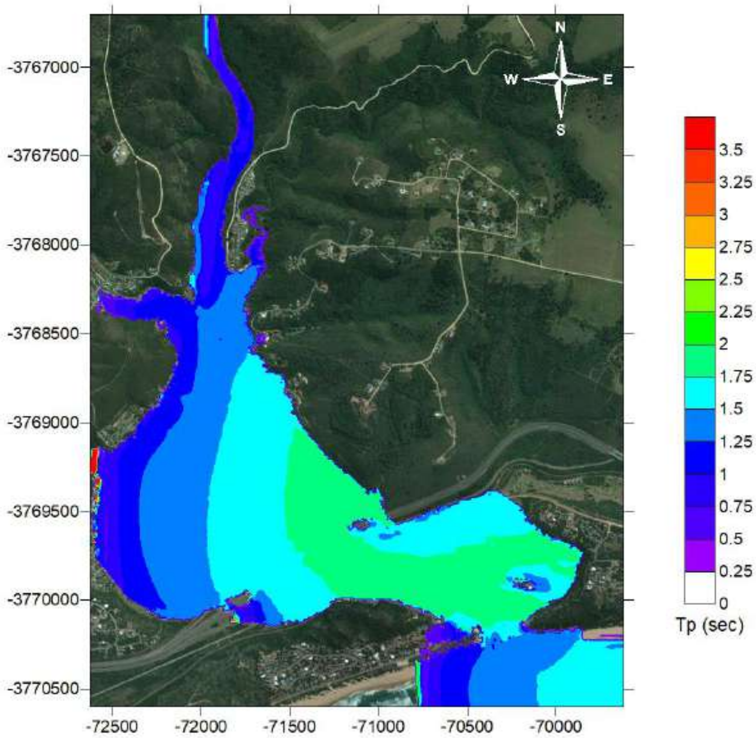


Figure D.2.20: Contour map showing the mean wave period for Scenario 7 for Groot Brak River with W'ly wind

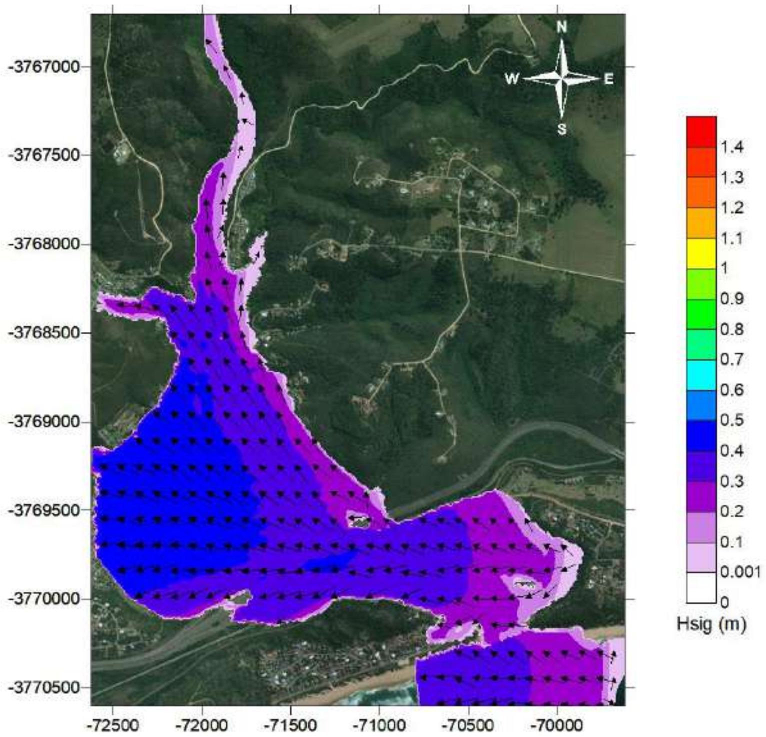


Figure D.2.21: Contour map showing the significant wave height with peak wave direction vectors for Scenario 8 for Groot Brak River with E'ly wind

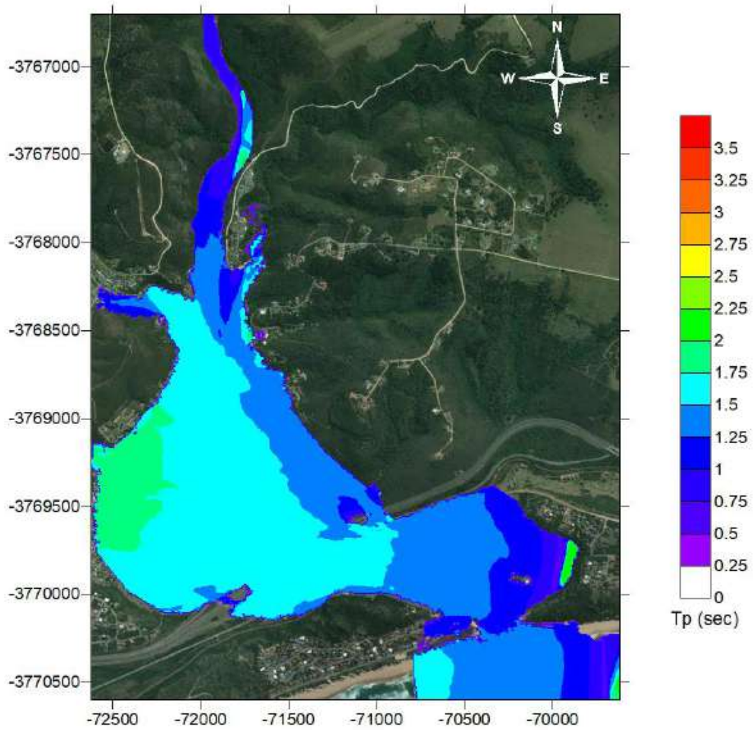


Figure D.2.22: Contour map showing the mean wave period for Scenario 8 for Groot Brak River with E'ly wind

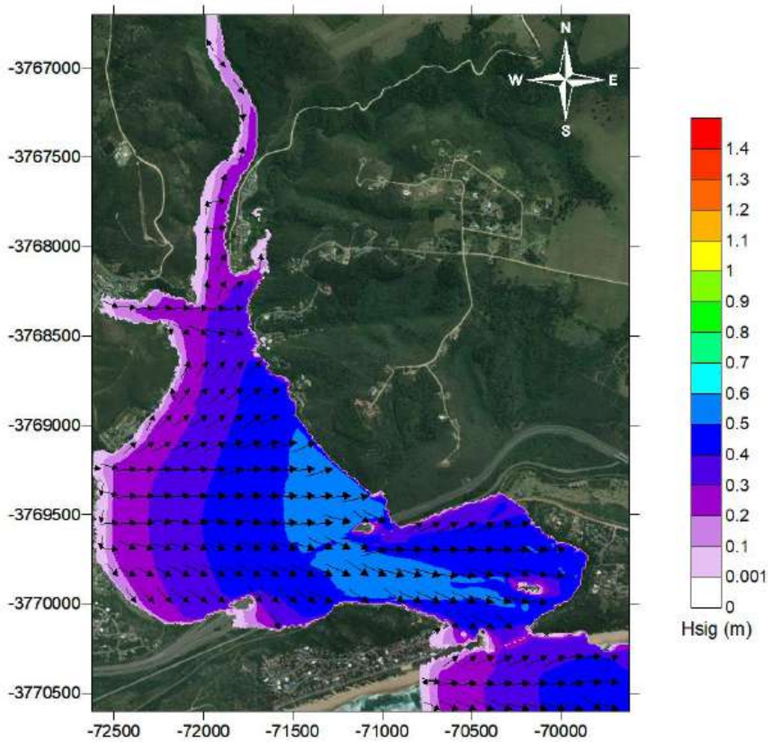


Figure D.2.23: Contour map showing the significant wave height with peak wave direction vectors for Scenario 8 for Groot Brak River with W'ly wind

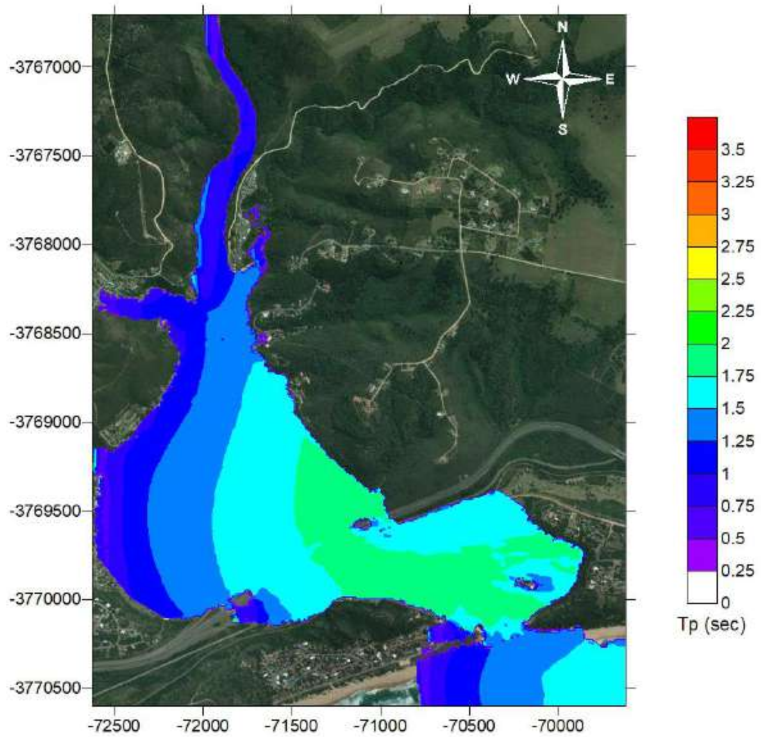


Figure D.2.24: Contour map showing the mean wave period for Scenario 8 for Groot Brak River with W'ly wind

APPENDIX E: EXTREME FLOOD LEVELS

COMBINED RESULTS FROM HYDRODYNAMIC MODELLING, SHORT WAVE MODELLING AND RUNUP CALCULATIONS AT SELECTED LOCATIONS

APPENDIX E1: EXTREME FLOOD LEVELS AT THE KLEIN BRAK RIVER ESTUARY

Table E1-1: Co-ordinates for selected locations on the Klein Brak River

Location	X-Coordinate (m)	Y-Coordinate (m)	Slope (%)	Location	X-Coordinate (m)	Y-Coordinate (m)	Slope (%)
2	-78789	-3774211	25%	**46**	-80429	-3771138	14%
3	-78956	-3774142	30%	**47**	-80224	-3770931	10%
4	-79019	-3774129	17%	**48**	-79935	-3770909	3%
5	-79309	-3774071	11%	**49**	-79639	-3770983	1%
6	-79573	-3773960	3%	**50**	-79467	-3770895	3%
7	-79785	-3773865	30%	**51**	-79631	-3770652	3%
8	-79898	-3773762	49%	**52**	-79875	-3770478	5%
9	-80056	-3773656	25%	**53**	-80079	-3770252	65%
10	-80193	-3773437	18%	**54**	-80316	-3770163	33%
11	-80313	-3773169	20%	**55**	-80184	-3770022	16%
12	-80545	-3772957	8%	**56**	-79980	-3769830	18%
13	-80778	-3772753	7%	**57**	-79928	-3769574	48%
14	-80911	-3772494	5%	**58**	-80149	-3769402	10%
15	-81132	-3772325	1%	**59**	-80027	-3769129	66%
16	-81431	-3772275	12%	**60**	-79899	-3768900	11%
17	-81703	-3772155	2%	**61**	-79966	-3768634	11%
18	-81798	-3771886	6%	**62**	-79899	-3768614	129%
19	-81857	-3771674	9%	**63**	-79857	-3768886	68%
20	-82162	-3771738	3%	**64**	-79942	-3769180	14%
21	-82377	-3771952	12%	**65**	-80053	-3769454	6%
22	-82514	-3772220	17%	**66**	-79826	-3769492	4%
23	-82750	-3772401	9%	**67**	-79793	-3769788	147%
24	-83043	-3772514	4%	**68**	-79972	-3770015	5%
25	-83243	-3772473	1%	**69**	-79852	-3770299	2%
26	-83546	-3772395	11%	**70**	-79574	-3770421	11%
27	-83787	-3772297	11%	**71**	-79307	-3770578	44%
28	-84011	-3772509	9%	**72**	-79079	-3770779	17%
29	-84132	-3772296	4%	**73**	-78948	-3771061	3%
30	-83905	-3772099	4%	**74**	-78950	-3771360	6%
31	-83609	-3772078	12%	**75**	-79012	-3771658	5%
32	-83339	-3771951	8%	**76**	-79093	-3771948	6%
33	-83138	-3771805	5%	**77**	-79225	-3772227	8%
34	-83086	-3771454	8%	**78**	-79353	-3772512	8%
35	-82953	-3771206	6%	**79**	-79440	-3772768	10%
36	-82830	-3770964	3%	**80**	-79492	-3773048	22%
37	-82628	-3770746	22%	**81**	-79513	-3773284	6%
38	-82313	-3770789	17%	**82**	-79420	-3773333	5%
39	-82056	-3770841	18%	**83**	-79201	-3773354	17%
40	-81762	-3770806	17%	**84**	-78950	-3773530	10%
41	-81567	-3770703	12%	**85**	-78883	-3773683	4%
42	-81371	-3770922	2%	**86**	-79122	-3773638	4%
43	-81130	-3771115	21%	**87**	-78994	-3773942	30%
44	-80899	-3771301	2%	**88**	-78921	-3773970	4%
45	-80606	-3771379	4%	**89**	-78634	-3773973	10%

Table E1-2: Scenario 1 i.e. Q50 current with open mouth

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)	Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
2	0.38	4.52	0.99	2.65	3.64	46	0.27	1.82	0.23	3.26	3.49
3	0.46	2.47	0.81	2.83	3.64	47	0.24	1.55	0.15	3.27	3.42
4	0.30	1.80	0.27	2.87	3.15	48	0.07	3.71	0.05	3.26	3.31
5	0.21	1.63	0.14	2.87	3.01	49	0.05	1.44	0.00	3.65	3.65
6	0.38	1.88	0.05	2.93	2.99	50	0.10	1.78	0.03	4.57	4.60
7	0.41	1.95	0.62	2.93	3.56	51	0.26	1.60	0.04	5.15	5.19
8	0.39	1.96	1.02	2.97	3.99	52	0.31	1.68	0.08	5.73	5.81
9	0.33	1.78	0.44	3.01	3.45	53	0.34	1.77	0.50	6.31	7.31
10	0.38	1.86	0.41	3.04	3.46	54	0.20	1.47	0.35	6.60	6.96
11	0.43	1.99	0.48	3.10	3.58	55	0.51	5.04	0.50	6.64	7.79
12	0.34	2.12	0.19	3.12	3.30	56	0.35	15.47	0.50	6.78	7.88
13	0.03	1.34	0.03	3.14	3.17	57	0.23	1.93	0.63	7.96	8.59
14	0.23	2.03	0.10	3.18	3.28	58	0.47	4.47	0.55	8.46	9.01
15	0.12	1.40	0.01	3.21	3.22	59	0.20	3.75	0.56	8.71	9.27
16	0.09	1.13	0.06	3.24	3.31	60	0.19	1.04	0.08	9.21	9.30
17	0.10	1.34	0.01	3.27	3.28	61	0.32	2.28	0.25	9.50	9.75
18	0.12	1.72	0.08	3.28	3.35	62	0.15	1.18	0.42	9.57	9.99
19	0.21	1.98	0.14	3.28	3.42	63	0.07	0.92	0.24	9.23	9.46
20	0.34	2.12	0.06	3.28	3.34	64	0.11	1.21	0.09	8.80	8.90
21	0.27	1.94	0.20	3.29	3.48	65	0.49	8.61	0.57	8.32	8.89
22	0.20	1.45	0.18	3.29	3.47	66	0.24	2.82	0.10	7.80	7.90
23	0.29	1.98	0.17	3.30	3.47	67	0.15	0.97	0.46	7.38	7.84
24	0.30	2.20	0.08	3.31	3.39	68	0.18	1.52	0.06	6.82	6.88
25	0.37	2.08	0.02	3.32	3.34	69	0.30	2.69	0.05	5.84	5.89
26	0.29	2.29	0.24	3.44	3.68	70	0.26	1.66	0.16	5.32	5.48
27	0.29	1.74	0.16	3.84	4.01	71	0.22	1.58	0.56	4.78	5.34
28	0.16	1.03	0.06	4.09	4.15	72	0.16	1.38	0.15	4.26	4.41
29	0.31	2.86	0.11	3.96	4.08	73	0.03	1.00	0.01	3.93	3.94
30	0.30	1.80	0.05	3.90	3.95	74	0.04	1.20	0.02	3.75	3.77
31	0.16	1.56	0.13	3.66	3.78	75	0.09	1.24	0.03	3.61	3.63
32	0.32	1.75	0.13	3.43	3.56	76	0.09	1.36	0.04	3.41	3.45
33	0.32	2.32	0.12	3.30	3.42	77	0.11	1.22	0.05	3.25	3.31
34	0.43	2.28	0.23	3.29	3.52	78	0.10	1.24	0.05	3.17	3.22
35	0.41	2.32	0.17	3.28	3.46	79	0.03	1.10	0.04	3.09	3.12
36	0.49	2.34	0.10	3.28	3.39	80	0.14	1.02	0.13	3.08	3.21
37	0.44	2.19	0.60	3.28	3.89	81	0.16	1.23	0.05	3.07	3.11
38	0.33	2.04	0.34	3.28	3.62	82	0.15	1.24	0.05	2.91	2.96
39	0.39	2.10	0.40	3.28	3.68	83	0.25	2.13	0.30	2.90	3.20
40	0.33	1.78	0.33	3.28	3.61	84	0.15	1.11	0.07	2.90	2.96
41	0.26	2.01	0.20	3.28	3.48	85	0.16	1.04	0.03	2.91	2.94
42	0.23	1.90	0.03	3.28	3.30	86	0.15	1.47	0.04	2.89	2.93
43	0.34	1.90	0.39	3.28	3.67	87	0.35	5.56	1.05	2.87	3.92
44	0.27	1.98	0.04	3.25	3.29	88	0.00	0.88	0.01	2.79	2.80
45	0.26	1.74	0.02	3.25	3.27	89	0.32	12.65	1.01	2.86	3.87

Table E1-3: Scenario 2 i.e. Q100 current with open mouth

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)	Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
2	0.53	5.75	1.39	2.82	4.21	**46**	0.28	2.12	0.27	3.42	3.69
3	0.46	2.13	0.70	2.97	3.67	**47**	0.26	1.68	0.17	3.42	3.60
4	0.31	1.87	0.29	3.03	3.32	**48**	0.07	2.02	0.03	3.42	3.45
5	0.23	1.64	0.15	3.05	3.19	**49**	0.07	7.68	0.02	3.65	3.67
6	0.41	1.95	0.05	3.11	3.17	**50**	0.28	2.21	0.06	4.71	4.76
7	0.42	2.00	0.65	3.11	3.76	**51**	0.30	1.67	0.05	5.34	5.39
8	0.44	2.09	1.13	3.16	4.29	**52**	0.39	2.12	0.11	5.96	6.08
9	0.37	1.87	0.49	3.21	3.70	**53**	0.37	1.84	0.50	6.65	7.74
10	0.58	2.46	0.67	3.24	3.91	**54**	0.22	1.54	0.39	6.94	7.32
11	0.48	2.11	0.53	3.30	3.83	**55**	0.52	3.91	0.50	6.94	7.84
12	0.44	2.21	0.22	3.31	3.53	**56**	0.76	16.38	0.50	7.09	9.53
13	0.22	1.87	0.12	3.33	3.45	**57**	0.23	1.89	0.63	8.28	8.91
14	0.30	2.48	0.14	3.36	3.50	**58**	0.45	3.73	0.45	8.79	9.24
15	0.19	1.56	0.01	3.39	3.40	**59**	0.22	1.62	0.67	9.03	9.70
16	0.17	1.81	0.14	3.40	3.54	**60**	0.20	1.08	0.09	9.56	9.65
17	0.18	2.01	0.02	3.42	3.45	**61**	0.22	1.26	0.11	9.89	10.00
18	0.18	2.17	0.12	3.42	3.54	**62**	0.14	1.25	0.41	9.87	10.27
19	0.32	1.91	0.17	3.42	3.60	**63**	0.11	0.92	0.35	9.58	9.93
20	0.38	2.23	0.06	3.43	3.49	**64**	0.13	1.89	0.16	9.14	9.30
21	0.30	1.91	0.20	3.44	3.64	**65**	0.49	7.86	0.52	8.62	9.14
22	0.23	1.48	0.20	3.44	3.63	**66**	0.39	6.01	0.28	8.09	8.36
23	0.32	1.98	0.18	3.44	3.62	**67**	0.18	1.03	0.56	7.67	8.22
24	0.34	2.29	0.09	3.45	3.54	**68**	0.20	1.53	0.06	7.17	7.23
25	0.42	2.19	0.03	3.46	3.48	**69**	0.38	3.10	0.07	6.14	6.21
26	0.34	2.38	0.27	3.51	3.78	**70**	0.30	1.71	0.17	5.53	5.70
27	0.34	1.85	0.19	3.96	4.15	**71**	0.25	1.61	0.60	4.98	5.57
28	0.19	1.28	0.08	4.23	4.31	**72**	0.16	1.42	0.16	4.40	4.56
29	0.38	2.04	0.02	4.10	4.12	**73**	0.08	0.95	0.01	4.07	4.08
30	0.34	1.93	0.06	4.03	4.08	**74**	0.05	1.24	0.03	3.87	3.90
31	0.20	1.80	0.16	3.75	3.91	**75**	0.12	1.19	0.03	3.73	3.76
32	0.35	1.88	0.15	3.48	3.64	**76**	0.09	1.46	0.05	3.53	3.58
33	0.42	2.38	0.14	3.44	3.58	**77**	0.15	1.39	0.07	3.39	3.46
34	0.50	2.39	0.26	3.43	3.70	**78**	0.13	1.47	0.07	3.36	3.42
35	0.54	2.41	0.21	3.43	3.63	**79**	0.18	1.16	0.09	3.31	3.40
36	0.54	2.39	0.11	3.43	3.54	**80**	0.16	1.11	0.16	3.28	3.44
37	0.48	2.26	0.65	3.43	4.08	**81**	0.17	1.38	0.06	3.26	3.32
38	0.37	2.11	0.37	3.43	3.79	**82**	0.22	1.51	0.07	3.10	3.17
39	0.43	2.20	0.44	3.43	3.87	**83**	0.27	1.70	0.25	3.09	3.34
40	0.37	1.87	0.37	3.43	3.79	**84**	0.17	1.17	0.08	3.07	3.15
41	0.31	2.18	0.24	3.43	3.67	**85**	0.19	1.16	0.04	3.08	3.12
42	0.28	2.26	0.04	3.42	3.46	**86**	0.16	1.44	0.04	3.07	3.11
43	0.37	2.00	0.42	3.42	3.85	**87**	0.44	6.11	1.31	3.06	4.37
44	0.35	2.11	0.05	3.41	3.46	**88**	0.05	9.19	0.14	2.97	3.11
45	0.33	1.92	0.02	3.41	3.43	**89**	0.69	14.39	1.95	3.41	5.37

Table E1-4: Scenario 3 i.e. Q50 current with closed mouth E'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)	Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
2	0.16	1.22	0.20	3.82	4.02	**46**	0.31	1.75	0.26	3.82	4.09
3	0.23	1.46	0.40	3.82	4.21	**47**	0.26	1.60	0.16	3.82	3.98
4	0.21	1.50	0.20	3.82	4.02	**48**	0.15	1.34	0.02	3.82	3.84
5	0.23	1.51	0.13	3.82	3.95	**49**	0.13	1.36	0.01	3.82	3.83
6	0.30	1.71	0.04	3.82	3.86	**50**	0.13	1.30	0.03	4.57	4.60
7	0.34	1.83	0.54	3.82	4.36	**51**	0.21	1.42	0.04	5.15	5.19
8	0.34	1.89	0.89	3.82	4.71	**52**	0.22	1.49	0.06	5.73	5.79
9	0.30	1.67	0.45	3.82	4.27	**53**	0.24	1.42	0.50	6.31	6.99
10	0.36	1.81	0.37	3.82	4.19	**54**	0.16	1.35	0.35	6.62	6.97
11	0.40	1.95	0.45	3.82	4.27	**55**	0.24	1.50	0.19	6.65	6.84
12	0.39	2.01	0.17	3.82	3.99	**56**	0.06	1.17	0.08	6.77	6.85
13	0.33	2.00	0.15	3.82	3.97	**57**	0.16	1.14	0.39	7.95	8.34
14	0.40	2.12	0.12	3.82	3.95	**58**	0.22	1.26	0.10	8.43	8.53
15	0.28	1.87	0.02	3.82	3.84	**59**	0.16	1.03	0.44	8.69	9.14
16	0.27	1.75	0.17	3.82	3.99	**60**	0.13	0.97	0.06	9.21	9.27
17	0.27	1.75	0.03	3.83	3.85	**61**	0.14	1.02	0.07	9.48	9.55
18	0.31	2.05	0.15	3.82	3.97	**62**	0.05	0.99	0.13	9.54	9.67
19	0.35	2.19	0.20	3.82	4.02	**63**	0.06	0.92	0.19	9.21	9.41
20	0.27	1.93	0.05	3.82	3.87	**64**	0.04	1.00	0.04	8.79	8.83
21	0.22	1.62	0.15	3.82	3.97	**65**	0.13	1.19	0.05	8.27	8.32
22	0.17	1.39	0.16	3.82	3.98	**66**	0.10	0.96	0.02	7.79	7.81
23	0.23	1.76	0.13	3.83	3.96	**67**	0.07	0.93	0.19	7.34	7.53
24	0.27	1.94	0.07	3.83	3.90	**68**	0.12	1.16	0.03	6.81	6.85
25	0.33	1.93	0.02	3.83	3.85	**69**	0.18	1.54	0.02	5.83	5.86
26	0.35	2.15	0.25	3.83	4.08	**70**	0.20	1.50	0.12	5.32	5.44
27	0.26	1.70	0.15	3.87	4.03	**71**	0.15	1.32	0.37	4.78	5.15
28	0.12	1.04	0.05	4.09	4.15	**72**	0.09	1.06	0.09	4.26	4.35
29	0.23	1.49	0.05	3.97	4.01	**73**	0.07	0.93	0.01	3.94	3.95
30	0.20	1.64	0.06	3.90	3.96	**74**	0.03	0.98	0.01	3.82	3.84
31	0.20	1.63	0.14	3.86	4.01	**75**	0.05	0.94	0.02	3.84	3.86
32	0.29	1.76	0.13	3.83	3.96	**76**	0.06	1.00	0.02	3.83	3.86
33	0.43	2.18	0.14	3.83	3.96	**77**	0.12	1.02	0.05	3.84	3.89
34	0.46	2.26	0.24	3.82	4.06	**78**	0.15	1.21	0.06	3.83	3.89
35	0.44	2.24	0.17	3.82	3.99	**79**	0.15	1.13	0.07	3.82	3.89
36	0.43	2.26	0.09	3.82	3.91	**80**	0.11	0.99	0.12	3.82	3.94
37	0.38	2.26	0.58	3.82	4.40	**81**	0.14	1.20	0.04	3.82	3.86
38	0.29	2.04	0.32	3.82	4.13	**82**	0.26	1.53	0.08	3.82	3.90
39	0.35	2.21	0.40	3.82	4.22	**83**	0.20	1.46	0.18	3.82	4.00
40	0.33	1.88	0.36	3.82	4.18	**84**	0.14	1.13	0.07	3.82	3.89
41	0.27	1.90	0.20	3.82	4.02	**85**	0.16	1.09	0.03	3.83	3.86
42	0.25	1.90	0.03	3.82	3.85	**86**	0.20	1.27	0.01	3.82	3.83
43	0.29	1.99	0.38	3.84	4.22	**87**	0.10	1.20	0.18	3.82	4.00
44	0.28	2.03	0.04	3.82	3.86	**88**	0.19	1.44	0.05	3.82	3.86
45	0.33	1.86	0.07	3.83	3.90	**89**	0.15	1.30	0.08	3.82	3.90

Table E1-5: Scenario 3 i.e. Q50 current with closed mouth W'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)	Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
2	0.29	1.74	0.40	3.82	4.22	**46**	0.14	1.38	0.11	3.82	3.94
3	0.19	1.75	0.37	3.82	4.19	**47**	0.24	1.72	0.15	3.82	3.97
4	0.36	2.06	0.35	3.82	4.16	**48**	0.29	1.93	0.05	3.82	3.87
5	0.30	1.88	0.21	3.82	4.03	**49**	0.13	1.54	0.01	3.82	3.83
6	0.26	1.69	0.04	3.82	3.85	**50**	0.14	1.25	0.03	4.57	4.60
7	0.22	1.64	0.37	3.82	4.19	**51**	0.18	1.35	0.03	5.15	5.18
8	0.16	1.73	0.42	3.82	4.24	**52**	0.14	1.22	0.04	5.73	5.77
9	0.25	1.91	0.41	3.82	4.23	**53**	0.06	1.00	0.18	6.31	6.48
10	0.15	2.00	0.23	3.82	4.05	**54**	0.06	0.94	0.13	6.62	6.74
11	0.33	2.16	0.41	3.82	4.24	**55**	0.09	1.02	0.08	6.65	6.73
12	0.23	1.78	0.11	3.82	3.92	**56**	0.07	1.23	0.09	6.77	6.86
13	0.18	1.80	0.09	3.82	3.91	**57**	0.17	1.27	0.43	7.95	8.38
14	0.21	1.83	0.07	3.82	3.89	**58**	0.02	0.97	0.02	8.43	8.46
15	0.30	1.74	0.02	3.82	3.84	**59**	0.09	0.97	0.26	8.69	8.95
16	0.24	1.58	0.18	3.82	4.00	**60**	0.10	1.04	0.06	9.21	9.27
17	0.15	1.21	0.01	3.83	3.84	**61**	0.05	1.06	0.04	9.48	9.52
18	0.10	1.31	0.04	3.82	3.87	**62**	0.21	1.17	0.61	9.54	10.15
19	0.31	2.10	0.16	3.82	3.98	**63**	0.17	1.07	0.47	9.21	9.69
20	0.45	2.09	0.07	3.82	3.89	**64**	0.21	1.20	0.15	8.79	8.93
21	0.46	2.06	0.31	3.82	4.13	**65**	0.18	1.09	0.05	8.27	8.32
22	0.43	1.99	0.41	3.82	4.23	**66**	0.20	1.29	0.04	7.79	7.83
23	0.39	1.90	0.18	3.83	4.01	**67**	0.24	1.32	0.71	7.34	8.06
24	0.30	1.66	0.06	3.83	3.89	**68**	0.23	1.33	0.06	6.81	6.87
25	0.25	1.47	0.01	3.83	3.84	**69**	0.22	1.32	0.02	5.83	5.86
26	0.19	1.43	0.11	3.83	3.94	**70**	0.26	1.49	0.14	5.32	5.46
27	0.27	1.60	0.14	3.87	4.02	**71**	0.29	1.57	0.61	4.78	5.39
28	0.26	1.48	0.12	4.09	4.21	**72**	0.33	1.69	0.32	4.26	4.58
29	0.13	1.34	0.03	3.97	4.00	**73**	0.39	1.93	0.06	3.94	4.00
30	0.19	1.44	0.03	3.90	3.93	**74**	0.37	2.13	0.15	3.82	3.97
31	0.11	1.26	0.09	3.86	3.95	**75**	0.40	1.95	0.11	3.84	3.95
32	0.24	1.63	0.12	3.83	3.94	**76**	0.42	2.14	0.16	3.83	4.00
33	0.09	1.52	0.04	3.83	3.86	**77**	0.41	2.07	0.21	3.84	4.05
34	0.07	1.21	0.04	3.82	3.86	**78**	0.45	2.11	0.21	3.83	4.04
35	0.13	1.28	0.05	3.82	3.86	**79**	0.44	2.10	0.26	3.82	4.08
36	0.17	1.23	0.03	3.82	3.85	**80**	0.49	2.18	0.59	3.82	4.41
37	0.21	1.54	0.28	3.82	4.10	**81**	0.50	2.31	0.19	3.82	4.01
38	0.35	1.83	0.36	3.82	4.18	**82**	0.22	1.50	0.06	3.82	3.88
39	0.38	2.06	0.43	3.82	4.25	**83**	0.32	1.66	0.27	3.82	4.08
40	0.21	2.08	0.26	3.82	4.08	**84**	0.39	1.88	0.19	3.82	4.01
41	0.31	1.77	0.23	3.82	4.05	**85**	0.29	1.81	0.07	3.83	3.90
42	0.45	2.18	0.05	3.82	3.87	**86**	0.40	1.87	0.05	3.82	3.87
43	0.50	2.28	0.62	3.84	4.46	**87**	0.43	2.00	0.67	3.82	4.49
44	0.51	2.38	0.08	3.82	3.90	**88**	0.12	1.36	0.03	3.82	3.85
45	0.35	2.23	0.08	3.83	3.91	**89**	0.27	1.54	0.14	3.82	3.95

