ESTUARINE IMPACT ASSESSMENT AND HYDRODYNAMIC MODELLING REPORT FOR THE DREDGING OF MILNERTON LAGOON, CAPE TOWN

2025

Anchor Environmental Consultants Report No. 2214/3

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Report prepared for:

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EXECUTIVE SUMMARY

Introduction

The water quality of the Milnerton Lagoon has declined significantly in recent years, as a result of high levels of pollution and other human impacts, with consequences to both human well-being and ecological function. Recommendations from the 2023 Water Quality Remediation Plan include targeted dredging of portions of the system. The purpose of the proposed dredging is to attempt to improve hydrodynamic functioning of the estuarine system and (optionally) to remove, dewater and dispose of (offsite) the organic, nutrient-rich fine sediment. This organic 'sludge' originates from the catchment and from poorly treated effluent and contributes to the poor water quality and odour in the lagoon.

In theory this dredging may serve to improve hydrodynamic functioning of the system, by facilitating better tidal exchange and therefore, salinity-induced estuarine circulation. These impacts are, however, highly site specific, and difficult to 'test in field' and therefore require numerical modelling studies to assess the impacts of these anthropogenic modifications on system function. To this end, Infinity Environmental (Pty) Ltd has appointed Anchor Environmental Consultants (Pty) Ltd (Anchor) to conduct a hydrodynamic dispersion modelling study to assess potential impacts that proposed dredge options may have on the lower Diep Estuary. The results of this hydrodynamic modelling study are also used to inform an Estuarine Impact Assessment study, which assesses management options required to achieve certain desired ecological outcomes.

Project description

There are two proposed dredge options under consideration. The first (referred to here as '**dredge and move'**) involves a limited dredge that focuses on potentially improving hydrodynamic functioning in the lower reaches of the system through the creation of a scour channel. It is proposed that up to 30 000 m^2 of material will be dredged to create a channel of ~20 m width, to a depth of 1 m below land levelling datum (LLD) and side slopes with a 1:5 slope. This material will be moved from the estuary channel to the eastern bank to create 'flats' 0.5 m above LLD in the intertidal zone. This proposed intervention includes the creation of a berm upstream of the small island at the Wooden Bridge, using 600 m^3 of dredged material, as a means to potentially concentrate flows west of the island and increase flow velocities.

Optionally, the dredging may also involve the separation, dewatering, and offsite disposal of the organic sediment fraction of the dredged material ('**dredge, clean and move**'). If this option is implemented, dredged material from the estuary channel will be removed and cycloned to separate clean sand from organic silt and fine sediment, which will then be pumped into geotextile tubes for dewatering on the open park area adjacent to Marine Drive. After dewatering, the dried organic sediment would be disposed of off-site. The volume of material for offsite disposal is estimated at 6000 m^2, which would be transported by road to a licensed landfill site at Vissershok. The sand recovered from the cyclone will be placed back into the lagoon adjacent to the dredge channel ('enrichment'), raising the bed level by 400 mm.

Data sources

The Diep Estuary is a well-studied system, and a good deal of effort has been undertaken recently to collect data pertaining to water quality and quantity. Data used in this report have been drawn from existing literature, including the Water Quality Remediation Plan for the Milnerton Lagoon (2023), the Diep River Estuarine Management Plan (2022) as well as surveys undertaken Hutchings & Clark (2010), Gihwala & Hutchings (2021) and Gammon & Clark (2022) *inter alia*.

Freshwater flow inputs into the head of the estuary are derived from two sources – the general catchment, and the Potsdam Waste Water Treatment Works (WWTW). The long-term daily catchment flows (for the period 1968/01/01 to 2022/04/29) used in this report were provided by Gerrit Basson and his team at ASP Tech. These flows were generated from the catchment by a hydrological rainfall-runoff model (SHETRAN). Catchment flow data from 2022/04/30 to 2024/11/07 were sourced from the Department of Water and Sanitation (DWS) gauging station G2H042. This station lies outside of the estuarine functional zone and does not capture the full flow of other tributaries entering the estuarine system. However, it was used as a basis for estimating the flows over the modelled period (2024), based on the historical relationship with the modelled SHETRAN data. Data for the Potsdam WWTW (from 2012/07/01 to 2024/09/31) were sourced from the City of Cape Town.

In situ salinity data was collected through the deployment of AquaTROLL instrument at Woodbridge Island for March-June 2024, while water levels and salinity were collected for August-November 2024. In situ sediment quality data were provided by Infinity Environmental. Table Bay hourly tidal data was supplied by the Hydrographic Office of the South African Navy. Bathymetric data were sourced from the September 2024 survey of the system by Tritan Survey (Pty) Ltd.

