



**Western Cape
Government**

Environmental Affairs &
Development Planning



BANK EROSION IN THE BERG RIVER ESTUARY

Causes and Concerns

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Prepared by:

Anchor Research & Monitoring (Pty) Ltd
in association with Zutari



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ZUTARI
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EXECUTIVE SUMMARY

Erosion of channel banks in the Berg River Estuary is potentially threatening valuable habitat and this study has been undertaken to investigate the causes of the bank erosion and make proposals for options for rehabilitation of the banks. BirdLife South Africa previously identified five areas where bank erosion threatens important habitat and King (2017) wrote a report on potential options for protecting these banks from further damage. These are sites at Admiral Island, Carinus Bridge, Cerebos Saltworks, Kuifkopvisvange and Kliphoeck.

A review of existing bathymetric data for the estuary was undertaken and cross-sections previously surveyed were found close to all the sites identified by BirdLife South Africa. The depth of the channel varied from as much as 9 m near Carinus Bridge to 3.5 m near Admiral Island. Historical aerial photographs of the estuary were also obtained and studied. Except for changes to the Admiral Island salt marsh in the 1980s and Carinus Bridge before 2003, very little change was evident since 1938.

Erosion at Admiral Island (located mainly on the inside of a bend) appears to be related to wave action, possibly caused by boats and wind, while erosion at the other sites (located on the outside of bends) appears to be due to flow and waves with the possibility of the channel moving slowly as would be expected in this environment. Wind wave erosion was observed occurring at Carinus Bridge. The predominant wind direction according to wind data at Langebaanweg is from the southwest.

Flow velocities have previously been measured in the estuary and were found to generally be less than 1 m/s. Beck and Basson (2004) modelled the hydrodynamics of the estuary and found that velocities for the most part were predicted to be less than 2 m/s during an extreme flood simulation. Velocities up to about 0.6 m/s can be expected not to cause scour. They also modelled the sediment dynamics and found that during extreme flood events the channel can be expected to widen with sediment scoured from the banks and deposited in the channel centre.

Dredging appears to have a less significant impact on bank erosion than the other mechanisms (waves and flow), because large areas of salt marsh close to the harbour do not appear to have retreated significantly more than in other parts of the estuary where dredging has never taken place.

The impact of sea level rise is a potential threat to banks in the future, as waves attack areas higher up the banks.

King (2017) proposed three designs be piloted for their effectiveness: regrading of the bank slope and planting with suitable indigenous vegetation; regrading of the bank slope and construction of a toe berm to prevent wash away of material into the channel and planting with suitable indigenous vegetation; and regrading of the bank slope and laying down of geo cells in which soil can be placed and suitable vegetation planted.

An existing area of riprap revetment at Carinus Bridge has been in operation for nearly 20 years and is performing well. The riprap has vegetated naturally as well. It appears that the banks on each end of the riprap section may have retreated further in the past 20 years.

Quantities were determined for each site and for each option and the costs determined for each. It is recommended that the options recommended by King (2017) are piloted at Admiral Island on a small scale so that no Environmental Impact Assessment (EIA) is required and their performance assessed. If they are found to be performing well then, they can be rolled out to larger areas once an EIA has been undertaken.

It is recommended that riprap be investigated as an option as well-designed riprap can provide excellent services for many years virtually maintenance free.

Authors:

Martin Kleynhans – Zutari
James Cullis – Zutari

Editors:

Jane Turpie - Project Leader (Anchor)
Annabel Marian Horn - Project Manager (DEA&DP)

Steercom:

Pierre de Villiers - Cape Nature
Caren George – DEA&DP
Wilna Kloppers – DEA&DP
Marlé M Kunneke – DEA&DP
Steve Lamberth - DEFF
Giselle Murison – Birdlife SA
Lara van Niekerk - CSIR

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1. INTRODUCTION

Erosion of banks in the Berg River Estuary has been identified as an area of concern as it is potentially threatening important habitat, critical infrastructure and properties along the Berg River.

River channels in environments like this tend to be dynamic and the location of the channel can be expected to move over long periods of time. But in the past century many anthropogenic developments have impacted on the estuary including the opening of the harbour mouth in the 1960s, the construction of bridges at Velddrif (Carinus Bridge) and the Sishen-Saldanha Railway bridge upstream, the construction of several saltworks on the floodplain and associated levees, boating and the waves caused by boats, dredging of the harbour at Laaiplek, construction of the Port Owen Marina, and changes in the flow regime and sediment supply to the estuary due to developments in the catchment upstream. Keeping the above impacts in mind, it may become necessary in some locations to construct interventions in key locations to protect the remaining habitat from further damage or to restore lost habitat. These could consist of both hard and soft or “green” engineering solutions

This report identifies several key sites where erosion has been identified as a potential problem, considers the reasons for the erosion, the options for stabilisation of the banks including both hard and soft or “green” engineering solutions and presents provisional cost estimates for each option.

Information on existing areas of concern was provided by BirdLife South Africa (in partnership with CapeNature, Berg River Municipality and the Lower Berg River Conservancy) and information on potential soft engineering or “green” infrastructure solutions was provided in a report by Hans King. A site investigation was undertaken in November 2019 to review the identified areas of concern. A review of potential solutions and provisional cost estimates are provided in Appendix 1 for the different options.

Finally, recommendations are made in terms of the best options to be considered for each site.

2. BATHYMETRY OF THE BERG RIVER ESTUARY

The bathymetry of the estuary has been surveyed several times including repeatedly at various locations (Clark & Ractliffe, 2007). The figures below show that the depth of the channel varies quite significantly through the estuary and that it reaches its deepest point at Carinus Bridge where flow is constricted through the bridge opening. Cross-sections surveyed in the region of the sites are shown (cross-sections are facing downstream) and where available the repeat surveys are shown.

Knowledge of the bathymetry is necessary to inform the erosion protection design as some of the options require knowledge of the depth and side slopes of the channel so that the base and a suitable slope for the revetment can be determined. This is particularly relevant for the design of riprap revetment where it is preferable to design a revetment that will protect the entire channel slope including the section underwater, to prevent failure of the revetment during extreme events when erosion can cause undercutting of the revetment and progressive failure. There are also limits to the slope of the revetment and if the channel side slopes are too steep then the channel sides will need to be regraded, which will result in higher costs for construction.

The repeat surveys show that in general the river channel remained reasonably stable between 2003 and 2006. They also show by their general shape where flow is concentrated – at the deep sections – which also tends to coincide with the outside of bends as would be expected. And finally, they show the depth and the slopes of the channel sides.

The bathymetry shown in the cross-sections was used to estimate the depth to which erosion protection should extend, determine the volume of material which may need to be moved if the channel side slopes are too steep and give an indication of the stability of the cross-sections from the surveys of 2003, 2004 and 2006.

Figure 1 shows the locations of the cross-sections shown in **Figure 2** to **Figure 14**.

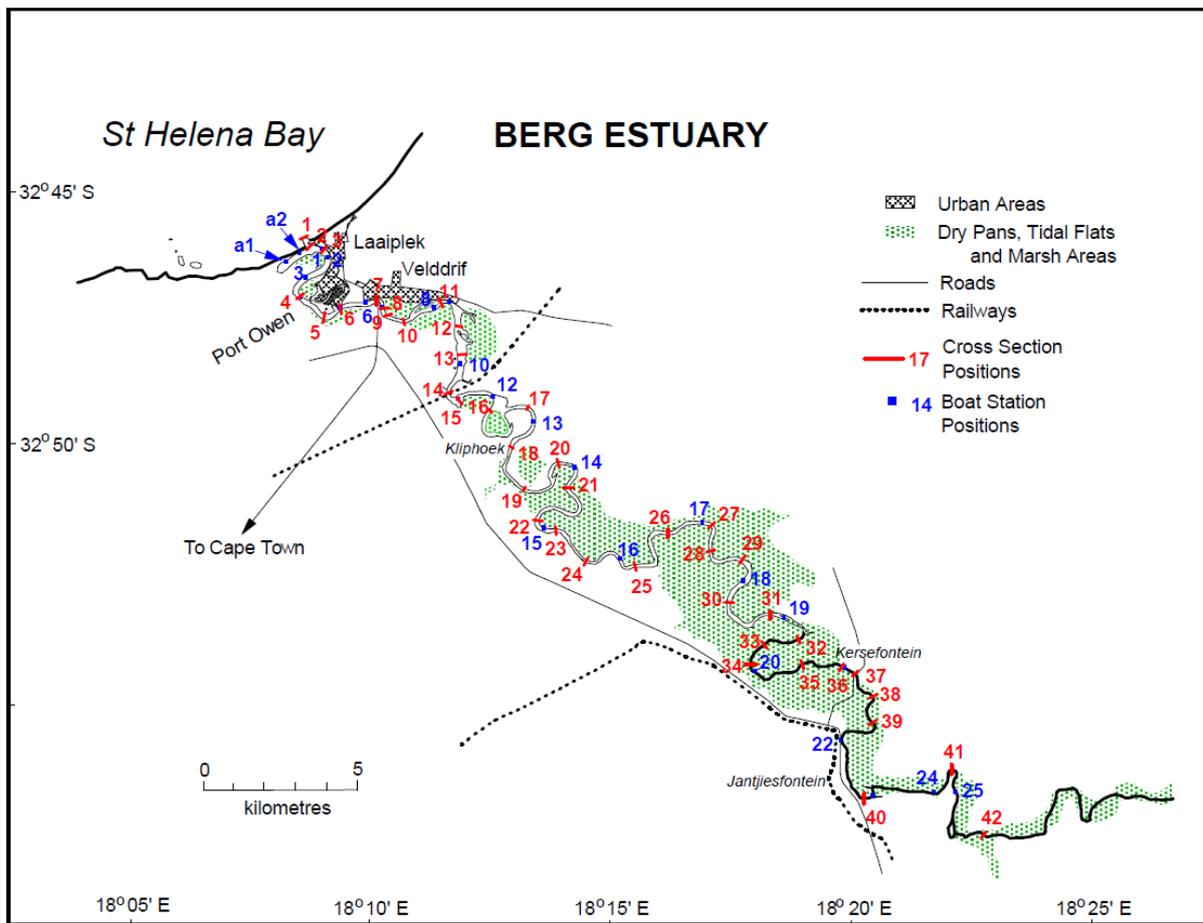


Figure 1: Sites shown in the figures below that were surveyed in 2003 (Clark & Ractliffe, 2007). Some of the sites were surveyed again in 2004 and 2006.

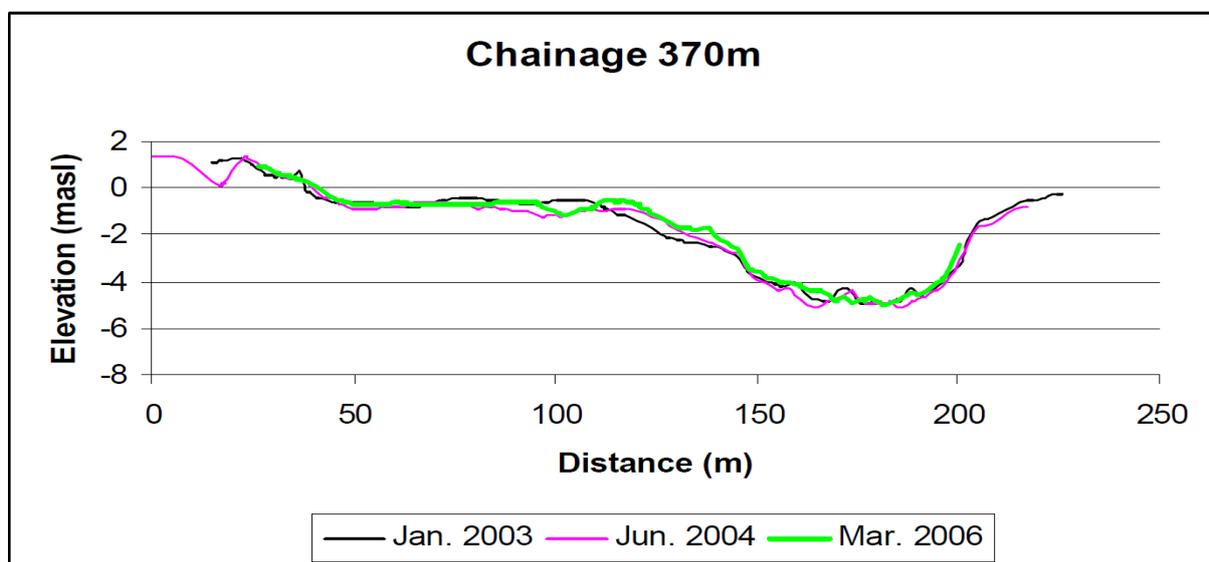


Figure 2: Cross-section 3 at chainage 370 m in the harbour at Laaiplek. Channel depth was about 5 m (Clark & Ractliffe, 2007)

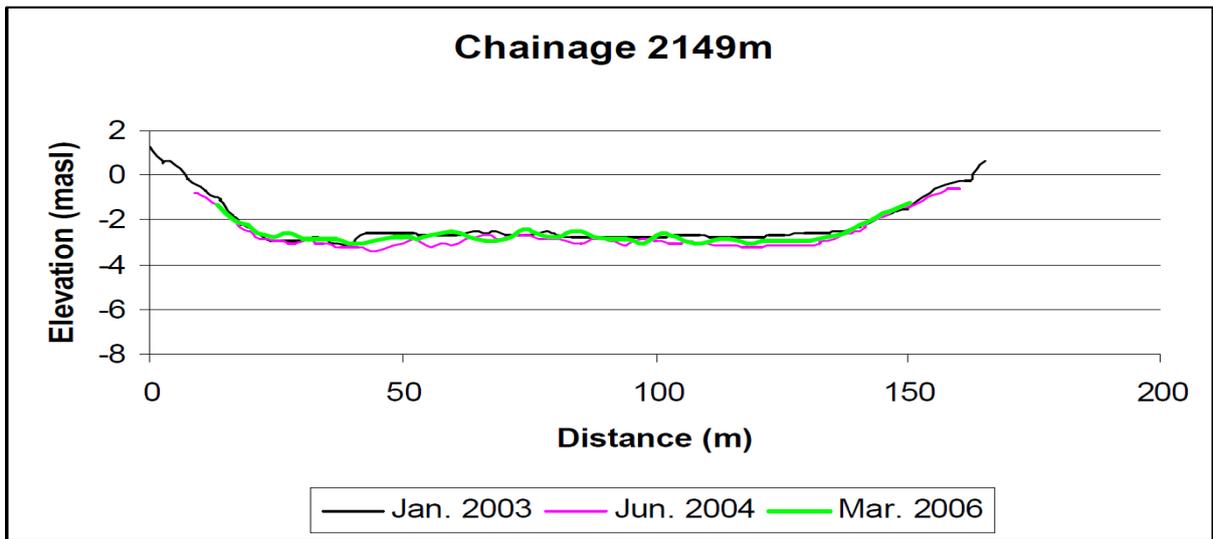


Figure 3: Cross-section 4 at chainage 2149 m located just downstream of the Port Owen Marina. Channel depth was about 3.5 m (Clark & Ractliffe, 2007).