Table E1-6: Scenario 4 i.e. Q100 current with closed mouth E'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)	Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
2	0.18	1.34	0.23	3.96	4.19	**46**	0.34	1.83	0.29	3.97	4.26
3	0.25	1.53	0.43	3.97	4.39	**47**	0.28	1.70	0.18	3.97	4.15
4	0.22	1.58	0.22	3.97	4.19	**48**	0.18	1.53	0.03	3.97	4.00
5	0.24	1.55	0.14	3.97	4.11	**49**	0.18	1.48	0.01	3.97	3.98
6	0.31	1.77	0.04	3.97	4.01	**50**	0.21	1.45	0.04	4.71	4.75
7	0.34	1.85	0.55	3.97	4.52	**51**	0.23	1.47	0.04	5.34	5.38
8	0.35	1.92	0.91	3.97	4.88	**52**	0.24	1.51	0.06	5.96	6.03
9	0.31	1.71	0.46	3.97	4.44	**53**	0.24	1.47	0.50	6.65	7.36
10	0.37	1.84	0.38	3.97	4.36	**54**	0.17	1.38	0.37	6.94	7.30
11	0.41	1.98	0.46	3.98	4.44	**55**	0.26	1.54	0.21	6.94	7.15
12	0.40	2.03	0.18	3.97	4.15	**56**	0.17	1.18	0.14	7.09	7.23
13	0.38	2.04	0.16	3.97	4.13	**57**	0.16	1.14	0.39	8.23	8.63
14	0.43	2.16	0.13	3.98	4.11	**58**	0.22	1.26	0.10	8.76	8.85
15	0.30	1.93	0.02	3.98	4.00	**59**	0.16	1.03	0.43	9.02	9.46
16	0.30	1.87	0.19	3.98	4.17	**60**	0.13	0.97	0.07	9.56	9.62
17	0.31	1.89	0.03	3.98	4.01	**61**	0.14	1.03	0.08	9.87	9.95
18	0.37	2.16	0.17	3.98	4.15	**62**	0.05	0.99	0.14	9.88	10.01
19	0.41	2.22	0.22	3.97	4.19	**63**	0.07	0.92	0.21	9.58	9.79
20	0.28	1.95	0.05	3.98	4.02	**64**	0.03	1.04	0.05	9.15	9.20
21	0.22	1.59	0.15	3.98	4.13	**65**	0.12	1.16	0.04	8.61	8.65
22	0.17	1.38	0.16	3.98	4.14	**66**	0.10	0.96	0.02	8.14	8.16
23	0.22	1.69	0.13	3.99	4.11	**67**	0.07	0.93	0.19	7.67	7.86
24	0.27	1.91	0.07	3.98	4.05	**68**	0.12	1.15	0.04	7.14	7.18
25	0.33	1.93	0.02	3.99	4.01	**69**	0.19	1.58	0.02	6.14	6.16
26	0.38	2.16	0.26	3.98	4.25	**70**	0.20	1.53	0.14	5.53	5.67
27	0.30	1.84	0.18	4.04	4.21	**71**	0.16	1.33	0.47	4.97	5.44
28	0.17	1.26	0.08	4.22	4.30	**72**	0.10	1.07	0.11	4.40	4.51
29	0.27	1.61	0.05	4.10	4.15	**73**	0.07	0.93	0.01	4.07	4.08
30	0.22	1.67	0.06	4.02	4.08	**74**	0.03	0.99	0.02	3.98	4.00
31	0.31	1.81	0.20	4.02	4.22	**75**	0.04	0.96	0.02	4.00	4.02
32	0.30	1.79	0.13	3.99	4.12	**76**	0.06	1.01	0.03	3.99	4.02
33	0.44	2.20	0.14	3.98	4.12	**77**	0.12	1.02	0.06	3.98	4.04
34	0.47	2.29	0.24	3.98	4.22	**78**	0.17	1.27	0.08	3.99	4.07
35	0.45	2.27	0.18	3.97	4.15	**79**	0.15	1.14	0.09	3.97	4.06
36	0.44	2.30	0.10	3.97	4.07	**80**	0.10	1.01	0.14	3.97	4.11
37	0.39	2.30	0.60	3.97	4.57	**81**	0.16	1.27	0.06	3.97	4.03
38	0.30	2.06	0.32	3.97	4.30	**82**	0.26	1.55	0.08	3.97	4.05
39	0.37	2.25	0.42	3.98	4.39	**83**	0.20	1.48	0.23	3.97	4.19
40	0.34	1.92	0.37	3.97	4.35	**84**	0.15	1.15	0.09	3.97	4.05
41	0.27	1.92	0.20	3.97	4.18	**85**	0.16	1.09	0.04	3.98	4.02
42	0.27	1.89	0.03	3.97	4.00	**86**	0.21	1.27	0.01	3.97	3.97
43	0.30	2.05	0.39	3.98	4.38	**87**	0.10	1.25	0.23	3.97	4.21
44	0.30	2.06	0.05	3.97	4.02	**88**	0.23	1.53	0.06	3.96	4.02
45	0.36	1.95	0.00	3.98	3.98	**89**	0.17	1.46	0.12	3.97	4.09

Table E1-7: Scenario 4 i.e. Q100 current with closed mouth W'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)	Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
2	0.30	1.80	0.42	3.96	4.38	**46**	0.15	1.40	0.12	3.97	4.10
3	0.19	1.83	0.39	3.97	4.36	**47**	0.25	1.69	0.15	3.97	4.13
4	0.40	2.21	0.39	3.97	4.36	**48**	0.32	2.00	0.05	3.97	4.03
5	0.34	2.05	0.24	3.97	4.21	**49**	0.20	1.68	0.01	3.97	3.98
6	0.27	1.77	0.04	3.97	4.01	**50**	0.17	1.38	0.03	4.71	4.74
7	0.22	1.65	0.38	3.97	4.35	**51**	0.18	1.34	0.03	5.34	5.37
8	0.16	1.80	0.44	3.97	4.41	**52**	0.16	1.21	0.04	5.96	6.00
9	0.27	1.95	0.44	3.97	4.41	**53**	0.07	0.99	0.21	6.65	6.86
10	0.16	2.06	0.24	3.97	4.21	**54**	0.10	0.96	0.16	6.94	7.09
11	0.36	2.25	0.45	3.98	4.42	**55**	0.11	1.03	0.09	6.94	7.03
12	0.25	1.89	0.12	3.97	4.09	**56**	0.10	1.24	0.12	7.09	7.20
13	0.19	1.85	0.10	3.97	4.07	**57**	0.17	1.27	0.43	8.23	8.66
14	0.23	1.98	0.08	3.98	4.05	**58**	0.02	0.97	0.02	8.76	8.78
15	0.34	1.90	0.02	3.98	4.00	**59**	0.09	0.98	0.25	9.02	9.28
16	0.26	1.63	0.19	3.98	4.17	**60**	0.11	1.01	0.06	9.56	9.62
17	0.17	1.26	0.02	3.98	3.99	**61**	0.05	1.05	0.05	9.87	9.92
18	0.12	1.24	0.05	3.98	4.02	**62**	0.21	1.17	0.61	9.88	10.49
19	0.34	2.06	0.17	3.97	4.14	**63**	0.18	1.10	0.50	9.58	10.08
20	0.46	2.12	0.07	3.98	4.05	**64**	0.21	1.21	0.15	9.15	9.30
21	0.47	2.08	0.31	3.98	4.30	**65**	0.19	1.10	0.05	8.61	8.66
22	0.44	2.01	0.41	3.98	4.39	**66**	0.21	1.30	0.04	8.14	8.18
23	0.40	1.91	0.19	3.99	4.17	**67**	0.24	1.36	0.73	7.67	8.40
24	0.31	1.68	0.07	3.98	4.05	**68**	0.24	1.37	0.06	7.14	7.20
25	0.26	1.50	0.01	3.99	4.00	**69**	0.23	1.34	0.02	6.14	6.16
26	0.20	1.49	0.12	3.98	4.10	**70**	0.27	1.52	0.14	5.53	5.67
27	0.29	1.62	0.15	4.04	4.19	**71**	0.30	1.60	0.64	4.97	5.61
28	0.29	1.55	0.13	4.22	4.35	**72**	0.36	1.79	0.35	4.40	4.75
29	0.15	1.34	0.02	4.10	4.11	**73**	0.42	2.01	0.07	4.07	4.14
30	0.21	1.48	0.02	4.02	4.05	**74**	0.41	2.20	0.16	3.98	4.14
31	0.23	1.57	0.16	4.02	4.18	**75**	0.44	2.09	0.12	4.00	4.12
32	0.25	1.69	0.12	3.99	4.11	**76**	0.47	2.25	0.18	3.99	4.17
33	0.09	1.47	0.04	3.98	4.02	**77**	0.45	2.18	0.23	3.98	4.21
34	0.07	1.17	0.04	3.98	4.02	**78**	0.49	2.23	0.23	3.99	4.21
35	0.13	1.23	0.04	3.97	4.02	**79**	0.48	2.22	0.29	3.97	4.26
36	0.17	1.21	0.03	3.97	4.00	**80**	0.51	2.25	0.62	3.97	4.60
37	0.21	1.56	0.29	3.97	4.26	**81**	0.54	2.39	0.20	3.97	4.17
38	0.35	1.85	0.36	3.97	4.34	**82**	0.26	1.67	0.07	3.97	4.04
39	0.39	2.07	0.44	3.98	4.41	**83**	0.34	1.74	0.29	3.97	4.26
40	0.21	2.04	0.26	3.97	4.23	**84**	0.45	2.05	0.22	3.97	4.18
41	0.32	1.81	0.24	3.97	4.21	**85**	0.34	2.05	0.09	3.98	4.06
42	0.45	2.18	0.05	3.97	4.03	**86**	0.46	2.08	0.10	3.97	4.07
43	0.50	2.31	0.63	3.98	4.61	**87**	0.47	2.13	0.74	3.97	4.72
44	0.52	2.39	0.08	3.97	4.05	**88**	0.12	1.35	0.03	3.96	4.00
45	0.38	2.25	0.07	3.98	4.05	**89**	0.28	1.55	0.14	3.97	4.11

Table E1-8: Scenario 5 i.e. Q50 future with open mouth

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)	Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
2	0.14	1.16	0.18	3.64	3.81	**46**	0.38	1.99	0.30	3.72	4.02
3	0.22	1.38	0.32	3.49	3.80	**47**	0.33	1.89	0.22	3.72	3.94
4	0.19	1.39	0.17	3.61	3.78	**48**	0.23	1.77	0.04	3.72	3.76
5	0.24	1.51	0.14	3.61	3.74	**49**	0.24	1.63	0.01	3.75	3.76
6	0.31	1.73	0.04	3.60	3.64	**50**	0.23	1.51	0.04	4.68	4.73
7	0.33	1.80	0.52	3.65	4.17	**51**	0.24	1.50	0.04	5.31	5.35
8	0.33	1.87	0.87	3.61	4.47	**52**	0.25	1.55	0.07	5.93	5.99
9	0.31	1.71	0.41	3.67	4.07	**53**	0.25	1.51	0.50	6.61	7.36
10	0.38	1.89	0.41	3.65	4.06	**54**	0.17	1.39	0.31	6.88	7.19
11	0.44	2.06	0.50	3.70	4.19	**55**	0.27	1.59	0.26	6.89	7.15
12	0.43	2.10	0.21	3.69	3.90	**56**	0.18	1.19	0.16	7.02	7.18
13	0.40	2.08	0.18	3.69	3.87	**57**	0.16	1.15	0.38	8.16	8.54
14	0.46	2.23	0.16	3.71	3.87	**58**	0.21	1.23	0.10	8.77	8.87
15	0.35	2.06	0.02	3.72	3.74	**59**	0.17	1.04	0.44	9.00	9.45
16	0.35	2.05	0.23	3.73	3.96	**60**	0.14	0.97	0.07	9.53	9.59
17	0.37	2.08	0.04	3.73	3.77	**61**	0.15	1.04	0.08	9.86	9.94
18	0.43	2.25	0.19	3.73	3.92	**62**	0.05	0.98	0.14	9.84	9.98
19	0.44	2.27	0.24	3.73	3.97	**63**	0.07	0.92	0.23	9.55	9.77
20	0.28	1.91	0.05	3.74	3.78	**64**	0.04	0.98	0.05	9.12	9.17
21	0.23	1.60	0.15	3.74	3.89	**65**	0.13	1.17	0.04	8.61	8.65
22	0.18	1.39	0.16	3.74	3.90	**66**	0.10	0.96	0.02	8.08	8.10
23	0.24	1.69	0.13	3.74	3.87	**67**	0.07	0.93	0.21	7.61	7.81
24	0.28	1.89	0.06	3.75	3.81	**68**	0.12	1.16	0.04	7.09	7.13
25	0.34	1.93	0.02	3.76	3.78	**69**	0.20	1.62	0.03	6.09	6.12
26	0.40	2.18	0.27	3.78	4.04	**70**	0.21	1.55	0.13	5.50	5.63
27	0.36	2.03	0.21	4.05	4.26	**71**	0.17	1.36	0.41	4.95	5.36
28	0.17	1.25	0.07	4.25	4.32	**72**	0.10	1.07	0.10	4.38	4.48
29	0.30	1.73	0.07	4.14	4.21	**73**	0.10	0.94	0.01	4.08	4.09
30	0.26	1.68	0.04	4.08	4.13	**74**	0.07	0.94	0.02	3.89	3.92
31	0.33	1.87	0.22	3.91	4.13	**75**	0.06	0.97	0.02	3.78	3.80
32	0.31	1.85	0.14	3.77	3.91	**76**	0.08	0.98	0.03	3.73	3.76
33	0.45	2.22	0.14	3.74	3.88	**77**	0.16	1.20	0.06	3.71	3.77
34	0.48	2.34	0.25	3.74	3.99	**78**	0.19	1.31	0.07	3.70	3.77
35	0.47	2.32	0.18	3.74	3.92	**79**	0.17	1.20	0.10	3.68	3.77
36	0.46	2.35	0.10	3.74	3.84	**80**	0.17	1.38	0.20	3.66	3.86
37	0.41	2.37	0.63	3.74	4.37	**81**	0.25	1.49	0.07	3.66	3.73
38	0.34	2.20	0.36	3.74	4.10	**82**	0.27	1.56	0.08	3.58	3.66
39	0.39	2.33	0.45	3.74	4.19	**83**	0.20	1.46	0.18	3.59	3.77
40	0.36	2.00	0.39	3.74	4.12	**84**	0.18	1.17	0.08	3.54	3.62
41	0.29	1.97	0.21	3.74	3.95	**85**	0.17	1.13	0.03	3.57	3.60
42	0.29	2.00	0.03	3.74	3.77	**86**	0.22	1.32	0.01	3.62	3.63
43	0.33	2.15	0.44	3.78	4.21	**87**	0.08	1.14	0.16	3.66	3.82
44	0.34	2.16	0.05	3.72	3.77	**88**	0.22	1.43	0.02	3.52	3.54
45	0.40	2.05	0.09	3.73	3.81	**89**	0.14	1.21	0.08	3.77	3.85

Table E1-9: Scenario 6 i.e. Q100 future with open mouth

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)	Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
2	0.73	8.19	2.19	3.69	5.88	**46**	0.44	2.16	0.35	3.89	4.24
3	0.83	5.79	2.17	3.61	5.77	**47**	0.38	1.85	0.23	3.89	4.13
4	0.54	4.78	0.98	3.73	4.71	**48**	0.21	2.25	0.03	3.89	3.92
5	0.38	1.84	0.21	3.77	3.98	**49**	0.23	11.11	0.06	3.91	3.97
6	0.49	2.09	0.06	3.76	3.83	**50**	0.38	3.09	0.11	4.82	4.94
7	0.52	2.25	0.81	3.80	4.61	**51**	0.32	1.73	0.05	5.53	5.59
8	0.51	2.32	1.33	3.76	5.08	**52**	0.39	1.91	0.10	6.17	6.27
9	0.41	2.01	0.55	3.84	4.39	**53**	0.40	1.91	0.50	6.91	8.08
10	0.47	2.10	0.51	3.83	4.34	**54**	0.23	1.57	0.40	7.18	7.58
11	0.53	2.27	0.60	3.87	4.47	**55**	0.59	4.31	0.50	7.18	8.25
12	0.54	2.41	0.27	3.86	4.13	**56**	0.95	16.75	0.50	7.33	10.39
13	0.38	2.44	0.21	3.87	4.08	**57**	0.24	1.91	0.66	8.47	9.13
14	0.49	2.44	0.18	3.87	4.04	**58**	0.54	4.64	0.61	9.03	9.65
15	0.33	2.03	0.02	3.89	3.91	**59**	0.30	2.21	0.90	9.30	10.20
16	0.33	2.09	0.23	3.90	4.13	**60**	0.21	1.09	0.09	9.88	9.97
17	0.28	2.12	0.03	3.90	3.93	**61**	0.22	1.27	0.12	10.22	10.34
18	0.36	2.41	0.18	3.89	4.08	**62**	0.14	1.31	0.42	10.20	10.62
19	0.42	2.28	0.23	3.89	4.13	**63**	0.13	0.94	0.40	9.91	10.31
20	0.43	2.47	0.08	3.90	3.97	**64**	0.14	1.89	0.17	9.45	9.62
21	0.33	2.07	0.23	3.90	4.14	**65**	0.61	9.42	0.69	8.92	9.61
22	0.24	1.58	0.21	3.90	4.12	**66**	0.32	4.30	0.18	8.34	8.51
23	0.35	2.10	0.20	3.91	4.11	**67**	0.18	1.02	0.56	7.93	8.49
24	0.43	2.38	0.11	3.91	4.02	**68**	0.21	1.58	0.06	7.36	7.42
25	0.49	2.35	0.03	3.92	3.95	**69**	0.36	2.56	0.05	6.39	6.44
26	0.47	2.57	0.34	3.93	4.27	**70**	0.34	1.78	0.19	5.70	5.89
27	0.42	2.09	0.24	4.13	4.36	**71**	0.28	1.67	0.66	5.16	5.81
28	0.19	1.36	0.09	4.36	4.45	**72**	0.19	1.56	0.19	4.53	4.72
29	0.42	2.12	0.02	4.24	4.26	**73**	0.17	0.99	0.02	4.24	4.25
30	0.40	2.04	0.05	4.17	4.22	**74**	0.13	1.11	0.04	4.07	4.11
31	0.45	2.10	0.29	3.99	4.28	**75**	0.14	1.38	0.04	3.97	4.01
32	0.43	2.05	0.19	3.93	4.11	**76**	0.14	1.71	0.07	3.92	3.98
33	0.58	2.67	0.19	3.91	4.10	**77**	0.21	1.46	0.09	3.89	3.97
34	0.64	2.65	0.33	3.90	4.23	**78**	0.24	1.55	0.10	3.87	3.97
35	0.65	2.64	0.25	3.90	4.14	**79**	0.22	1.53	0.14	3.86	4.00
36	0.66	2.62	0.13	3.90	4.03	**80**	0.20	1.24	0.20	3.84	4.04
37	0.58	2.50	0.79	3.90	4.69	**81**	0.22	1.51	0.07	3.83	3.89
38	0.47	2.34	0.46	3.90	4.36	**82**	0.43	1.94	0.13	3.77	3.90
39	0.57	2.53	0.59	3.90	4.48	**83**	0.32	1.78	0.29	3.72	4.01
40	0.46	2.10	0.46	3.90	4.36	**84**	0.21	1.38	0.10	3.66	3.76
41	0.42	2.48	0.32	3.90	4.22	**85**	0.21	1.36	0.03	3.74	3.77
42	0.38	2.40	0.05	3.90	3.94	**86**	0.31	1.66	0.04	3.78	3.82
43	0.47	2.27	0.54	3.94	4.48	**87**	0.41	5.01	1.11	3.79	4.90
44	0.49	2.45	0.07	3.89	3.96	**88**	0.62	6.91	0.39	3.70	4.09
45	0.46	2.15	0.10	3.89	3.99	**89**	1.17	15.78	2.85	3.87	6.73

Table E1-10: Scenario 7 i.e. Q50 future with closed mouth E'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)	Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
2	0.14	1.12	0.17	4.05	4.23	**46**	0.36	1.89	0.30	4.08	4.39
3	0.22	1.36	0.35	4.08	4.44	**47**	0.30	1.79	0.19	4.09	4.28
4	0.19	1.34	0.17	4.10	4.27	**48**	0.20	1.62	0.03	4.08	4.11
5	0.23	1.48	0.13	4.06	4.19	**49**	0.19	1.46	0.01	4.07	4.07
6	0.30	1.68	0.04	4.10	4.14	**50**	0.16	1.34	0.03	4.70	4.73
7	0.33	1.80	0.53	4.09	4.62	**51**	0.22	1.46	0.04	5.32	5.36
8	0.34	1.87	0.87	4.06	4.94	**52**	0.23	1.50	0.06	5.93	6.00
9	0.30	1.69	0.45	4.09	4.54	**53**	0.24	1.45	0.70	6.60	7.29
10	0.37	1.86	0.39	4.09	4.48	**54**	0.17	1.37	0.36	6.87	7.23
11	0.41	2.00	0.47	4.08	4.55	**55**	0.25	1.51	0.20	6.88	7.08
12	0.41	2.05	0.18	4.08	4.26	**56**	0.16	1.17	0.14	7.01	7.15
13	0.37	2.05	0.16	4.08	4.24	**57**	0.16	1.14	0.39	8.22	8.61
14	0.44	2.18	0.13	4.10	4.23	**58**	0.22	1.26	0.10	8.73	8.83
15	0.32	1.99	0.02	4.08	4.10	**59**	0.16	1.03	0.43	8.98	9.41
16	0.32	1.94	0.21	4.08	4.29	**60**	0.13	0.97	0.07	9.52	9.58
17	0.33	1.98	0.03	4.09	4.12	**61**	0.15	1.03	0.07	9.84	9.91
18	0.40	2.20	0.18	4.08	4.26	**62**	0.05	0.99	0.13	9.83	9.96
19	0.42	2.21	0.22	4.08	4.29	**63**	0.07	0.92	0.19	9.54	9.73
20	0.27	1.93	0.05	4.08	4.13	**64**	0.03	1.04	0.04	9.10	9.14
21	0.22	1.59	0.15	4.08	4.23	**65**	0.13	1.17	0.04	8.58	8.62
22	0.17	1.40	0.16	4.08	4.24	**66**	0.10	0.96	0.02	8.02	8.04
23	0.23	1.69	0.13	4.09	4.21	**67**	0.07	0.93	0.19	7.62	7.82
24	0.28	1.90	0.07	4.08	4.15	**68**	0.12	1.16	0.04	7.01	7.05
25	0.34	1.94	0.02	4.09	4.11	**69**	0.19	1.57	0.02	6.10	6.12
26	0.38	2.18	0.27	4.09	4.35	**70**	0.21	1.53	0.13	5.50	5.63
27	0.32	1.92	0.19	4.14	4.33	**71**	0.16	1.33	0.39	4.95	5.34
28	0.16	1.26	0.07	4.21	4.28	**72**	0.10	1.07	0.09	4.38	4.47
29	0.28	1.64	0.05	4.10	4.15	**73**	0.08	0.93	0.01	4.10	4.11
30	0.24	1.68	0.06	4.08	4.13	**74**	0.04	0.96	0.02	4.09	4.11
31	0.32	1.83	0.21	4.12	4.33	**75**	0.05	0.96	0.02	4.11	4.12
32	0.31	1.82	0.14	4.08	4.22	**76**	0.06	0.99	0.03	4.10	4.12
33	0.45	2.21	0.14	4.08	4.22	**77**	0.12	1.02	0.05	4.10	4.14
34	0.48	2.31	0.25	4.08	4.33	**78**	0.17	1.29	0.07	4.10	4.17
35	0.46	2.29	0.18	4.08	4.26	**79**	0.15	1.15	0.07	4.07	4.15
36	0.45	2.32	0.10	4.07	4.17	**80**	0.13	1.08	0.14	4.09	4.23
37	0.40	2.33	0.61	4.08	4.69	**81**	0.17	1.27	0.05	4.09	4.14
38	0.32	2.12	0.34	4.07	4.41	**82**	0.27	1.56	0.08	4.10	4.18
39	0.37	2.28	0.43	4.08	4.51	**83**	0.20	1.46	0.18	4.07	4.25
40	0.34	1.94	0.38	4.07	4.45	**84**	0.16	1.16	0.07	4.08	4.15
41	0.28	1.95	0.20	4.08	4.28	**85**	0.16	1.10	0.03	4.07	4.10
42	0.27	1.97	0.03	4.07	4.11	**86**	0.21	1.28	0.01	4.09	4.09
43	0.32	2.08	0.41	4.10	4.50	**87**	0.09	1.18	0.18	4.10	4.27
44	0.32	2.10	0.05	4.08	4.12	**88**	0.21	1.34	0.01	4.16	4.17
45	0.37	2.00	0.00	4.08	4.08	**89**	0.10	1.07	0.05	4.04	4.10

Table E1-11: Scenario 7 i.e. Q50 current with closed mouth W'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)	Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
2	0.31	1.85	0.44	4.05	4.49	**46**	0.16	1.43	0.13	4.08	4.21
3	0.22	1.90	0.43	4.08	4.51	**47**	0.26	1.70	0.16	4.09	4.25
4	0.43	2.33	0.42	4.10	4.52	**48**	0.34	2.03	0.06	4.08	4.14
5	0.37	2.16	0.27	4.06	4.33	**49**	0.24	1.84	0.01	4.07	4.08
6	0.28	1.81	0.04	4.10	4.14	**50**	0.16	1.33	0.03	4.70	4.73
7	0.22	1.65	0.38	4.09	4.47	**51**	0.18	1.34	0.03	5.32	5.35
8	0.17	1.87	0.46	4.06	4.52	**52**	0.16	1.21	0.04	5.93	5.97
9	0.28	1.98	0.45	4.09	4.53	**53**	0.07	1.00	0.20	6.60	6.80
10	0.16	2.16	0.26	4.09	4.35	**54**	0.08	0.95	0.15	6.87	7.01
11	0.37	2.28	0.46	4.08	4.54	**55**	0.11	1.04	0.09	6.88	6.97
12	0.26	1.96	0.12	4.08	4.21	**56**	0.10	1.24	0.11	7.01	7.13
13	0.20	1.88	0.10	4.08	4.18	**57**	0.17	1.27	0.43	8.22	8.65
14	0.24	2.05	0.08	4.10	4.18	**58**	0.02	0.98	0.02	8.73	8.76
15	0.35	1.96	0.02	4.08	4.10	**59**	0.09	0.99	0.25	8.98	9.24
16	0.27	1.66	0.20	4.08	4.28	**60**	0.11	1.01	0.06	9.52	9.58
17	0.18	1.27	0.02	4.09	4.11	**61**	0.05	1.06	0.05	9.84	9.89
18	0.13	1.27	0.05	4.08	4.13	**62**	0.21	1.17	0.61	9.83	10.44
19	0.35	2.05	0.17	4.08	4.24	**63**	0.18	1.10	0.50	9.54	10.04
20	0.47	2.13	0.08	4.08	4.15	**64**	0.21	1.21	0.15	9.10	9.25
21	0.47	2.09	0.32	4.08	4.40	**65**	0.19	1.10	0.05	8.58	8.63
22	0.44	2.02	0.42	4.08	4.50	**66**	0.21	1.29	0.04	8.02	8.06
23	0.40	1.92	0.19	4.09	4.27	**67**	0.24	1.33	0.72	7.62	8.34
24	0.31	1.68	0.07	4.08	4.15	**68**	0.24	1.36	0.06	7.01	7.08
25	0.26	1.51	0.01	4.09	4.10	**69**	0.23	1.33	0.02	6.10	6.12
26	0.21	1.51	0.12	4.09	4.21	**70**	0.28	1.52	0.15	5.50	5.65
27	0.29	1.62	0.15	4.14	4.29	**71**	0.30	1.60	0.64	4.95	5.59
28	0.28	1.55	0.13	4.21	4.34	**72**	0.36	1.79	0.36	4.38	4.73
29	0.15	1.34	0.02	4.10	4.12	**73**	0.42	2.02	0.07	4.10	4.17
30	0.21	1.48	0.02	4.08	4.10	**74**	0.43	2.22	0.17	4.09	4.26
31	0.23	1.57	0.16	4.12	4.28	**75**	0.46	2.17	0.13	4.11	4.24
32	0.26	1.70	0.13	4.08	4.21	**76**	0.50	2.31	0.19	4.10	4.29
33	0.09	1.44	0.03	4.08	4.12	**77**	0.47	2.24	0.24	4.10	4.34
34	0.07	1.10	0.04	4.08	4.12	**78**	0.52	2.31	0.24	4.10	4.35
35	0.13	1.20	0.04	4.08	4.12	**79**	0.51	2.31	0.31	4.07	4.38
36	0.17	1.18	0.03	4.07	4.10	**80**	0.53	2.32	0.66	4.09	4.75
37	0.21	1.54	0.28	4.08	4.36	**81**	0.55	2.43	0.21	4.09	4.30
38	0.35	1.85	0.37	4.07	4.44	**82**	0.27	1.73	0.08	4.10	4.18
39	0.39	2.08	0.44	4.08	4.52	**83**	0.35	1.77	0.30	4.07	4.36
40	0.24	2.05	0.28	4.07	4.35	**84**	0.46	2.12	0.23	4.08	4.31
41	0.33	1.84	0.25	4.08	4.32	**85**	0.36	2.14	0.09	4.07	4.16
42	0.46	2.20	0.06	4.07	4.13	**86**	0.49	2.17	0.12	4.09	4.21
43	0.51	2.32	0.63	4.10	4.73	**87**	0.49	2.19	0.78	4.10	4.88
44	0.52	2.40	0.08	4.08	4.15	**88**	0.19	1.45	0.05	4.16	4.20
45	0.39	2.23	0.06	4.08	4.14	**89**	0.28	1.57	0.14	4.04	4.18