Legislative context

An overview of legislation and policy applicable to management of estuaries in South Africa and specifically to the Diep Estuary is presented in this report. The 2019 published classes and resource quality objectives of water resources Diep Estuary stipulates that the system is to be maintained at a minimum D Ecological Category. This Category indicates that there has been a large shift in natural processes and ecosystem functions from the natural condition. While this score represents an already degraded system, there has been further negative shifts in the system since then, with substantial deteriorations in water quality in recent years, and a near-complete collapse in the fish community. The Diep Estuary Water Quality Objectives require an average salinity of 20 in the lower estuary (Milnerton Lagoon), with a maximum salinity of 35.

Affected environment

The hydrodynamic function and characteristics of an estuary is affected by several key drivers. As estuaries form the interface between the marine and freshwater environment, oceanic factors can play a significant role in the hydrodynamic and biogeochemical characteristics of a system. These oceanic influences include sea level variations from tides and weather effects (i.e., storm surges), as well as water quality parameters such as salinity (the most important in this case), temperature, dissolved oxygen and nutrient concentrations. In a similar fashion, the quantity and quality of freshwater entering the system (and changes thereof) is critical in shaping form and function. Channel morphology and sediment structure (which is often determined by freshwater inflow) as well as external influences on the system such as wind, rain, air temperature, insolation and evaporation, also affect the manner in which the water circulates and mixes within the estuarine system.

The catchment of the Diep Estuary system is approximately 1 495 km^2, and falls within the City of Cape Town, West Coast and Cape Winelands District Municipalities. The predominant land use within the catchment is agriculture, with urban residential and industrial development in the area immediately surrounding the estuary. Hydrology in the catchment is strongly seasonal and is characterised by winter rainfall and dry summers.

The hydrological functioning within the Diep Estuary catchment has experienced substantial anthropogenic change, with flows entering the catchment decreasing by 39% from the natural levels, mainly as a result of agricultural abstraction of water.

Modelled inflow data for the Diep Estuary as well as measured flow data (DWS gauge G2H042) show a cyclical pattern in the natural flushing of the estuary by floods (floods larger than 50 m^3/s) from the Diep River catchment. While modelled data only extends to 2022, there is a flood peak of >50 m^3/s in measured gauge data in 2023 (four events), which likely translates to similar flows at the head of the estuary. Of particular interest here is that there are eight days of flows >50 m^3/s in measured gauge data in 2024 (compared to four in 2023, and two in 2020). This represents a significant flood event, which scoured the estuary in some areas (Gus Holm, pers. Comm. 2024).

Estuary flows are also supplemented by treated wastewater discharged from the Potsdam WWTW — indeed, during periods of low flow (i.e., the dry summers), this WWTW discharge makes up most of (if not all of) the freshwater inflow at the head of the estuary. This WWTW flows pays a critical role in keeping the mouth of the estuary open (which is the preferred state due to poor water quality). However, during some periods (such as in the dry summer seasons of 2017-2018), the Potsdam WWTW inflow has not been sufficient, and the mouth has closed.

There have also been significant changes in water quality within the Diep Estuary over the years, and the system no longer functions as it would have naturally. These changes include large shifts in salinity within the system, as well as increases in nutrient and microbial pollution. The primary source of microbial and nutrient pollution in the Diep River can be traced to agricultural runoff in the greater Diep River catchment, discharge of the Potsdam WWTW effluent water into the system, and a number of large stormwater drains that discharge directly into the Diep Estuary.

Under natural conditions, the Diep Estuary mouth would close periodically during summer, which, with high evaporation rates, resulted in the development of a reverse salinity gradient. In recent years, the discharge from the Potsdam WWTW into the estuary has maintained flow levels such that the estuary mouth has remained open almost permanently, but has also majorly reduced salinity, resulting in an increasingly freshwater dominated system.

These changes to flow and water quality have had significant impacts on the function, health and biological communities of the system — there has been a significant decrease in benthic macrofauna community species richness in the Diep Estuary over time, with, and an increase in freshwater species (reflecting the freshwater dominated nature of the system). There have also been clear declines in fish species richness over time, from 12 species in 1954 to five in 2016, as well as drastic declines in the number of juveniles of important linefish species such as white steenbras and white stumpnose. Indeed, only five individual fish from three species were caught during in seine and gill net fish surveys conducted in August 2022, of which two were invasive species. Given that most of these native species caught in previous surveys were absent from the 2022 sampling events, this appears to indicate an almost entirely collapse of fish populations in the system.

Far-field hydrodynamic and sediment modelling results

The role of hydrodynamic modelling is to develop a mathematical representation of a system, accounting for these diverse and complex drivers, to answer questions around water quality, circulation patterns and management requirements. Given the particular questions and concerns around the lower Diep Estuary (tidal flushing and the impacts thereof on water quality/ecology), it was critical that water dynamics be resolved through the water column to fully assess stratification characteristics along the estuary. Therefore, the system and proposed dredging activities were modelled using the sediment transport and morphological capability of the Delft3D modelling system, and in particular, the Delft3D-FLOW system (FLOW is the hydro-morphodynamics package of the integrated Delft3D modelling suite).