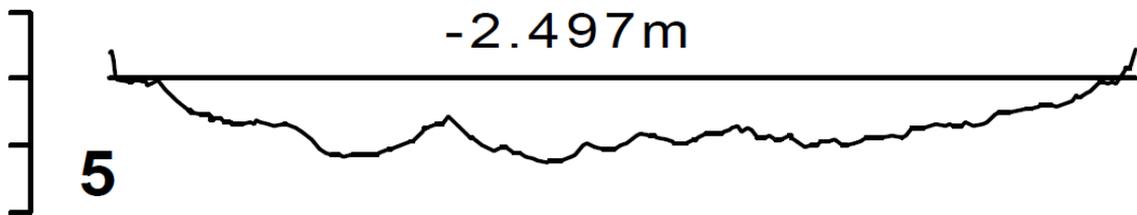


Figure 4: Cross-section 5 at Admiral Island. Channel depth was about 2.5 m (Clark & Ractliffe, 2007)

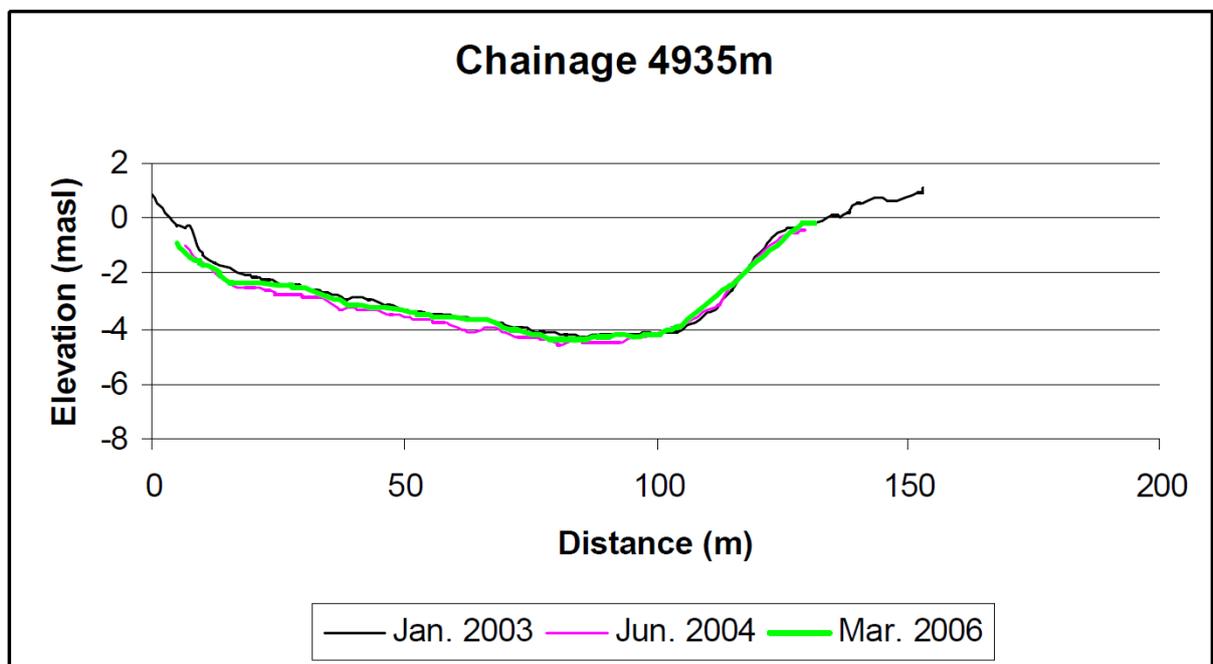


Figure 5: Cross-section 6 at chainage 4935 m located in the region of Admiral Island. Channel depth was about 4.5 m (Clark & Ractliffe, 2007).

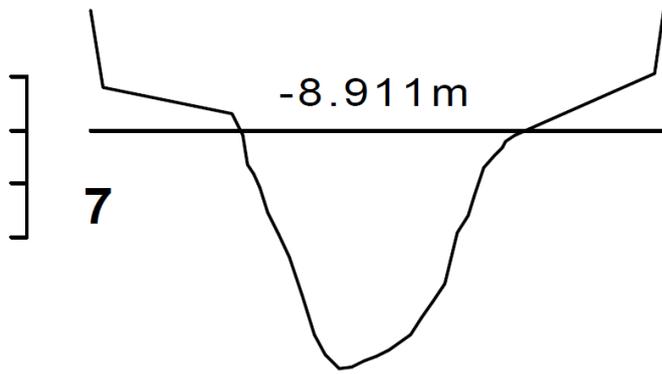


Figure 6: Cross-section 7 at the Carinus Bridge crossing. Channel depth was about 8.9 m (Clark & Ractliffe, 2007).



Figure 7: Cross-section 8 at Carinus Bridge site. Channel depth was about 3.6 m (Clark & Ractliffe, 2007).



Figure 8: Cross section 9 between Carinus Bridge site and Cerebos Saltworks. Channel depth was about 2.8 m (Clark & Ractliffe, 2007).

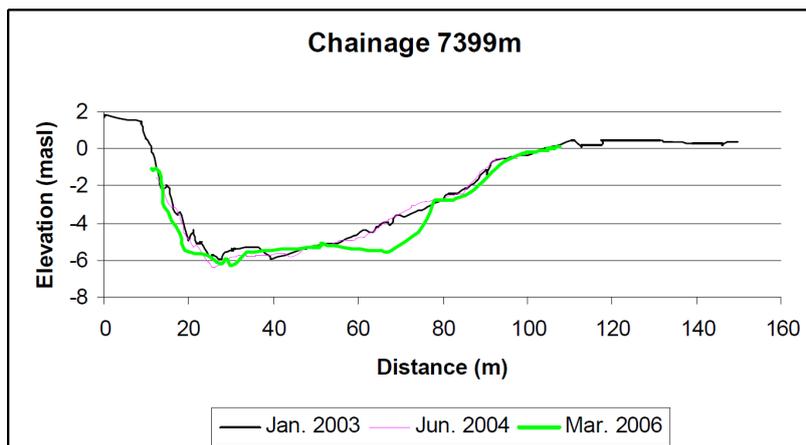


Figure 9: Cross section 10 at chainage 7399 m located in the region of Cerebos Saltworks. Channel depth was about 6.2 m (Clark & Ractliffe, 2007).

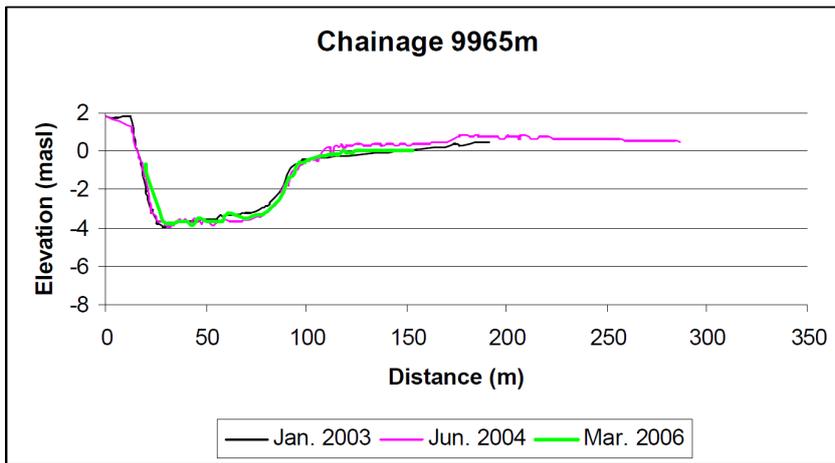


Figure 10: Cross-section 12 at chainage 9965 m located in the region of Kuifkopvisvanger. Channel depth was about 4 m (Clark & Ractliffe, 2007).

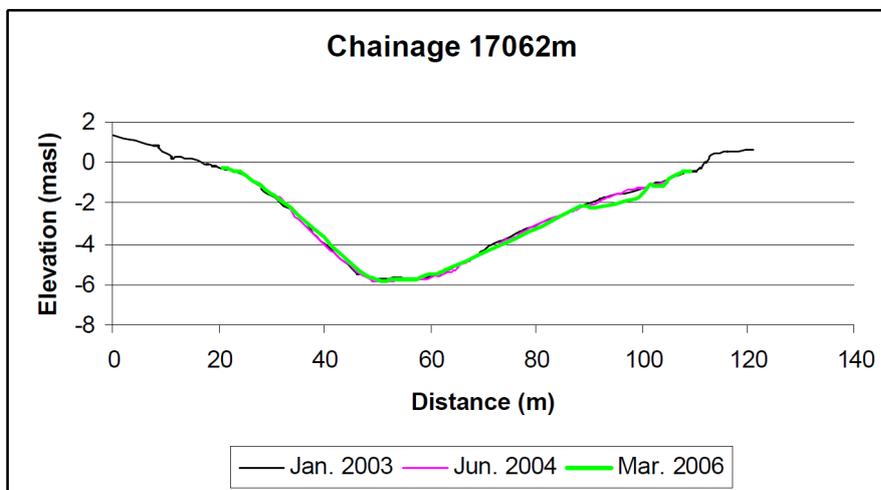


Figure 11: Cross-section 18 at chainage 17062 m located downstream of the Kliphoek site. Channel depth was about 5.8 m (Clark & Ractliffe, 2007).

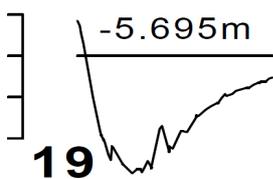


Figure 12: Cross-section 19 located downstream of Kliphoek. Channel depth was about 5.7 m (Clark & Ractliffe, 2007)

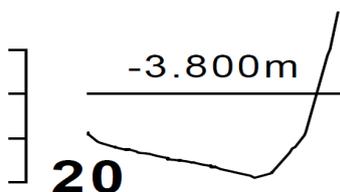


Figure 13: Cross-section 20 located upstream of Kliphoek. Channel depth was about 3.8 m (Clark & Ractliffe, 2007)

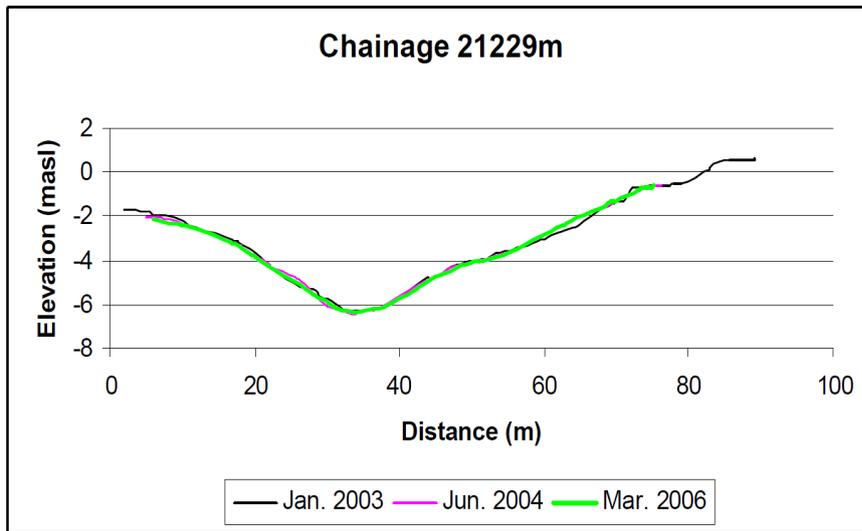


Figure 14: Cross section 21 at chainage 21229 m located upstream of the Kliphoek site. Channel depth was about 6.4 m (Clark & Ractliffe, 2007)

3. HISTORICAL AERIAL PHOTOGRAPHS AND BANK EROSION

A record of historical aerial photos of the estuary exists since 1938. Clear photos at approximately 20 year intervals have been selected from this record: 1938, 1960, 1986, 2003 and 2019 and these are shown in **Figure 15** to **Figure 19**. The sites are numbered in the figures according to **Figure 20**. Unfortunately, the photos are mostly very dark, particularly the older ones, but what is clear is that no massive changes in the positions of the channel have taken place since 1938.