Table E1-12: Scenario 8 i.e. Q100 future with closed mouth E'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)	Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
2	0.14	1.16	0.18	4.24	4.42	**46**	0.38	1.99	0.33	4.27	4.60
3	0.22	1.38	0.36	4.37	4.73	**47**	0.33	1.89	0.21	4.28	4.49
4	0.19	1.39	0.18	4.36	4.54	**48**	0.23	1.77	0.04	4.26	4.30
5	0.24	1.51	0.14	4.25	4.39	**49**	0.24	1.63	0.01	4.32	4.33
6	0.31	1.73	0.04	4.31	4.35	**50**	0.23	1.51	0.04	4.82	4.86
7	0.33	1.80	0.53	4.28	4.81	**51**	0.24	1.50	0.04	5.52	5.56
8	0.33	1.87	0.87	4.25	5.12	**52**	0.25	1.55	0.07	6.17	6.23
9	0.31	1.71	0.46	4.29	4.75	**53**	0.25	1.51	0.75	6.90	7.65
10	0.38	1.89	0.40	4.28	4.68	**54**	0.17	1.39	0.37	7.19	7.56
11	0.44	2.06	0.50	4.29	4.79	**55**	0.27	1.59	0.22	7.18	7.40
12	0.43	2.10	0.19	4.27	4.46	**56**	0.18	1.19	0.15	7.33	7.48
13	0.40	2.08	0.17	4.26	4.43	**57**	0.16	1.15	0.40	8.45	8.85
14	0.46	2.23	0.14	4.26	4.40	**58**	0.21	1.23	0.09	9.01	9.11
15	0.35	2.06	0.02	4.28	4.30	**59**	0.17	1.04	0.45	9.30	9.75
16	0.35	2.05	0.23	4.28	4.51	**60**	0.14	0.97	0.07	9.87	9.94
17	0.37	2.08	0.04	4.29	4.33	**61**	0.15	1.04	0.08	10.21	10.29
18	0.43	2.25	0.19	4.28	4.47	**62**	0.05	0.98	0.14	10.19	10.33
19	0.44	2.27	0.23	4.27	4.50	**63**	0.07	0.92	0.20	9.90	10.10
20	0.28	1.91	0.05	4.27	4.31	**64**	0.04	0.98	0.05	9.44	9.49
21	0.23	1.60	0.15	4.28	4.43	**65**	0.13	1.17	0.04	8.90	8.94
22	0.18	1.39	0.16	4.27	4.43	**66**	0.10	0.96	0.02	8.33	8.35
23	0.24	1.69	0.13	4.28	4.41	**67**	0.07	0.93	0.20	7.94	8.14
24	0.28	1.89	0.06	4.28	4.34	**68**	0.12	1.16	0.04	7.34	7.38
25	0.34	1.93	0.02	4.28	4.30	**69**	0.20	1.62	0.03	6.38	6.41
26	0.40	2.18	0.27	4.28	4.55	**70**	0.21	1.55	0.13	5.70	5.83
27	0.36	2.03	0.21	4.33	4.54	**71**	0.17	1.36	0.40	5.14	5.54
28	0.17	1.25	0.07	4.34	4.42	**72**	0.10	1.07	0.10	4.51	4.61
29	0.30	1.73	0.06	4.30	4.36	**73**	0.10	0.94	0.01	4.29	4.31
30	0.26	1.68	0.04	4.27	4.32	**74**	0.07	0.94	0.02	4.26	4.29
31	0.33	1.87	0.21	4.32	4.53	**75**	0.06	0.97	0.02	4.31	4.33
32	0.31	1.85	0.14	4.28	4.42	**76**	0.08	0.98	0.03	4.28	4.31
33	0.45	2.22	0.14	4.28	4.42	**77**	0.16	1.20	0.06	4.28	4.34
34	0.48	2.34	0.25	4.27	4.52	**78**	0.19	1.31	0.07	4.28	4.35
35	0.47	2.32	0.19	4.27	4.45	**79**	0.17	1.20	0.08	4.26	4.35
36	0.46	2.35	0.10	4.27	4.37	**80**	0.17	1.38	0.20	4.28	4.48
37	0.41	2.37	0.63	4.27	4.90	**81**	0.25	1.49	0.07	4.27	4.34
38	0.34	2.20	0.36	4.27	4.63	**82**	0.27	1.56	0.08	4.30	4.38
39	0.39	2.33	0.45	4.27	4.72	**83**	0.20	1.46	0.18	4.27	4.45
40	0.36	2.00	0.40	4.27	4.67	**84**	0.18	1.17	0.08	4.26	4.34
41	0.29	1.97	0.21	4.27	4.48	**85**	0.17	1.13	0.04	4.25	4.28
42	0.29	2.00	0.03	4.28	4.31	**86**	0.22	1.32	0.01	4.29	4.30
43	0.33	2.15	0.44	4.28	4.71	**87**	0.08	1.14	0.16	4.33	4.49
44	0.34	2.16	0.05	4.26	4.32	**88**	0.22	1.43	0.02	4.46	4.48
45	0.40	2.05	0.09	4.27	4.36	**89**	0.14	1.21	0.07	4.30	4.37

Table E1-13: Scenario 8 i.e. Q100 future with closed mouth W'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)	Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
2	0.32	1.85	0.45	4.24	4.69	**46**	0.17	1.51	0.14	4.27	4.41
3	0.23	2.05	0.48	4.37	4.85	**47**	0.27	1.69	0.16	4.28	4.44
4	0.49	2.51	0.49	4.36	4.85	**48**	0.36	2.09	0.06	4.26	4.32
5	0.39	2.27	0.29	4.25	4.54	**49**	0.33	2.09	0.02	4.32	4.33
6	0.31	1.96	0.05	4.31	4.35	**50**	0.18	1.48	0.04	4.82	4.86
7	0.22	1.66	0.38	4.28	4.66	**51**	0.19	1.39	0.03	5.52	5.55
8	0.17	1.84	0.45	4.25	4.70	**52**	0.16	1.24	0.04	6.17	6.21
9	0.28	2.02	0.46	4.29	4.75	**53**	0.08	1.01	0.25	6.90	7.16
10	0.17	2.19	0.26	4.28	4.54	**54**	0.08	0.94	0.14	7.19	7.33
11	0.37	2.33	0.47	4.29	4.77	**55**	0.15	1.20	0.12	7.18	7.30
12	0.30	2.07	0.14	4.27	4.41	**56**	0.11	1.28	0.12	7.33	7.45
13	0.22	1.75	0.10	4.26	4.36	**57**	0.17	1.27	0.43	8.45	8.88
14	0.26	2.09	0.09	4.26	4.35	**58**	0.02	0.94	0.02	9.01	9.04
15	0.37	2.00	0.02	4.28	4.30	**59**	0.10	0.97	0.29	9.30	9.59
16	0.28	1.69	0.20	4.28	4.48	**60**	0.11	1.03	0.06	9.87	9.93
17	0.19	1.26	0.02	4.29	4.31	**61**	0.05	1.05	0.05	10.21	10.26
18	0.14	1.29	0.05	4.28	4.33	**62**	0.21	1.17	0.61	10.19	10.80
19	0.36	2.08	0.18	4.27	4.45	**63**	0.18	1.10	0.49	9.90	10.39
20	0.48	2.15	0.08	4.27	4.34	**64**	0.22	1.23	0.15	9.44	9.59
21	0.48	2.11	0.32	4.28	4.60	**65**	0.19	1.10	0.05	8.90	8.95
22	0.45	2.03	0.43	4.27	4.70	**66**	0.21	1.30	0.04	8.33	8.37
23	0.41	1.94	0.19	4.28	4.47	**67**	0.26	1.41	0.76	7.94	8.70
24	0.32	1.70	0.07	4.28	4.34	**68**	0.24	1.39	0.06	7.34	7.41
25	0.27	1.54	0.01	4.28	4.30	**69**	0.24	1.37	0.02	6.38	6.40
26	0.22	1.53	0.13	4.28	4.41	**70**	0.28	1.54	0.15	5.70	5.85
27	0.31	1.65	0.16	4.33	4.49	**71**	0.32	1.64	0.67	5.14	5.81
28	0.30	1.59	0.14	4.34	4.48	**72**	0.40	1.91	0.39	4.51	4.91
29	0.17	1.36	0.01	4.30	4.31	**73**	0.45	2.12	0.07	4.29	4.37
30	0.22	1.50	0.02	4.27	4.30	**74**	0.48	2.31	0.18	4.26	4.44
31	0.25	1.62	0.17	4.32	4.49	**75**	0.51	2.29	0.14	4.31	4.46
32	0.26	1.70	0.13	4.28	4.40	**76**	0.54	2.41	0.21	4.28	4.49
33	0.09	1.24	0.03	4.28	4.31	**77**	0.52	2.35	0.27	4.28	4.55
34	0.08	1.05	0.04	4.27	4.31	**78**	0.56	2.42	0.27	4.28	4.54
35	0.13	1.15	0.04	4.27	4.31	**79**	0.56	2.42	0.34	4.26	4.60
36	0.19	1.19	0.03	4.27	4.29	**80**	0.56	2.39	0.69	4.28	4.97
37	0.22	1.52	0.29	4.27	4.56	**81**	0.59	2.50	0.22	4.27	4.49
38	0.36	1.86	0.37	4.27	4.64	**82**	0.33	1.85	0.09	4.30	4.38
39	0.40	2.10	0.45	4.27	4.72	**83**	0.38	1.85	0.32	4.27	4.59
40	0.28	2.09	0.30	4.27	4.57	**84**	0.49	2.23	0.25	4.26	4.51
41	0.34	1.87	0.25	4.27	4.52	**85**	0.40	2.21	0.10	4.25	4.35
42	0.47	2.22	0.06	4.28	4.33	**86**	0.53	2.31	0.15	4.29	4.43
43	0.52	2.35	0.65	4.28	4.93	**87**	0.51	2.30	0.84	4.33	5.17
44	0.53	2.41	0.08	4.26	4.34	**88**	0.19	1.45	0.05	4.46	4.51
45	0.40	2.21	0.05	4.27	4.32	**89**	0.28	1.59	0.15	4.30	4.44

APPENDIX E2: EXTREME FLOOD LEVELS AT THE GROOT BRAK RIVER ESTUARY

Table E2-1: Co-ordinates for selected locations on the Groot Brak River

Location	X-Coordinate (m)	Y-Coordinate (m)	Slope (%)
1	-71934	-3769997	21
2	-72199	-3770061	11
3	-72444	-3769915	12
4	-72564	-3769668	14
5	-72549	-3769358	9
6	-72475	-3769165	4
7	-72254	-3768957	11
8	-72111	-3768697	10
9	-72186	-3768409	14
10	-72023	-3768340	29
11	-72018	-3768041	23
12	-71991	-3767742	41
13	-71819	-3767495	10
14	-71805	-3767180	33
15	-71756	-3767156	26
16	-71722	-3767407	30
17	-71764	-3767539	96
18	-71833	-3767674	40
19	-71899	-3767924	13
20	-71856	-3768161	11
21	-71761	-3768328	23
22	-71715	-3768626	7
23	-71542	-3768846	9
24	-71382	-3769120	8
25	-71151	-3769322	22
26	-70987	-3769489	18
27	-70891	-3769598	9
28	-70583	-3769503	13
29	-70368	-3769440	8
30	-70130	-3769597	54
31	-69874	-3769742	17
32	-69968	-3769961	18
33	-70186	-3770095	13
34	-70483	-3770133	12
35	-70723	-3770035	17
36	-70994	-3769959	19
37	-71295	-3770012	10
38	-71564	-3770102	11
39	-70352	-3769864	3
40	-70322	-3769837	1
41	-70144	-3769837	2
42	-70176	-3769964	11
43	-70328	-3769857	3

Table E2-2: Scenario 1 i.e. Q50 current with open mouth

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
1	0.16	1.63	0.22	4.11	4.33
2	0.21	1.62	0.07	4.13	4.19
3	0.38	1.82	0.25	4.13	4.38
4	0.42	1.99	0.34	4.14	4.47
5	0.40	2.06	0.22	4.14	4.37
6	0.40	2.17	0.12	4.15	4.26
7	0.49	2.13	0.33	4.17	4.50
8	0.46	2.05	0.27	4.23	4.49
9	0.28	1.66	0.20	4.26	4.46
10	0.37	1.85	0.44	4.50	4.94
11	0.36	1.82	0.45	5.54	5.99
12	0.30	1.60	0.64	6.34	6.98
13	0.20	1.30	0.10	6.86	6.96
14	0.18	1.36	0.38	8.35	8.73
15	0.31	5.67	0.93	8.16	9.09
16	0.18	1.50	0.31	7.72	8.03
17	0.12	1.57	0.35	7.29	7.64
18	0.14	1.74	0.37	6.64	7.01
19	0.20	1.68	0.16	5.62	5.78
20	0.24	1.73	0.17	4.81	4.98
21	0.17	1.58	0.25	4.46	4.72
22	0.30	2.02	0.09	4.18	4.27
23	0.35	1.90	0.17	4.16	4.33
24	0.38	1.78	0.14	4.13	4.27
25	0.30	1.64	0.32	4.04	4.36
26	0.20	1.48	0.20	3.88	4.07
27	0.37	2.89	0.32	3.35	3.68
28	0.21	5.83	0.67	3.37	4.04
29	0.39	1.82	0.17	3.35	3.52
30	0.29	1.66	0.67	3.37	4.04
31	0.13	1.19	0.06	3.32	3.39
32	0.06	3.16	0.17	3.31	3.48
33	0.75	11.94	1.12	3.36	4.49
34	0.28	2.18	0.23	3.29	3.52
35	0.34	1.90	0.32	3.37	3.69
36	0.35	1.91	0.09	3.38	3.47
37	0.16	1.59	0.10	3.77	3.87
38	0.24	1.64	0.14	3.80	3.94
39	0.77	7.00	1.07	3.31	4.39
40	0.28	3.33	0.39	3.36	3.75
41	0.14	1.73	0.19	3.37	3.56
42	0.91	9.73	1.27	3.23	4.50
43	0.22	3.02	0.31	3.36	3.67

Table E2-3: Scenario 2 i.e. Q100 current with open mouth

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
1	0.17	1.66	0.23	4.11	4.34
2	0.22	1.62	0.07	4.13	4.20
3	0.39	1.83	0.25	4.13	4.39
4	0.43	1.99	0.34	4.14	4.48
5	0.41	2.08	0.23	4.14	4.37
6	0.41	2.19	0.12	4.15	4.27
7	0.50	2.13	0.34	4.17	4.50
8	0.48	2.09	0.27	4.24	4.51
9	0.35	1.78	0.23	4.43	4.67
10	0.40	1.89	0.47	4.81	5.28
11	0.35	1.86	0.45	5.88	6.33
12	0.32	1.71	0.71	6.63	7.34
13	0.24	1.46	0.12	7.20	7.32
14	0.19	1.38	0.40	8.76	9.16
15	0.30	3.58	0.76	8.48	9.24
16	0.19	1.55	0.33	8.02	8.35
17	0.15	1.76	0.42	7.62	8.04
18	0.15	1.83	0.40	6.99	7.39
19	0.25	1.74	0.18	6.04	6.22
20	0.27	1.80	0.19	5.03	5.22
21	0.20	1.61	0.27	4.72	4.99
22	0.31	2.02	0.09	4.18	4.27
23	0.36	1.93	0.18	4.16	4.34
24	0.40	1.80	0.14	4.13	4.28
25	0.31	1.67	0.34	4.04	4.37
26	0.21	1.51	0.20	3.88	4.09
27	0.40	3.35	0.39	3.37	3.76
28	0.23	6.34	0.74	3.38	4.12
29	0.41	1.85	0.18	3.37	3.55
30	0.30	1.69	0.70	3.39	4.09
31	0.15	1.23	0.07	3.35	3.42
32	0.06	2.38	0.17	3.33	3.50
33	0.68	11.27	1.01	3.37	4.38
34	0.33	2.52	0.29	3.32	3.60
35	0.38	1.99	0.35	3.40	3.75
36	0.37	1.96	0.10	3.39	3.49
37	0.17	1.62	0.10	3.77	3.87
38	0.24	1.64	0.14	3.80	3.95
39	0.85	7.76	1.19	3.33	4.52
40	0.30	3.32	0.43	3.37	3.80
41	0.20	1.25	0.27	3.39	3.67
42	0.78	8.29	1.09	3.24	4.33
43	0.24	3.05	0.34	3.37	3.71

Table E2-4: Scenario 3 i.e. Q50 current with closed mouth E'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
1	0.28	1.81	0.32	4.90	5.22
2	0.32	1.80	0.19	4.90	5.10
3	0.37	1.95	0.14	4.90	5.05
4	0.42	2.13	0.37	4.90	5.27
5	0.42	2.13	0.24	4.91	5.15
6	0.37	2.25	0.12	4.91	5.02
7	0.42	2.14	0.31	4.92	5.23
8	0.37	1.97	0.23	4.94	5.17
9	0.35	1.93	0.26	4.98	5.23
10	0.30	1.83	0.58	5.02	5.60
11	0.26	1.41	0.27	5.74	6.01
12	0.23	1.30	0.42	6.42	6.84
13	0.12	0.93	0.05	6.95	7.00
14	0.12	0.93	0.18	8.46	8.64
15	0.01	1.78	0.02	8.28	8.30
16	0.03	1.72	0.09	7.79	7.88
17	0.02	1.97	0.04	7.38	7.42
18	0.06	1.13	0.16	6.73	6.89
19	0.12	1.47	0.11	5.85	5.96
20	0.11	1.72	0.11	5.19	5.30
21	0.05	2.51	0.15	5.06	5.21
22	0.20	1.83	0.09	4.92	5.01
23	0.17	1.66	0.10	4.92	5.02
24	0.19	1.62	0.10	4.91	5.01
25	0.17	1.49	0.22	4.90	5.12
26	0.10	1.36	0.13	4.92	5.04
27	0.31	1.82	0.18	4.85	5.03
28	0.28	1.66	0.21	4.85	5.05
29	0.20	1.48	0.09	4.85	4.94
30	0.14	1.34	0.42	4.85	5.27
31	0.00	2.63	0.01	4.85	4.85
32	0.01	1.12	0.03	4.87	4.90
33	0.15	1.29	0.11	4.91	5.02
34	0.21	1.58	0.15	4.86	5.01
35	0.29	1.69	0.26	4.87	5.13
36	0.31	1.79	0.31	4.92	5.23
37	0.24	1.87	0.14	4.88	5.02
38	0.31	1.87	0.19	4.88	5.06
39	0.19	1.40	0.27	4.88	5.14
40	0.18	1.45	0.25	4.85	5.10
41	0.21	1.41	0.29	4.85	5.13
42	0.17	1.25	0.24	4.83	5.07
43	0.15	1.42	0.21	4.86	5.07

Table E2-5: Scenario 3 i.e. Q50 current with closed mouth W'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
1	0.36	1.78	0.40	4.90	5.30
2	0.25	1.54	0.14	4.90	5.04
3	0.17	1.20	0.05	4.90	4.96
4	0.06	1.05	0.06	4.90	4.96
5	0.02	1.05	0.02	4.91	4.93
6	0.16	1.07	0.03	4.91	4.94
7	0.18	1.37	0.11	4.92	5.02
8	0.15	1.42	0.09	4.94	5.03
9	0.19	1.34	0.13	4.98	5.11
10	0.20	1.45	0.31	5.02	5.33
11	0.05	1.77	0.12	5.74	5.86
12	0.02	1.59	0.06	6.42	6.48
13	0.06	1.32	0.05	6.95	7.00
14	0.14	1.18	0.24	8.46	8.70
15	0.16	1.20	0.20	8.28	8.48
16	0.24	1.29	0.31	7.79	8.10
17	0.21	1.35	0.65	7.38	8.03
18	0.23	1.32	0.46	6.73	7.19
19	0.23	1.26	0.15	5.85	6.00
20	0.25	1.46	0.16	5.19	5.35
21	0.22	1.55	0.33	5.06	5.38
22	0.33	1.81	0.15	4.92	5.06
23	0.42	2.07	0.24	4.92	5.16
24	0.43	2.21	0.23	4.91	5.14
25	0.47	2.28	0.64	4.90	5.55
26	0.42	2.28	0.53	4.92	5.44
27	0.23	1.75	0.13	4.85	4.98
28	0.30	1.83	0.21	4.85	5.05
29	0.29	1.98	0.14	4.85	4.99
30	0.42	2.06	1.24	4.85	6.09
31	0.43	2.11	0.47	4.85	5.31
32	0.40	1.98	0.44	4.87	5.31
33	0.43	2.13	0.38	4.91	5.28
34	0.36	1.97	0.23	4.86	5.09
35	0.34	2.01	0.33	4.87	5.20
36	0.46	2.21	0.47	4.92	5.39
37	0.42	2.06	0.24	4.88	5.12
38	0.30	1.69	0.19	4.88	5.07
39	0.44	2.14	0.62	4.88	5.50
40	0.42	2.07	0.59	4.85	5.44
41	0.32	1.88	0.44	4.85	5.29
42	0.43	2.13	0.60	4.83	5.44
43	0.43	2.18	0.60	4.86	5.47

Table E2-6: Scenario 4 i.e. Q100 current with closed mouth E'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
1	0.29	1.81	0.33	4.96	5.29
2	0.32	1.79	0.19	4.96	5.16
3	0.38	1.97	0.15	4.96	5.11
4	0.42	2.14	0.37	4.96	5.34
5	0.42	2.14	0.24	4.97	5.21
6	0.38	2.23	0.12	4.97	5.09
7	0.42	2.14	0.31	4.98	5.29
8	0.37	1.99	0.24	5.02	5.25
9	0.35	1.96	0.26	5.07	5.33
10	0.31	1.84	0.59	5.25	5.84
11	0.22	1.46	0.26	6.07	6.33
12	0.23	1.29	0.42	6.74	7.16
13	0.13	0.94	0.06	7.30	7.36
14	0.12	0.92	0.17	8.81	8.98
15	0.01	2.24	0.02	8.57	8.59
16	0.02	2.04	0.06	8.10	8.16
17	0.02	2.12	0.05	7.73	7.78
18	0.06	1.11	0.16	7.08	7.24
19	0.12	1.47	0.11	6.21	6.32
20	0.15	1.32	0.10	5.35	5.45
21	0.05	2.38	0.16	5.20	5.37
22	0.18	1.82	0.09	4.99	5.08
23	0.18	1.68	0.11	4.98	5.09
24	0.20	1.64	0.10	4.97	5.07
25	0.17	1.50	0.22	4.96	5.18
26	0.10	1.38	0.13	4.97	5.10
27	0.32	1.85	0.18	4.91	5.09
28	0.29	1.67	0.21	4.90	5.11
29	0.20	1.49	0.09	4.89	4.99
30	0.14	1.34	0.42	4.90	5.31
31	0.00	2.60	0.00	4.89	4.89
32	0.01	1.03	0.03	4.92	4.95
33	0.15	1.29	0.11	4.98	5.09
34	0.21	1.56	0.15	4.90	5.05
35	0.29	1.69	0.26	4.92	5.18
36	0.31	1.79	0.32	4.98	5.30
37	0.24	1.86	0.14	4.94	5.08
38	0.31	1.86	0.18	4.94	5.12
39	0.22	1.42	0.31	4.93	5.24
40	0.18	1.45	0.25	4.89	5.15
41	0.21	1.40	0.29	4.89	5.18
42	0.17	1.25	0.24	4.87	5.11
43	0.18	1.39	0.25	4.91	5.16

Table E2-7: Scenario 4 i.e. Q100 current with closed mouth W'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
1	0.36	1.79	0.40	4.96	5.36
2	0.25	1.54	0.14	4.96	5.10
3	0.17	1.17	0.05	4.96	5.02
4	0.05	1.04	0.05	4.96	5.02
5	0.02	1.09	0.02	4.97	4.99
6	0.14	1.04	0.03	4.97	5.00
7	0.18	1.37	0.11	4.98	5.09
8	0.15	1.41	0.09	5.02	5.11
9	0.19	1.35	0.13	5.07	5.20
10	0.21	1.46	0.31	5.25	5.56
11	0.05	1.90	0.14	6.07	6.21
12	0.02	1.68	0.07	6.74	6.81
13	0.08	1.29	0.06	7.30	7.36
14	0.14	1.17	0.24	8.81	9.05
15	0.17	1.15	0.20	8.57	8.77
16	0.23	1.27	0.30	8.10	8.40
17	0.22	1.37	0.67	7.73	8.40
18	0.22	1.32	0.46	7.08	7.54
19	0.23	1.27	0.16	6.21	6.37
20	0.24	1.45	0.15	5.35	5.50
21	0.28	1.65	0.39	5.20	5.59
22	0.30	1.80	0.14	4.99	5.12
23	0.42	2.07	0.25	4.98	5.23
24	0.44	2.22	0.23	4.97	5.21
25	0.48	2.29	0.65	4.96	5.61
26	0.43	2.28	0.53	4.97	5.50
27	0.23	1.70	0.13	4.91	5.03
28	0.30	1.83	0.21	4.90	5.10
29	0.30	2.00	0.14	4.89	5.04
30	0.42	2.06	1.25	4.90	6.14
31	0.44	2.11	0.47	4.89	5.36
32	0.40	1.98	0.44	4.92	5.36
33	0.44	2.13	0.38	4.98	5.36
34	0.37	1.98	0.24	4.90	5.14
35	0.35	2.03	0.34	4.92	5.26
36	0.46	2.23	0.48	4.98	5.46
37	0.43	2.06	0.24	4.94	5.18
38	0.29	1.68	0.19	4.94	5.13
39	0.45	2.14	0.62	4.93	5.55
40	0.43	2.08	0.60	4.89	5.49
41	0.32	1.88	0.45	4.89	5.34
42	0.43	2.14	0.61	4.87	5.48
43	0.44	2.18	0.62	4.91	5.53

Table E2-8: Scenario 5 i.e. Q50 future with open mouth

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
1	0.16	1.50	0.20	4.11	4.31
2	0.22	1.59	0.07	4.13	4.19
3	0.38	1.82	0.25	4.13	4.38
4	0.43	2.01	0.34	4.14	4.48
5	0.42	2.11	0.23	4.14	4.38
6	0.42	2.23	0.12	4.15	4.27
7	0.50	2.20	0.35	4.17	4.51
8	0.49	2.13	0.28	4.24	4.53
9	0.38	1.85	0.26	4.50	4.76
10	0.44	2.02	0.52	4.86	5.38
11	0.41	1.97	0.51	5.91	6.42
12	0.34	1.70	0.73	6.64	7.37
13	0.37	2.86	0.29	7.21	7.50
14	0.24	1.65	0.53	8.75	9.28
15	0.26	2.40	0.52	8.49	9.01
16	0.20	1.62	0.36	8.03	8.39
17	0.18	1.87	0.53	7.63	8.16
18	0.23	2.02	0.58	7.00	7.58
19	0.26	1.82	0.20	6.06	6.26
20	0.26	2.06	0.21	5.07	5.28
21	0.23	1.78	0.32	4.77	5.09
22	0.32	2.15	0.09	4.18	4.28
23	0.36	1.96	0.18	4.16	4.34
24	0.41	1.87	0.15	4.13	4.28
25	0.40	2.03	0.47	4.04	4.51
26	0.28	1.73	0.27	3.99	4.26
27	0.61	10.46	1.50	3.62	5.12
28	0.40	6.26	1.00	3.60	4.61
29	0.51	2.19	0.24	3.61	3.85
30	0.36	1.90	0.86	3.64	4.49
31	0.14	1.44	0.08	3.61	3.69
32	0.05	2.08	0.13	3.72	3.85
33	0.87	11.07	1.12	3.63	4.75
34	0.33	3.84	0.43	3.59	4.02
35	0.43	2.80	0.52	3.64	4.17
36	0.41	2.06	0.11	3.63	3.74
37	0.18	1.82	0.12	3.77	3.89
38	0.24	1.81	0.16	3.80	3.96
39	1.09	11.05	1.52	3.65	5.17
40	0.36	3.74	0.50	3.62	4.12
41	0.28	1.66	0.39	3.62	4.01
42	0.73	7.30	1.03	3.56	4.58
43	0.35	4.73	0.49	3.61	4.10