This far-field modelling was used to simulate the extent, duration and behaviour of saline intrusion (as a proxy for estuarine circulation) within the Diep Estuary under a range of environmental conditions (different seasons and freshwater flow regimes) and impact scenarios (prior to dredging and with dredging). The modelling assumes a continuous field for all properties within the modelled fluid field, thus enabling high accuracy without computational cost of small element sizes within the grid. Given the known seasonality in flow and hydrodynamic behaviour of the system, these refence states were simulated for a dry “low flow” period and a wet, “high flow” period, based on inflow data. The dry season was modelled for 15 March 2024 to 30 April 2024, while the wet season was modelled for 15 July 2024 to 31 August 2024.

Modelled results suggest that the difference between pre-dredge and post-dredge salinities are minimal at maximum tidal extents (peak high tide and peak low tide). However, the larger post-dredge cross sectional area facilitates larger saline intrusion and saline wedge development in the lower estuary during high energy incoming and outgoing tides (i.e., spring high tides). This can enable increased exchange between saline water and fresh water in the lower estuarine system. The period of greatest concern is when there is minimal freshwater flow and low tidal forcing, which can lead to insufficient tidal exchange to remove deposited sediment and sludge.

During the dry season, modelled average salinities in the lower water column near the mouth (0.2 km from the mouth) were 11.6% higher post-dredging. In the pre-dredging scenario, the salinity levels drop to ~1 twice every tidal cycle because the freshwater inflow from the Potsdam WWTW is capable of completely replacing the saline water present in the lower system. Conversely, dredging provides a larger volume for saline entrapment and requires more freshwater flow to reduce the salinity to the same extent as the pre-dredging scenario. The model also shows that a natural halocline develops readily in the post dredging scenario for the incoming and outgoing tides. Further upstream at 2.9 km form the mouth, the pre-dredging and post-dredging differences in average salinity in the lower water column are much less pronounced (an increase of 0.4%). The model therefore shows that while dredging does provide an increase in salinity to the lower estuary during the dry season, it does not improve the salinity penetration further upstream. It is assumed that while dredging allows more water to enter the lower estuary, the net available energy from tidal forcing and freshwater inflow does not facilitate the additional penetration of the saline water further up the estuary.

While there is a constant freshwater inflow from the Potsdam WWTW during the dry season, the wet season simulations are characterised by large freshwater inflows (i.e., flood events). When these large flows are present, the system is entirely fresh. Model results indicate that, over the period modelled, dredging resulted in a 54% increase in salinity in the lower water column (average of 6.8 after dredging, and 3.1 before dredging). This is likely because the large flood events result in large scale mouth scour and changes to the bathymetry, allowing more saltwater penetration into the system. Despite this, this increased salinity near the mouth is not translated further up the system — indeed, there is no saline penetration at 2.9 km upstream at any point during the wet season.

The modelled scenarios suggest that freshwater inflow as well as tidal forcing are coupled and interact with bed shear stresses and velocity magnitudes within the dredge channel. During the wet season, these factors interact constructively, leading to higher velocity magnitudes and bed shear stresses before each low tide. For example, increased freshwater inflow amplifies the outgoing tide resulting in higher peak velocities and shear stresses while the troughs remain unchanged during incoming tide. Conversely, in drier periods, the estuarine velocity is primarily driven by tidal forcing. The increased water volume in the dredged channel likely requires more energy to mobilise and consequently, results in lower velocities and bed shear stresses.

A critical shear stress of 0.10 N/m^2 was calculated under the assumption of a constant fluid density and a Shields' parameter of 1000 kg/m^3 and 0.05 respectively. Pre-dredge results for the wet season show that the modelled bed shear stresses only exceed the required critical shear stress at the 90^{th} percentile, indicating that bulk-sediment transport only occurs during high energy scenarios. Post-dredge scenarios show a consistent reduction in bed shear stresses across all scenarios, suggesting that dredging reduces the intensity of shear stress loading on the bed within the channel. This reduction may have implications for real-world sediment transport and erosion characteristics, potentially resulting in increased deposition within the dredge channel, especially if the mouth closes. However, the enhanced tidal prism may also more readily flush out accumulated material through the mouth (with the overall larger volume flow rate in dredged area). Note however that this improvement will only likely be realised in the lower portions of the system towards the mouth.

Impact assessment

Impacts associated with the proposed project activities include construction phase impacts (linked to the dredging activity itself) and operational phase impacts, which describe the results of the dredging on estuarine form and function over the longer term. These potential impacts (both positive and negative) expected during the construction and operational phases, before and after mitigation, are summarised in Table 1.