Some erosion of the bank is visible in the period between 1986 and 2003 at Carinus Bridge (Site 2) but little change is visible thereafter, and it appears that some of the salt marsh may have disappeared from Admiral Island (Site 1) in 1986 when compared to 1960, which may have been due to construction of Port Owen, but the salt marsh appears to have had a similar extent in 2003 to what it had in 1960.

Development in the estuary of bridges, the new mouth for Laaiplek harbour and the saltworks are all visible through the history shown in these photos.



Figure 15: Aerial photograph of the estuary in 1938



Figure 16: Aerial photo of the estuary in 1960



Figure 17: Aerial photo of the estuary in 1986



Figure 18: Aerial photo of the estuary in 2003



Figure 19: Aerial photo of the estuary in 2019

4. BANK EROSION PROBLEMS

4.1. Introduction

BirdLife South Africa (Murison, pers. comm.) identified five areas where bank erosion is occurring that were of concern because of rapid bank loss that had been observed and because it was suggested that the sites might encompass a wide range of underlying causes driving bank erosion. These are at Kliphoek, Kuifkopvisvanger, Cerebos Saltworks, Carinus Bridge and Admiral Island.

BirdLife South Africa have subsequently mapped all significant erosion areas throughout the estuary and this map is currently out for comment with local community stakeholders, CapeNature and the Berg River Municipality (Murison, Pers. Comm.). From this map, the intention is to identify those areas where boat waves are contributing to erosion impacts (for use in the recreational By-Laws), and where there is direct loss of key bird habitat.

The initial five sites identified by BirdLife South Africa are shown in **Figure 20** and formed the starting point for this study.

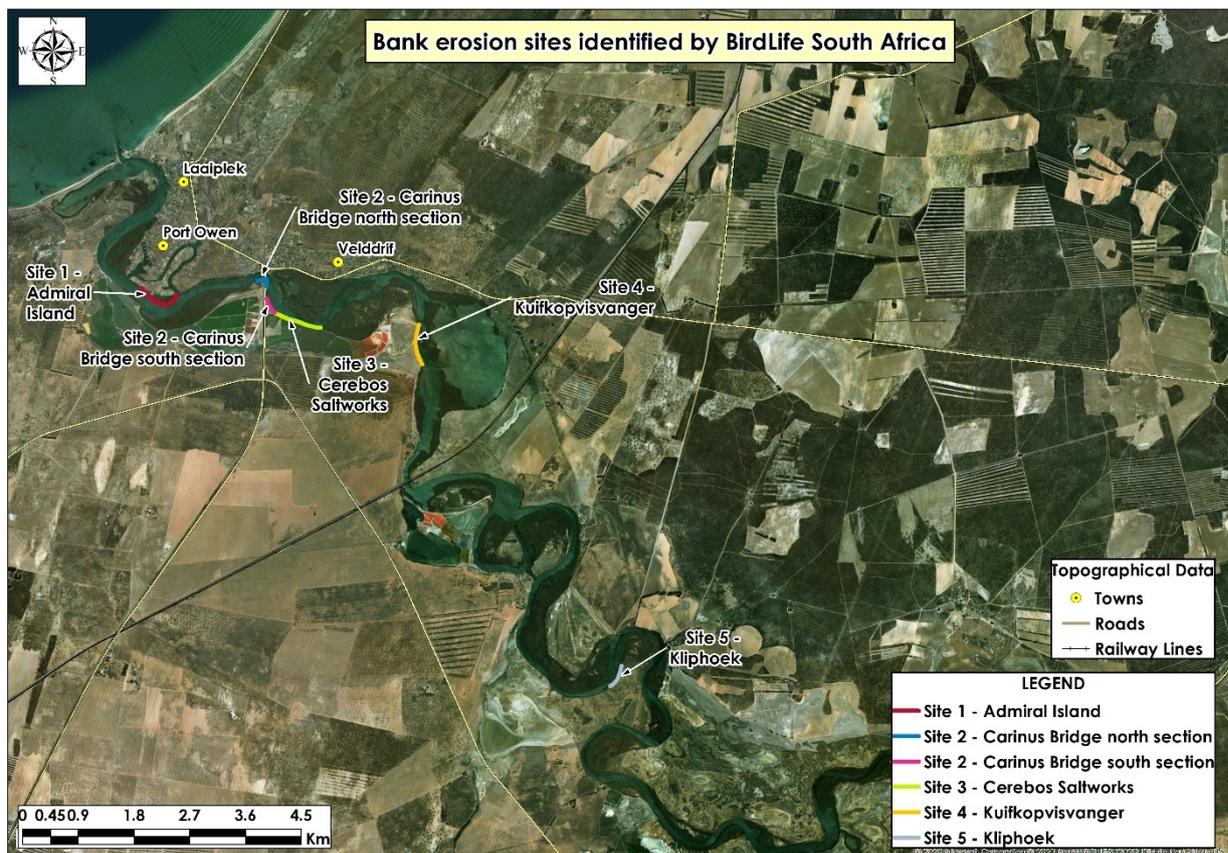


Figure 20: The five bank erosion sites that were short listed by BirdLife South Africa (Murison, pers. comm.)

4.2. Estuary site visit

The Berg River Estuary was visited on the 8th of November 2019 by Martin Kleynhans (Zutari), Annabel Horn (WC-DEADP), Zahn van Wyngaard (WC-DEADP), Barry Clark (Anchor Research and Monitoring), Giselle Murison (BirdLife South Africa) and Charles Malherbe (West Coast District Municipality).

The visit began at Kersefontein from where Annabel and Charles took the boat and met the rest of the party at Kliphoek River Resort. The entire party boarded the boat at Kliphoek River Resort

and sailed back upstream to the most upstream erosion site, located some 6 km upstream of Kliphoek.

From there they sailed downstream to the river mouth before disembarking at the Laaipek Hotel. A summary of the observations at each site are given below.

4.3. Site 1: Admiral Island

The salt marsh adjacent to Admiral Island (**Figure 20**) is retreating at what may be a significant rate. The upstream part of the salt marsh lies on the outside of a bend but the rest lies on the inside of a bend where deposition of sediment would be expected to occur. The salt marsh margin which is eroding is approximately 770 m long. Residents at Admiral Island placed marker poles on 2 and 3 December 2016 along the salt marsh margin and within 3 months the average bank retreat was measured at 150 mm to a depth of 700 mm over 220 m, and a year later the average retreat was 0.93 m over a bank section of 640 m (Murison, pers. comm.). During the site visit in November 2019, the bank was noted to have retreated at least 1 metre from many of the marker poles.

The residents at Admiral Island blame wind waves for most of the erosion, stating that winds in excess of 20 km/h or 11 knots are to blame (Murison, pers. comm.). Winds at this velocity or greater occur for 16 % to 17% of the time from the south, based on wind data at Langebaanweg located some 20 km to the south (**Figure 49**).

Considering the position of the salt marsh, which is predominantly on the inside of a bend, it is likely that the main cause of erosion is from waves and not from flow as this should be in an area of sediment deposition due to flow. The bank is exposed to winds from the south and is also in a section of the channel which gets frequent boat traffic, lying between Port Owen and the mouth and it is likely that waves are the dominant cause of erosion at this site. **Figure 22** shows the effects of boat waves on the bank.



Figure 21: Site 1: Admiral Island. The arrows show the flow direction



Figure 22: Marker poles showing a previous bank position and the current eroding bank at Admiral Island. The effect of boat waves from the wake of the boat can also be seen. (Photo: Martin Kleynhans)



Figure 23: Marker poles showing a previous bank position and the current eroding bank at Admiral Island (Photo: Martin Kleynhans)

4.4. Site 2: Carinus Bridge

The bank upstream of Carinus Bridge (**Figures 18-20**) has been retreating for some time. In the early 2000s riprap revetment was constructed for a section of the bank, which is discussed in Section 6.2. The riprap has performed very well and is in good condition. The bank upstream and downstream of this however has retreated further, including the left bank through the bridge section and downstream to the salt marsh. The position of the bank upstream of the riprap revetment appears to have retreated slightly and the bank downstream of the revetment appears to have retreated even more as can be clearly seen in **Figure 55**.

The erosion section at Carinus Bridge to the south of the riprap section is approximately 270 m long and the section to the north of the riprap section including the section through the bridge opening is approximately 280 m long.

Erosion here could be due to flow, being located on the outside of a bend, and wind and boat waves. On the day of the site visit the bank was visibly eroding due to wind waves during a strong southeaster, with cloudy water along the bank caused by suspension of fines from the bank.

The scour issue through the bridge section itself may be the responsibility of the provincial roads department, with the sections upstream and downstream of the bridge section being potentially important from a habitat point of view, but the section upstream of the bridge may also be of long term concern for the provincial roads department since continued retreat of the bank will eventually threaten the road.

The location of the erosion problem upstream of Carinus Bridge, on the outside of a bend, suggests that flow is playing a significant part in the erosion of the bank. It is likely that the bank erosion at Carinus Bridge is part of a long-term natural process where the channel is migrating laterally over time to the west, as typically occurs in alluvial meandering rivers. Stabilisation of the bank should then be informed by the value of the habitat that is potentially being lost but also in the context of limitation of damage to the road embankment and bridge, especially in the context of the reduced habitat in the estuary due to anthropogenic development. New habitat may be forming on the opposite bank as the channel moves southwestward. Considering the proximity of the bank location to the road embankment, there isn't much more room for the river before it starts to threaten the integrity of the road embankment.



Figure 24: Areas with bank erosion at Carinus Bridge and the saltworks. The north and south sections at Carinus Bridge are shown by the blue and pink lines respectively. The section between the pink and blue lines is where the existing riprap protection exists. The white arrows indicate the flow direction



Figure 25: Bank erosion just upstream of the riprap revetment. The extent of the riprap revetment is shown. Photo is looking downstream towards Carinus Bridge. (Photo: Martin Kleynhans)



Figure 26: Bank erosion downstream of the Carinus Bridge. Photo is looking downstream. The likely cause of erosion here is flow through the bridge section and boat waves. (Photo: Martin Kleynhans)



Figure 27: Bank erosion downstream of the riprap section showing the wind waves. Photo looking downstream. (Photo: Martin Kleynhans)



Figure 28: Bank erosion downstream of the riprap section, showing the wind waves eroding the bank and the cloudy water along the bank indicating suspension of fines from the bank. Photo looking upstream. (Photo: Martin Kleynhans)

4.5. Site 3: Cerebos Saltworks

The bank at the Cerebos Saltworks (**Figure 20**) currently is part of a levee which protects the saltworks from the Berg River. Erosion at the toe of this levee is ongoing, and it is assumed that Cerebos routinely rebuilds the levee when necessary. The section adjacent to the saltworks is approximately 780 m long.

The levee is located on the outside of a bend and it is likely that some of the erosion is flow related. Boat and wind waves may also be a cause but since the levee faces north, the summer winds from the south may not be the cause. Wind wave erosion may however be caused by winds during the winter months.

The location of the erosion problem, on the outside of a bend, suggests that flow is playing a significant part in the erosion of the bank. It is likely that the bank erosion at Cerebos Saltworks is part of a long-term natural process where the channel is migrating laterally over time to the southwest, as typically occurs in alluvial meandering rivers. Stabilisation of the bank should then be informed by the value of the habitat that is potentially being lost and in the context of the potential closure of the saltworks, especially in the context of the reduced habitat in the estuary due to anthropogenic development. New habitat may be forming on the opposite bank as the channel moves southwestward.

4.6. Site 4: Kuifkopvisvanger

The Kuifkopvisvanger site (**Figure 20**) is located on the outside of a bend downstream of the Transnet Sishen Saldanha railway bridge. The section of bank that is eroding is approximately 675 m long. The bank is very steep and is collapsing into the channel. The landowner has attempted to prevent further erosion by dumping rubble along the bank. This is not only unsightly but also is not very effective.

The photographs show the steep bank and the mechanism for bank erosion, which generally consists of erosion of the bank toe until the bank is undercut, the then bank collapses and the sediment falls into the channel where it is transported away from the bank and possibly down the channel.

Erosion has been monitored here since June 2007 by the landowner, by planting poles at 10 m intervals along a 400 m long section of bank, set 10 m back from the original bank line (Murison, pers. comm.). In 2010 the bank had retreated an average of 2.1 m and at one position up to 6.2 m – an average retreat rate along the section of 0.7 m/annum. By 2016 the bank had retreated an average of 3.3 m and up to a maximum of 7.0 m at one of the poles – an average retreat rate of 0.4 m/annum since 2007 and 0.2 m/annum since 2010. The data suggest that the rate of retreat reduced through the monitoring period and this could possibly be due to reduced flows during the drought which began in about September of 2014. Murison (pers. comm.) said that retreat increased through the drought and could be due to die back of the reeds which in turn was due to decreased freshwater inflows from the Berg River and a consequent increase in salinity levels in the estuary.

The bank is located on the outside of a bend and hence it is expected that the erosion is at least to some extent caused by flow during flood events. The channel runs in a south to north direction here and hence is aligned to the summer wind direction, allowing for a long fetch and hence wind wave erosion may be a contributor in addition to boat waves and flow related erosion.

The location of the erosion problem, on the outside of a bend, suggests that flow is playing a significant part in the erosion of the bank. It is likely that the bank erosion at Kuifkopvisvanger is part of a long-term natural process where the channel is migrating laterally over time towards the west, as typically occurs in alluvial meandering rivers. Stabilisation of the bank should then be informed by the value of the habitat that is potentially being lost, especially in the context of the reduced habitat in the estuary due to anthropogenic development. New habitat may be forming on the opposite bank as the channel moves westward.