Table E2-9: Scenario 6 i.e. Q100 future with open mouth

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
1	0.18	1.62	0.23	4.20	4.44
2	0.25	1.71	0.08	4.21	4.29
3	0.40	1.86	0.26	4.21	4.47
4	0.45	2.05	0.36	4.21	4.57
5	0.43	2.14	0.24	4.22	4.46
6	0.43	2.27	0.13	4.22	4.35
7	0.53	2.24	0.36	4.27	4.63
8	0.52	2.19	0.30	4.41	4.71
9	0.45	2.03	0.31	4.71	5.02
10	0.48	2.11	0.57	5.18	5.75
11	0.44	2.03	0.55	6.28	6.83
12	0.37	1.86	0.83	6.89	7.72
13	0.55	7.20	0.91	7.47	8.38
14	0.27	1.86	0.63	8.97	9.60
15	0.23	1.61	0.33	8.65	8.98
16	0.22	1.69	0.39	8.25	8.64
17	0.19	1.90	0.56	7.90	8.46
18	0.24	2.10	0.61	7.32	7.93
19	0.29	1.92	0.22	6.45	6.67
20	0.29	1.96	0.21	5.28	5.49
21	0.26	1.74	0.34	5.03	5.37
22	0.34	2.08	0.09	4.28	4.38
23	0.37	1.96	0.18	4.26	4.44
24	0.46	1.98	0.17	4.24	4.41
25	0.43	2.15	0.51	4.19	4.70
26	0.27	1.71	0.26	4.14	4.40
27	0.85	8.79	1.49	3.79	5.28
28	0.49	6.78	1.20	3.76	4.96
29	0.58	2.43	0.28	3.76	4.04
30	0.42	1.94	0.95	3.76	4.70
31	0.15	1.64	0.09	3.73	3.83
32	0.05	2.15	0.14	3.80	3.94
33	0.96	11.99	1.27	3.65	4.93
34	0.33	3.55	0.40	3.69	4.10
35	0.44	2.60	0.49	3.77	4.26
36	0.43	2.07	0.11	3.79	3.90
37	0.19	1.83	0.13	3.90	4.02
38	0.27	1.88	0.17	3.90	4.07
39	1.15	11.77	1.61	3.73	5.34
40	0.40	3.53	0.57	3.76	4.32
41	0.28	2.17	0.39	3.76	4.14
42	0.80	7.79	1.12	3.67	4.78
43	0.39	4.46	0.55	3.76	4.31

Table E2-10: Scenario 7 i.e. Q50 future with closed mouth E'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
1	0.31	1.84	0.35	5.77	6.12
2	0.35	1.93	0.22	5.77	5.99
3	0.41	2.09	0.16	5.77	5.93
4	0.46	2.25	0.41	5.77	6.18
5	0.46	2.26	0.27	5.77	6.04
6	0.43	2.24	0.12	5.78	5.90
7	0.45	2.23	0.33	5.78	6.11
8	0.40	2.07	0.26	5.79	6.05
9	0.38	2.06	0.29	5.78	6.07
10	0.32	1.89	0.62	5.90	6.52
11	0.28	1.54	0.31	6.42	6.73
12	0.24	1.35	0.44	6.75	7.19
13	0.13	0.94	0.06	7.31	7.37
14	0.12	0.92	0.17	8.79	8.96
15	0.01	2.54	0.02	8.61	8.63
16	0.03	2.24	0.08	8.10	8.18
17	0.03	2.38	0.06	7.71	7.77
18	0.06	1.18	0.17	7.09	7.26
19	0.13	1.57	0.12	6.25	6.37
20	0.20	1.41	0.12	5.85	5.97
21	0.10	1.82	0.21	5.82	6.03
22	0.24	1.82	0.10	5.78	5.88
23	0.20	1.77	0.12	5.78	5.89
24	0.23	1.73	0.11	5.78	5.89
25	0.18	1.60	0.25	5.77	6.02
26	0.12	1.49	0.15	5.78	5.93
27	0.34	1.86	0.19	5.78	5.96
28	0.30	1.69	0.22	5.76	5.98
29	0.22	1.56	0.10	5.77	5.87
30	0.15	1.38	0.43	5.76	6.20
31	0.01	2.57	0.02	5.76	5.78
32	0.02	1.13	0.04	5.77	5.81
33	0.15	1.28	0.11	5.77	5.88
34	0.16	1.52	0.13	5.80	5.93
35	0.31	1.71	0.27	5.77	6.04
36	0.35	1.88	0.35	5.80	6.15
37	0.24	1.91	0.15	5.77	5.92
38	0.32	1.92	0.19	5.77	5.96
39	0.24	1.54	0.33	5.78	6.11
40	0.24	1.52	0.33	5.76	6.10
41	0.22	1.43	0.30	5.76	6.07
42	0.18	1.32	0.26	5.76	6.02
43	0.23	1.49	0.32	5.77	6.10

Table E2-11: Scenario 7 i.e. Q50 current with closed mouth W'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
1	0.38	1.86	0.43	5.77	6.20
2	0.27	1.59	0.14	5.77	5.92
3	0.17	1.23	0.06	5.77	5.83
4	0.03	1.19	0.05	5.77	5.82
5	0.04	1.11	0.03	5.77	5.81
6	0.17	1.17	0.03	5.78	5.81
7	0.20	1.35	0.11	5.78	5.89
8	0.18	1.46	0.10	5.79	5.89
9	0.21	1.44	0.15	5.78	5.93
10	0.21	1.54	0.33	5.90	6.24
11	0.04	1.66	0.10	6.42	6.52
12	0.03	1.82	0.10	6.75	6.85
13	0.08	1.36	0.06	7.31	7.37
14	0.15	1.21	0.25	8.79	9.04
15	0.17	1.17	0.20	8.61	8.81
16	0.23	1.31	0.31	8.10	8.41
17	0.23	1.42	0.69	7.71	8.40
18	0.23	1.37	0.48	7.09	7.57
19	0.23	1.32	0.16	6.25	6.41
20	0.25	1.54	0.17	5.85	6.02
21	0.33	1.73	0.45	5.82	6.27
22	0.39	1.91	0.17	5.78	5.94
23	0.45	2.12	0.26	5.78	6.04
24	0.48	2.24	0.25	5.78	6.03
25	0.50	2.37	0.69	5.77	6.46
26	0.46	2.37	0.57	5.78	6.35
27	0.37	1.98	0.18	5.78	5.96
28	0.36	1.96	0.24	5.76	6.01
29	0.36	2.05	0.16	5.77	5.93
30	0.46	2.20	1.38	5.76	7.14
31	0.44	2.21	0.49	5.76	6.25
32	0.43	2.07	0.48	5.77	6.25
33	0.49	2.32	0.44	5.77	6.20
34	0.44	2.12	0.28	5.80	6.08
35	0.44	2.27	0.43	5.77	6.20
36	0.52	2.37	0.54	5.80	6.34
37	0.46	2.15	0.26	5.77	6.03
38	0.34	1.85	0.22	5.77	5.99
39	0.50	2.31	0.71	5.78	6.48
40	0.49	2.27	0.69	5.76	6.45
41	0.40	2.05	0.56	5.76	6.32
42	0.45	2.20	0.63	5.76	6.39
43	0.51	2.34	0.72	5.77	6.49

Table E2-12: Scenario 8 i.e. Q100 future with closed mouth E'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
1	0.32	1.87	0.36	5.86	6.22
2	0.35	1.96	0.22	5.86	6.08
3	0.41	2.12	0.17	5.86	6.03
4	0.46	2.25	0.41	5.86	6.27
5	0.47	2.28	0.27	5.86	6.14
6	0.44	2.26	0.13	5.86	5.99
7	0.46	2.24	0.34	5.87	6.21
8	0.41	2.09	0.26	5.89	6.15
9	0.39	2.07	0.29	5.88	6.17
10	0.33	1.91	0.63	6.09	6.72
11	0.29	1.60	0.33	6.67	7.00
12	0.25	1.39	0.47	6.98	7.45
13	0.13	0.95	0.06	7.56	7.62
14	0.11	0.91	0.17	8.98	9.15
15	0.01	2.31	0.02	8.63	8.65
16	0.03	2.20	0.08	8.28	8.36
17	0.03	2.49	0.07	7.97	8.04
18	0.07	1.27	0.17	7.38	7.55
19	0.14	1.54	0.12	6.59	6.71
20	0.20	1.47	0.13	5.97	6.10
21	0.10	1.91	0.23	5.94	6.17
22	0.24	1.85	0.11	5.87	5.97
23	0.20	1.80	0.12	5.87	5.99
24	0.23	1.76	0.12	5.86	5.98
25	0.18	1.59	0.25	5.86	6.11
26	0.13	1.47	0.16	5.87	6.03
27	0.35	1.87	0.19	5.87	6.06
28	0.30	1.69	0.22	5.85	6.06
29	0.23	1.57	0.10	5.85	5.95
30	0.15	1.40	0.44	5.84	6.28
31	0.01	2.58	0.02	5.84	5.87
32	0.01	1.15	0.04	5.86	5.90
33	0.15	1.30	0.11	5.85	5.97
34	0.17	1.53	0.13	5.90	6.03
35	0.31	1.72	0.27	5.86	6.13
36	0.35	1.90	0.36	5.90	6.25
37	0.24	1.92	0.15	5.86	6.01
38	0.33	1.94	0.20	5.86	6.05
39	0.24	1.56	0.33	5.86	6.20
40	0.24	1.55	0.34	5.85	6.18
41	0.22	1.45	0.30	5.85	6.15
42	0.18	1.34	0.26	5.84	6.09
43	0.23	1.51	0.33	5.86	6.18

Table E2-13: Scenario 8 i.e. Q100 future with closed mouth W'ly wind

Location	Significant wave height (m)	Peak wave period (sec)	Runup (m)	Energy level (masl)	Extreme flood level (masl)
1	0.37	1.81	0.41	5.86	6.28
2	0.25	1.53	0.14	5.86	6.00
3	0.17	1.18	0.05	5.86	5.92
4	0.04	0.95	0.04	5.86	5.90
5	0.04	0.95	0.03	5.86	5.89
6	0.17	1.13	0.03	5.86	5.90
7	0.19	1.29	0.10	5.87	5.97
8	0.17	1.38	0.09	5.89	5.98
9	0.21	1.40	0.14	5.88	6.02
10	0.21	1.49	0.32	6.09	6.41
11	0.04	1.65	0.11	6.67	6.78
12	0.04	1.87	0.10	6.98	7.08
13	0.10	1.16	0.06	7.56	7.62
14	0.14	1.19	0.24	8.98	9.22
15	0.18	1.15	0.21	8.63	8.84
16	0.23	1.27	0.30	8.28	8.58
17	0.22	1.35	0.68	7.97	8.65
18	0.23	1.33	0.47	7.38	7.85
19	0.23	1.27	0.16	6.59	6.75
20	0.26	1.50	0.16	5.97	6.13
21	0.33	1.70	0.44	5.94	6.38
22	0.38	1.87	0.16	5.87	6.03
23	0.46	2.08	0.26	5.87	6.12
24	0.49	2.21	0.25	5.86	6.11
25	0.51	2.34	0.68	5.86	6.55
26	0.47	2.29	0.56	5.87	6.43
27	0.38	2.00	0.19	5.87	6.06
28	0.35	1.98	0.24	5.85	6.09
29	0.35	2.03	0.16	5.85	6.00
30	0.44	2.16	1.33	5.84	7.18
31	0.46	2.21	0.50	5.84	6.34
32	0.42	2.02	0.46	5.86	6.32
33	0.48	2.28	0.42	5.85	6.28
34	0.43	2.10	0.27	5.90	6.17
35	0.43	2.27	0.42	5.86	6.29
36	0.51	2.35	0.53	5.90	6.43
37	0.45	2.11	0.25	5.86	6.11
38	0.33	1.80	0.22	5.86	6.07
39	0.50	2.27	0.70	5.86	6.56
40	0.49	2.22	0.68	5.85	6.53
41	0.40	2.03	0.56	5.85	6.41
42	0.45	2.16	0.62	5.84	6.46
43	0.50	2.29	0.71	5.86	6.56

APPENDIX F: GEOTECHNICAL DATA OF BED SEDIMENT SAMPLES

SG AND GRADING RESULTS FOR BED SEDIMENT SAMPLES TAKEN FROM THE ESTUARIES (SG AND GRADING)

Table F.1: Bed grab sample locations in the estuaries

No	Sample Name	River	Sieve & Hydrometer Analysis d50 (mm)	SG	Co-ordinates	
1	GB1	Groot Brak River	10.000	2.629	-34.028660°	22.222260°
2	GB2		1.490	2.610	-34.033340°	22.221330°
3	GB3		0.500	2.554	-34.039600°	22.221030°
4	GB4		1.500	2.313	-34.043360°	22.220500°
5	GB5		0.480	2.585	-34.047210°	22.221490°
6	GB6		0.370	2.602	-34.050730°	22.222550°
7	GB7		0.250	2.586	-34.053630°	22.219370°
8	GB8		0.360	2.645	-34.053060°	22.223860°
9	GB9		0.350	2.655	-34.049590°	22.226990°
10	GB10		0.260	2.522	-34.049560°	22.230220°
11	KB1	Klein Brak River	0.053	2.333	-34.055400°	22.132410°
12	KB2		0.270	2.542	-34.061860°	22.114260°
13	KB3		0.560	2.602	-34.068500°	22.056320°
14	KB4		0.650	2.552	-34.065570°	22.133690°
15	KB5		0.120	2.453	-34.065440°	22.122560°
16	KB6		0.630	2.649	-34.038230°	22.132150°
17	KB7		0.380	2.614	-34.072740°	22.123790°
18	KB8		0.340	2.671	-34.076230°	22.130640°
19	KB9		0.300	2.595	-34.082530°	22.131300°
20	KB10		0.095	2.513	-34.086990°	22.133320°

ASTM Method

Sample Name	GB1
Date	2020/02/12
Container	1
Wet Mass	70
Dry Mass	70

	Airdry	Dry
Total Mass	2595	2595.00
Container Mass	65	65.00

Sieve Analysis

Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00	532	20.50	79.50
9.50	837	32.25	47.24
4.75	519	20.00	27.24
2.36	344	13.26	13.99
<2.36	363.00	13.99	0.00

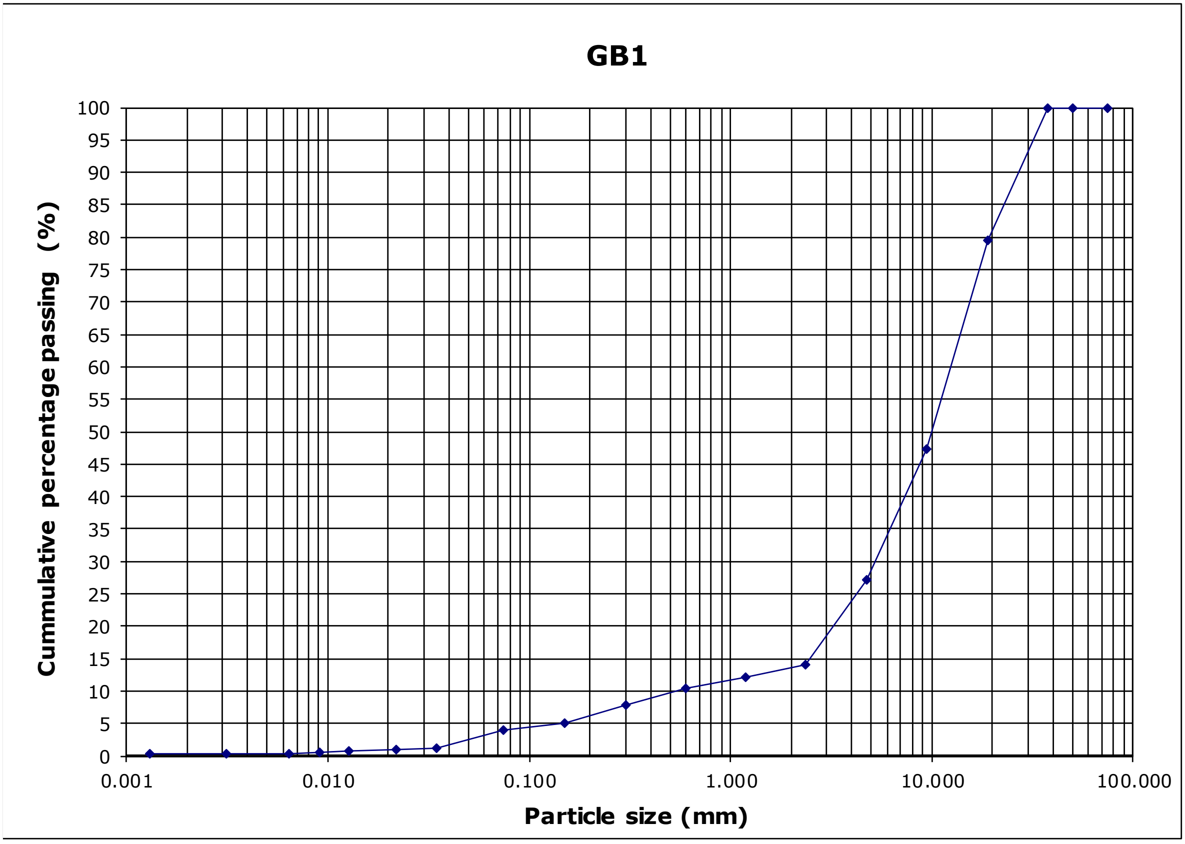
Hydrometer readings

Time (min)	True reading	Temp C	Corrected
2	10	26	5.00
5	9	26	4.00
15	8	26	3.00
30	7	26	2.00
60	6	26	1.00
250	6	26	1.00
1440	6	26	1.00

Sieve test

Sieve size (mm)	Mass (g)
2.36-1.18	9
1.18-0.60	8
0.60-0.30	12
0.30-0.150	13
0.150-0.075	5
<0.075	18.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	79.50	19
mm	47.24	9.5
mm	27.24	4.75
mm	13.99	2.36
mm	12.05	1.18
mm	10.33	0.6
mm	7.75	0.3
mm	4.95	0.15
mm	3.87	0.075
mm	1.08	0.0345
mm	0.86	0.0219
mm	0.65	0.0127
mm	0.43	0.0091
mm	0.22	0.0064
mm	0.22	0.0031
mm	0.22	0.0013



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
0.2	1.9	2.8	3.9	18.4	72.8

ASTM Method

Sample Name	GB2
Date	2020/02/12
Container	2
Wet Mass	70
Dry Mass	70

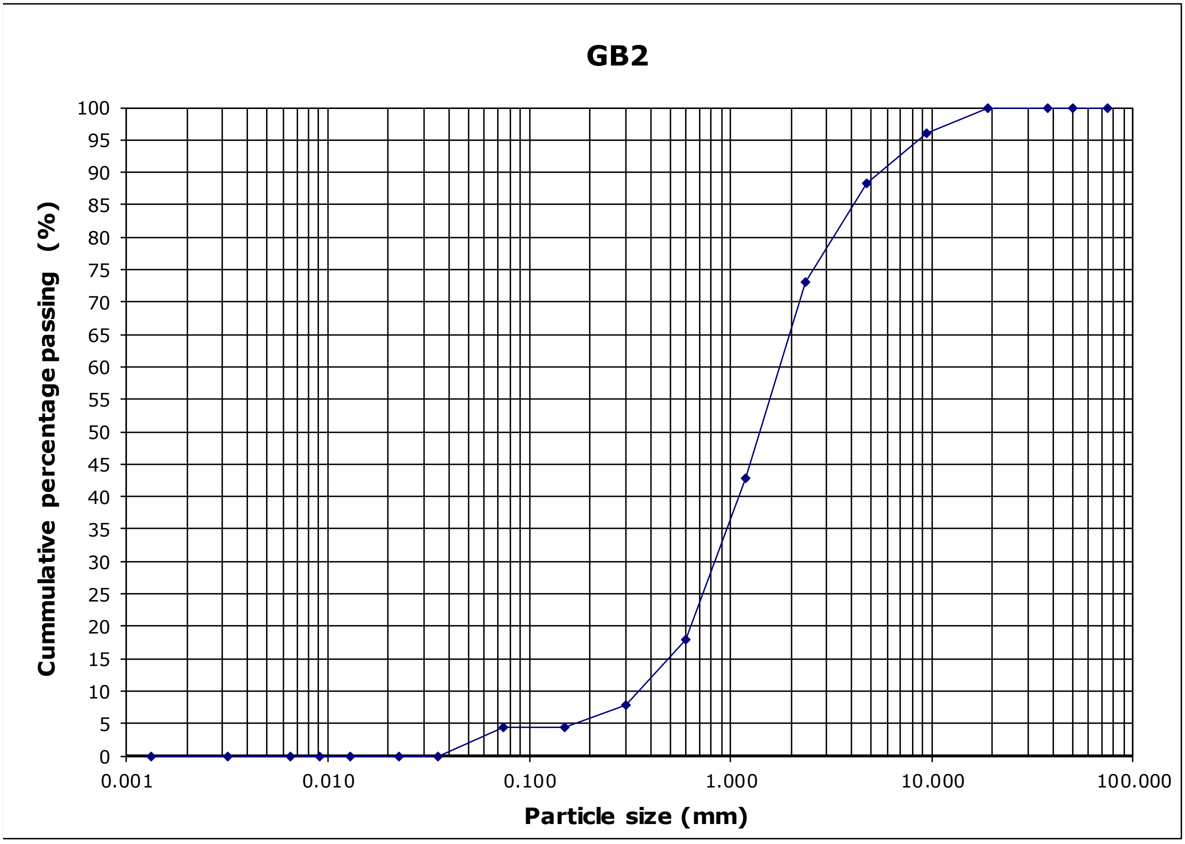
	Airdry	Dry
Total Mass	510	510.00
Container Mass	65	65.00

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50	20	3.92	96.08
4.75	40	7.84	88.24
2.36	77	15.10	73.14
<2.36	373.00	73.14	0.00

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	5	26	0.00
5	5	26	0.00
15	5	26	0.00
30	5	26	0.00
60	5	26	0.00
250	5	26	0.00
1440	5	26	0.00

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	27
1.18-0.60	22
0.60-0.30	9
0.30-0.150	3
0.150-0.075	0
<0.075	4.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	96.08	9.5
mm	88.24	4.75
mm	73.14	2.36
mm	42.76	1.18
mm	18.00	0.6
mm	7.88	0.3
mm	4.50	0.15
mm	4.50	0.075
mm	0.00	0.0354
mm	0.00	0.0224
mm	0.00	0.0129
mm	0.00	0.0091
mm	0.00	0.0065
mm	0.00	0.0032
mm	0.00	0.0013



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
0.0	1.7	2.8	7.6	76.1	11.8

ASTM Method

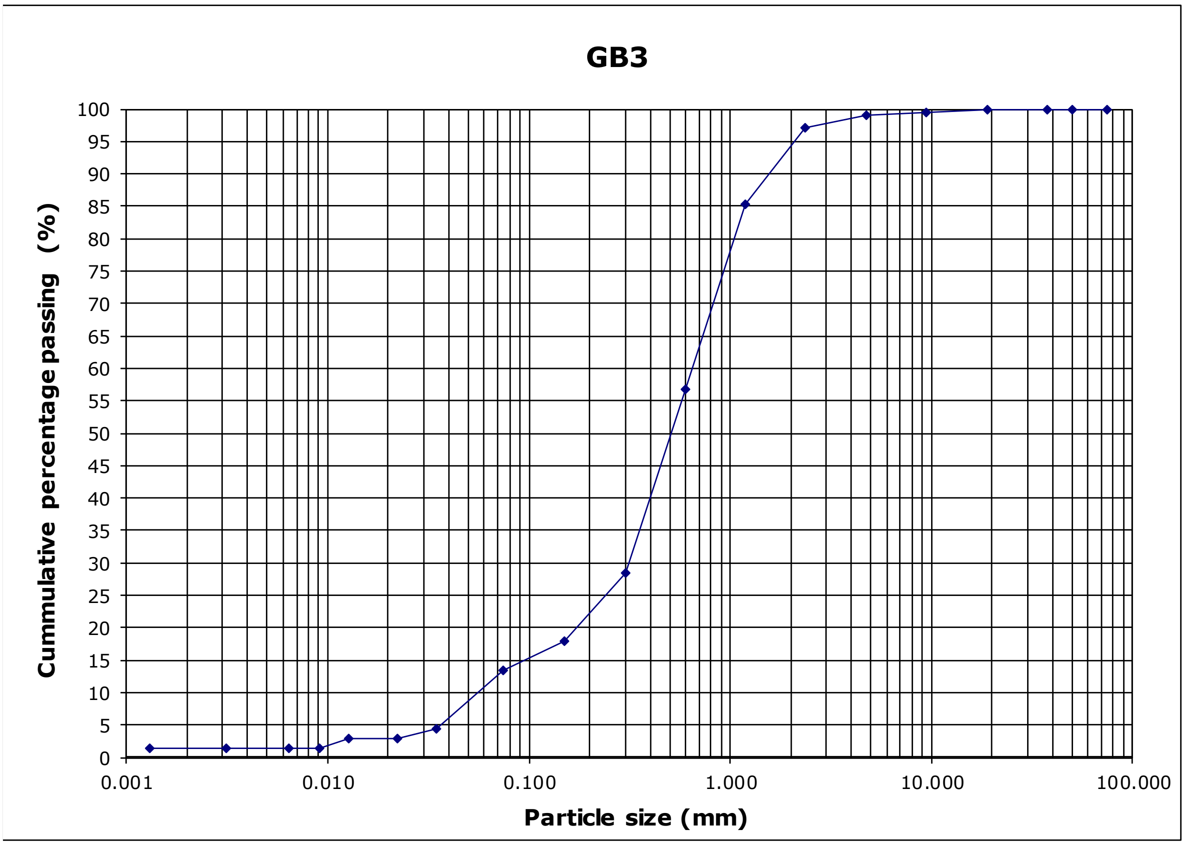
Sample Name	GB3	
Date	2020/02/12	
Container	3	
Wet Mass	70	
Dry Mass	70	
	Airdry	Dry
Total Mass	425	425.00
Container Mass	65	65.00

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	8
1.18-0.60	19
0.60-0.30	19
0.30-0.150	7
0.150-0.075	3
<0.075	9.00

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50	2	0.47	99.53
4.75	2	0.47	99.06
2.36	8	1.88	97.18
<2.36	413.00	97.18	0.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	99.53	9.5
mm	99.06	4.75
mm	97.18	2.36
mm	85.22	1.18
mm	56.81	0.6
mm	28.41	0.3
mm	17.94	0.15
mm	13.46	0.075
mm	4.49	0.0348
mm	2.99	0.0222
mm	2.99	0.0128
mm	1.50	0.0091
mm	1.50	0.0064
mm	1.50	0.0031
mm	1.50	0.0013

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	8	26	3.00
5	7	26	2.00
15	7	26	2.00
30	6	26	1.00
60	6	26	1.00
250	6	26	1.00
1440	6	26	1.00



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
1.5	6.4	10.1	22.3	58.8	0.9

ASTM Method

Sample Name	GB4
Date	2020/02/12
Container	4
Wet Mass	70
Dry Mass	70

	Airdry	Dry
Total Mass	1597	1597.00
Container Mass	65	65.00

Sieve Analysis

Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50	5	0.31	99.69
4.75	19	1.19	98.50
2.36	36	2.25	96.24
<2.36	1537.00	96.24	0.00

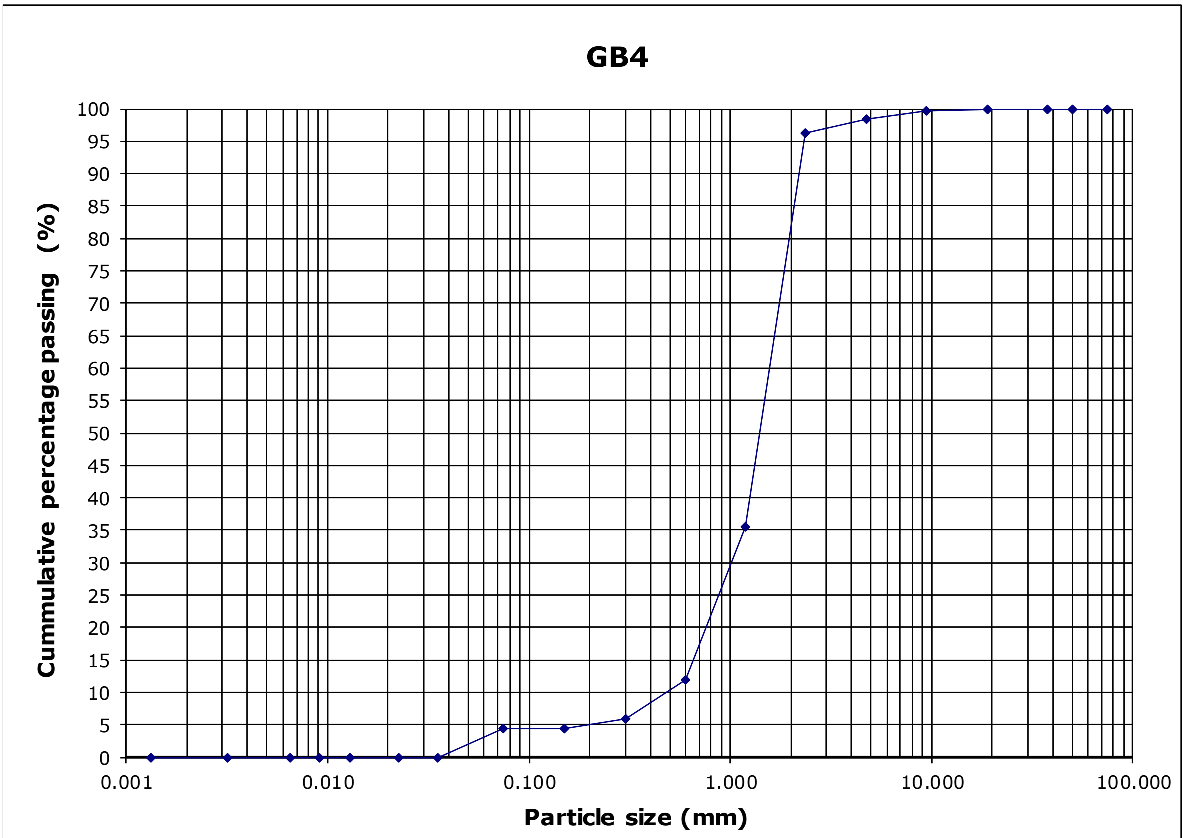
Hydrometer readings

Time (min)	True reading	Temp C	Corrected
2	5	26	0.00
5	5	26	0.00
15	5	26	0.00
30	5	26	0.00
60	5	26	0.00
250	5	26	0.00
1440	5	26	0.00

Sieve test

Sieve size (mm)	Mass (g)
2.36-1.18	41
1.18-0.60	16
0.60-0.30	4
0.30-0.150	1
0.150-0.075	0
<0.075	3.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	99.69	9.5
mm	98.50	4.75
mm	96.24	2.36
mm	35.54	1.18
mm	11.85	0.6
mm	5.92	0.3
mm	4.44	0.15
mm	4.44	0.075
mm	0.00	0.0354
mm	0.00	0.0224
mm	0.00	0.0129
mm	0.00	0.0091
mm	0.00	0.0065
mm	0.00	0.0032
mm	0.00	0.0013