Table 1. Summary of potential construction and operational phases of the proposed dredging, dewatering and enrichment activities on the lower Diep Estuary.

<table>
<tr><th></th><th>Impact</th><th>Significance before mitigation</th><th>Significance with mitigation</th><th>Status</th><th>Confidence</th></tr>
<tr><td rowspan="3">Construction phase</td><td>Impact 1a: Disturbance to and mortality of estuarine communities in the dredge footprint - dredge and move.</td><td>LOW</td><td>LOW</td><td>-'ve</td><td>High</td></tr>
<tr><td>Impact 1b: Disturbance to and mortality of estuarine communities in the dredge footprint - dredge, clean and move.</td><td>LOW</td><td>LOW</td><td>-'ve</td><td>High</td></tr>
<tr><td>Impact 2: Impact to estuarine habitat due to dewatering process - dredge, clean and move.</td><td>INSIGNIFICANT</td><td>n/a</td><td>-'ve</td><td>High</td></tr>
<tr><td>Construc tion</td><td>Impact 3a: Noise impacts on surrounding estuarine ecology due to dredging activities - dredge and move.</td><td>LOW</td><td>VERY LOW</td><td>-'ve</td><td>High</td></tr>
</table>

	Impact	Significance before mitigation	Significance with mitigation	Status	Confidence
	Impact 3b: Noise impacts on surrounding estuarine ecology due to dredging, dewatering and sand enrichment activities - dredge, clean and move.	MEDIUM	MEDIUM	-'ve	High
	Impact 4a. Smothering of estuarine fauna from dredging activities - dredge and move.	LOW	LOW	-'ve	High
	Impact 4b. Smothering of estuarine fauna from dredging, dewatering and sand enrichment activities - dredge, clean and move.	LOW	LOW	-'ve	High
	Impact 5a: Impacts on estuarine water quality- dredge and move.	MEDIUM	MEDIUM	-'ve	High
	Impact 5b: Impacts on estuarine water quality- dredge, clean and move.	LOW	LOW	-'ve	High
	Impact 6: Waste generation and improper disposal – both options.	MEDIUM	VERY LOW	-ve	High
Operational phase	Impact 7a: Impacts of proposed dredging on magnitude of the estuarine tidal prism - dredge and move.	LOW	LOW	+'ve	High
	Impact 7b: Impacts of proposed dredging on magnitude of the estuarine tidal prism - dredge, clean and move.	LOW	LOW	+'ve	High
	Impact 8a: Impacts of a deeper channel at the mouth of sludge settlement and flushing - dredge and move.	VERY LOW	VERY LOW	+'ve	Low
	Impact 8b: Impacts of a deeper channel at the mouth of sludge settlement and flushing - dredge, clean and move.	VERY LOW	VERY LOW	+'ve	Low
	Impact 9a: Impacts on estuarine health linked to new intertidal areas resulting from sediment enrichment - dredge and move.	VERY LOW	VERY LOW	+'ve	Low
	Impact 9b: Impacts on estuarine health linked to new intertidal areas resulting from sediment enrichment – dredge, clean and move.	VERY LOW	VERY LOW	+'ve	Low

The No-Go alternative represents the baseline against which the project related impacts are assessed. The no-go option would entail maintaining the current status quo, i.e. no dredging activities in the lower Diep Estuary. The Construction Phase impacts are assessed as of Insignificant to Medium significance after mitigation — the no-go option would mean that none of these negative Construction phase impacts occur. However, the no-go option also means that the positive impacts assessed for the Operational Phase (rated as Low to Very Low positive impacts) will not be realised. The realisation of these positive benefits is contingent on the required mitigation measures are implemented and provided that the mouth is kept open.

Mitigation and monitoring

There are as series of recommended mitigation measures that should be taken to avoid, minimize, or offset adverse impacts, or enhance positive impacts, identified during the Impact Assessment. They include:

- Any equipment to be used in the estuary must be thoroughly rinsed/cleaned prior to use to ensure no transfer of introduced species form other systems.
- All feasible measures for reducing noise during dredging should be investigated and employed. Mobile equipment, vehicles and power generation equipment must be suitably maintained during the project. A maintenance plan must be implemented to ensure all diesel motors and generators receive adequate maintenance to minimise noise emissions and potential pollution events.
- Highly disturbing (light, noise) activities should be constrained to the daytime where possible to minimise noise and light disturbance at night.
- The spatial extent of impacts must be constrained to the minimum required. Dredging and dewatering activities should be planned to minimize the duration and extent of disturbance to water bodies.
- For land-based activities that may result in erosion, contractors are to install erosion control barriers such as silt fences, sediment traps, drainage channels or sediment curtains to minimise sediment runoff into the water during the proposed activities. This is pertinent if construction is to take place during the wet season.
- All staff must be informed and trained about estuarine species and the responsible disposal of construction waste. This training must be integrated into toolbox talks or onsite awareness sessions to ensure that waste management practices are understood and followed diligently. Additionally, contractors must prepare a method statement outlining specific waste management procedures, which must be approved by the resident engineer before construction activities commence.
- Suitable handling and disposal protocols must be clearly explained, and sign boarded. A reduce, reuse, recycle policy must be drafted and adhered to.
- Waste disposal at licensed landfill sites by qualified contractors is mandatory, with proof of disposal submitted to the appointed Environmental Officer. Waste management certification must be obtained, and detailed records of all stored and disposed waste, including quantity, nature, and fate, must be maintained for auditing purposes.
- Adequate sanitary facilities and ablutions must be provided for all personnel throughout the project area. Enforcement of facility usage and cleanliness is crucial.
- Improvement of inflow water from the catchment and various point sources (including the Potsdam WWTW) is imperative to improve estuarine health over the long term.
- It is imperative that the channel be maintained at this depth and the mouth be kept open at all times.

Monitoring requirements include that Dissolved Oxygen (DO) monitoring take place in the lower reaches of the system, with control sites upstream of Woodbridge Island. Should the 95%ile DO levels in the lower system fall below 10% of the control sites, additional management actions may be required (such as oxygenation).

Conclusions

Based on the modelling results presented here, it is unlikely that dredging will result in a significant improvement in tidal forcing in the Diep Estuary as a whole, and it is unlikely that the dredging activities will result in a change to the Estuarine Health Score of the system. Model results for low flow scenario (i.e., worst-case) indicate that the dredging increases tidal exchange between the estuary and the ocean, with higher salinities (~35) in the lower system. This translates to a small ~10% increase in average salinity in the lower estuary, with larger (~54%) increases on average during the wet season. This improvement in tidal flux (as demonstrated by saline inflow) does not appear to be not translated further up the system, and the positive impacts will be limited to the lower reaches of the system. Therefore, the impact is assessed to be a Low, positive impact. It is imperative that the channel be maintained at this depth to ensure continued function (and associated benefit) over time.

The large flood events that were included in the modelled wet season were relatively unusual across the available hydrological time scale, and caution must be taken when applying this scenario as 'representative' of future wet seasons. It is likely that during the years of no flow days > 50 m^3/s, the system will behave as a 'dry season' system, regardless of the time of year. This is of particular concern in the face of decreased catchment flows due to climate change.

There are, however, additional small positive impacts (assessed with low confidence) to the system that may be associated with the proposed activities. For example, the new, narrow dredged channel in the lower reaches of the system may concentrate any 'sludge' that has been transported down the system, where the enhanced tidal prism may more readily flush it out through the mouth (with the overall larger volume flow rate in dredged area). Assuming that the additional sediment is colonised by benthic macrofauna, this has the potential to expand the feeding area available to waders and other waterbirds which feed on the intertidal mud/sandflats. In addition, the creation of larger tidal flats adjacent to the dredge area will be exposed at low tide, along with any deposited material. Exposure to air may facilitate oxygenation of these sediments.

These model results and associated assessment suggest that dredging will not address all of the challenges faced by the Milnerton Lagoon. The quality of inflow from the catchment has been identified as a critical determinant of the overall health of the estuarine system — for long term, high significance positive impacts to be realised, improvement of inflow water from the catchment and various point sources (including the Potsdam WWTW) is imperative to improve estuarine health over the long term.

It is imperative that the mouth be kept open at all times. Any mouth closure will lead to a drop in tidal forcing which, which combined with the lower bed shear stress in the dredge channel, will likely lead to the settling of organic matter from upstream, as well as dramatic decreases in oxygen level due to the poor quality of the freshwater inflow.

DECLARATION OF INDEPENDENCE

Anchor Environmental Consultants (Pty) Ltd is an independent consultancy and has no business, financial, personal or other interest in the activity, application or appeal in respect of which the company was appointed other than fair renumeration for work performed in connection with the activity, application or appeal. No circumstances arose during the course of the project that compromised the objectivity of the specialists that performed the work.

BACKGROUND AND QUALIFICATIONS OF SPECIALIST CONSULTANTS

The study was undertaken Ms Amy Wright, Mr Hrishabh Rajeev, Ms Lily Bovim, Mr Michael Armitage and Dr Barry Clark.