Figure 32: Site 4: Kuifkopvisvanger. The arrow indicates the flow direction



Figure 33: Steep and eroding bank in the foreground and attempts at erosion protection in the background. Photo looking downstream. (Photo: Martin Kleynhans)



Figure 34: Attempts at erosion protection by dumping of rubble. Photo looking upstream. (Photo: Martin Kleynhans)



Figure 35: Typical rubble that has been dumped to protect the bank. (Photo: Martin Kleynhans)



Figure 36: A section of the bank where no rubble has been dumped showing the mechanism for erosion which consists of progressive undercutting of the steep bank until collapse occurs and the bank position retreats. (Photo: Martin Kleynhans)

4.7. Site 5: Kliphoek

The Kliphoek site (**Figure 20**) is located on the outside of a bend in a meander upstream of Kliphoek. The bank erosion at Kliphoek extends over a distance of approximately 400 m, where the bank has been undercut and is progressively eroding back. There is an additional section downstream of at least 300 m length where there has been bank erosion but a strip of reeds has grown which is protecting the bank from further erosion. These are shown in the figures below.

Considering the orientation of the bank, wind wave erosion may only be caused by wind from the southwest, west or northwest. The wind rose for Langebaanweg (**Figure 49**) suggests that winds in this area blow from the southwest for significant periods. It is likely that the erosion here is caused by flow, wind and possibly boat waves. Boats are visible in this reach in some of the photographs.

The location of the erosion problem, on the outside of a bend, suggests that flow is playing a significant part in the erosion of the bank. It is likely that the bank erosion at Kliphoek is part of a long-term natural process where the channel is migrating laterally over time to the southeast, as typically occurs in alluvial meandering rivers. Stabilisation of the bank should then be informed by the value of the habitat that is potentially being lost, especially in the context of the reduced habitat in the estuary due to anthropogenic development. New habitat may be forming on the opposite bank as the channel moves southeastward.

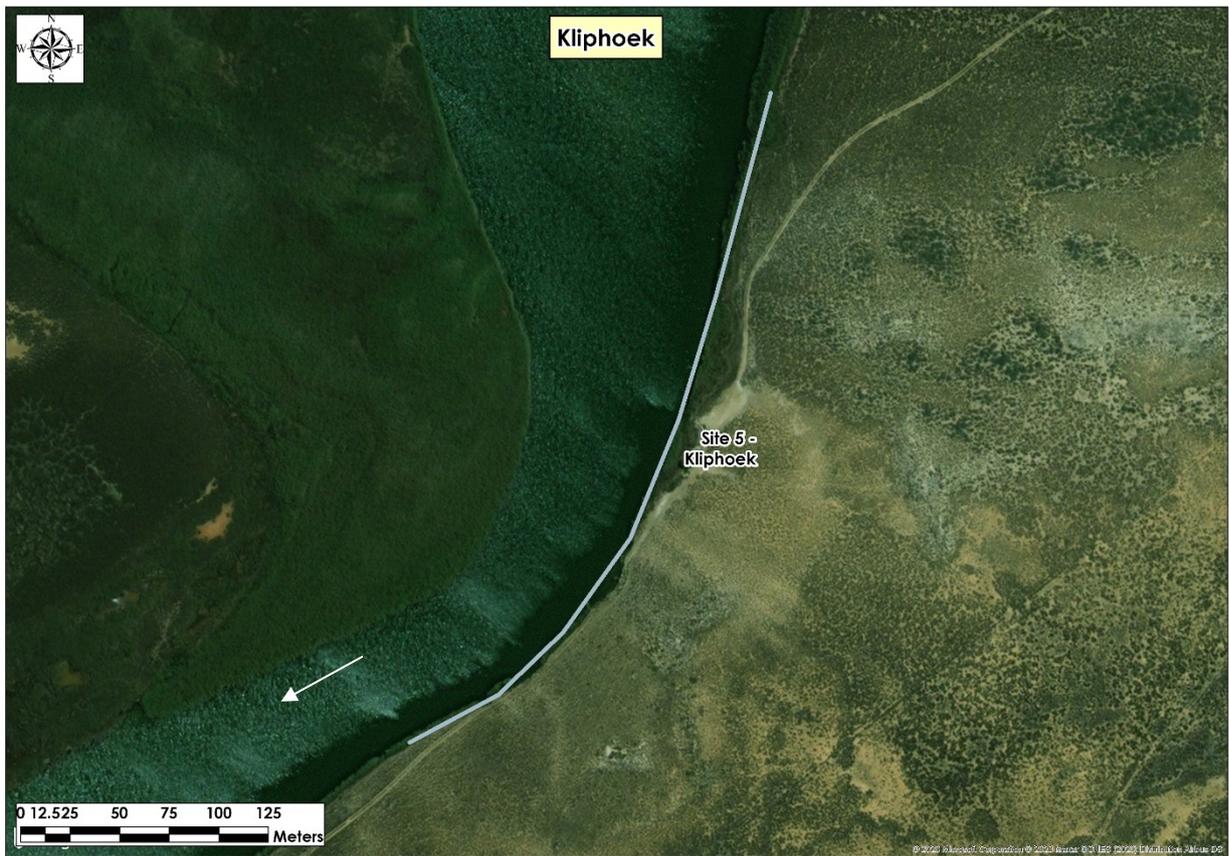


Figure 37: The Kliphoek site. The arrow shows the flow direction. Waves visible in the photo suggest that the wind was blowing from the south and that the south bank was relatively calm at the time of the photograph



Figure 38: View of most of the Kliphoek bank erosion site from upstream. (Photo: Martin Kleynhans)



Figure 39: A stable section of the bank at Kliphoek. (Photo: Martin Kleynhans)



Figure 40: Eroding section of the bank at Kliphoek. (Photo: Martin Kleynhans)



Figure 41: Eroding section of the bank at Kliphoek with some reeds growing in front. (Photo: Martin Kleynhans)



Figure 42: Example of unstable bank (left) and reeds stabilizing the bank and protecting the bank from wave and flow erosion (right), at the downstream end of the Kliphoek site. (Photo: Martin Kleynhans)



Figure 43: Reeds stabilizing the bank downstream of Kliphoek. (Photo: Martin Kleynhans)

5. POTENTIAL CAUSES OF BANK EROSION

5.1. Introduction

Bank erosion in the Berg River Estuary can be reduced to four potential causes:

- scour due to flow (especially during floods but also due to tidal action),
- erosion from wind waves,
- erosion from boat waves,
- potential steepening of the channel bathymetry due to dredging of the channel, and
- rising water levels due to long-term sea level rise.

Various areas showing erosion of banks were observed during the site visit. Certain areas were observed with bank erosion which may in the future lead to a threat to infrastructure, mainly buildings but for this project only the sites initially identified by BirdLife South Africa are summarised below. As stated previously, BirdLife South Africa has now mapped all significant erosion areas throughout the estuary and this map is currently out for comment with local community stakeholders, CapeNature and the Berg River Municipality (Murison, pers. comm.). From this map, the intention is to identify those areas where boat waves are contributing to erosion impacts (for use in the recreational By-Laws), and where there is direct loss of key bird habitat (Murison, pers. comm.). This may alter where to concentrate the rehabilitation efforts (Murison, pers. comm.).

5.2. Erosion due to flow

Erosion of banks can be expected during flood events when flow velocities exceed critical values and the banks begin to erode. It is possible that erosion is also caused by tidal flows.

Velocities measured with an Acoustic Doppler Current Profiler (ADCP) in the channel opposite Port Owen Marina (**Figure 44**) from 28 May to 13 June 2016 to inform the design of a suitable disposal plan for sediment dredged from Port Owen Marina, measured tidal velocities in excess of 0.5 m/s for approximately 25% of the time, of which approximately 18% of the time was on an ebb tide (**Figure 45**) (Hutchings & Clark, 2016). The two-week measurement period included a spring and a neap tide.



Figure 44: Location of the Acoustic Doppler Current Profiler (ADCP) deployed in the Berg Estuary channel at approximately 3.5 m water depth over the period 28 May – 13 June 2016 (Hutchings & Clark, 2016)

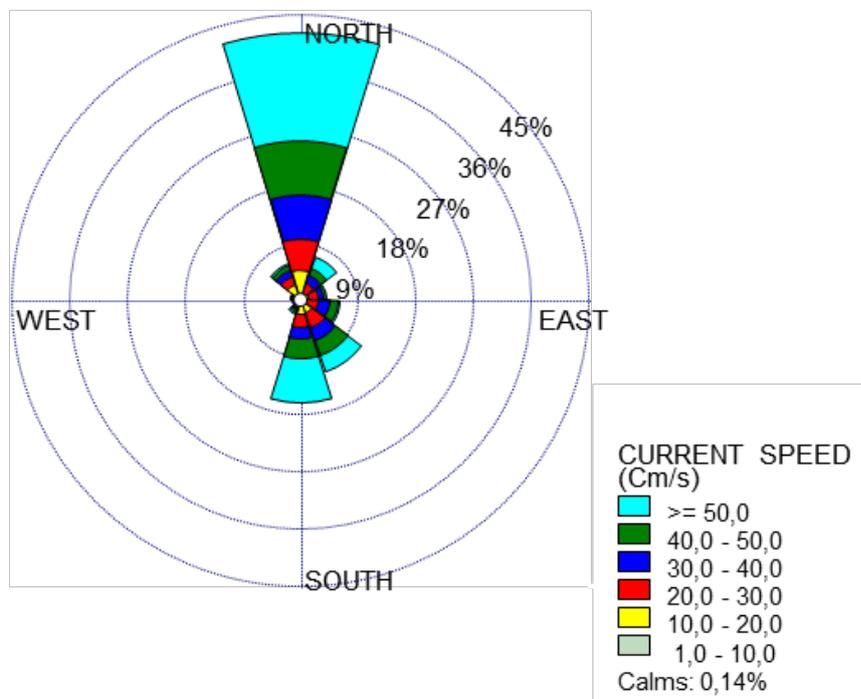


Figure 45: Current rose showing all data collected during the deployment of the ADCP from 18 May to 13 June 2016 (Hutchings & Clark, 2016)

A previous study in 2008 undertaken by Triton Survey determined a peak flow rate in the estuary near the Port Owen Marina entrance during neap ebb tide of 254 m³/s. It was found that the highest velocities occurred near the bed of the channel where they exceeded 0.5 m/s.

According to SANRAL (2013) at depths exceeding 1.5 m, a velocity of at least 0.55 m/s is required to mobilise a fine sand material and cause scour. At velocities lower than this, in depths of at least 1.5 m, deposition can be expected. As depths decrease the velocity at which scour will take place reduces so that at very shallow depths lower velocities are required to prevent deposition – for example at a depth of 0.2 m, a velocity of approximately 0.2 m/s will allow deposition.

The measured velocities near Port Owen Marina are close to the limit for deposition, thus it is likely that under tidal flows only little erosion is taking place and that flow related erosion on the river banks is due to flood events.

Beck and Basson (2004) modelled the Berg River Estuary using a 2D hydrodynamic model, which included sediment dynamics. Peak tidal velocities for spring and neap tides are shown in **Figure 46** and **Figure 47** and the figures show that the maximum velocities due to tidal action occur in the lower estuary near Port Owen Marina where velocities in excess of 1 m/s were predicted to occur. Spring tides have larger differences in flow than neap tides.

They also modelled various flood events passing through the estuary and the velocities for a large flood event are shown in **Figure 48**. They noted that the model predicted that the channel would scour towards the banks and deposit towards the channel centre. The model also predicted this to occur in the upper reaches near Kersefontein and in the lower reaches near the mouth, however Beck and Basson only discussed the impacts on the upper estuary.

The modelling of Beck and Basson (2004) suggests that at least some of the bank erosion is caused by flow during flood events. The sites at Kliphhoek, Kuifkopvisvanger, Cerebos Saltworks and Carinus Bridge are all located on the outside of bends and this is where erosion due to flow would be expected to occur.