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
0.0	1.6	2.8	3.9	90.1	1.5

ASTM Method

Sample Name	GB5
Date	2020/02/12
Container	5
Wet Mass	70
Dry Mass	70

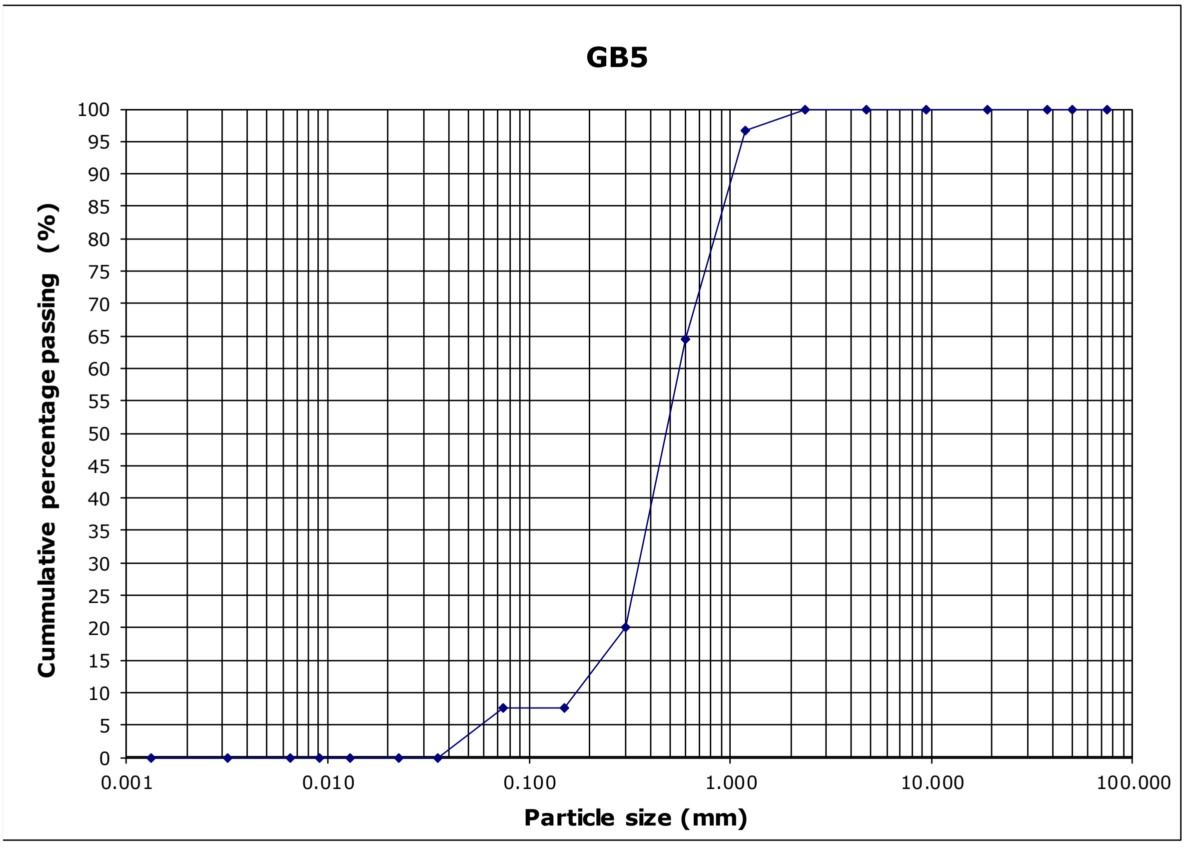
	Airdry	Dry
Total Mass	578	578.00
Container Mass	65	65.00

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50		0.00	100.00
4.75		0.00	100.00
2.36	1	0.17	99.83
<2.36	577.00	99.83	0.00

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	5	26	0.00
5	5	26	0.00
15	5	26	0.00
30	5	26	0.00
60	5	26	0.00
250	5	26	0.00
1440	5	26	0.00

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	2
1.18-0.60	21
0.60-0.30	29
0.30-0.150	8
0.150-0.075	0
<0.075	5.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	100.00	4.75
mm	99.83	2.36
mm	96.76	1.18
mm	64.50	0.6
mm	19.97	0.3
mm	7.68	0.15
mm	7.68	0.075
mm	0.00	0.0354
mm	0.00	0.0224
mm	0.00	0.0129
mm	0.00	0.0091
mm	0.00	0.0065
mm	0.00	0.0032
mm	0.00	0.0013



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
0.0	2.8	4.8	30.8	61.5	0.0

ASTM Method

Sample Name	GB6
Date	2020/02/12
Container	6
Wet Mass	70
Dry Mass	70

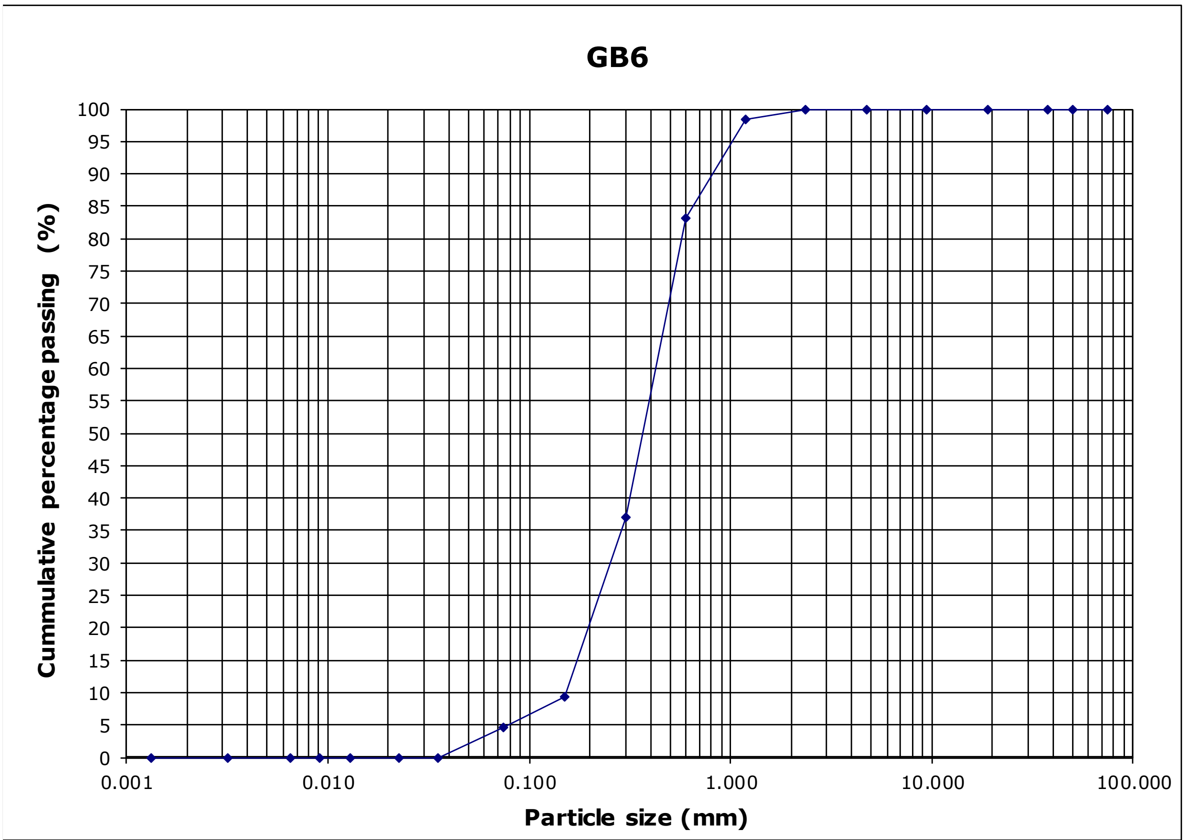
	Airdry	Dry
Total Mass	847	847.00
Container Mass	65	65.00

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50		0.00	100.00
4.75		0.00	100.00
2.36	0	0.00	100.00
<2.36	847.00	100.00	0.00

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	5	26	0.00
5	5	26	0.00
15	5	26	0.00
30	5	26	0.00
60	5	26	0.00
250	5	26	0.00
1440	5	26	0.00

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	1
1.18-0.60	10
0.60-0.30	30
0.30-0.150	18
0.150-0.075	3
<0.075	3.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	100.00	4.75
mm	100.00	2.36
mm	98.46	1.18
mm	83.08	0.6
mm	36.92	0.3
mm	9.23	0.15
mm	4.62	0.075
mm	0.00	0.0354
mm	0.00	0.0224
mm	0.00	0.0129
mm	0.00	0.0091
mm	0.00	0.0065
mm	0.00	0.0032
mm	0.00	0.0013



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
0.0	1.7	7.5	46.9	43.8	0.0

ASTM Method

Sample Name	GB7
Date	2020/02/12
Container	7
Wet Mass	70
Dry Mass	70

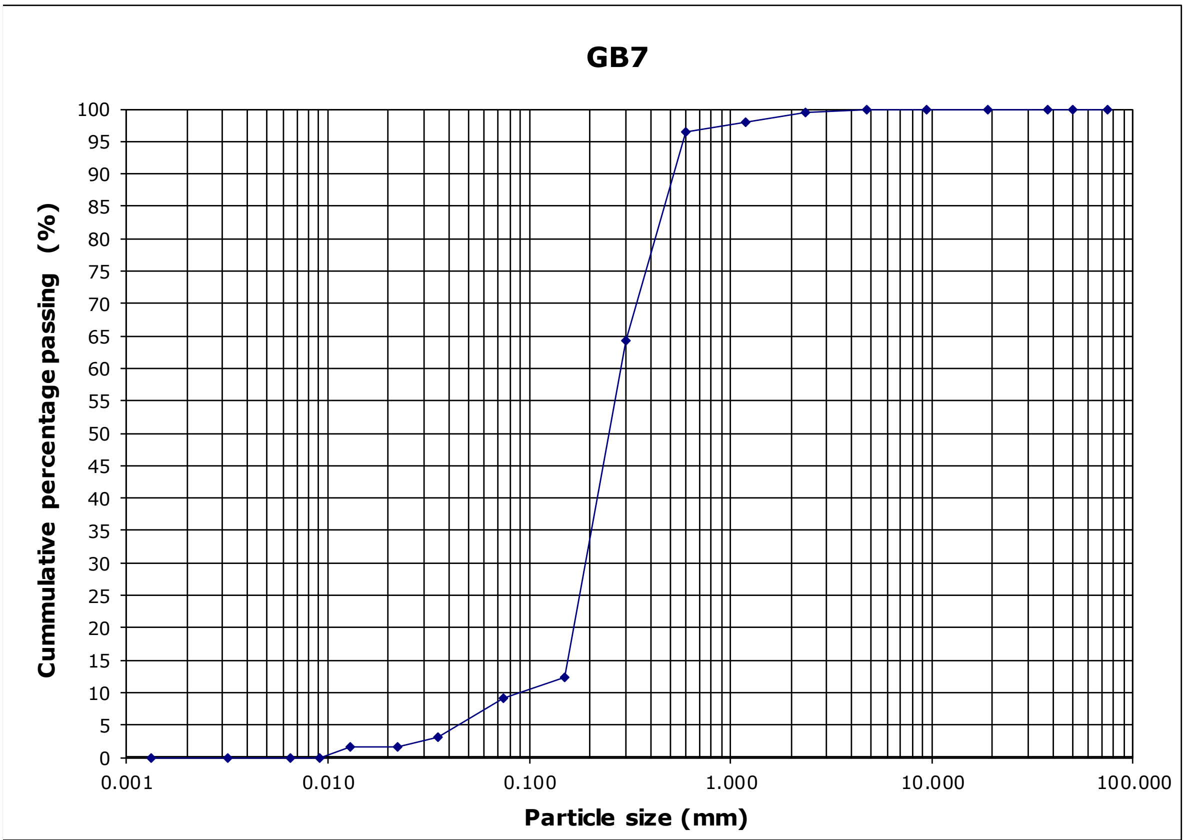
	Airdry	Dry
Total Mass	634	634.00
Container Mass	65	65.00

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50		0.00	100.00
4.75		0.00	100.00
2.36	3	0.47	99.53
<2.36	631.00	99.53	0.00

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	7	26	2.00
5	6	26	1.00
15	6	26	1.00
30	5	26	0.00
60	5	26	0.00
250	5	26	0.00
1440	5	26	0.00

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	1
1.18-0.60	1
0.60-0.30	21
0.30-0.150	34
0.150-0.075	2
<0.075	6.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	100.00	4.75
mm	99.53	2.36
mm	98.00	1.18
mm	96.46	0.6
mm	64.31	0.3
mm	12.25	0.15
mm	9.19	0.075
mm	3.06	0.0351
mm	1.53	0.0223
mm	1.53	0.0128
mm	0.00	0.0091
mm	0.00	0.0065
mm	0.00	0.0032
mm	0.00	0.0013



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
0.0	5.4	6.9	65.5	22.3	0.0

ASTM Method

Sample Name	GB8
Date	2020/02/12
Container	8
Wet Mass	70
Dry Mass	70

	Airdry	Dry
Total Mass	478	478.00
Container Mass	65	65.00

Sieve test

Sieve size (mm)	Mass (g)
2.36-1.18	1
1.18-0.60	1
0.60-0.30	41
0.30-0.150	17
0.150-0.075	1
<0.075	4.00

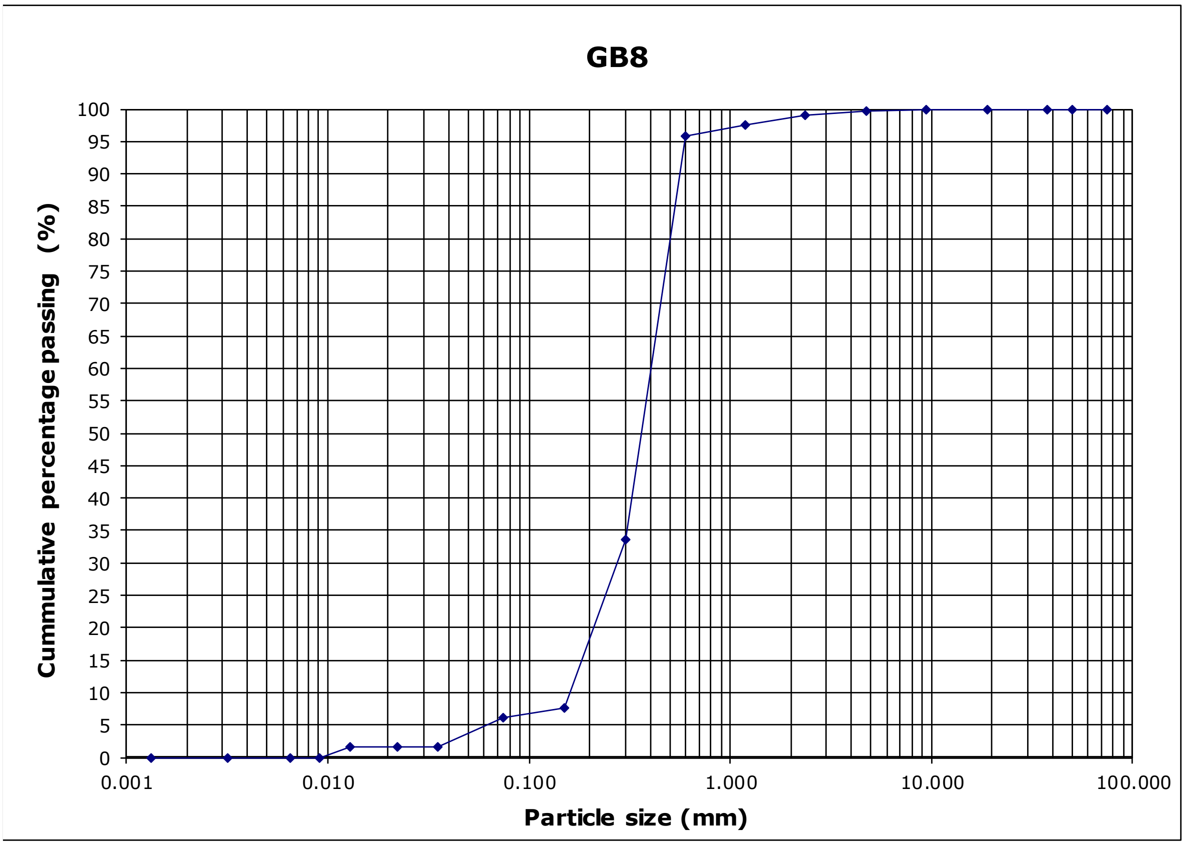
Sieve Analysis

Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50		0.00	100.00
4.75	2	0.42	99.58
2.36	3	0.63	98.95
<2.36	473.00	98.95	0.00

Hydrometer readings

Time (min)	True reading	Temp C	Corrected
2	6	26	1.00
5	6	26	1.00
15	6	26	1.00
30	5	26	0.00
60	5	26	0.00
250	5	26	0.00
1440	5	26	0.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	99.58	4.75
mm	98.95	2.36
mm	97.43	1.18
mm	95.91	0.6
mm	33.49	0.3
mm	7.61	0.15
mm	6.09	0.075
mm	1.52	0.0352
mm	1.52	0.0223
mm	1.52	0.0128
mm	0.00	0.0091
mm	0.00	0.0065
mm	0.00	0.0032
mm	0.00	0.0013



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
0.0	3.2	4.4	51.9	40.1	0.4

ASTM Method

Sample Name	GB9
Date	2020/02/12
Container	10
Wet Mass	62
Dry Mass	62

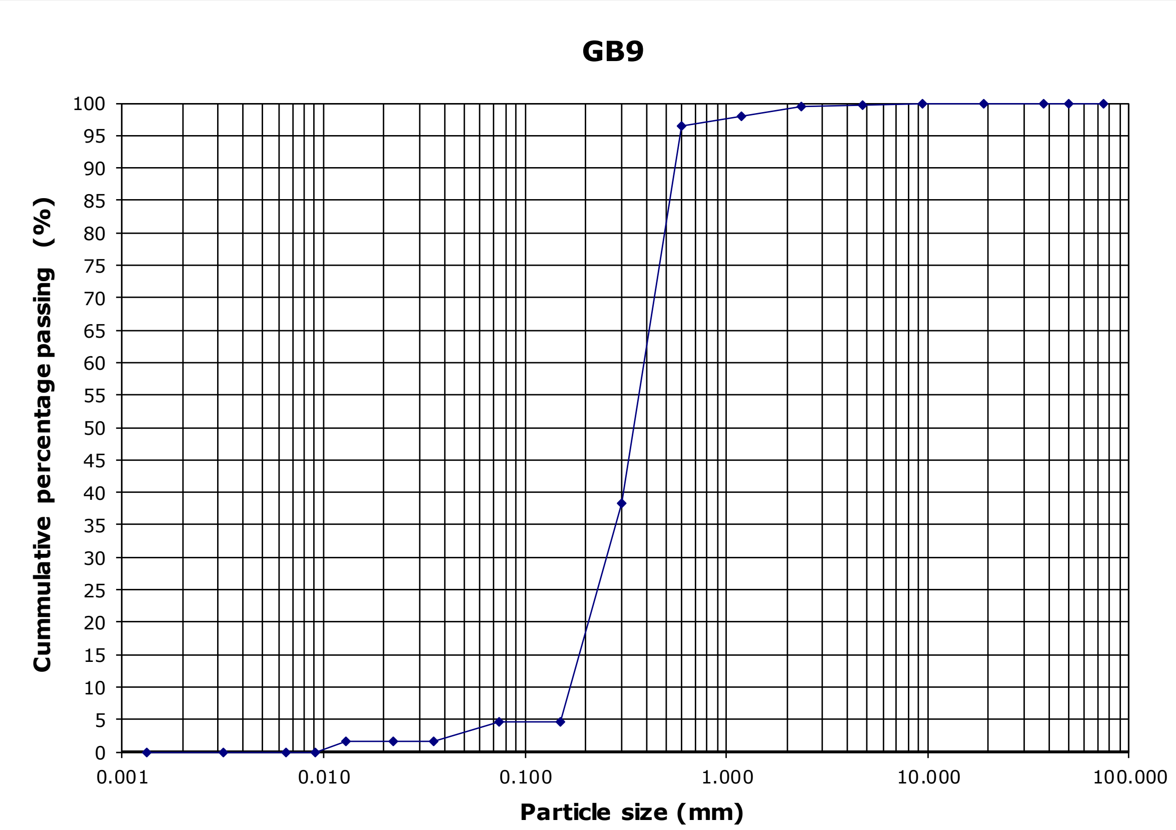
	Airdry	Dry
Total Mass	870	870.00
Container Mass	65	65.00

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50		0.00	100.00
4.75	3	0.34	99.66
2.36	2	0.23	99.43
<2.36	865.00	99.43	0.00

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	6	26	1.00
5	6	26	1.00
15	6	26	1.00
30	5	26	0.00
60	5	26	0.00
250	5	26	0.00
1440	5	26	0.00

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	1
1.18-0.60	1
0.60-0.30	38
0.30-0.150	22
0.150-0.075	0
<0.075	3.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	99.66	4.75
mm	99.43	2.36
mm	97.90	1.18
mm	96.37	0.6
mm	38.24	0.3
mm	4.59	0.15
mm	4.59	0.075
mm	1.53	0.0352
mm	1.53	0.0223
mm	1.53	0.0128
mm	0.00	0.0091
mm	0.00	0.0065
mm	0.00	0.0032
mm	0.00	0.0013



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
0.0	2.7	1.9	57.9	37.2	0.3

ASTM Method

Sample Name	GB10
Date	2020/02/12
Container	2
Wet Mass	55
Dry Mass	54

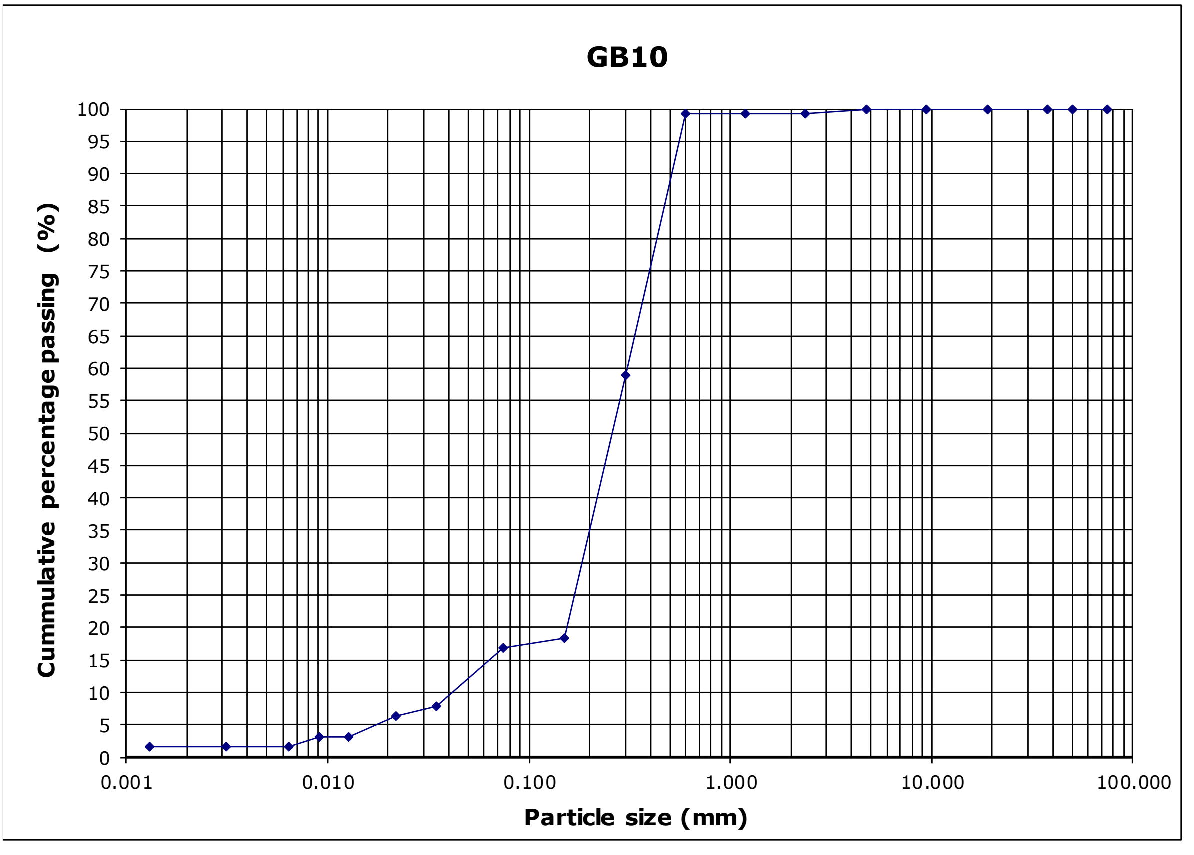
	Airdry	Dry
Total Mass	733	719.67
Container Mass	65	63.82

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	0
1.18-0.60	0
0.60-0.30	26
0.30-0.150	26
0.150-0.075	1
<0.075	10.82

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50		0.00	100.00
4.75		0.00	100.00
2.36	5	0.69	99.31
<2.36	714.67	99.31	0.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	100.00	4.75
mm	99.31	2.36
mm	99.31	1.18
mm	99.31	0.6
mm	58.85	0.3
mm	18.39	0.15
mm	16.83	0.075
mm	7.78	0.0345
mm	6.22	0.0219
mm	3.11	0.0128
mm	3.11	0.0091
mm	1.56	0.0064
mm	1.56	0.0031
mm	1.56	0.0013

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	10	26	5.00
5	9	26	4.00
15	7	26	2.00
30	7	26	2.00
60	6	26	1.00
250	6	26	1.00
1440	6	26	1.00



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
1.6	9.7	7.1	57.3	24.3	0.0

ASTM Method

Sample Name	KB1
Date	2020/02/12
Container	10
Wet Mass	70
Dry Mass	70

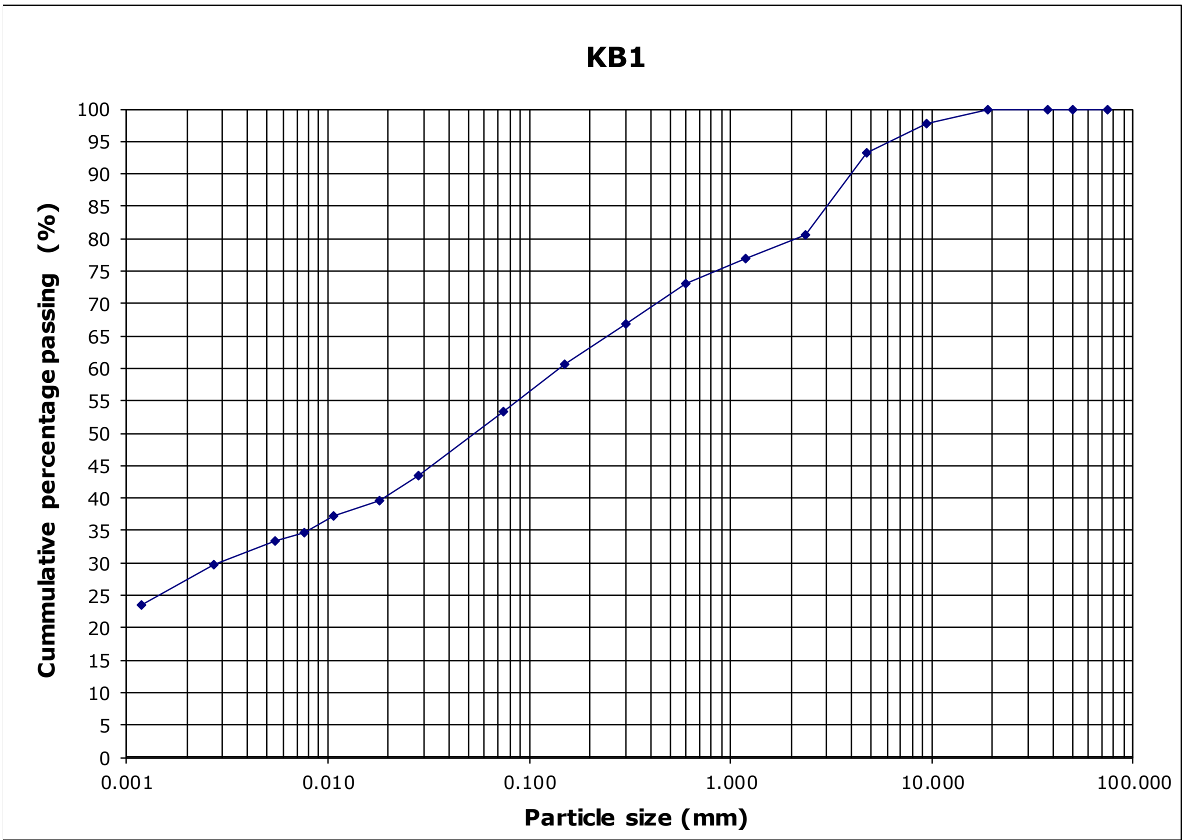
	Airdry	Dry
Total Mass	509	509.00
Container Mass	65	65.00

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50	12	2.36	97.64
4.75	22	4.32	93.32
2.36	65	12.77	80.55
<2.36	410.00	80.55	0.00

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	40	26	35.00
5	37	26	32.00
15	35	26	30.00
30	33	26	28.00
60	32	26	27.00
250	29	26	24.00
1440	24	26	19.00

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	3
1.18-0.60	3
0.60-0.30	5
0.30-0.150	5
0.150-0.075	6
<0.075	43.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	97.64	9.5
mm	93.32	4.75
mm	80.55	2.36
mm	76.83	1.18
mm	73.11	0.6
mm	66.92	0.3
mm	60.72	0.15
mm	53.29	0.075
mm	43.37	0.0280
mm	39.66	0.0182
mm	37.18	0.0107
mm	34.70	0.0077
mm	33.46	0.0055
mm	29.74	0.0027
mm	23.55	0.0012



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
26.8	21.2	12.7	8.8	23.8	6.7