Amy Wright has an MSc degree in Biological Sciences and BSc. Hons. degrees in Marine Biology and Applied Biology from the University of Cape Town. She is currently a Senior Consultant for Marine Ecosystems & Resources at Anchor Environmental and a professionally registered Natural Scientist (SACNASP 131256). She is a marine ecologist with direct experience in two- and three-dimensional hydrodynamic modelling of marine and estuarine systems to inform impact assessments and regulatory compliance, as well as monitoring program design and implementation. She has dispersion modelling, impact assessment, permitting and environmental auditing experience across a range of diverse industries, including land- and sea-based mariculture, maritime and estuarine engineering, dredging and offshore mining operations, reverse osmosis operations, power and gas facility intake, discharge and cooling (including green hydrogen systems), offshore oil and gas operations, fisheries processing and discharge, and shipping (ballast, antifoulants, heavy metals). She has worked in systems across South Africa, Namibia, Mozambique, Mauritius, Kenya and Tanzania.

Hrishabh Rajeev has a BSc (Eng) in Mechanical Engineering with experience in hydrodynamic modelling, renewable energy development and software development. His BSc (Eng) degree involved measuring the accuracy of Computation Fluid Dynamic (CFD) meshing techniques, through the development of CFD code specific to his thesis. He is presently a Junior Consultant at Anchor Environmental Consultants. As a consultant he has been primarily concerned with hydrodynamic modelling of marine and estuarine systems with experience in the Delft3D modelling suite (FLOW), CorMIX, OpenFOAM and multiple programming languages (including C, C++, Python, JavaScript, Java). Hrishabh has experience in hydrodynamic modelling across diverse industries, including offshore benthic mining, oil and gas and fisheries. He has also worked as a Mechanical/SCADA Engineer for wind turbine manufacturing and as a freelance software developer.

Lily Bovim has always had a strong interest in the marine environment, and this has been the focus of her career, starting with a BSc in Marine Biology and Oceanography. After completing a BSc Honours, she held various research and field assistant positions before undertaking an internship with the Freshwater Research Centre. Lily was awarded an Erasmus Mundus scholarship to pursue an International Master of Marine Biological Resources, specialising in Marine Resource Management, which included semesters at multiple European universities and an internship at the Thünen Institute of Baltic Sea Fisheries. Her MSc thesis focused on the depth and temperature preferences of satellite tagged meagre *Argyrosomus regius* in the NE Atlantic. She graduated Magna Cum Laude from her MSc.

Dr Barry Clark has more than 30 years' experience in marine biological research and consulting on coastal zone and marine issues. He has worked as a scientific researcher, lecturer and consultant and has experience in tropical, subtropical and temperate ecosystems. He is presently Director of an Environmental Consultancy firm (Anchor Environmental Consultants) and Research Associate at the University of Cape Town. As a consultant has been concerned primarily with conservation planning, monitoring and assessment of human impacts on estuarine, rocky shore, sandy beach, mangrove, and coral reef ecosystems as well as coastal and littoral zone processes, aquaculture and fisheries. Dr Clark is the author of 27 scientific publications in class A scientific journals as well as numerous scientific reports and popular articles in the free press. Geographically, his main area of expertise is southern Africa (South Africa, Lesotho, Namibia, Mozambique, Tanzania, Seychelles, Mauritius and Angola), but he also has working experience from elsewhere in Africa (Republic of Congo, Sierra Leone, Republic of Guinea, Liberia, Cote d'Ivoire, Ghana, Nigeria), the Middle East (UAE, Saudi Arabia) and Europe (Azerbaijan, Greenland).

REVIEWERS

This study was reviewed by Dr Hardus Diedericks, a senior lecturer at the Division of Applied Mathematics at Stellenbosch University. Dr Diedericks has a PhD from the Stellenbosch University, and extensive experience in the field of hydrodynamics and sediment transport, particularly in the use of Delft3D to simulate hydrodynamic processes. He is primarily involved in research projects concerning the production of turbulence under breaking and non-breaking waves. He has also been involved in developing and validating Finite Element and Finite Difference models of nearshore coastal processes, sediment transport and morphological changes. He has consulted for Delft Hydraulics (now Deltares), the CSIR and the Water Research Commission amongst others.

SIGNATURES OF LEAD SPECIALIST

I, Amy Wright, declare that:

i. I act as the independent specialist in this application;
ii. I have performed the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant;
iii. I declare that there are no circumstances that may compromise my objectivity in performing such work;
iv. I have expertise in conducting the specialist report relevant to this application, and guidelines that have relevance to the proposed activity;
v. I have no, and will not engage in, conflicting interests in the undertaking of the activity;
vi. I undertake to disclose to the applicant and the competent authority all material information in my possession that reasonably has or may have the potential of influencing any decision to be taken with respect to the application by the competent authority and the objectivity of any report, plan or document to be prepared by myself for submission to the competent authority; and,
vii. All the particulars furnished by me in this form are true and correct.

Signature

Date: April 2025

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GLOSSARY

Alien species: Species that occur outside their natural range and dispersal potential. Alien species are spread by human activity, intended or unintended, to new areas. May or may not become 'invasive species'.