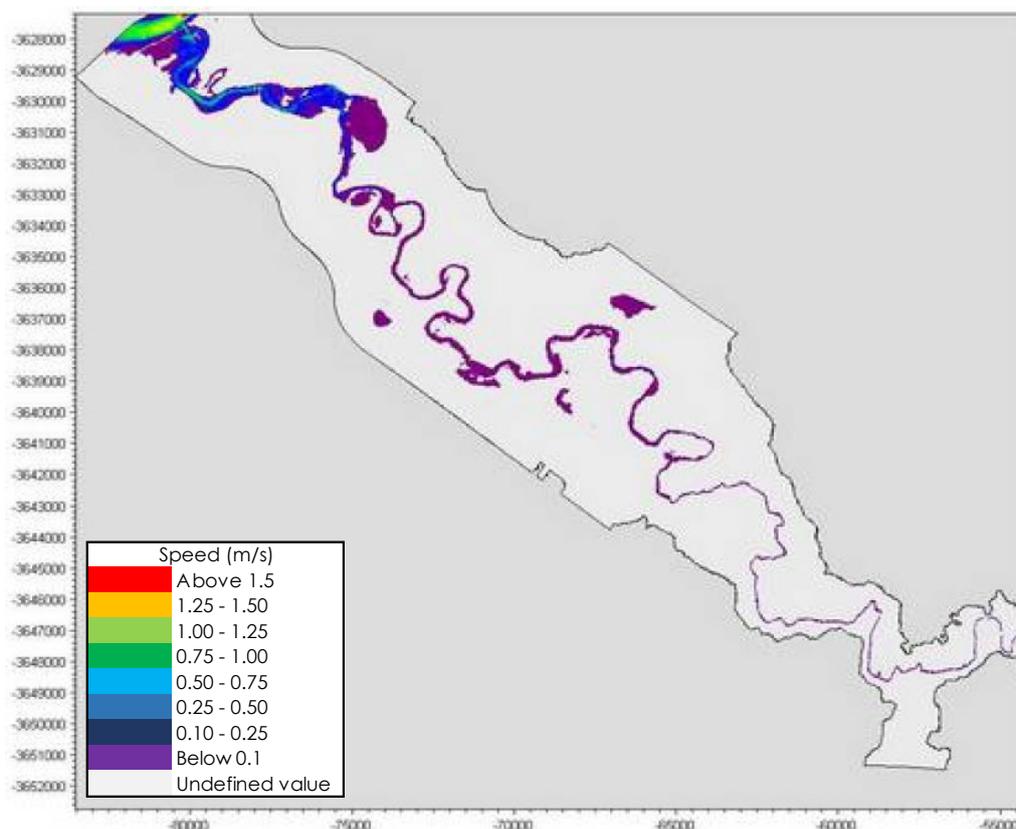


Figure 46: Modelled peak velocities during spring tide (Beck & Basson, 2004)

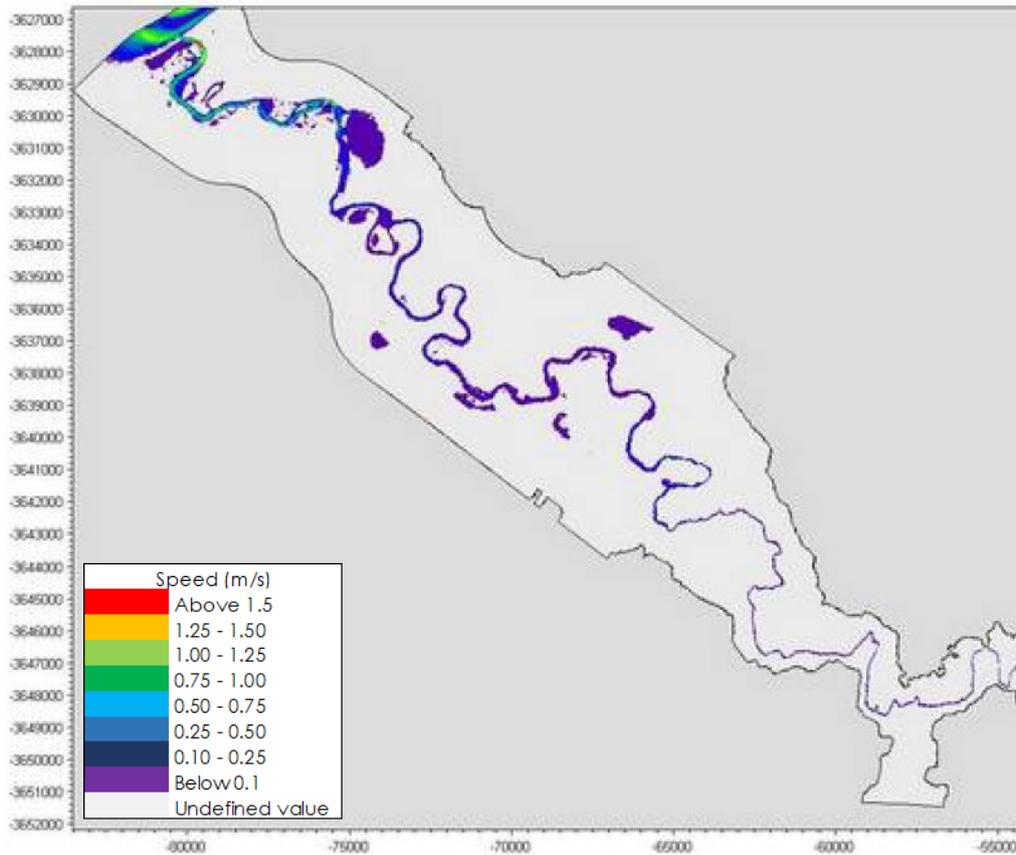


Figure 47: Modelled peak velocities during neap tide (Beck & Basson, 2004)

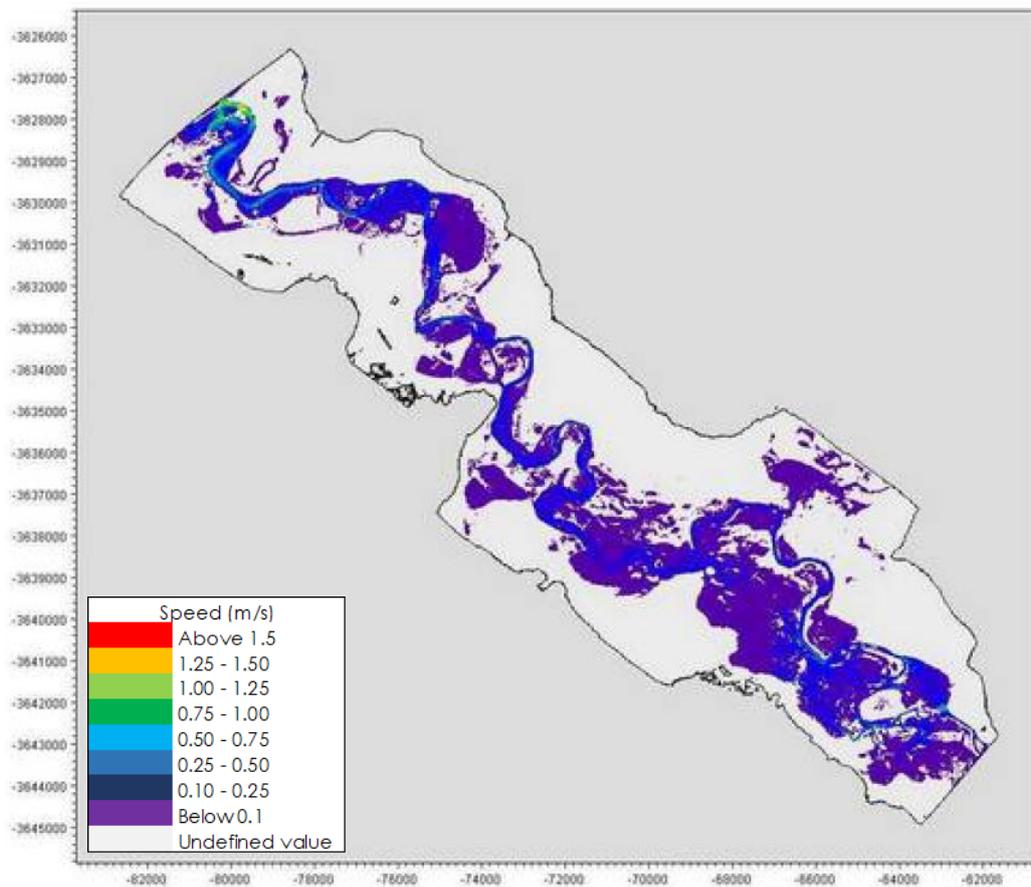


Figure 48: Maximum velocities during a flood of 890 m³/s (Beck & Basson, 2004)

5.3. Erosion due to waves

A significant cause of erosion appears to be due to waves caused by wind and boats. The wind rose shown in **Figure 49** is for Langebaanweg, located some 15 to 20 km to the south of the Berg River Estuary and shows that the predominant wind directions are from the southwest (mostly summer) and the northeast (mostly winter). Winds from the southwest occurred for approximately 40% of the time and 5% of the time wind blew from this general direction with a strength in excess of 15 knots (approximately 28 km/h). Thus, wind erosion would be expected to occur on banks where the river is aligned in a southwest - northeast direction to achieve a long fetch length, or on banks that are on the northeast side of the channel opposite an area of open water.

On the day of the site visit the wind was blowing from the south/southeast and significant wind waves were observed at the Carinus Bridge site and erosion of the bank was visibly occurring, which is discussed in more detail later in this report.

According to Murison (pers. comm.) waves caused by boats are particularly relevant at sites where according to recreational use by-law zonation, motor/ power-boating is allowed, including wind-surfing e.g. at Kuifkopvisvanger and Kliphoeck; and erosion of the banks by waves generated by boats has been observed. The impact of boat waves is particularly severe in high volume summer and holiday periods. Where banks have no natural protection, e.g. from reed beds lost during drought, these impacts (both from wind and boat waves) are visibly worse.

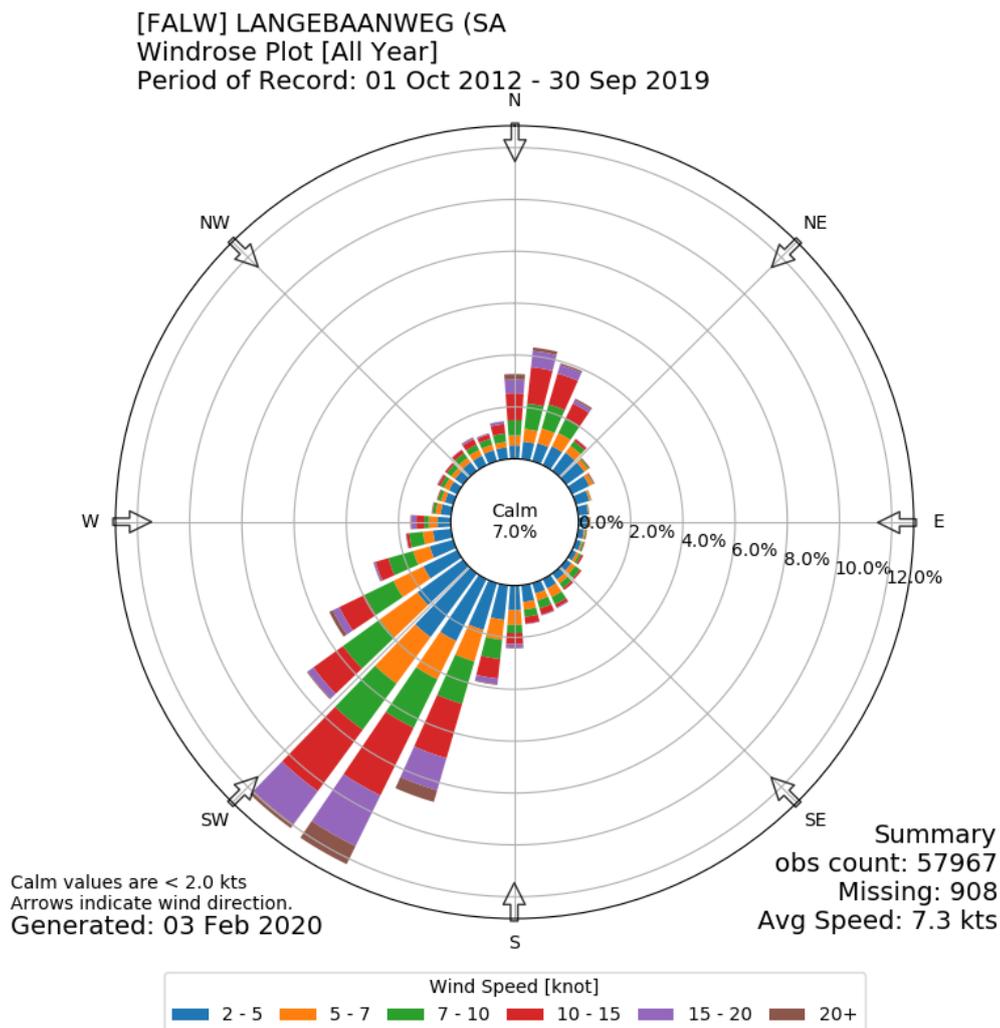


Figure 49: Wind rose for Langebaanweg airforce base, located some 15 to 20 km south of the Berg River Estuary. Wind speeds are annual and were obtained on 3 February 2020. (IEM and NOAA, 2020)

5.4. The potential impact of dredging

It is possible that dredging in the lower estuary has contributed to bank erosion in that area as well, due to steepening of the channel slopes, however it is not clear whether this is a significant cause. The dredging plans for Laaipele Harbour, both proposed and historical, show that dredging has been limited to the reach from the upstream end of the fishing harbour to the estuary mouth.

The dredging for Port Owen Marina appears to have been limited to the canals of the marina and the latest dredging application proposes to dispose of fine dredged material into the Berg River channel adjacent to the marina, to be washed downstream and into the ocean by disposing of the sediments during the outgoing tide with flow rates in excess of 200 m³/s, which equate to cross-section averaged velocities greater than 0.4 m/s.

For Laaipele Harbour, dredging has not recently taken place there - the last time it was dredged appears to have been in 2000. According to the Port Owen Marina Authority, Port Owen was last significantly dredged in 2000 and 2001 when about 71,000 m³ were dredged from the canals. Further dredging took place in 2009. Dredging was again undertaken in 2015, 2016 and 2017 when a total of 23,500 m³ was dredged. Since then no dredging has taken place.

The canals of the marina are currently sedimented so that they are essentially impassable to vessels. This suggests that sediment is still moving through the Berg River Estuary and depositing in the low velocity areas of the estuary, like the canals.

With the recent drought from 2014 to 2018, flows ceased in the Lower Berg for a significant period and floods were much reduced. Since the winter of 2018 there have been a few flood events when sediment may have been transported to the estuary. It is possible that some of the sediment depositing in the canals is coming from other parts of the estuary, like the river banks upstream.

The grading of the sediments in the canals has apparently become finer in the past decade and currently consists of >97% fines. This suggests that velocities in the canals have been low over an extended period as the coarser material was not able to enter the canals.

During the site visit it was noted that some of the salt marsh margins appeared reasonably healthy including those on the right bank upstream of Laaipele Harbour but downstream of Port Owen Marina, those on the opposite bank to Laaipele Harbour and those on the opposite bank to Port Owen Marina. If erosion were to take place anywhere due to dredging, it would be expected that it would take place at these locations closest to the dredged harbour. Additionally, the salt marsh margin on salt marshes upstream of Carinus Bridge also appeared to be in healthy condition.