ASTM Method

Sample Name	KB2
Date	2020/02/12
Container	11
Wet Mass	82
Dry Mass	82

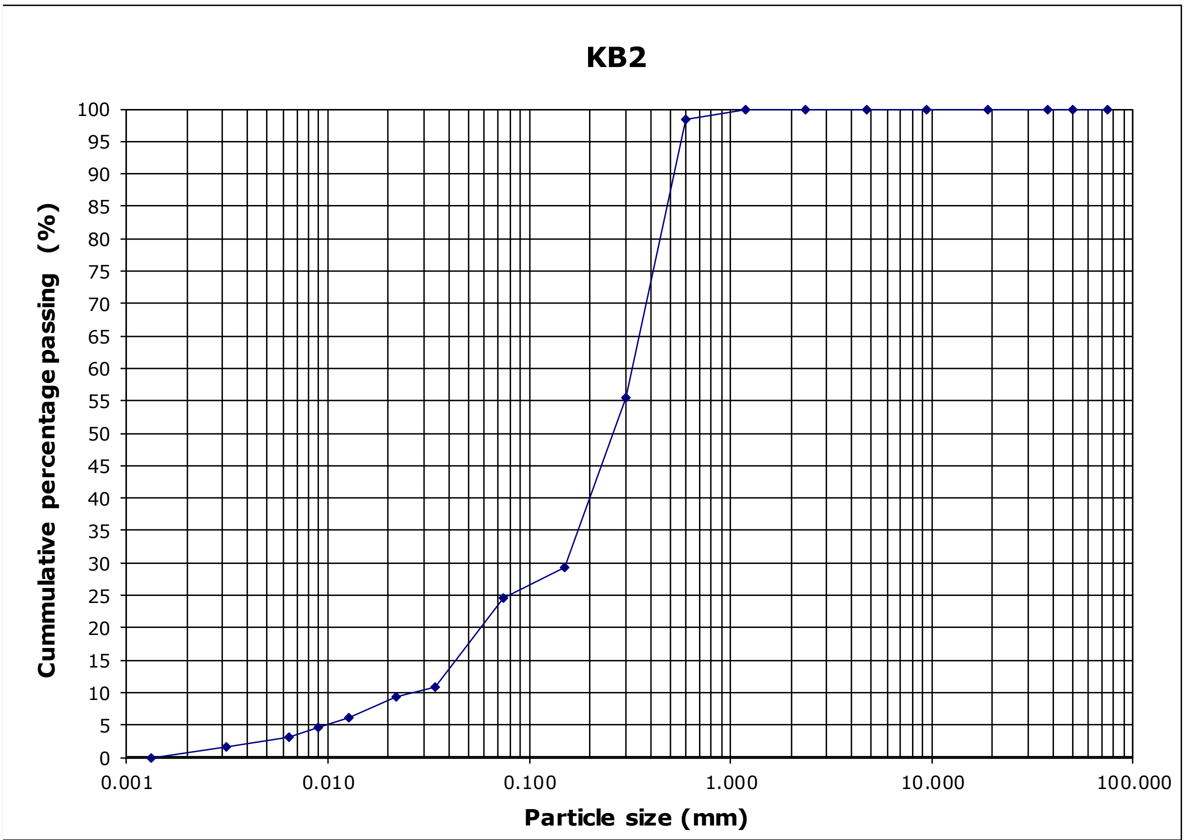
	Airdry	Dry
Total Mass	662	662.00
Container Mass	65	65.00

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50		0.00	100.00
4.75		0.00	100.00
2.36	0	0.00	100.00
<2.36	662.00	100.00	0.00

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	12	26	7.00
5	11	26	6.00
15	9	26	4.00
30	8	26	3.00
60	7	26	2.00
250	6	26	1.00
1440	5	26	0.00

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	0
1.18-0.60	1
0.60-0.30	28
0.30-0.150	17
0.150-0.075	3
<0.075	16.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	100.00	4.75
mm	100.00	2.36
mm	100.00	1.18
mm	98.46	0.6
mm	55.38	0.3
mm	29.23	0.15
mm	24.62	0.075
mm	10.77	0.0340
mm	9.23	0.0217
mm	6.15	0.0126
mm	4.62	0.0090
mm	3.08	0.0064
mm	1.54	0.0031
mm	0.00	0.0013



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
0.6	15.6	13.1	44.1	26.7	0.0

ASTM Method

Sample Name	KB3
Date	2020/02/12
Container	4
Wet Mass	82
Dry Mass	82

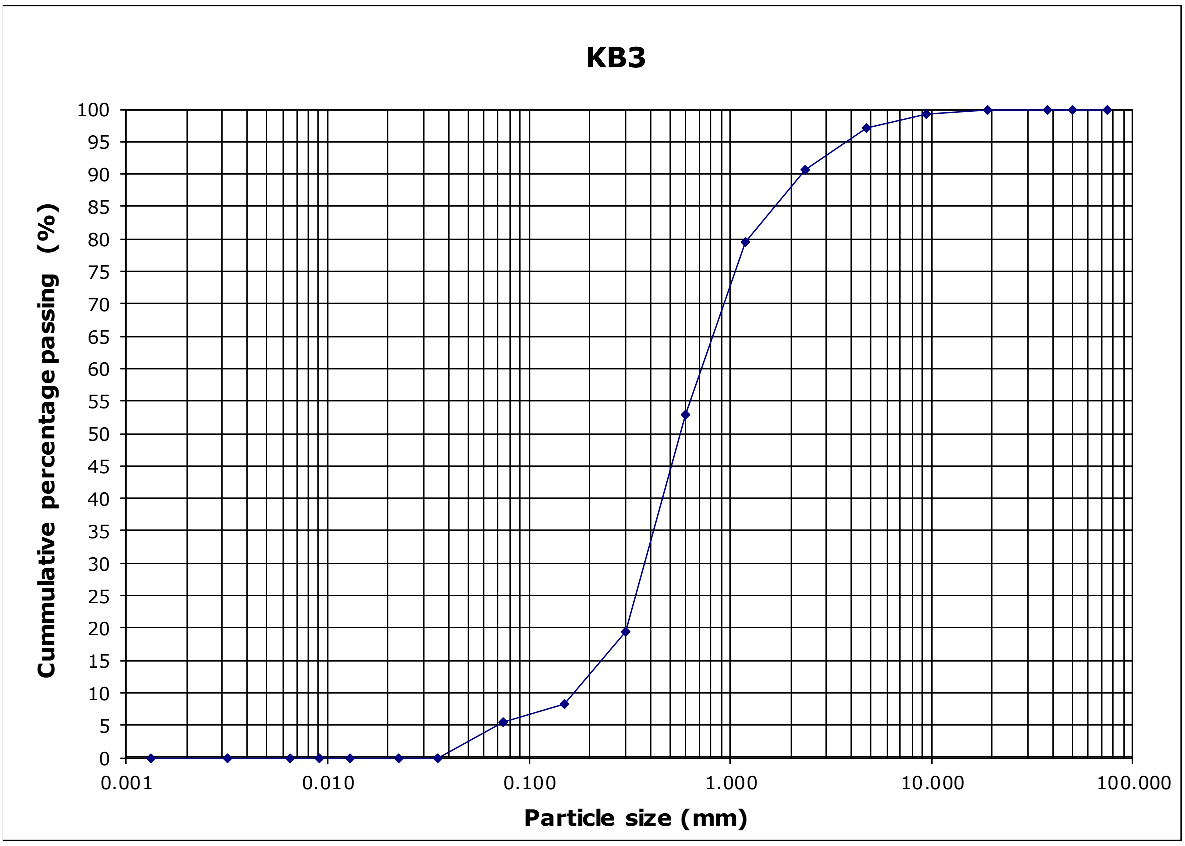
	Airdry	Dry
Total Mass	606	606.00
Container Mass	65	65.00

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	8
1.18-0.60	19
0.60-0.30	24
0.30-0.150	8
0.150-0.075	2
<0.075	4.00

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50	4	0.66	99.34
4.75	14	2.31	97.03
2.36	39	6.44	90.59
<2.36	549.00	90.59	0.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	99.34	9.5
mm	97.03	4.75
mm	90.59	2.36
mm	79.44	1.18
mm	52.96	0.6
mm	19.51	0.3
mm	8.36	0.15
mm	5.58	0.075
mm	0.00	0.0354
mm	0.00	0.0224
mm	0.00	0.0129
mm	0.00	0.0091
mm	0.00	0.0065
mm	0.00	0.0032
mm	0.00	0.0013

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	5	26	0.00
5	5	26	0.00
15	5	26	0.00
30	5	26	0.00
60	5	26	0.00
250	5	26	0.00
1440	5	26	0.00



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
0.0	2.1	6.3	25.1	63.6	3.0

ASTM Method

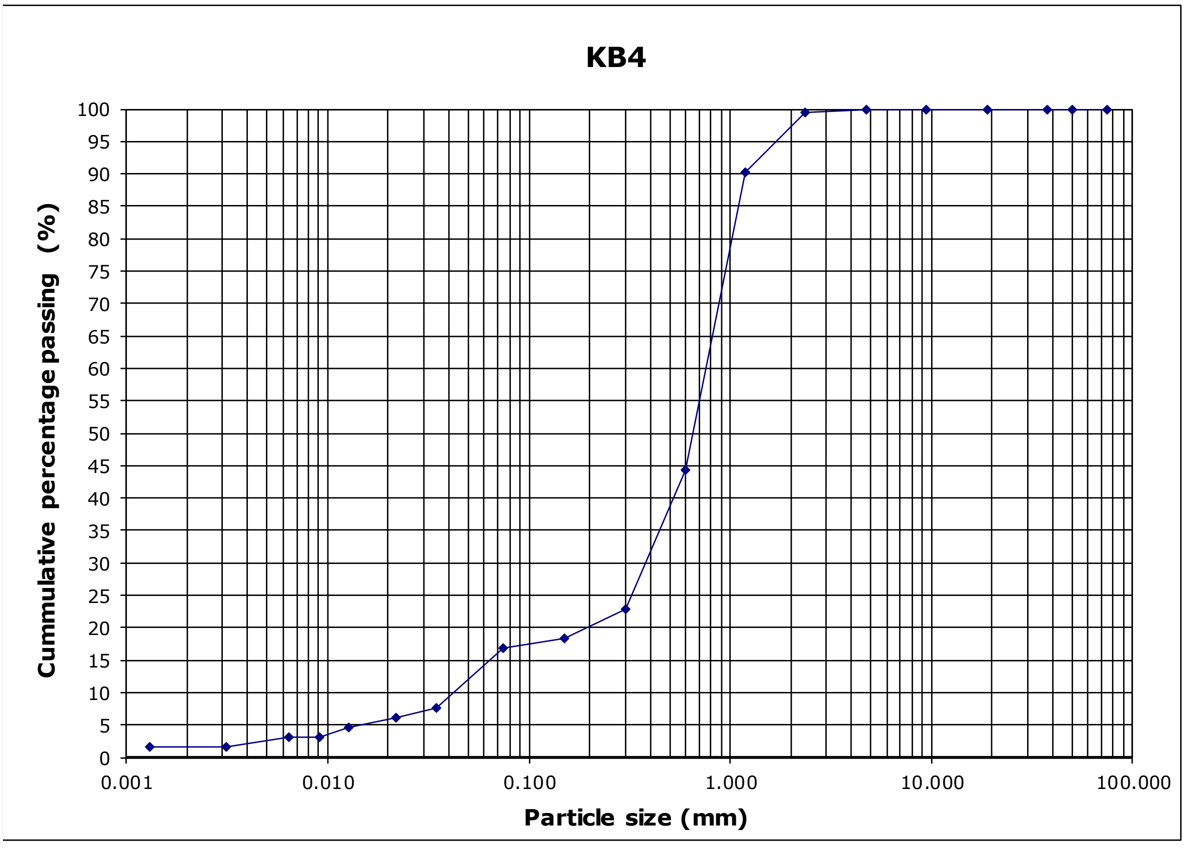
Sample Name	KB4	
Date	2020/02/12	
Container	3	
Wet Mass	67	
Dry Mass	67	
	Airdry	Dry
Total Mass	545	545.00
Container Mass	65	65.00

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	6
1.18-0.60	30
0.60-0.30	14
0.30-0.150	3
0.150-0.075	1
<0.075	11.00

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50		0.00	100.00
4.75	1	0.18	99.82
2.36	2	0.37	99.45
<2.36	542.00	99.45	0.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	99.82	4.75
mm	99.45	2.36
mm	90.27	1.18
mm	44.37	0.6
mm	22.95	0.3
mm	18.36	0.15
mm	16.83	0.075
mm	7.65	0.0345
mm	6.12	0.0219
mm	4.59	0.0127
mm	3.06	0.0091
mm	3.06	0.0064
mm	1.53	0.0031
mm	1.53	0.0013

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	10	26	5.00
5	9	26	4.00
15	8	26	3.00
30	7	26	2.00
60	7	26	2.00
250	6	26	1.00
1440	6	26	1.00



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
1.5	9.6	7.2	13.5	67.9	0.2

ASTM Method

Sample Name	KB5
Date	2020/02/12
Container	9
Wet Mass	72
Dry Mass	72

	Airdry	Dry
Total Mass	637	637.00
Container Mass	65	65.00

Sieve Analysis

Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50	2	0.31	99.69
4.75	2	0.31	99.37
2.36	3	0.47	98.90
<2.36	630.00	98.90	0.00

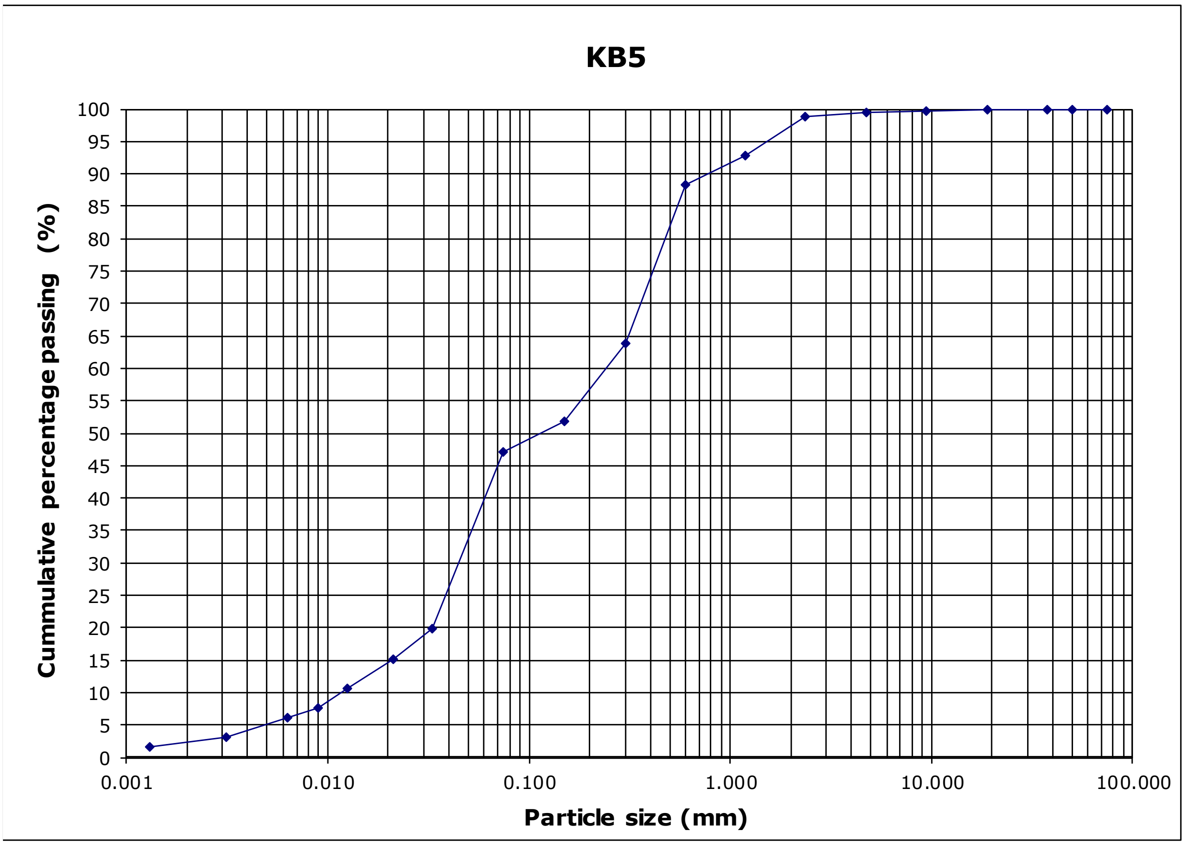
Hydrometer readings

Time (min)	True reading	Temp C	Corrected
2	18	26	13.00
5	15	26	10.00
15	12	26	7.00
30	10	26	5.00
60	9	26	4.00
250	7	26	2.00
1440	6	26	1.00

Sieve test

Sieve size (mm)	Mass (g)
2.36-1.18	4
1.18-0.60	3
0.60-0.30	16
0.30-0.150	8
0.150-0.075	3
<0.075	31.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	99.69	9.5
mm	99.37	4.75
mm	98.90	2.36
mm	92.81	1.18
mm	88.25	0.6
mm	63.91	0.3
mm	51.73	0.15
mm	47.17	0.075
mm	19.78	0.0328
mm	15.22	0.0211
mm	10.65	0.0124
mm	7.61	0.0089
mm	6.09	0.0063
mm	3.04	0.0031
mm	1.52	0.0013



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
2.1	28.8	20.8	22.3	25.3	0.6

ASTM Method

Sample Name	KB6
Date	2020/02/12
Container	14
Wet Mass	78
Dry Mass	78

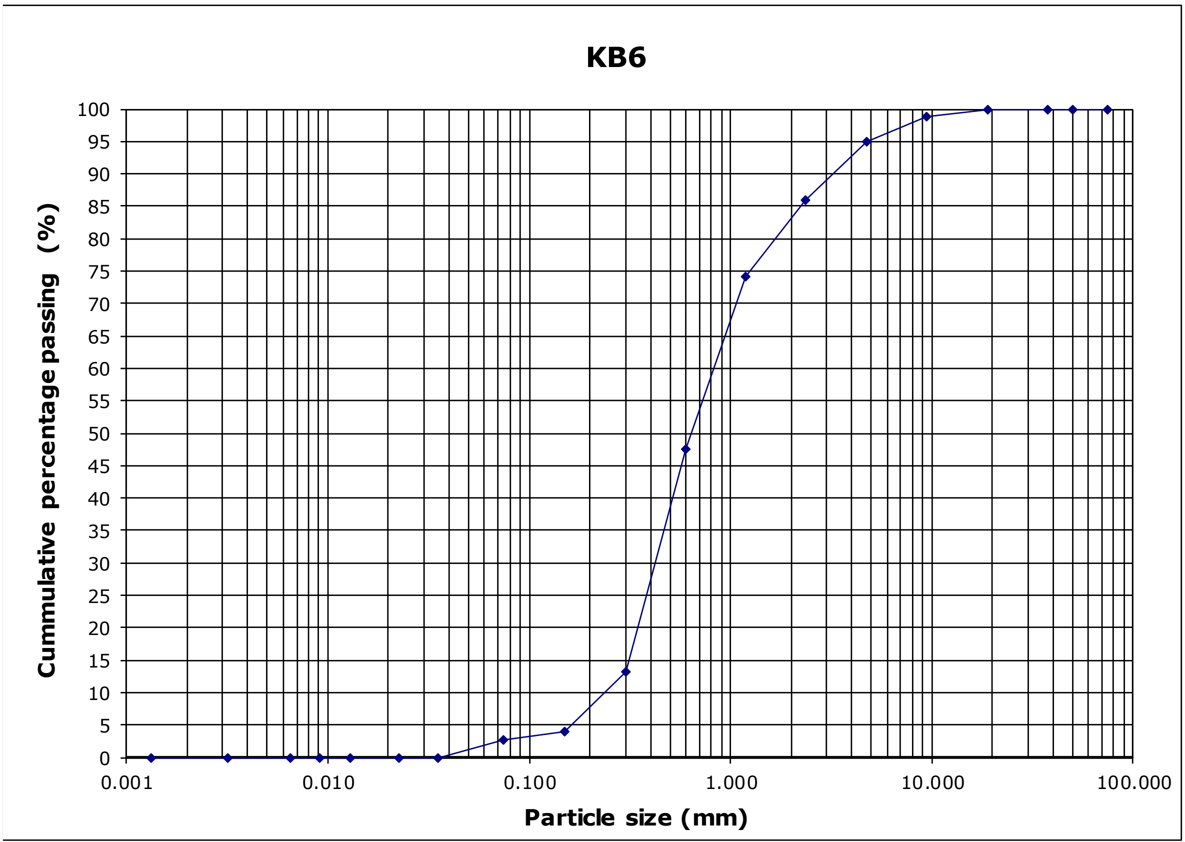
	Airdry	Dry
Total Mass	783	783.00
Container Mass	65	65.00

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50	9	1.15	98.85
4.75	31	3.96	94.89
2.36	70	8.94	85.95
<2.36	673.00	85.95	0.00

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	5	26	0.00
5	5	26	0.00
15	5	26	0.00
30	5	26	0.00
60	5	26	0.00
250	5	26	0.00
1440	5	26	0.00

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	9
1.18-0.60	20
0.60-0.30	26
0.30-0.150	7
0.150-0.075	1
<0.075	2.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	98.85	9.5
mm	94.89	4.75
mm	85.95	2.36
mm	74.05	1.18
mm	47.60	0.6
mm	13.22	0.3
mm	3.97	0.15
mm	2.64	0.075
mm	0.00	0.0354
mm	0.00	0.0224
mm	0.00	0.0129
mm	0.00	0.0091
mm	0.00	0.0065
mm	0.00	0.0032
mm	0.00	0.0013



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
0.0	1.0	3.0	23.6	67.3	5.1

ASTM Method

Sample Name	KB7
Date	2020/02/12
Container	15
Wet Mass	72
Dry Mass	72

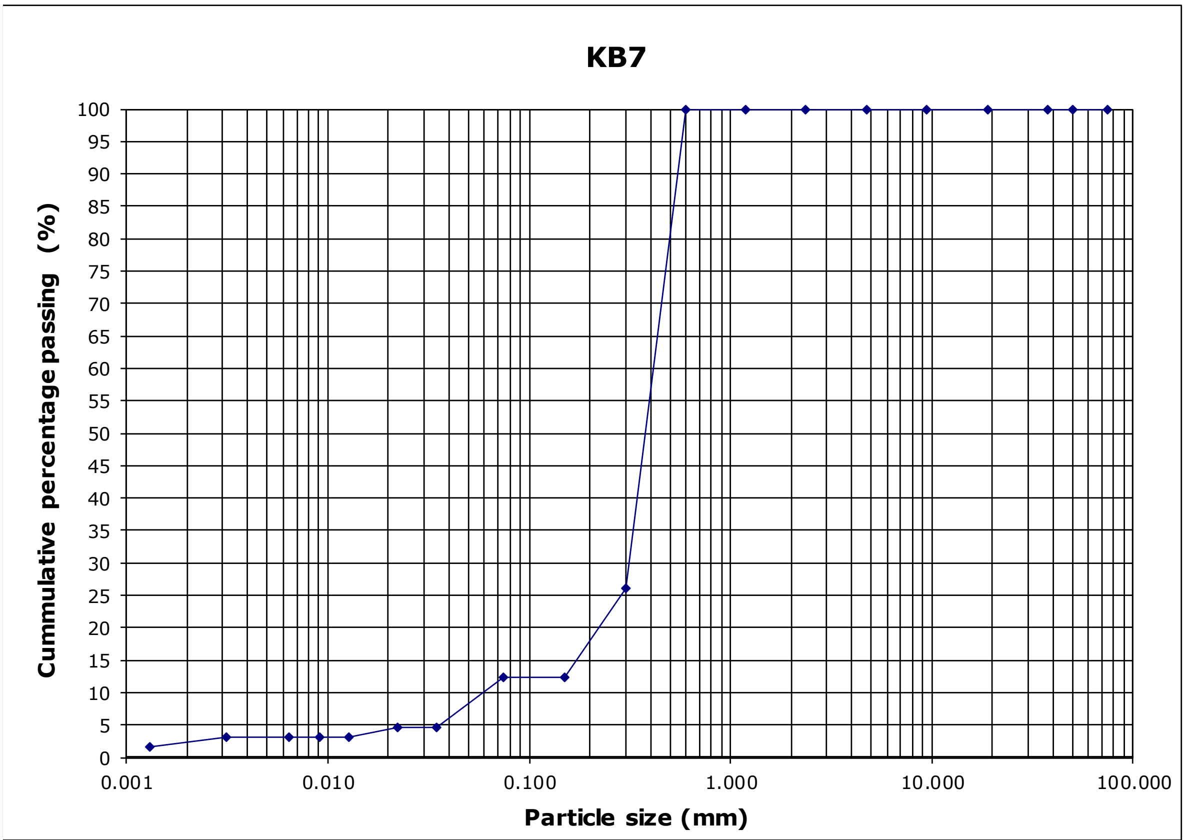
	Airdry	Dry
Total Mass	1002	1002.00
Container Mass	65	65.00

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50		0.00	100.00
4.75		0.00	100.00
2.36	0	0.00	100.00
<2.36	1002.00	100.00	0.00

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	8	26	3.00
5	8	26	3.00
15	7	26	2.00
30	7	26	2.00
60	7	26	2.00
250	7	26	2.00
1440	6	26	1.00

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	0
1.18-0.60	0
0.60-0.30	48
0.30-0.150	9
0.150-0.075	0
<0.075	8.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	100.00	4.75
mm	100.00	2.36
mm	100.00	1.18
mm	100.00	0.6
mm	26.15	0.3
mm	12.31	0.15
mm	12.31	0.075
mm	4.62	0.0348
mm	4.62	0.0220
mm	3.08	0.0128
mm	3.08	0.0091
mm	3.08	0.0064
mm	3.08	0.0031
mm	1.54	0.0013



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
2.1	5.4	4.8	44.6	43.1	0.0

ASTM Method

Sample Name	KB8
Date	2020/02/12
Container	8
Wet Mass	64
Dry Mass	63

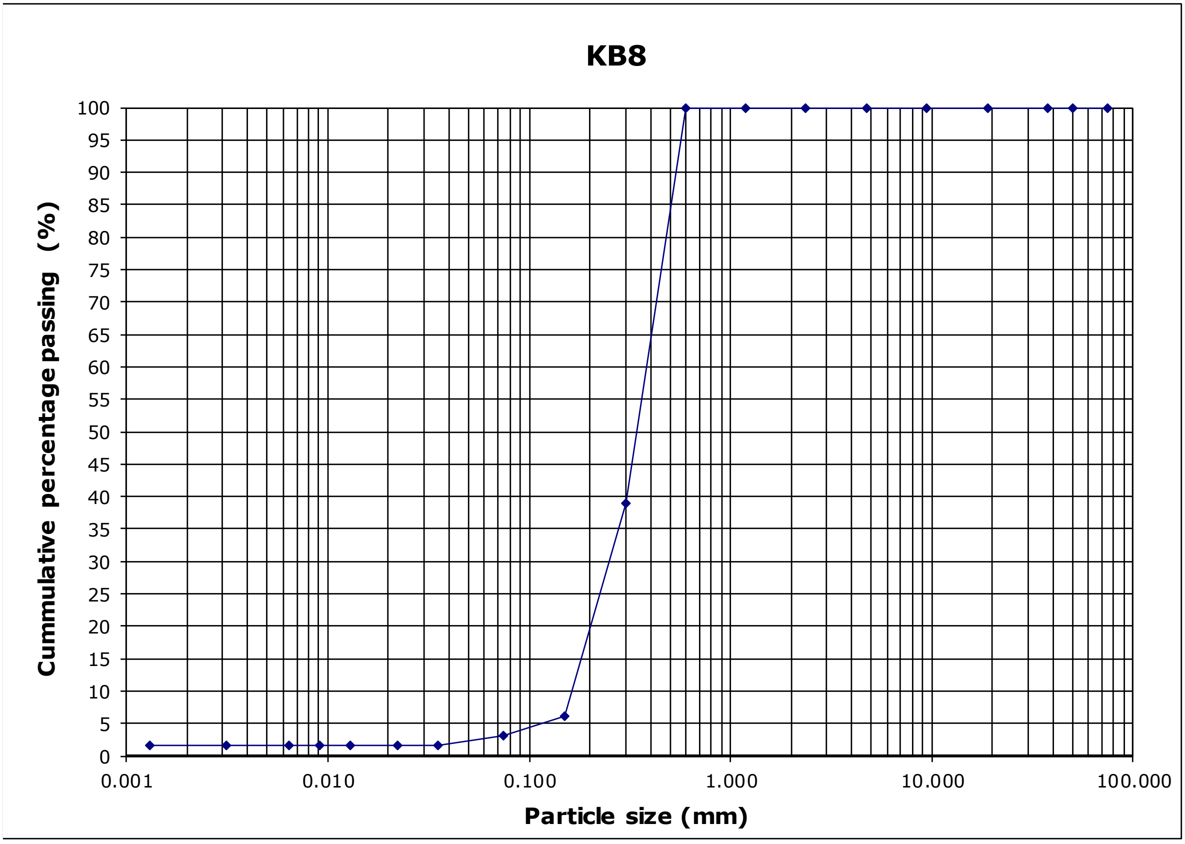
	Airdry	Dry
Total Mass	728	716.63
Container Mass	65	63.98

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50		0.00	100.00
4.75		0.00	100.00
2.36	1	0.14	99.86
<2.36	715.63	99.86	0.00

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	6	26	1.00
5	6	26	1.00
15	6	26	1.00
30	6	26	1.00
60	6	26	1.00
250	6	26	1.00
1440	6	26	1.00

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	0
1.18-0.60	0
0.60-0.30	39
0.30-0.150	21
0.150-0.075	2
<0.075	1.98

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	100.00	4.75
mm	99.86	2.36
mm	99.86	1.18
mm	99.86	0.6
mm	38.99	0.3
mm	6.22	0.15
mm	3.10	0.075
mm	1.56	0.0352
mm	1.56	0.0223
mm	1.56	0.0128
mm	1.56	0.0091
mm	1.56	0.0064
mm	1.56	0.0031
mm	1.56	0.0013



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
1.6	0.6	4.1	58.1	35.6	0.0

ASTM Method

Sample Name	KB9
Date	2020/02/12
Container	7
Wet Mass	73
Dry Mass	73

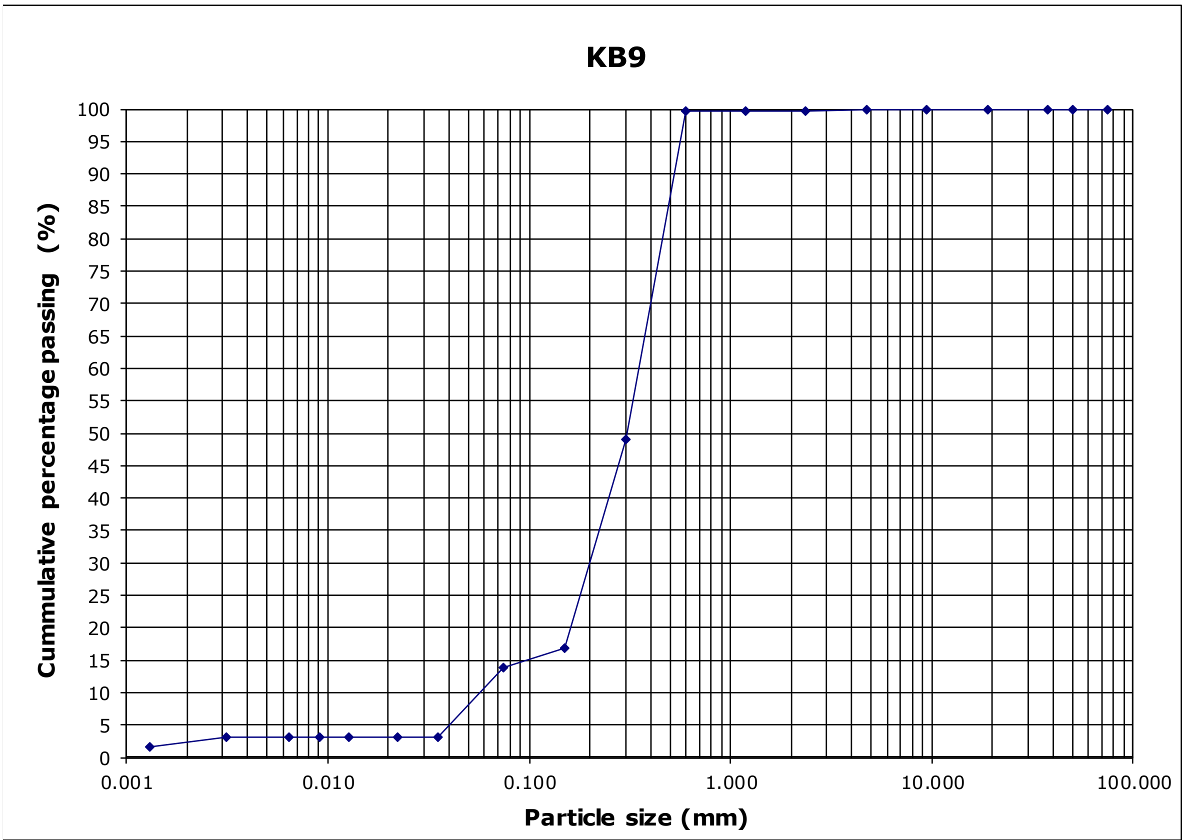
	Airdry	Dry
Total Mass	890	890.00
Container Mass	65	65.00