Anoxic: No oxygen; water having dissolved oxygen (DO) concentrations < 0.5 mg/L.

Anthropogenic: Relating to or resulting from the influence of human beings on nature.

AquaTROLL: A water quality data logger that records temperature and salinity at regular intervals throughout the day.

Bathymetry: The underwater depth of ocean floors, lake floors, or river floors; the underwater equivalent to hypsometry or topography.

Benthic: The benthic zone is the ecological region at the lowest level of a body of water such as an ocean, estuary or lake, including the sediment surface and some sub-surface layers. Organisms living in this zone are collectively referred to as the "benthos", e.g., the benthic invertebrate community, including crustaceans and polychaetes.

Bioavailable: The ability of a substance to be absorbed and used by the body.

Biotic: Relating to or resulting from living organisms.

Bioturbation: The disturbance of sedimentary deposits by living organisms. It includes burrowing, ingestion, and defecation of sediment grains. Bioturbating activities have a profound effect on the environment and communities.

Catchment: Areas of land where runoff collects to a specific zone.

Cohesive Sediment: Sediment smaller than 63 µm where electromagnetic forces cause them to bind together.

Computational grid: Area in which hydrodynamic momentum equations are applied.

Construction phase: The stage of project development comprising site preparation as well as all construction activities associated with the development.

Cumulative impacts: Direct and indirect impacts that act together with current or future potential impacts of other activities or proposed activities in the area/region that affect the same resources and/or receptors.

Curvilinear grid: A form of structured grids that are not dependent on rectangular spaces. They can wrap around more complex geometries

Delft3D-FLOW: A multi-dimensional hydrodynamic and transport simulation software package which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing on a boundary fitted structured rectilinear or curvilinear grids.

Diffusivity: The rate at which particles can spread within a medium.

Diversity: the number of different species present in an ecosystem and relative abundance of each of those species." Diversity is greatest when all the species present are equally abundant in the area.

Ecological Water Requirements: Also referred to as Ecological Flow Requirements, quantifies the water regime (quality, quantity and timing) required to ensure the adequate functioning and future persistence of estuaries.

Ecosystem: a biological community of interacting organisms and their physical environment – a complex network or interconnected system.

Environment: The external circumstances, conditions and objects that affect the existence of an individual, organism or group. These circumstances include biophysical, social, economic, historical and cultural aspects.

Environmental Impact Assessment: A process of evaluating the environmental and socio-economic consequences of a proposed course of action or project.

Estuarine Functional Zone: Delineated by a 5 m above mean sea level (MSL) contour as proxy indicator, the area in and around an estuary which includes the open water area, estuarine habitat (such as sand and mudflats, rock and plant communities) and the surrounding floodplain area.

Estuary: An estuary is defined in terms of the National Environmental Management: Integrated Coastal Management Act (ICMA) and the NEMA 2014 EIA Regulations as "a body of surface water— a) that is permanently or periodically open to the sea; b) in which a rise and fall of the water level as a result of the tides is measurable at spring tides when the body of surface water is open to the sea; or in respect of which the salinity is higher than fresh water as a result of the influence of the sea, and where there is a salinity gradient between the tidal reach and the mouth of the body of surface water.''

Eutrophication: Excessive richness of nutrients in a lake or other body of water, frequently due to run-off from the land, which causes a dense growth of plant life.

Far field: The region of the receiving water where buoyant spreading motions and passive diffusion control the trajectory and dilution of the effluent discharge plume.

Filter feeding: (Of an aquatic animal) feeding by filtering out plankton or nutrients suspended in the water.

Granulometry: Distribution or measurement of grain sizes in sand, rock, or other deposits.

Halocline: A rapid change in salinity with depth.

Head (of estuary): The upstream part of the system where freshwater enters.

Hydrodynamic momentum equations: Mathematical models that are used to simulate and understand the dynamics of floods and water flow.

Hydrodynamics: Referring to forces acting on or exerted by water.

Hypoxic: Low oxygen; water having dissolved oxygen (DO) concentrations < 2 mg/L.

Impact: A change to the existing environment, either adverse or beneficial, that is directly or indirectly due to the development of the project and its associated activities.

Invasive species: Alien species capable of spreading beyond the initial introduction area and have the potential to cause significant harm to the environment, economy or society.

Invertebrate: An animal without a backbone (e.g., a starfish, crab, or worm).

Macrobenthos/macrofauna: Those animals retained by a 1.0-mm-mesh sieve. Macrobenthic invertebrates are defined as organisms that live on or inside the deposit at the bottom of a water body.

Macrophyte: An aquatic plant large enough to be seen by the naked eye.

Microalgae: Microscopic algae, typically found in freshwater and marine systems, living in both the water column and sediment. They are unicellular species which exist individually, or in chains or groups.