A good way to confirm that these salt marsh margins are indeed stable is to place marker poles and to observe the margin – as has been done at Admiral Island by BirdLife South Africa.

5.5. The potential impact of sea level rise

Sea levels are predicted to rise significantly as the earth warms and increases in global sea levels have already occurred. These will lead to regrading of banks as wave cut terraces become too deep to protect banks from wave attack, and new wave cut terraces will be formed. This can also be expected to occur within the Berg River Estuary.

5.6. The possibility of reduced sediment input during the drought

Murison (pers. comm.) reported increased rates of bank retreat and movement of the deep part of the channel at Kuifkopvisvanger during the drought of 2015 to 2017. It is possible that part of this could be due to decreased sediment supply from the catchment upstream, due to the extreme low flows during this period and the lack of floods.

5.7. Die back of reeds during the drought

Reed die back in the estuary occurred upstream as far as Kersefontein due to increases in salinity levels in the estuary during the drought of 2015 to 2017, due in turn to low to no flows entering the estuary from the Berg River. The reeds play an important part in reducing wave energy, reducing flow velocities, holding the bank material together and thereby reducing erosion on the banks. According to Murison (pers. comm.), where banks have no natural protection, e.g. from reed beds lost during drought, the impacts from wind and boat waves are visibly worse. It is possible that part of the reason for increased bank retreat at the upstream sites is partly due to this.

6. PREVIOUS STUDIES AND EROSION PROTECTION WORKS

6.1. Potential pilot studies for soft or “green” engineering options

King (2017) recommended that several designs are piloted at three of the sites identified by BirdLife South Africa: Admiral Island, Carinus Bridge and Kuifkopvisvanger. The suggested alternatives included re-grading the bank to a shallower slope and planting with suitable indigenous species, regrading of the bank with a low wall located below the mid-tide level at the downslope end and planting with suitable indigenous species, and regrading of the bank and placement and planting of Geo Cells.

King (2017) recommended that the three techniques be piloted at a small scale where no environmental authorization would be required. They also recommended that other measures be implemented including prevention of trampling of the salt flats through the construction of board walks, limiting vehicle access, and that boat waves should be limited.

Regrading of the bank and planting with suitable indigenous species would be a low-cost solution and may require the laying down of coir or jute matting to temporarily protect the soil from erosion while the plants grow. Kaytech supply a product called Soil-saver and Maccaferri a product called Bio-jute. King listed suitable species to be planted on the banks and at which locations up the bank.

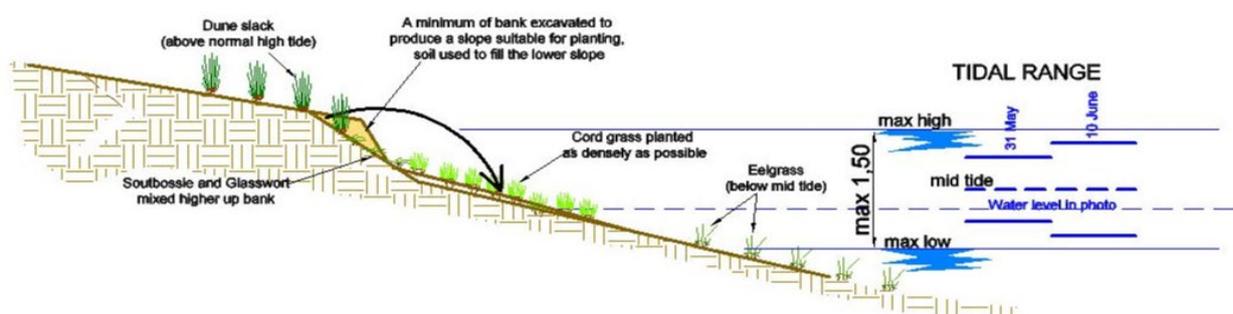


Figure 50: Regrading of the bank and planting out with suitable indigenous species (King, 2017)

Regrading of the bank with a low wall at the downslope end located below the mid-tide level would require construction of either a small rock berm which could be wrapped in a high density polyethylene (HDPE) mesh, a geotextile bag designed for shoreline applications (such as

EnviroRock manufactured by Kaytech in Atlantis) or by driving timber into the bank and connecting with geotextile.

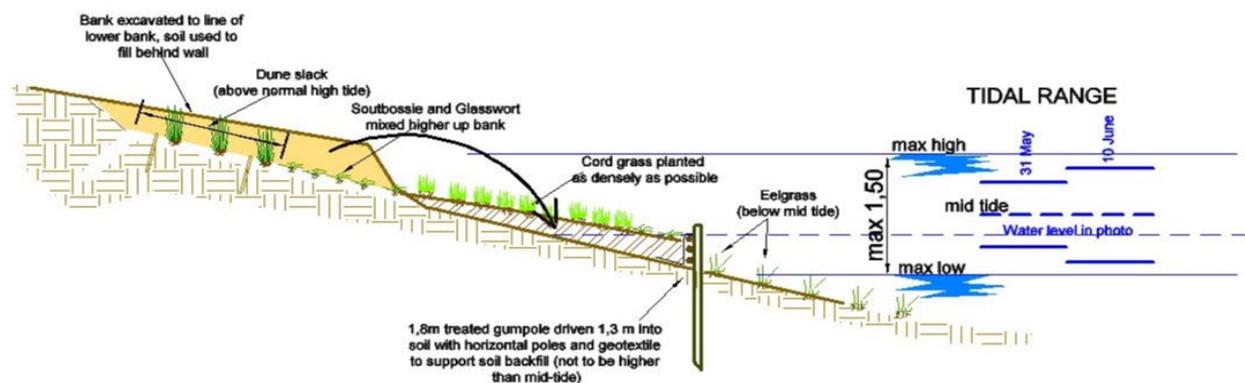


Figure 51: Regrading of the bank with a timber wall at the downslope end (King, 2017)

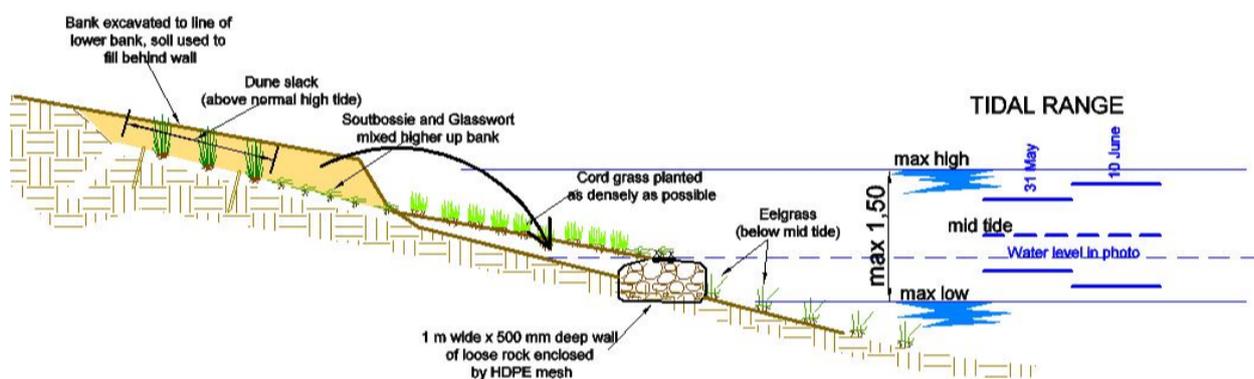


Figure 52: Regrading of the bank with a rock filled mesh sack berm at the downslope end (King, 2017)

Regrading of the bank, installation of geo cells and planting with suitable indigenous species is shown in **Figure 53**.

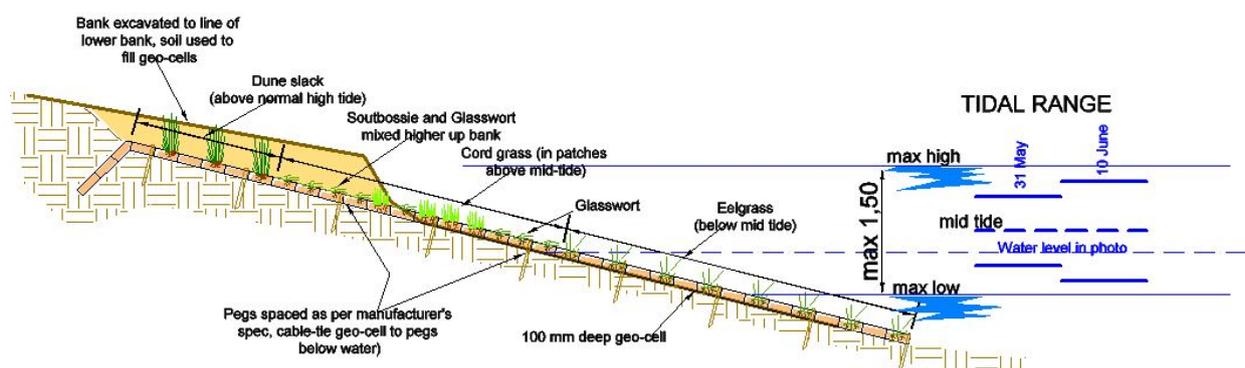


Figure 53: Geo cells vegetated with appropriate indigenous species (King, 2017)

6.2. Riprap protection at Carinus Bridge

The bank at Carinus Bridge was eroding and threatening the integrity of the road at Carinus Bridge. A section of the bank was protected using riprap in the early 2000s and the section was inspected during the site visit. The riprap section is shown in **Figure 56** to **Figure 58**. The riprap

erosion protection is performing very well and has not only prevented quite serious bank retreat (**Figure 55**), when the rest of the bank is compared to the section protected by the riprap, but also that the riprap has revegetated and is providing habitat as well. The channel is about 3.6 m deep here according to the survey of 2003 (**Figure 7**) and the riprap extends to a depth near the base of the channel, hence a large volume of riprap was required for this revetment.

The advantages of the riprap design used is that it is long lasting, relatively maintenance free, does not corrode or have other longevity issues, some habitat can exist on the riprap, and it is suited to high energy areas where soft options will not work. The chief disadvantage is that riprap is expensive.

A typical section through a riprap revetment is shown in **Figure 54**.

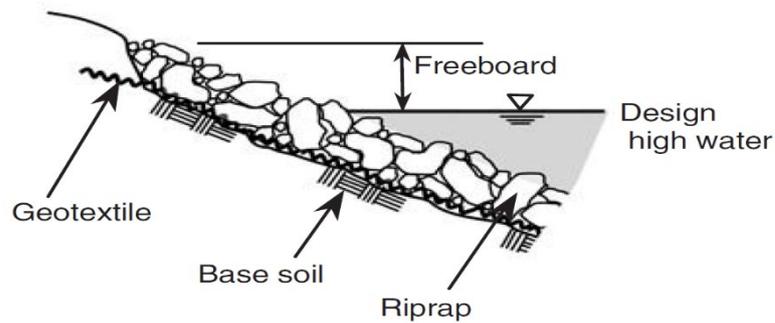


Figure 54: Typical riprap design (NCHRP, 2006)



Figure 55: Satellite view of the channel and bank upstream of Carinus Bridge with the section protected by riprap shown. The position of the riprap section compared to the rest of the bank upstream and downstream demonstrates the continued bank retreat (Microsoft Bing image, date circa 2015)



Figure 56: The riprap at Carinus Bridge having revegetated successfully. Photo looking upstream. (Photo: Martin Kleynhans)



Figure 57: The riprap at Carinus Bridge looking downstream towards Carinus Bridge. The section of riprap further away in the photograph, facing to the southeast has less vegetation than the rest and this could be due to increased exposure to wave energy in this area. (Photo: Martin Kleynhans)



Figure 58: The Carinus Bridge riprap looking upstream from near the downstream end. (Photo: Martin Kleynhans)

7. POTENTIAL SOLUTIONS

Various options that are used in erosion protection applications in rivers are given in Table 1. They have been ordered from cheapest to expensive and a recommendation given for each option.

Table 1: Summary of erosion protection options that could be employed to protect the banks in the estuary

Option	Option	Cost	Suitability	Recommendation
1	Regrade bank and revegetate	Lowest cost	Suitable for areas with low wave and flow energy.	Recommended for a pilot project.
2	Regrade bank with low wall at downslope end and revegetate	Relatively low cost	Suitable for areas with low wave and flow energy.	Recommended for a pilot project.
3	Regrade bank, install geo cells and revegetate	Relatively low cost	Suitable for areas with low wave and flow energy. Maybe be able to tolerate higher energy than options 1 and 2 above.	Recommended for a pilot project.
4	Floating rafts	Should be less than the heavier options below	Depending upon the design, would provide protection to the banks from waves. But would require frequent maintenance. Potentially a complicated design.	Not recommended.
	Bendway weirs	Expensive	Do not perform well in sediment deficient reaches. Provide protection against flow related erosion but not against wave related erosion	Not recommended.
5	Spurs or groynes	Expensive	Provide protection against flow related erosion but not against wave related erosion	Not recommended.
5	Reno mattresses and gabions	Expensive	Can revegetate after installation. The wires will eventually corrode limiting the lifespan of the structure. Lower rock quantities than riprap, but requires the additional cost of the baskets. Wire baskets can be vandalised.	Not recommended.
6	Riprap	Expensive	Can revegetate. If designed properly can have a nearly unlimited lifespan (i.e. a permanent solution). Low maintenance.	Recommended for high energy locations if budgets allow.
7	Concrete retaining walls	Expensive	Would provide protection against wave and flow erosion but would not fit in well with the environment and would not provide any intertidal habitat.	Not recommended.