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50		0.00	100.00
4.75		0.00	100.00
2.36	3	0.34	99.66
<2.36	887.00	99.66	0.00

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	7	26	2.00
5	7	26	2.00
15	7	26	2.00
30	7	26	2.00
60	7	26	2.00
250	7	26	2.00
1440	6	26	1.00

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	0
1.18-0.60	0
0.60-0.30	33
0.30-0.150	21
0.150-0.075	2
<0.075	9.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	100.00	4.75
mm	99.66	2.36
mm	99.66	1.18
mm	99.66	0.6
mm	49.06	0.3
mm	16.87	0.15
mm	13.80	0.075
mm	3.07	0.0351
mm	3.07	0.0222
mm	3.07	0.0128
mm	3.07	0.0091
mm	3.07	0.0064
mm	3.07	0.0031
mm	1.53	0.0013



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
2.1	5.0	9.8	53.3	29.9	0.0

ASTM Method

Sample Name	KB10
Date	2020/02/12
Container	2
Wet Mass	76
Dry Mass	76

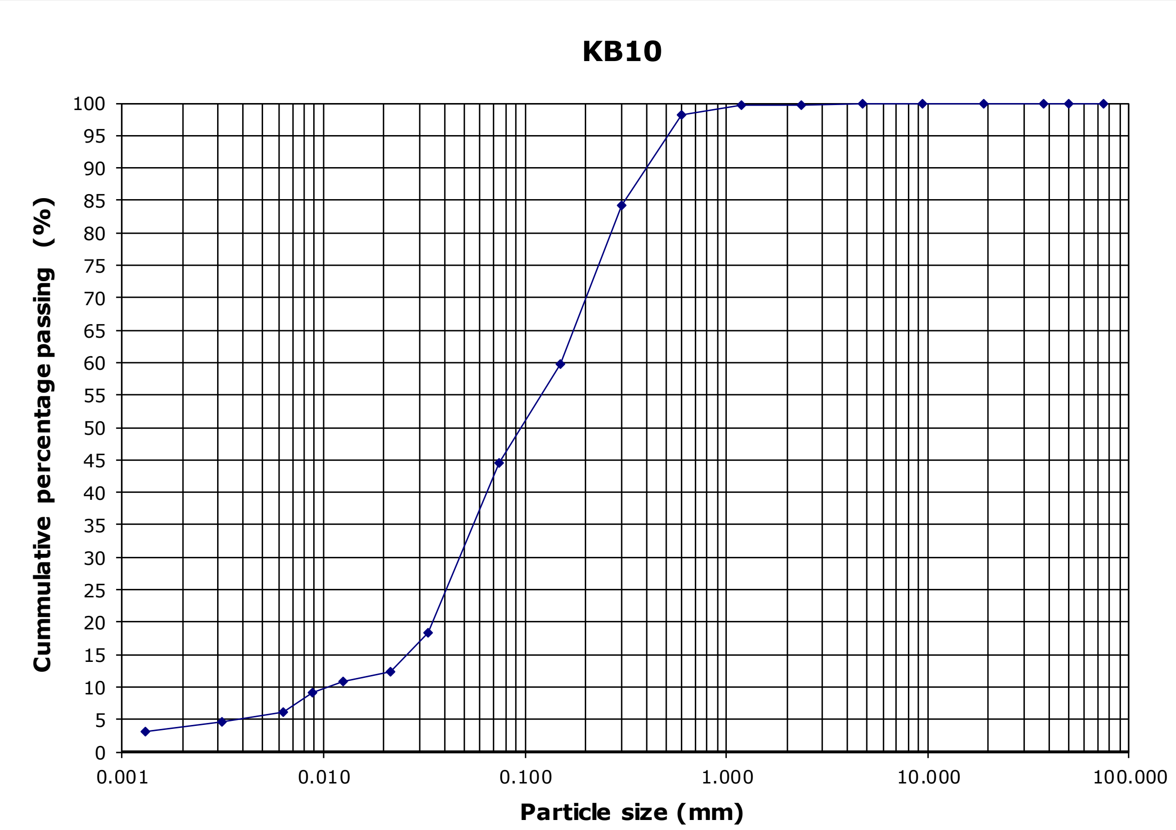
	Airdry	Dry
Total Mass	557	557.00
Container Mass	65	65.00

Sieve Analysis			
Sieve Size (mm)	Mass leftover (g)	% on sieve	% greater
75.00		0.00	100.00
50.00		0.00	100.00
37.50		0.00	100.00
19.00		0.00	100.00
9.50		0.00	100.00
4.75		0.00	100.00
2.36	2	0.36	99.64
<2.36	555.00	99.64	0.00

Hydrometer readings			
Time (min)	True reading	Temp C	Corrected
2	17	26	12.00
5	13	26	8.00
15	12	26	7.00
30	11	26	6.00
60	9	26	4.00
250	8	26	3.00
1440	7	26	2.00

Sieve test	
Sieve size (mm)	Mass (g)
2.36-1.18	0
1.18-0.60	1
0.60-0.30	9
0.30-0.150	16
0.150-0.075	10
<0.075	29.00

Unit	% Concentration	Diameter (mm)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	100.00	4.75
mm	99.64	2.36
mm	99.64	1.18
mm	98.11	0.6
mm	84.31	0.3
mm	59.78	0.15
mm	44.46	0.075
mm	18.40	0.0330
mm	12.26	0.0214
mm	10.73	0.0124
mm	9.20	0.0088
mm	6.13	0.0063
mm	4.60	0.0031
mm	3.07	0.0013



Clay < 0.002	Silt 0.002-0.05	Fine sand 0.05-0.15	Medium sand 0.15-0.425	Coarse sand 0.425-4.75	Gravel > 4.75
3.7	25.3	30.9	30.3	9.9	0.0

APPENDIX G: ESTUARY BERM CREST LEVELS

APPENDIX G1: KLEIN BRAK ESTUARY MOUTH BOUNDARY CONDITIONS

INTRODUCTION

For the purpose of determination of flood levels in the Klein Brak Estuary with the numerical model, MIKE21C, the boundary conditions at the mouth must be specified. In the closed mouth state, the maximum mouth berm level must be specified (refer Box G1-1 below). Also, since the mouth has a rocky sill which limits scour depth in the mouth, the rocky sill level must be specified. Estimates of the maximum berm level and the rocky sill level are presented in this appendix with data that supports/substantiate these estimates.

Box G1-1: Excerpt from (DWS, 2015); Examples of Klein Brak open and closed mouth states

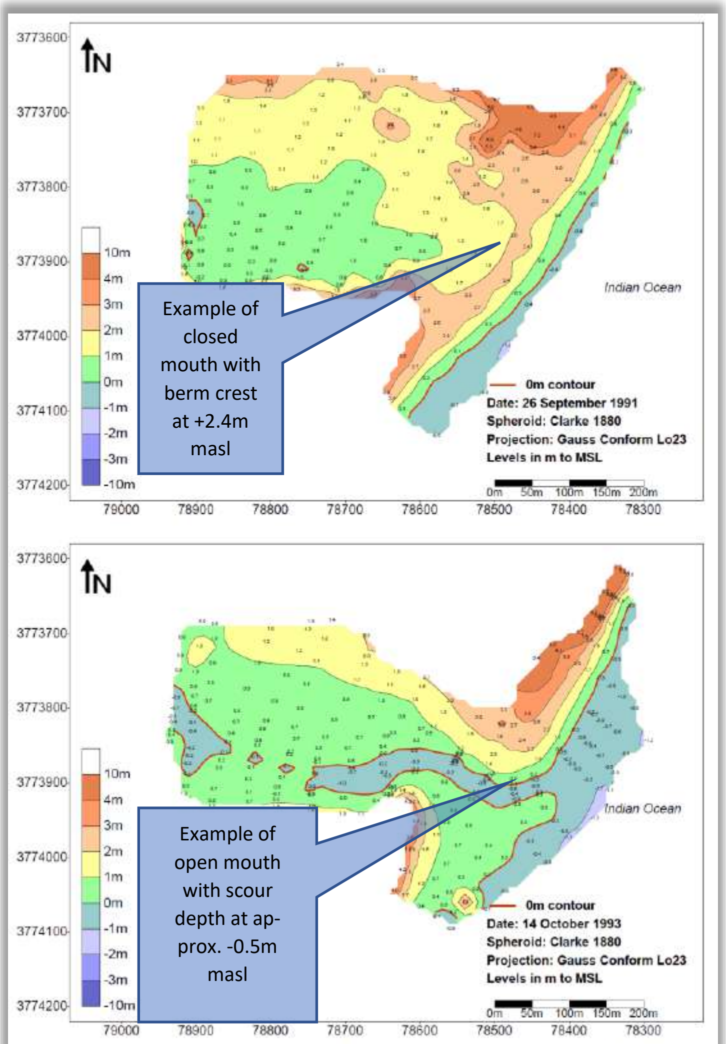


Figure A.1a Klein Brak Estuary: Mouth survey contour plots – 1991 and 1993

The Klein Brak estuary is classified as a "temporary open-closed" (TOC) estuary and is generally in an open state, allowing tidal influence within the estuary. The south-western side of the mouth has a rocky shelf bottom, which restricts the depth of the mouth channel. The position and width of the mouth channel varies over time. Regular artificial breaching is not practiced at the Klein Brak Estuary mouth (Bickerton *et al.*, 1983). Examples of open and closed mouth situations are presented in Boxes G1-2 and G1-3 below.

Box G1-2: Excerpt from DWS (2015); Examples of Klein Brak closed and open mouth states

Figure A4.a: Satellite image of the Klein Brak Estuary for 7 August 2005 showing closed mouth conditions (Source Google Earth).

Figure A4.a: Satellite image of the Klein Brak Estuary for 3 December 2005 showing a very constricted mouth conditions (Source: Google Earth).

Box G1-3: Excerpt from DWS (2015); Examples of Klein Brak open mouth states, indicating rocky sill in mouth

28 February 2010

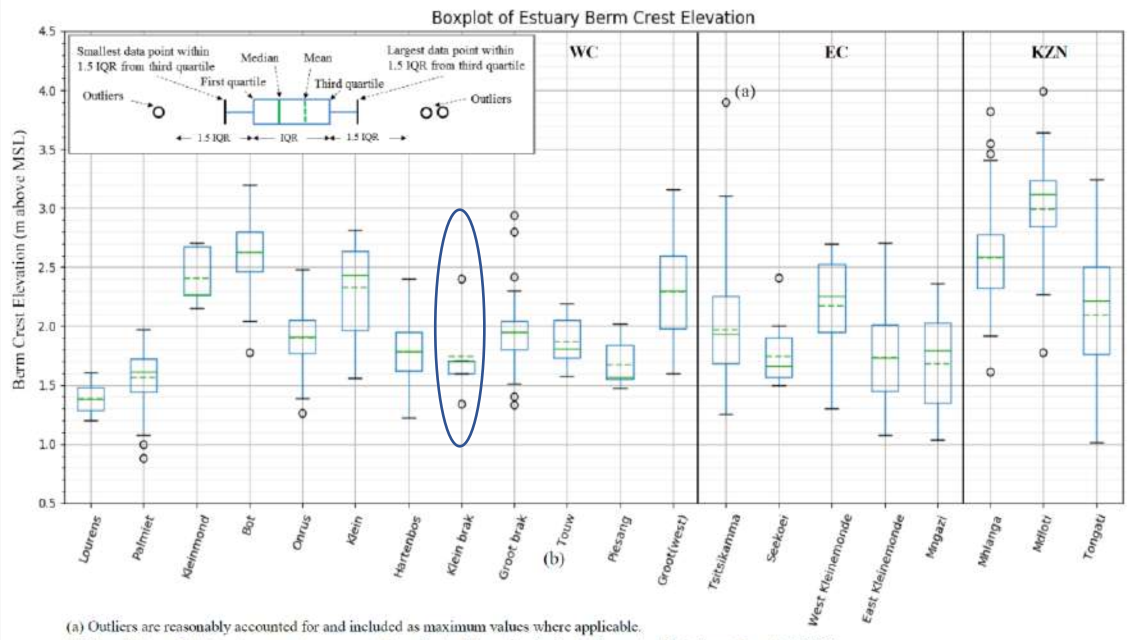
13 September 2013

Figure A5.d: **Klein Brak Estuary mouth showing progressive sedimentation in the lower reaches above railway bridge (Source: Google Earth).**

MAXIMUM BERM CREST LEVEL OF KLEIN BRAK ESTUARY

Booysen (2017) summarized the available information on maximum berm crest levels (maximum level of the berm crest at the saddle location of the berms) of estuaries on the Western Cape coast, Eastern Cape coast and on the KwaZulu-Natal coast – refer Box G1-4 below. These maximum berm crest levels are based on survey levels and levels derived from recorded estuary water levels at the time when mouth breaching commenced. The available recorded berm crest levels (included in the data in Box G1-4) for Klein Brak estuary are presented in Box G1-5 below.

Box G1-4: Excerpt from Booysen (2015); Statistical summary of recorded maximum berm level of estuaries on the Western Cape, Eastern Cape and KZN coasts



(a) Outliers are reasonably accounted for and included as maximum values where applicable.
(b) Touw Estuary data is not an accurate representation of natural berm levels due to frequent artificial breaching (§ 4.2.3.3).

Figure 5-1: Boxplot providing a statistical summary of the recorded berm crest elevations of the selected South African TOCEs

Box G1-5: Excerpt from Booysen (2015); Berm crest elevations for Klein Brak Estuary derived from surveys and recorded estuary water levels.

BERM CREST ELEVATIONS DERIVED FROM ESTUARINE WATER LEVEL DATA AND MOUTH/BERM SURVEYS

Klein Brak Estuary			**K1T020**		
#	Date of breach/survey	Time of breach	Corrected water level at breach/berm height **(m above MSL)**	Berm saddle point from survey **(m above MSL)**	Source
1	1988-08-11			1.60	CSIR survey
2	1989-07-06			1.70	
3	1991-09-26			2.40	
4	2005-09-10	07:38	1.34		DWS Estuarine water levels
5	2006-05-02	05:14	1.71		

Booysen (2017) developed and evaluated different methods of predicting the long term maximum berm crest level for estuaries on the Western Cape coast, Eastern Cape coast and on the KwaZulu-Natal coast. Booysen developed two Long-Term predictor methods with similar accuracy when compared to recorded berm levels. Based on Method 2 the predicted maximum berm crest levels for Klein Brak and Groot Brak estuaries are similar and are as follows:

- Klein Brak: 2.58 masl
- Groot Brak: 2.63 masl

Booysen's Method 2 has the following accuracy indicators when compared to recorded maximum berm crest levels:

- R2 = 0.69
- MAE = 0.26 m
- RMSEP = 0.34 m

Based on the above information on maximum berm crest level, a maximum crest level for Klein Brak Estuary for a flood-line study of 2.8 masl could be used based on the empirical equation, but the following factors should also be considered:

- the dataset of mouth closures at Klein Brak is much smaller than at Groot Brak, the record length is relatively short and only a few closure events were recorded/surveyed.
- The ASP (2018) study used 4.0 masl for the closed mouth condition (current scenario) at Groot Brak. The closed berm crest level at Klein Brak is however expected to be lower than the berm at Groot Brak due to:
  - the bedrock at the Klein Brak Mouth causing smaller waves at the berm
  - the Kleinbrak mouth being more protected in the bay
  - the Groot Brak mouth experiencing longer closed conditions due to the dam in the catchment which reduces low flows and attenuates floods and wind sediment transport.
- Due to prolonged droughts and the refurbished DWS Moordkuils abstraction works in the catchment, the low flows at the estuary could be reduced in future, leading to longer mouth closures and possible higher berm crest levels.

From the above the closed Klein Brak mouth berm crest level recommended for use in this study is 3.5 masl for the current scenario.

ROCKY SILL LEVEL IN MOUTH OF KLEIN BRAK ESTUARY

Based on the survey of the open mouth of the Klein Brak Estuary as shown in Box G1-1, a rocky sill level of -0.5 masl is recommended.

APPENDIX G2: GROOT BRAK ESTUARY MOUTH BOUNDARY CONDITIONS

INTRODUCTION

For the purpose of determination of flood levels in the Groot Brak Estuary with the numerical model, MIKE21C, the boundary conditions at the mouth must be specified. In the closed mouth state, the expected maximum natural mouth berm saddle level without artificial manipulation/breaching must be specified. An estimate of the maximum berm saddle level is presented in this appendix with data that supports/substantiate these estimates.

Box G2-1: Excerpt from (Viljoen, 2017); Examples of Groot Brak near closed mouth state with berm level predominantly between +2 and +3 masl

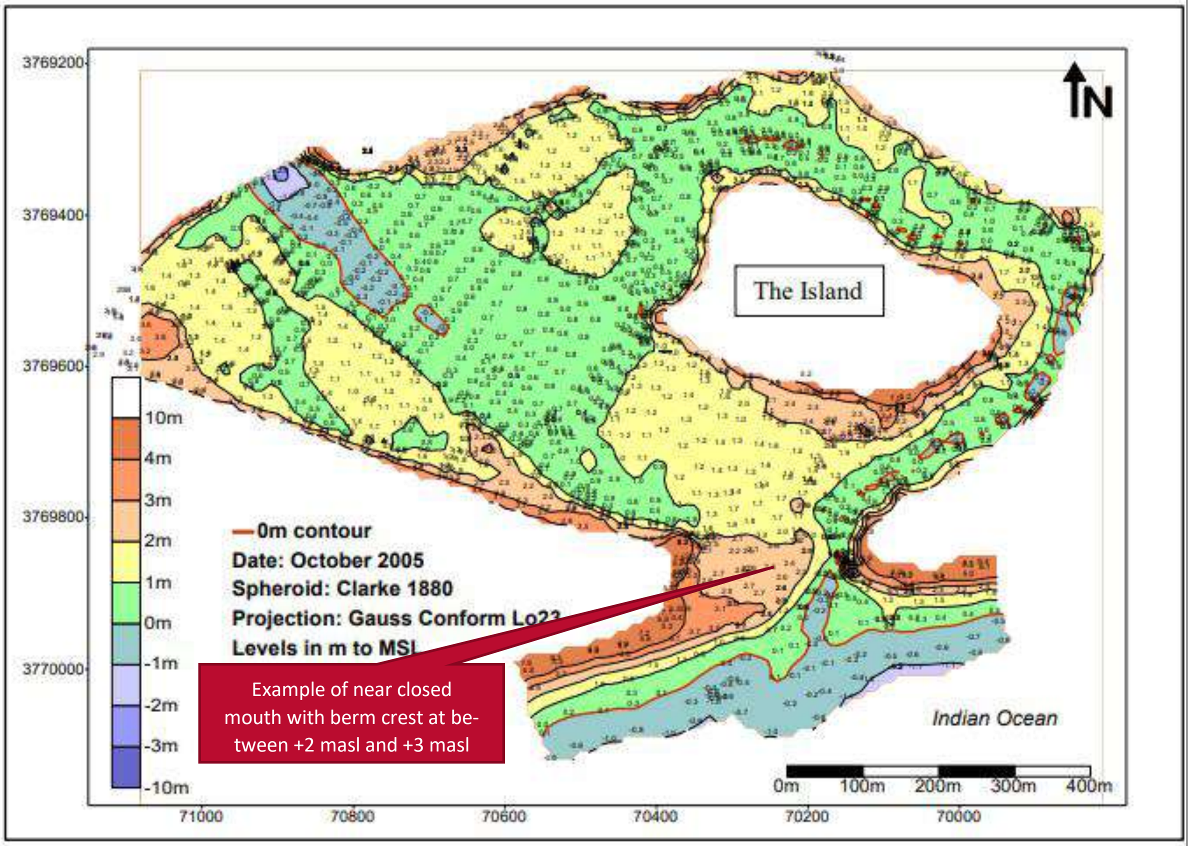


Figure 3-8: Bathymetric survey of the lower estuary basin done in 2005 (Source: Huizinga 2017)

The Groot Brak estuary is classified as a "temporary open-closed" (TOC). Regular artificial breaching is practiced at the Groot Brak Estuary mouth (Viljoen, 2017). Between 1990 and 2017 the mouth has been breached at an average of approximately 5 times per year. This is done to protect the low laying properties in the estuary basin area according to an emergency breaching protocol DEA&DP (2018).

Box G2-2: Excerpt from DEA&DP (2018); Examples of Groot Brak closed mouth state in 1976

Box G2-3: Excerpt from DEA&DP (2018); Examples of Groot Brak open mouth state during Nov 2015

MAXIMUM BERM CREST LEVEL OF GROOT BRAK ESTUARY

Booysen (2017) summarized the available information on maximum berm crest levels (maximum level of the berm crest at the saddle location of the berms) of estuaries on the Western Cape coast, Eastern Cape coast and on the KwaZulu-Natal coast – refer Box G2-4 below. These maximum berm crest levels are based on survey levels and levels derived from recorded estuary water levels at the time when mouth breaching commenced. The available recorded berm crest levels (included in the data in Box G2-5) for Groot Brak estuary are presented in Box G2-4 below. Due to artificial manipulation/breaching of the Groot Brak berm in the estuary mouth, both the recorded maximum berm levels shown in Box G2-4 and the maximum recorded water levels in Box G2-5 would have been lower than if the berm was not artificially breached.

Box G2-4: Excerpt from Booysen (2015); Statistical summary of recorded maximum berm level of estuaries on the Western Cape, Eastern Cape and KZN coasts

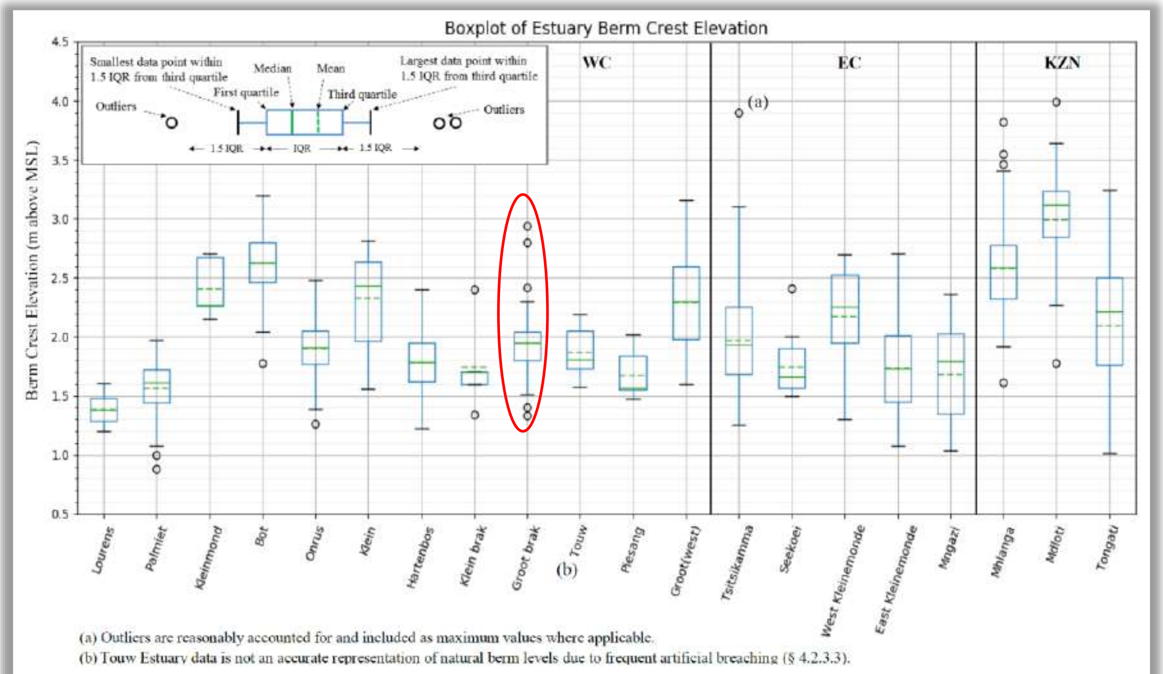


Figure 5-1: Boxplot providing a statistical summary of the recorded berm crest elevations of the selected South African TOCEs

Box G2-5: Excerpt from Booysen (2017); Berm crest elevations for Groot Brak Estuary derived from surveys and recorded estuary water levels.

Groot Brak Estuary			K2T004		
#	Date of breach/survey	Time of breach	Corrected water level at breach/berm height (m above MSL)	Berm saddle point from survey (m above MSL)	Source
1	1988-06-02	01:17	1.97		DWS Estuarine water levels
2	1988-07-15	14:57	1.97		
3	1988-08-03	19:21	1.91		
4	1988-08-30	10:34	2.11		
5	1988-12-14			1.40	CSIR survey
6	1989-04-14	22:42	1.98		DWS Estuarine water levels
7	1989-07-07			2.80	CSIR survey
8	1989-07-07	22:21	2.08		DWS Estuarine water levels
9	1989-10-03	20:30	2.29		
10	1990-05-23	19:47	2.06		
11	1990-06-09			1.70	CSIR survey
12	1990-06-27			2.30	
13	1990-10-02	18:25	1.76		DWS Estuarine water levels
14	1990-11-30	17:16	2.04		
15	1991-03-14	15:55	2.14		
16	1991-07-09	18:19	1.95		
17	1991-10-30	23:12	2.19		
18	1991-12-18	15:28	2.09		
19	1992-03-17	17:35	2.20		
20	1992-05-06	11:21	2.29		
21	1992-06-26	16:11	2.18		
22	1992-08-10	17:00	2.17		
23	1992-10-16		1.89		
24	1993-05-18	17:02	1.78		
25	1993-06-02	18:08	1.91		
26	1993-07-16	18:34	1.81		
27	1993-09-13	15:54	1.67		
28	1994-02-05	10:29	1.81		
29	1994-05-20	14:42	1.78		
30	1994-07-19	15:12	1.89		
31	1994-08-03	01:36	1.94		
32	1995-07-18	10:57	1.87		
33	1995-09-05	13:59	1.87		
34	1996-10-10	14:34	1.87		
35	1997-07-22	00:37	1.63		

Box G2-5 (continued): Excerpt from Booysen (2017); Berm crest elevations for Groot Brak Estuary derived from surveys and recorded estuary water levels.