The four recommended options were costed by estimating quantities, based on the bathymetry contained in Section 2, the lengths of bank and the designs provided by King (2017).

A local geotextile manufacturer was consulted, Kaytech who have a factory in Atlantis. Their EnviroRock geotextile bag designed for shoreline applications was included in the design to provide the toe wall for option 2 in **Table 1 (Figure 59)**. Two walls heights were allowed for, 1 m and 0.5 m, and two filling options for the bags was allowed for, imported sand or material that could be excavated on site from the bank. Excavation on site would allow for savings in cost but may be unacceptable from an environmental point of view, thus both options were included.

The advantage of sand filled geotextile bags is that they can be filled with material available at the site. The disadvantage may be that they do not encourage intertidal habitat. This disadvantage could be minimised by sinking the bags into the bank and using only one layer with a height of approximately 0.5m.



Figure 59: Sand filled geotextile bags for shoreline applications. Photo: Kaytech EnviroRock bags at Amanzimtoti

The riprap was designed using the method recommended by SANRAL (2013) to design the riprap to protect against scour from flow. The method requires inputs such as average velocity of flow in the channel, average depth of the channel, the bank slope, the riprap rock density, the riprap angle of repose and a stability factor for the rock. The design was determined to require a median riprap size of approximately 3 cm, mainly due to the relatively low average channel velocities of less than 2 m/s based on the modelling of Beck and Basson (2004).

The riprap was then designed to protect against wave erosion based on the method recommended by the United States Bureau of Reclamation (USBR, 2014). The method requires a design wind velocity over water and a wind fetch from which the significant wave height is determined. The average height of the largest 10 percent of waves within a wave series is then determined. The specific gravity of the rock, density of the rock, slope of the bank to be protected are then provided as inputs to an equation from which is determined the required median rock weight, from which the median rock size can be determined. The riprap layer thickness is then finally determined. The wind fetch was determined to be between 1 and 1.5 km for each of the sites and the design wind velocity was 100 km/h which resulted in a design wave of 0.7 to 0.9 m. This resulted in a median rock size of between 0.14 m at Carinus Bridge and 0.21 m at Kliphoek, Kuifkopvisvanger and Cerebos Saltworks corresponding to a riprap layer thickness of 0.29 m to 0.41 m respectively. The riprap quantities are given in **Table 10** in Appendix 1.

Preliminary cost estimates per meter of bank for the four recommended options are given in **Table 2**. The costs differ for each site because of the differing heights of the banks and depths of the channel.

Table 2: Costs per metre of bank for each option at each site

Option	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvanger	Site 5 Kliphoek
Reshape and revegetate	R871.62	R5,167.46	R3,871.21	R8,885.81	R6,031.42	R3,175.53
Toe berm 1m high - imported sand fill	R5,556.17	R9,852.00	R8,555.75	R13,570.36	R10,715.97	R7,860.08
Toe berm 0.5m high - imported sand fill	R3,204.84	R7,500.67	R6,204.43	R11,219.03	R8,364.64	R5,508.75
Toe berm 1 m high - insitu sand fill	R4,783.92	R9,079.76	R7,783.51	R12,798.11	R9,943.72	R7,087.83
Toe berm 0.5 m high - insitu sand fill	R2,818.72	R7,114.55	R5,818.30	R10,832.90	R7,978.52	R5,122.63
Geo Cell	R1,387.11	R5,682.95	R4,386.70	R9,401.30	R6,546.91	R3,691.02
Riprap	R12,002.22	R14,455.21	R14,383.77	R20,945.63	R12,507.45	R10,049.96

The preliminary estimated total cost for application to each of the areas of concern are given in **Table 3**.

Table 3: Total costs including VAT for each option to rehabilitate each entire site

Option	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvanger	Site 5 Kliphoek
Reshape and revegetate	R671,150.32	R1,446,887.67	R1,045,226.79	R6,930,932.37	R4,071,210.00	R1,270,213.52
Toe berm	R4,278,249.62	R2,758,560.15	R2,310,053.81	R10,584,877.11	R7,233,277.58	R3,144,031.34
Toe berm 0.5m high - imported sand fill	R2,467,726.66	R2,100,188.16	R1,675,195.11	R8,750,840.86	R5,646,130.82	R2,203,499.93
Toe berm 1 m high - insitu sand fill	R3,683,621.32	R2,542,331.67	R2,101,547.79	R9,982,526.37	R6,712,012.50	R2,835,133.52
Toe berm 0.5 m high - insitu sand fill	R2,170,412.51	R1,992,073.92	R1,570,942.10	R8,449,665.49	R5,385,498.29	R2,049,051.02
Geo Cell	R1,068,078.23	R1,591,225.09	R1,184,409.30	R7,333,015.18	R4,419,166.29	R1,476,409.83
Riprap	R9,241,709.71	R4,047,457.70	R3,883,616.89	R16,337,594.21	R8,442,529.81	R4,019,985.57

Details of above cost estimates are provided in Appendix 1.

The cost estimates indicate that regrading of the bank and revegetating with suitable indigenous plant species would be the cheapest. The use of Geo Cells would be the next cheapest option followed by a 0.5 m high toe berm at the base of the regraded bank and filling the geotextile bags on site. Riprap is the most expensive option.

A reduction in boat waves is also recommended and according to Murison (pers. comm.) BirdLife South Africa is working with Berg River Municipality to highlight 'no wake' erosion sensitive areas in the By-laws. Further studies into the minimisation of boat waves through for example, a literature review should also be undertaken and solutions may include speed limits and draft limits in sensitive areas.

8. RECOMMENDATIONS

It is recommended that the three pilot designs suggested by King (2017) are implemented at Admiral Island close to each other, where approximately 3 m³ needs to be moved to rehabilitate 1 m run of bank for each of the three pilot options. The three options that can be trialled can be regrading and revegetating the bank, regrading the bank with a 0.5 m toe wall using geotextile bags filled with material from the site and regrading of the bank and installation of geocells (first three options listed in Appendix 1). If filling of bags with material from the site is unacceptable then material can be imported.

To be able to undertake the works without an Environmental Impact Assessment (EIA) approximately 2 m of bank can be rehabilitated in this manner using each of the first three options (each option requires the same volume of material to be moved). To rehabilitate the banks at the other sites, an EIA may be required, or preferably permission is granted by the relevant authorities to trial these options at a scale suitable to assess their effectiveness.

The pilot sites should then be monitored for a year or two and the performance of the designs evaluated. If any of them are found to perform well then an EIA, if required, can be undertaken and a larger section of bank rehabilitated. The option of a River Maintenance Management Plan (RMMP) for the estuary is currently being explored. This would allow for bankside rehabilitation without the need for EIAs, using only a selection of prescribed, green solutions. The option of a RMMP is apparently supported by the Department of Water and Sanitation and CapeNature and is recommended by King (2017). The Admiral Island site is particularly well suited as a trial site since the unit costs (cost per metre run of bank) are the lowest out of all the sites, due to the low height of the bank and the lower gradient bathymetry that exists here.

If none of the pilot options are found to be viable, then the use of a traditional revetment option like riprap should be considered. Although riprap is expensive, if properly designed it will work well with low maintenance requirements.

A reduction in boat waves at sensitive locations in the estuary is also recommended and according to Murison (pers. comm.) BirdLife South Africa is working with Berg River Municipality to highlight 'no wake' erosion sensitive areas in the by-laws. Further studies into the benefits of the minimisation of boat waves through should also be undertaken, and solutions may include speed limits and draft limits in sensitive areas.

9. REFERENCES

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10. APPENDIX 1: QUANTITIES AND COSTS FOR THE VARIOUS OPTIONS AT EACH SITE

Table 4: Estimated quantities and costs for reshaping and revegetating the bank

Reshape and revegetate	Quantities									Costs							
	Item	Unit	Rate	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvanger	Site 5 Kliphoeck	TOTAL quantities	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvanger	Site 5 Kliphoeck	TOTALS
Preliminary and General											R92,636.34	R199,708.44	R144,268.71	R956,650.43	R561,933.75	R175,322.78	R2,130,520.45
Clear and grub	m ²	R1.00	4620	1680	1620	4680	4050	2400	19050		R4,620.00	R1,680.00	R1,620.00	R4,680.00	R4,050.00	R2,400.00	R19,050.00
Reshape bank and compact	m ³	R53.00	2310	13370	9247	67458	38306	10800	141491		R122,430.00	R708,610.00	R490,073.33	R3,575,264.06	R2,030,231.25	R572,400.00	R7,499,008.65
Jute fabric	m ²	R20.00	4870	1771	1708	4933	4269	2530	20080		R97,398.15	R35,417.51	R34,152.60	R98,663.06	R85,381.50	R50,596.44	R401,609.26
Revegetate	m ²	R30.00	4870	1771	1708	4933	4269	2530	20080		R146,097.23	R53,126.26	R51,228.90	R147,994.59	R128,072.25	R75,894.66	R602,413.89
Contingency											R92,636.34	R199,708.44	R144,268.71	R956,650.43	R561,933.75	R175,322.78	R2,130,520.45
Subtotal - construction											R555,818.07	R1,198,250.66	R865,612.25	R5,739,902.58	R3,371,602.49	R1,051,936.66	R12,783,122.70
Prof fees											R27,790.90	R59,912.53	R43,280.61	R286,995.13	R168,580.12	R52,596.83	R639,156.14
Total excl. VAT											R583,608.97	R1,258,163.19	R908,892.86	R6,026,897.71	R3,540,182.61	R1,104,533.49	R13,422,278.84
Total incl. VAT											R671,150.32	R1,446,887.67	R1,045,226.79	R6,930,932.37	R4,071,210.00	R1,270,213.52	R15,435,620.67
Cost per m of bank											R871.62	R5,167.46	R3,871.21	R8,885.81	R6,031.42	R3,175.53	
m³/m bank			3	48	34	86	57	27									

Table 5: Estimated quantities and costs for reshaping and revegetating the bank with a 1 m high berm located at the toe of the slope below the mid-tide level. The price includes importing of sand fill for the bags

Toe berm 1m		Quantities								Costs						
Item	Unit	Rate	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvang er	Site 5 Kliphoe k	TOTAL quantities	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvang er	Site 5 Kliphoe k	TOTALS
Preliminary and General										R590,510.64	R380,753.64	R318,848.01	R1,460,990.63	R998,382.00	R433,958.78	R4,183,443.70
Clear and grub	m ²	R1.00	4620	1680	1620	4680	4050	2400	19050	R4,620.00	R1,680.00	R1,620.00	R4,680.00	R4,050.00	R2,400.00	R19,050.00
Reshape bank and compact	m ³	R53.00	2310	13370	9247	67458	38306	10800	141491	R122,430.00	R708,610.00	R490,073.33	R3,575,264.06	R2,030,231.25	R572,400.00	R7,499,008.65
Toe berm	m	R2,130.00	770	280	270	780	675	400	3175	R1,640,100.00	R596,400.00	R575,100.00	R1,661,400.00	R1,437,750.00	R852,000.00	R6,762,750.00
Imported sand fill for bags	m ³	R187.00	1756	638	616	1778	1539	912	7239	R328,297.20	R119,380.80	R115,117.20	R332,560.80	R287,793.00	R170,544.00	R1,353,693.00
Geotextile backing behind wall	m ²	R15.00	1540	560	540	1560	1350	800	6350	R23,100.00	R8,400.00	R8,100.00	R23,400.00	R20,250.00	R12,000.00	R95,250.00
Jute fabric on slope	m ²	R20.00	4870	1771	1708	4933	4269	2530	20080	R97,398.15	R35,417.51	R34,152.60	R98,663.06	R85,381.50	R50,596.44	R401,609.26
Revegetate	m ²	R30.00	4870	1771	1708	4933	4269	2530	20080	R146,097.23	R53,126.26	R51,228.90	R147,994.59	R128,072.25	R75,894.66	R602,413.89
Contingency										R590,510.64	R380,753.64	R318,848.01	R1,460,990.63	R998,382.00	R433,958.78	R4,183,443.70
Subtotal - construction										R3,543,063.87	R2,284,521.86	R1,913,088.05	R8,765,943.78	R5,990,291.99	R2,603,752.66	R25,100,662.20
Prof fees										R177,153.19	R114,226.09	R95,654.40	R438,297.19	R299,514.60	R130,187.63	R1,255,033.11
Total excl. VAT										R3,720,217.06	R2,398,747.95	R2,008,742.45	R9,204,240.97	R6,289,806.59	R2,733,940.29	R26,355,695.31
Total incl. VAT										R4,278,249.62	R2,758,560.15	R2,310,053.81	R10,584,877.11	R7,233,277.58	R3,144,031.34	R30,309,049.61
Cost per m of bank										R5,556.17	R9,852.00	R8,555.75	R13,570.36	R10,715.97	R7,860.08	
m³/m bank			3	48	34	86	57	27								

Table 6: Estimated quantities and costs for reshaping and revegetating the bank with a 0.5 m high berm located at the toe of the slope below the mid-tide level. The price includes importing of sand fill for the bags.

Toe berm 0.5 m	Quantities									Costs						
	Item	Unit	Rate	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvang er	Site 5 Kliphoe k	TOTAL quantities	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvang er	Site 5 Kliphoe k
Preliminary and General										R340,610.99	R289,881.04	R231,220.86	R1,207,845.53	R779,314.12	R304,140.78	R3,153,013.33
Clear and grub	m ²	R1.00	4620	1680	1620	4680	4050	2400	19050	R4,620.00	R1,680.00	R1,620.00	R4,680.00	R4,050.00	R2,400.00	R19,050.00
Reshape bank and compact	m ³	R53.00	2310	13370	9246	67457	38306.25	10800	141491	R122,430.00	R708,610.00	R490,073.33	R3,575,264.06	R2,030,231.25	R572,400.00	R7,499,008.65
Toe berm	m	R1,060.00	770	280	270	780	675	400	3175	R816,200.00	R296,800.00	R286,200.00	R826,800.00	R715,500.00	R424,000.00	R3,365,500.00
Imported sand fill for bags	m ³	R187.00	878	319	308	889	770	456	3620	R164,148.60	R59,690.40	R57,558.60	R166,280.40	R143,896.50	R85,272.00	R676,846.50
Geotextile backing behind wall	m ²	R15.00	770	280	270	780	675	400	3175	R11,550.00	R4,200.00	R4,050.00	R11,700.00	R10,125.00	R6,000.00	R47,625.00
Jute fabric on slope	m ²	R20.00	4869	1770	1707	4933	4269	2529	20080	R97,398.15	R35,417.51	R34,152.60	R98,663.06	R85,381.50	R50,596.44	R401,609.26
Revegetate	m ²	R30.00	4869	1770	1707	4933	4269	2529	20080	R146,097.23	R53,126.26	R51,228.90	R147,994.59	R128,072.25	R75,894.66	R602,413.89
Contingency										R340,610.99	R289,881.04	R231,220.86	R1,207,845.53	R779,314.12	R304,140.78	R3,153,013.33
Subtotal - construction										R2,043,665.97	R1,739,286.26	R1,387,325.15	R7,247,073.18	R4,675,884.74	R1,824,844.66	18,918,079.95
Prof fees										R102,183.30	R86,964.31	R69,366.26	R362,353.66	R233,794.24	R91,242.23	R945,904.00
Total excl. VAT										R2,145,849.27	R1,826,250.57	R1,456,691.40	R7,609,426.84	R4,909,678.97	R1,916,086.89	19,863,983.95
Total incl. VAT										R2,467,726.66	R2,100,188.16	R1,675,195.11	R8,750,840.86	R5,646,130.82	R2,203,499.93	22,843,581.54
Cost per m of bank										R3,204.84	R7,500.67	R6,204.43	R11,219.03	R8,364.64	R5,508.75	
m³/m bank			3	48	34	86	57	27								

Table 7: Estimated quantities and costs for reshaping and revegetating the bank with a 1 m high berm located at the toe of the slope below the mid-tide level. The price assumes that the bags can be filled with material from the site

Toe berm 1 m	Quantities									Costs							
	Item	Unit	Rate	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvanger	Site 5 Kliphoeck	TOTAL quantities	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvanger	Site 5 Kliphoeck	TOTALS
Preliminary and General											R508,436.34	R350,908.44	R290,068.71	1,377,850.43	R926,433.75	R391,322.78	R3,845,020.45
Clear and grub	m ²	R1.00	4620	1680	1620	4680	4050	2400	19050		R4,620.00	R1,680.00	R1,620.00	R4,680.00	R4,050.00	R2,400.00	R19,050.00
Reshape bank and compact	m ³	R53.00	2310	13370	9247	67458	38306	10800	141491		R122,430.00	R708,610.00	R490,073.33	3,575,264.06	R2,030,231.25	R572,400.00	R7,499,008.65
Toe berm	m	R2,130.00	770	280	270	780	675	400	3175		1,640,100.00	R596,400.00	R575,100.00	1,661,400.00	R1,437,750.00	R852,000.00	R6,762,750.00
Geotextile backing behind wall	m ²	R15.00	1540	560	540	1560	1350	800	6350		R23,100.00	R8,400.00	R8,100.00	R23,400.00	R20,250.00	R12,000.00	R95,250.00
Jute fabric on slope	m ²	R20.00	4869	1770	1707	4933	4269	2529	20080		R97,398.15	R35,417.51	R34,152.60	R98,663.06	R85,381.50	R50,596.44	R401,609.26
Revegetate	m ²	R30.00	4869	1770	1707	4933	4269	2529	20080		R146,097.23	R53,126.26	R51,228.90	R147,994.59	R128,072.25	R75,894.66	R602,413.89
Contingency											R508,436.34	R350,908.44	R290,068.71	1,377,850.43	R926,433.75	R391,322.78	R3,845,020.45
Subtotal - construction											3,050,618.07	2,105,450.66	1,740,412.25	8,267,102.58	5,558,602.49	2,347,936.66	23,070,122.70
Prof fees											R152,530.90	R105,272.53	R87,020.61	R413,355.13	R277,930.12	R117,396.83	R1,153,506.14
Total excl. VAT											3,203,148.97	2,210,723.19	1,827,432.86	8,680,457.71	5,836,532.61	2,465,333.49	24,223,628.84
Total incl. VAT											3,683,621.32	2,542,331.67	2,101,547.79	9,982,526.37	6,712,012.50	2,835,133.52	27,857,173.17
Cost per m of bank											R4,783.92	R9,079.76	R7,783.51	R12,798.11	R9,943.72	R7,087.83	
m³/m bank			3	48	34	86	57	27									

Table 8: Estimated quantities and costs for reshaping and revegetating the bank with a 0.5 m high berm located at the toe of the slope below the mid-tide level. The price assumes that the bags can be filled with material from the site

Toe berm 0.5 m		Quantities								Costs						
Item	Unit	Rate	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvanger	Site 5 Kliphoek	TOTAL quantities	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvanger	Site 5 Kliphoek	TOTALS
Preliminary and General										R299,573.84	R274,958.44	R216,831.21	R1,166,275.43	R743,340.00	R282,822.78	R2,983,801.70
Clear and grub	m ²	R1.00	4620	1680	1620	4680	4050	2400	19050	R4,620.00	R1,680.00	R1,620.00	R4,680.00	R4,050.00	R2,400.00	R19,050.00
Reshape bank and compact	m ³	R53.00	2310	13370	9247	67458	38306	10800	141491	R122,430.00	R708,610.00	R490,073.33	R3,575,264.06	R2,030,231.25	R572,400.00	R7,499,008.65
Toe berm	m	R1,060.00	770	280	270	780	675	400	3175	R816,200.00	R296,800.00	R286,200.00	R826,800.00	R715,500.00	R424,000.00	R3,365,500.00
Geotextile backing behind wall	m ²	R15.00	770	280	270	780	675	400	3175	R11,550.00	R4,200.00	R4,050.00	R11,700.00	R10,125.00	R6,000.00	R47,625.00
Jute fabric on slope	m ²	R20.00	4870	1771	1708	4933	4269	2530	20080	R97,398.15	R35,417.51	R34,152.60	R98,663.06	R85,381.50	R50,596.44	R401,609.26
Revegetate	m ²	R30.00	4870	1771	1708	4933	4269	2530	20080	R146,097.23	R53,126.26	R51,228.90	R147,994.59	R128,072.25	R75,894.66	R602,413.89
Contingency										R299,573.84	R274,958.44	R216,831.21	R1,166,275.43	R743,340.00	R282,822.78	R2,983,801.70
Subtotal - construction										R1,797,443.07	R1,649,750.66	R1,300,987.25	R6,997,652.58	R4,460,039.99	1,696,936.66	17,902,810.20
Prof fees										R89,872.15	R82,487.53	R65,049.36	R349,882.63	R223,002.00	R84,846.83	R895,140.51
Total excl. VAT										R1,887,315.22	R1,732,238.19	R1,366,036.61	R7,347,535.21	R4,683,041.99	1,781,783.49	18,797,950.71
Total incl. VAT										R2,170,412.51	R1,992,073.92	R1,570,942.10	R8,449,665.49	R5,385,498.29	2,049,051.02	21,617,643.32
Cost per m of bank										R2,818.72	R7,114.55	R5,818.30	R10,832.90	R7,978.52	R5,122.63	
m³/m bank			3	48	34	86	57	27								

Table 9: Estimated quantities and costs for reshaping, laying down geo cells and revegetating the bank

Toe berm		Quantities								Costs						
Item	Unit	Rate	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvanger	Site 5 Kliphoeck	TOTAL quantities	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvanger	Site 5 Kliphoeck	TOTALS
Preliminary and General										R147,422.81	R219,630.79	R163,479.54	R1,012,148.40	R609,960.84	R203,783.28	R2,356,425.66
Clear and grub	m ²	R1.00	4620	1680	1620	4680	4050	2400	19050	R4,620.00	R1,680.00	R1,620.00	R4,680.00	R4,050.00	R2,400.00	R19,050.00
Reshape bank and compact	m ³	R53.00	2310	13370	9247	67458	38306	10800	141491	R122,430.00	R708,610.00	R490,073.33	R3,575,264.06	R2,030,231.25	R572,400.00	R7,499,008.65
Geotextile backing layer behind Geo Cell	m ²	R15.00	4870	1771	1708	4933	4269	2530	20080	R73,048.61	R26,563.13	R25,614.45	R73,997.30	R64,036.12	R37,947.33	R301,206.95
Multicell	m ²	R50.00	4870	1771	1708	4933	4269	2530	20080	R243,495.38	R88,543.77	R85,381.50	R246,657.66	R213,453.74	R126,491.11	R1,004,023.16
Revegetate	m ²	R30.00	4870	1771	1708	4933	4269	2530	20080	R146,097.23	R53,126.26	R51,228.90	R147,994.59	R128,072.25	R75,894.66	R602,413.89
Contingency										R147,422.81	R219,630.79	R163,479.54	R1,012,148.40	R609,960.84	R203,783.28	R2,356,425.66
Sub-total construction										R884,536.83	R1,317,784.76	R980,877.27	R6,072,890.42	R3,659,765.04	R1,222,699.65	R14,138,553.97
Prof fees										R44,226.84	R65,889.24	R49,043.86	R303,644.52	R182,988.25	R61,134.98	R706,927.70
Total excl. VAT										R928,763.67	R1,383,674.00	R1,029,921.13	R6,376,534.94	R3,842,753.29	R1,283,834.64	R14,845,481.66
Total incl. VAT										R1,068,078.23	R1,591,225.09	R1,184,409.30	R7,333,015.18	R4,419,166.29	R1,476,409.83	R17,072,303.91
Cost per m of bank										R1,387.11	R5,682.95	R4,386.70	R9,401.30	R6,546.91	R3,691.02	
m³/m bank			3	48	34	86	57	27								

Table 10: Estimated quantities and costs for riprap revetment

Toe berm	Quantities									Costs							
	Item	Unit	Rate	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvang er	Site 5 Kliphoe k	TOTAL quantities	Site 1 Admiral Island	Site 2 Carinus Bridge N	Site 2 Carinus Bridge S	Site 3 Cerebos Saltworks	Site 4 Kuifkopvisvang er	Site 5 Kliphoe k	TOTALS
P&G											R1,275,598.30	R558,655.31	R536,040.98	R2,255,016.45	R1,165,290.52	R554,863.43	R6,345,465.00
Clear and grub	m ²	R1.00	4620	1680	1620	4680	4050	2400	19050	R4,620.00	R1,680.00	R1,620.00	R4,680.00	R4,050.00	R2,400.00	R19,050.00	
Reshape bank and compact	m ³	R53.00	2310	13370	9247	67458	38306	10800	141491	R122,430.00	R708,610.00	R490,073.33	R3,575,264.06	R2,030,231.25	R572,400.00	R7,499,008.65	
Surface prep for bedding of riprap	m ²	R7.00	20153	7425	8082	13790	7956	5893	63299	R141,070.67	R51,977.73	R56,571.94	R96,530.08	R55,690.43	R41,252.17	R443,093.01	
Geotextile AG400 or similar	m ²	R22.00	20153	7425	8082	13790	7956	5893	63299	R443,364.97	R163,358.59	R177,797.51	R303,380.24	R175,027.06	R129,649.67	R1,392,578.04	
Sand layer	m ³	R187.00	2015	743	808	1379	796	589	6330	R376,860.22	R138,854.80	R151,127.88	R257,873.20	R148,773.00	R110,202.22	R1,183,691.33	
Riprap	m ³	R546.00	7084	2046	2227	8488	3882	2358	26084	R3,867,950.13	R1,117,013.84	R1,215,744.35	R4,634,343.65	R2,119,318.09	R1,287,655.00	R14,242,025.07	
Revegetate	m ²	R30.00	4870	1771	1708	4933	4269	2530	20080	R146,097.23	R53,126.26	R51,228.90	R147,994.59	R128,072.25	R75,894.66	R602,413.89	
Contingency										R1,275,598.30	R558,655.31	R536,040.98	R2,255,016.45	R1,165,290.52	R554,863.43	R6,345,465.00	
Sub-total construction										R7,653,589.82	R3,351,931.85	R3,216,245.87	R13,530,098.73	R6,991,743.11	R3,329,180.60	R38,072,789.98	
Prof fees										R382,679.49	R167,596.59	R160,812.29	R676,504.94	R349,587.16	R166,459.03	R1,903,639.50	
Total excl. VAT										R8,036,269.31	R3,519,528.44	R3,377,058.17	R14,206,603.66	R7,341,330.27	R3,495,639.63	R39,976,429.48	
Total incl. VAT										R9,241,709.71	R4,047,457.70	R3,883,616.89	R16,337,594.21	R8,442,529.81	R4,019,985.57	R45,972,893.90	
Cost per m of bank										R12,002.22	R14,455.21	R14,383.77	R20,945.63	R12,507.45	R10,049.96		
m³/m bank			3	48	34	86	57	27									

Chief Directorate: Environmental Quality
Directorate: Pollution and Chemicals Management
Western Cape Department of Environmental Affairs and Development Planning
Private Bag X9086
Cape Town, 8000
Tel: +27 21 483 4656
Website: www.westerncape.gov.za/eadp

Email: Wilna.kloppers@westerncape.gov.za or Annabel.Horn@westerncape.gov.za



**Western Cape
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