Groot Brak Estuary			K2T004	
#	Date of breach/survey	Time of breach	Corrected water level at breach/berm height (m above MSL)	Berm saddle point from survey (m above MSL)
36	1997-08-26	15:48	2.04	
37	1998-03-25	17:14	1.51	
38	1998-04-28	12:08	1.71	
39	1998-09-04	17:00	1.83	
40	1998-11-13	13:47	1.98	
41	1999-03-13	16:47	2.07	
42	1999-06-24	12:06	2.00	
43	1999-09-21	15:54	2.02	
44	1999-11-12	00:21	1.76	
45	2000-03-01	12:38	1.89	
46	2000-09-22	11:47	1.95	
47	2001-01-02	13:29	1.69	
48	2001-02-14	22:06	1.76	
49	2001-09-13	13:29	1.97	
50	2002-05-25	03:53	2.21	
51	2002-07-23	20:38	1.91	
52	2002-08-23	21:27	1.74	
53	2002-09-04	22:35	1.84	
54	2002-11-04	15:45	2.13	
55	2002-12-17	15:38	1.83	
56	2003-02-13	15:02	1.97	
57	2003-03-25	06:09	2.25	
58	2003-08-22	13:05	1.99	
59	2004-04-01	14:36	1.96	
60	2004-05-07	09:35	1.88	
61	2004-09-23	12:48	2.01	
62	2004-10-12	10:13	1.67	
63	2005-09-29	13:48	2.01	
64	2005-10-27	03:09	1.33	
65	2006-08-01	18:24	2.25	
66	2007-02-15	05:20	1.74	
67	2007-09-25	14:23	1.94	
68	2008-09-01	19:01	2.42	
69	2008-11-13	19:23	1.79	
70	2009-03-24	14:11	1.96	
71	2009-07-03	14:56	1.95	
72	2011-02-01	19:37	2.03	
73	2011-06-08	13:41	2.94	
74	2012-07-14	16:18	2.05	
75	2013-08-09	09:13	1.88	
76	2013-08-28	10:54	1.99	
77	2013-09-03	07:25	1.53	
78	2013-10-22	01:27	1.71	
79	2014-09-23	13:42	2.04	
80	2014-11-18	05:02	1.64	
81	2015-04-01	15:17	2.00	
82	2015-06-09	15:52	1.77	
83	2015-06-24	14:47	1.94	
84	2015-07-21	16:27	1.92	

Booysen (2017) developed and evaluated different methods of predicting the long term maximum berm crest level for estuaries on the Western Cape coast, Eastern Cape coast and on the KwaZulu-Natal coast. Booysen developed two Long-Term predictor methods with similar accuracy when compared to recorded berm levels for the case of artificial berm breaching. Based on Method 2 the predicted maximum berm crest levels for Groot Brak and Klein Brak estuaries are similar and are as follows:

- Klein Brak: 2.58 masl
- Groot Brak: 2.63 masl

Booysen's Method 2 has the following accuracy indicators when compared to recorded maximum berm crest levels:

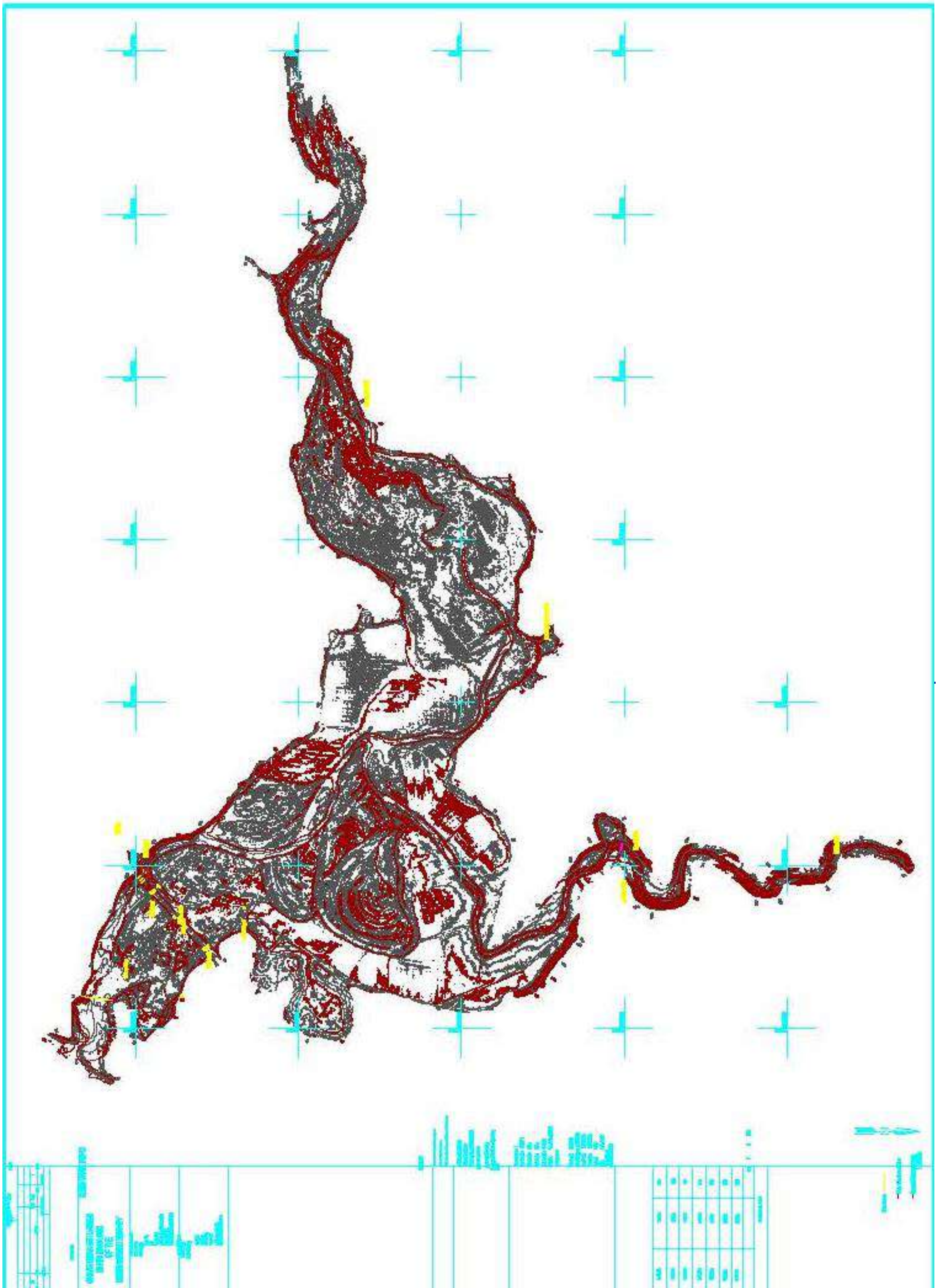
- R2 = 0.69
- MAE = 0.26 m
- RMSEP = 0.34 m

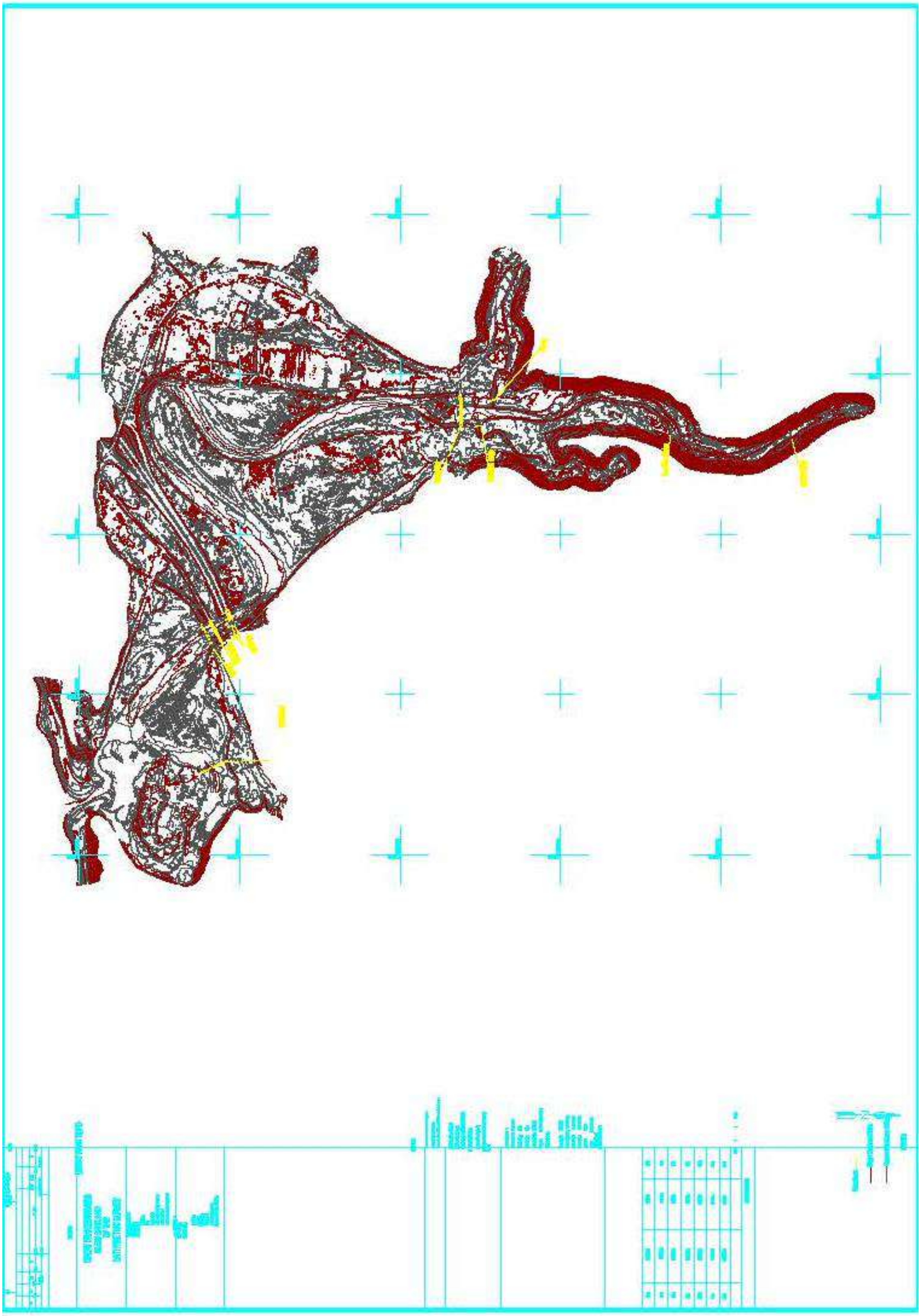
As indicated earlier, since the Groot Brak berm in the estuary is artificially breached when the water level in the estuary reach a stage when property is endangered, the the empirical method of Booysen (2017) and the maximum berm level derived from observed maximum water level during breaching will under estimate the natural maximum berm level.

Therefore, based on the above, a berm level between 3.5 and 4. 0 masl is recommended for the flood study of the Groot Brak estuary.

APPENDIX H: STRUCTURE SURVEY REPORTS

APPENDIX H1: CONTOUR DRAWINGS SUPPLIED BY UNDERWATER SURVEYS FOR THE KLEIN BRAK AND GROOT BRAK ESTUARIES RESPECTIVELY

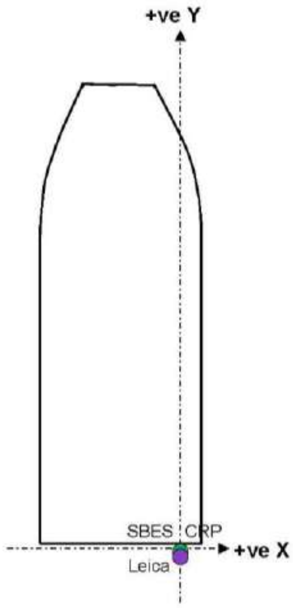




APPENDIX H2: VESSEL OFFSET DIAGRAM AND SURVEY CONTROL POINTS

"BADPROP" SURVEY SENSOR OFFSETS

Offset	X Offset (+ve starboard)	Y Offset (+ve forward)	Z Offset (+ve upward)
Common Reference Point (CRP)	0.000m	0.000m	0.000m
SBES Transducer	+0.001m	0.000m	0.000m
Leica RTK Antenna	0.000m	0.001m	+1.190m
Water Line	0.000m	0.000m	+0.250m



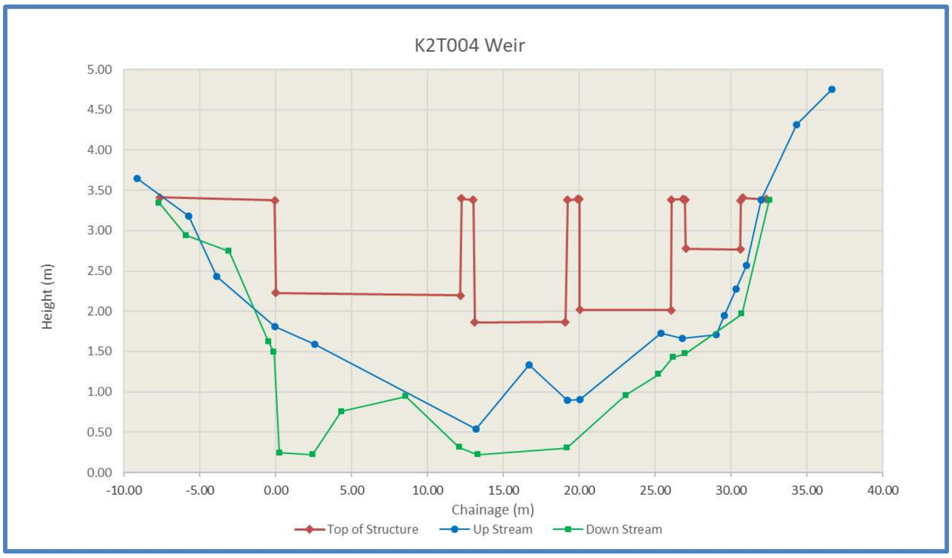
Offset Schematic
(not to scale)

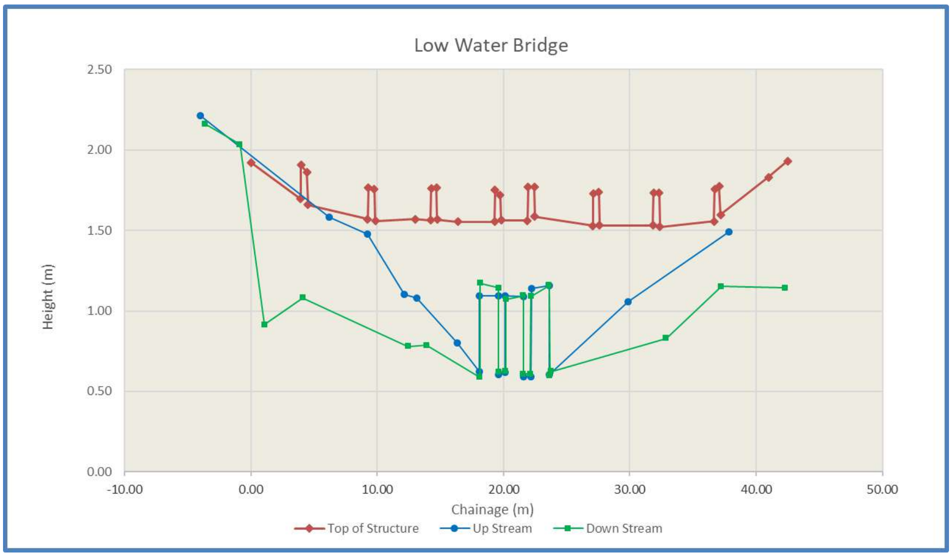
Western Cape Government
Greater Brak and Klein Brak Rivers

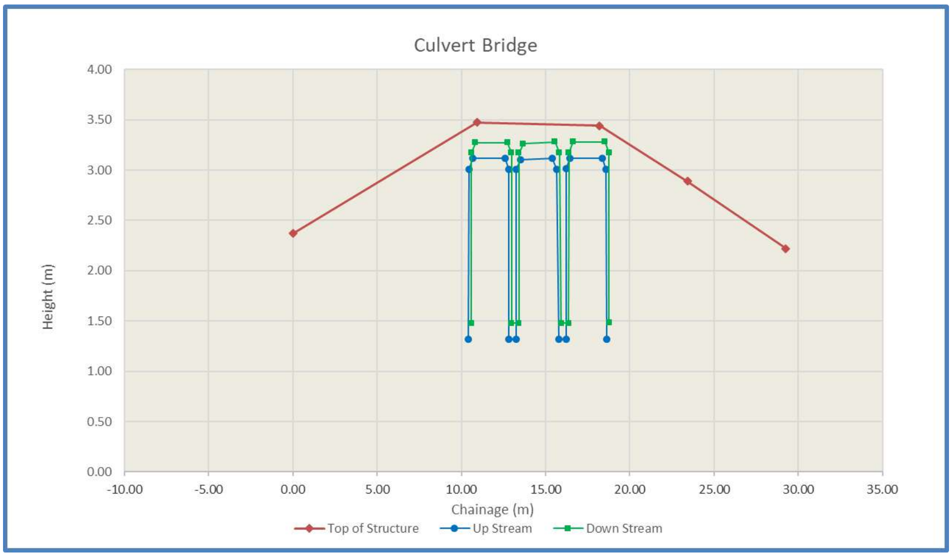
Ellipsoid	WGS1984
Datum	Hartbeeshoek 94
Projection	Gauss Conform WG 23/84
Central Meridian	23° East
Vertical Reference	Orthometric Heights referenced to SAGeoid2010 geoid model

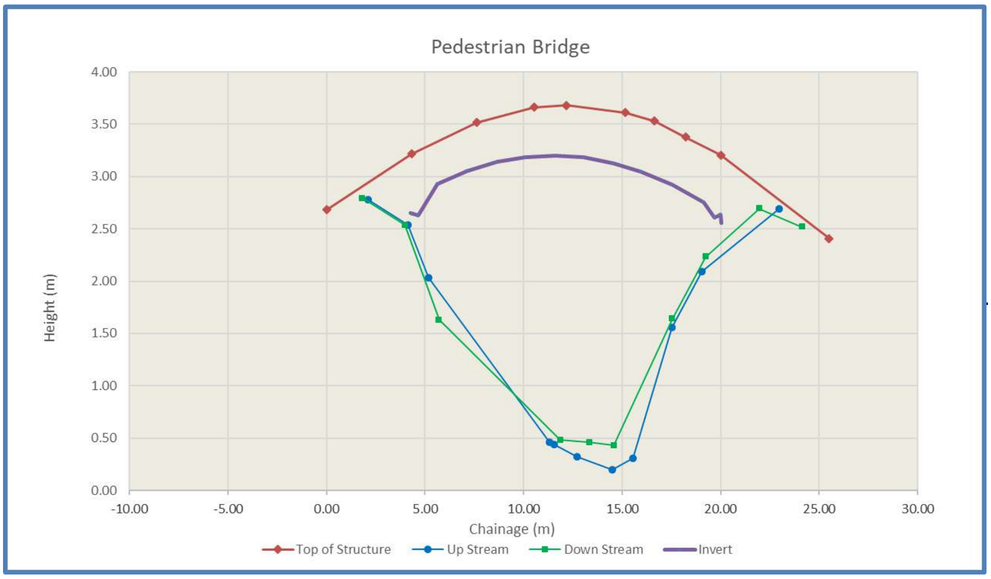
Point Name	Y Co-ordinate	X Co-ordinate	Orthometric Height (m) SAGeoid2010	Description
Primary Control				
443 Klein Brak	78238.95m	3773105.17m	75.90m	Std Pillar on Res
148 Geo 36	78272.46m	3773106.56m	74.10m	Std Pillar
GEOB	57114.97m	3764721.95m	199.83m	Trignet
Secondary Control				
PWL1	78480.36m	3773997.06m	5.08m	12mm Peg
BM2	78899.35m	3773969.21m	3.63m	12mm Peg
UWS1	79588.34m	3773806.93m	1.86m	Feno Marker
UWS2	79287.95m	3773892.82m	1.66m	Feno marker
GB1	72099.05m	3769908.78m	3.00m	Feno marker
GB2	70946.34m	3769554.73m	4.28m	Feno Marker
GB3	70329.28m	3769645.77m	1.76m	Feno Marker
KB1	80170.60m	3770028.79m	4.68m	Feno Marker

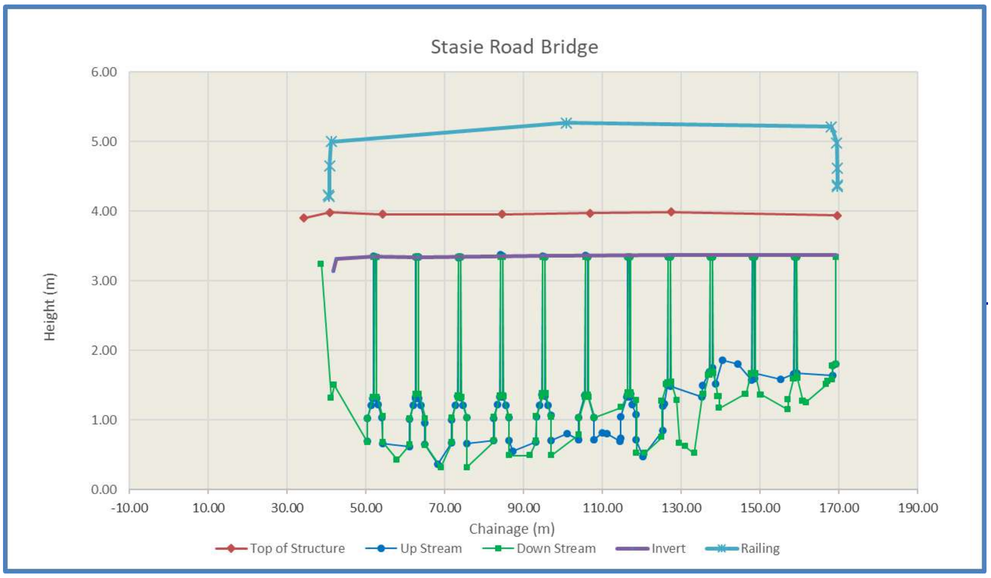
APPENDIX H3: GROOT BRAK STRUCTURE SECTIONS

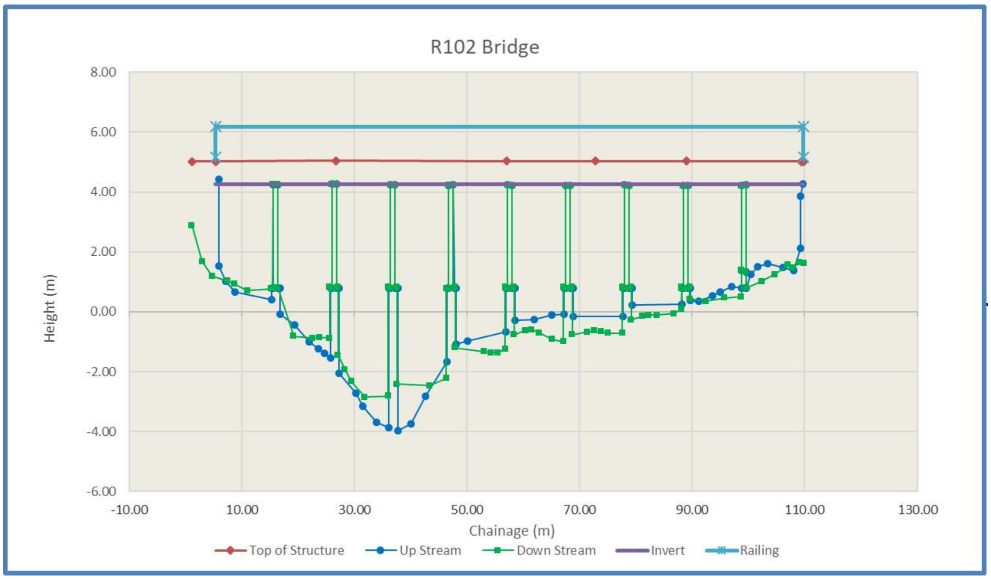


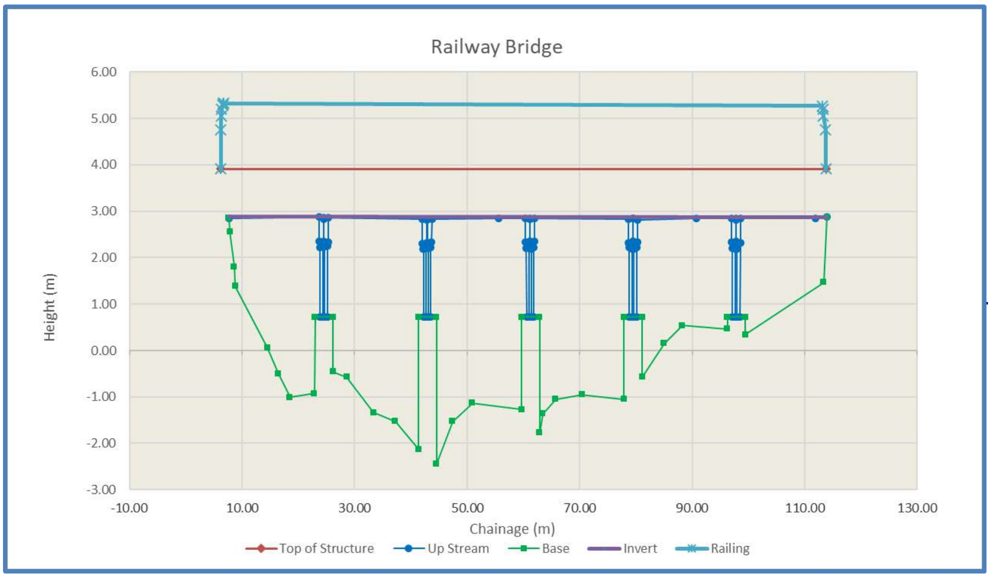


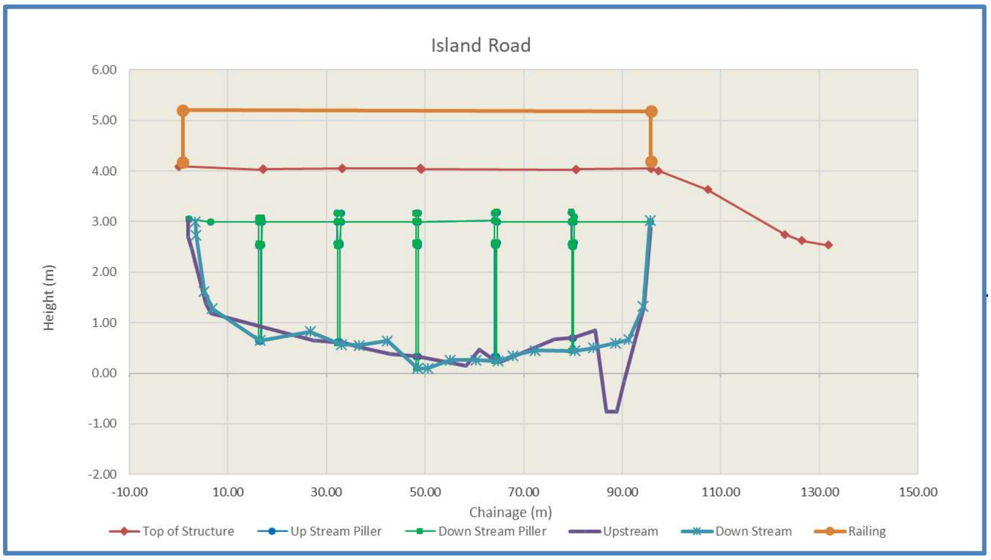



Pedestrian Bridge
Height (m)
Chainage (m)
Top of Structure
Up Stream
Down Stream
Invert


Stasie Road Bridge
Height (m)
Chainage (m)
Top of Structure
Up Stream
Down Stream
Invert
Railing


R102 Bridge
Height (m)
Chainage (m)
Top of Structure
Up Stream
Down Stream
Invert
Railing


Railway Bridge
Height (m)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-10.00
10.00
30.00
50.00
70.00
90.00
110.00
130.00
Chainage (m)
Top of Structure
Up Stream
Base
Invert
Railing


Island Road
Height (m)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-10.00
10.00
30.00
50.00
70.00
90.00
110.00
130.00
150.00
Chainage (m)
Top of Structure
Up Stream Piller
Down Stream Piller
Upstream
Down Stream
Railing

APPENDIX H4: LIST OF GROOT BRAK STRUCTURES

Structure:	K2T004
Description:	Weir
Location:	Great Brak River
Coordinates:	34° 1'42.90"S 22°13'19.31"E
Survey Method:	RTK GPS and Total Station
Photo:	

Structure:	Culvert Bridge
Description:	Bridge
Location:	Pine Creek
Coordinates:	34° 2'24.86"S 22°13'12.55"E
Survey Method:	RTK GPS
Photo:	

Structure:	Low Water Bridge
Description:	Bridge
Location:	Great Brak River
Coordinates:	34° 1'59.68"S 22°13'20.72"E
Survey Method:	RTK GPS
Photo:	

Structure:	Pedestrian Bridge
Description:	Bridge
Location:	Upstream Stasie Road
Coordinates:	34° 2'27.23"S 22°13'19.57"E
Survey Method:	RTK GPS and Total Station
Photo:	

Structure:	Stasie Road
Description:	Bridge
Location:	Great Brak
Coordinates:	34° 2'30.52"S 22°13'16.09"E
Survey Method:	RTK GPS and Total Station
Photo:	

Structure:	N2 Bridge
Description:	Bridge
Location:	Great Brak
Coordinates:	34° 3'2.88"S 22°13'51.49"E
Survey Method:	RTK GPS and Total Station
Photo:	

Structure:	R102 Road
Description:	Bridge
Location:	Great Brak
Coordinates:	34° 3'3.39"S 22°13'56.02"E
Survey Method:	RTK GPS and Total Station
Photo:	

Structure:	Railway Bridge
Description:	Bridge
Location:	Great Brak
Coordinates:	34° 3'7.59"S 22°13'52.18"E
Survey Method:	RTK GPS and Total Station
Photo:	

Structure:	Island Road
Description:	Bridge
Location:	Great Brak
Coordinates:	34° 3'4.72"S 22°14'15.57"E
Survey Method:	RTK GPS and Total Station
Photo:	

APPENDIX H5: LIST OF KLEIN BRAK STRUCTURES

Structure:	K1H005
Description:	Weir
Location:	Moordkuil River
Coordinates:	34° 2'22.90"S 22° 7'56.57"E
Survey Method:	RTK GPS and Total Station
Photo:	

Structure:	Low Water Bridge
Description:	Bridge
Location:	Moordkuil River
Coordinates:	34° 3'11.24"S 22° 8'2.71"E
Survey Method:	RTK GPS
Photo:	

Structure:	Moordkuil Sint
Description:	Bridge/Culvert
Location:	Moordkuil River
Coordinates:	34° 3'15.37"S 22° 7'55.03"E
Survey Method:	RTK GPS and Total Station
Photo:	

Structure:	Brandwag River Wall
Description:	Wall
Location:	Brandwag River
Coordinates:	34° 4'24.59"S 22° 5'43.12"E
Survey Method:	RTK GPS
Photo: Covered with plants	

Structure:	Brandwag River Obstructions (old road)
Description:	Earth Bridge with Culvert
Location:	Brandwag River
Coordinates:	34° 3'43.43"S 22° 6'48.59"E
Survey Method:	RTK GPS
Photo:	

Structure:	R102
Description:	Bridge
Location:	Klein Brak
Coordinates:	34° 5'14.35"S 22° 8'1.28"E
Survey Method:	RTK GPS and Total Station
Photo:	

Structure:	N2
Description:	Bridge
Location:	Klein Brak
Coordinates:	34° 5'15.48"S 22° 8'3.35"E
Survey Method:	RTK GPS and Total Station
Photo:	

Structure:	Railway Bridge
Description:	Bridge
Location:	Klein Brak
Coordinates:	34° 5'27.00"S 22° 8'39.59"E
Survey Method:	RTK GPS and Total Station
Photo:	

Structure:	N2 Culvert 1
Description:	Culvert
Location:	Klein Brak
Coordinates:	34° 5'12.32"S 22° 8'7.45"E
Survey Method:	RTK GPS and Total Station
Photo:	

Structure:	N2 Culvert 2
Description:	Culvert
Location:	Klein Brak
Coordinates:	34° 5'6.57"S 22° 8'14.85"E
Survey Method:	RTK GPS and Total Station
Photo:	

Structure:	R102 Bridge 2
Description:	Culvert
Location:	Klein Brak
Coordinates:	34° 5'10.87"S 22° 8'5.79"E
Survey Method:	RTK GPS and Total Station
Photo:	

Structure:	R102 Bridge 3
Description:	Culvert
Location:	Klein Brak
Coordinates:	34° 4'49.60"S 22° 8'12.71"E
Survey Method:	RTK GPS and Total Station
Photo:	

Structure:	N2 Culvert 3
Description:	Culvert
Location:	Klein Brak
Coordinates:	34° 4'59.39"S 22° 8'24.26"E
Survey Method:	RTK GPS and Total Station
Photo:	

APPENDIX I: FLOODLINE DRAWINGS

EXTREME FLOODLINES FOR THE GROOT BRAK AND KLEIN BRAK ESTUARIES FOR THE 50- AND 100-YEAR FLOODS FOR CURRENT AND FUTURE SCENARIOS

Chief Directorate: Management Support
Directorate: Strategic and Operational Support
Western Cape Government Department of Environmental Affairs and Development Planning
Private Bag X 9086
Cape Town, 8000
Tel: (021) 483 2990
Email: Nicole.Philander@westerncape.gov.za

www.westerncape.gov.za
www.westerncape.gov.za/eadp

Western Cape Government