Mitigation measures: Design or management measures that are intended to minimise or enhance an impact, depending on the desired effect. These measures are ideally incorporated into a design at an early stage.

Neap tide: A tide just after the first or third quarters of the moon when there is least difference between high and low water.

Operational phase: The stage of the works following the Construction Phase, during which the development will function or be used as anticipated in the Environmental Authorisation.

Plankton: The diverse collection of organisms found in water that are unable to propel themselves against a current.

Polychaete/a: Also known as the bristle worms. A paraphyletic class of annelid worms, generally marine. Each body segment has a pair of fleshy protrusions called parapodia that bear many bristles, called chaetae, which are made of chitin.

Present Ecological Category: Reflects the average of the abiotic components (habitat health rating) and biotic (biological health rating).

Reference condition: The reference or natural condition of an estuary refers to the ecological status when receiving 100% of the natural mean annual runoff (MAR) from the catchment.

Reference state: Or natural condition; the state of the system prior to anthropogenic impacts.

Remobilisation: The process of reintroducing a substance to circulate within a fluid.

Resource Quality Objectives: Numerical and descriptive statements regarding the biological, chemical and physical attributes that characterise a water resource (estuary in this case) and are designed to ensure the resource is adequately protected from degradation.

Salinity profile: The pattern of saltiness within the water, both with depth and across a certain distance.

Semidiurnal tide: A tidal cycle with two nearly equal high tides and low tides every lunar day.

Species: A category of biological classification ranking immediately below the genus, grouping related organisms. A species is identified by a two-part name; the name of the genus followed by a Latin or Latinised un-capitalised noun.

Spring tide: A tide just after a new or full moon, when there is the greatest difference between high and low water.

Taxon (plural – taxa): Refers to any unit used in the science of biological classification, or taxonomy.

Trace metals: Elements such as chromium, cobalt, copper, iron, magnesium, selenium, and zinc that normally occur at very low levels in the environment. Living things need very small amounts of some trace metals, but high levels of these same metals can be toxic.

Unconsolidated sediment: Sediment that is loosely arranged or unstratified (not in layers) or whose particles are not cemented together (soft rock); occurring either at the ground surface or at a depth below the surface.

Viscosity: How difficult it is for a portion of liquid to move in relation to neighbouring portions. It can also be described as the fluid's resistance to flow.

Water Reserve: The quantity and quality of water flow required in aquatic ecosystems required to meet basic human needs and to protect the natural functioning of a water resource.

Wind forcing: The movement of surface waters and the resulting transfer of energy to deeper waters by the predominant wind (i.e., a strong easterly wind will result in an eastward flowing surface current).

ABBREVIATIONS AND ACRONYMS

Anchor	Anchor Environmental Consultants (Pty) Ltd
CoCT	City of Cape Town
CSIR	Council for Scientific and Industrial Research
CWAC	Coordinated Waterbird Counts
DEA&DP	(Western Cape) Department of Environmental Affairs and Development Planning
DFFE	Department of Forestry, Fisheries and the Environment
DO	Dissolved oxygen
DWS	Department of Water and Sanitation
EAP	Environmental Assessment Practitioner
EFZ	Estuarine Functional Zone
EIA	Environmental Impact Assessment
EMP	Estuarine Management Plan
IBA	Important Bird and Biodiversity Area
ICMA	National Environmental Management: Integrated Coastal Management Act 24 of 2008 (as amended)
Infinity	Infinity Environmental (Pty) Ltd
masl	Metres above sea level
MLRA	Marine Living Resources Act 18 of 1998 (as amended)
MPA	Marine Protected Area
MSL	Mean sea level
NBA	National Biodiversity Assessment
NEM:BA	National Environmental Management: Biodiversity Act (Act No. 10 of 2004) (as amended)
NEM:PAA	National Environmental Management: Protected Areas Act (Act No. 57 of 2003) (as amended)
NEMA	National Environmental Management Act 107 of 1998 (as amended)
NWA	National Water Act (Act 36 of 1998) (as amended)
RQO	Resource Quality Objective
TOC	Total organic carbon
TON	Total organic nitrogen
WCNCB	Western Cape Nature Conservation Board
WWTW	Wastewater Treatment Works

1 INTRODUCTION

1.1 Background

Infinity Environmental (Pty) Ltd (Infinity) was appointed as the Environmental Assessment Practitioner (EAP) to undertake an Environmental Impact Assessment (EIA) process on behalf of the City of Cape Town (CoCT) for the proposed dredging of a portion of the lower Diep Estuary (Milnerton Lagoon). The 2023 Water Quality Remediation Plan (Infinity Environmental 2023), provided evidence that dredging of certain portions of the system could potentially improve water quality in the system.

The water quality of the Milnerton Lagoon has declined significantly in recent years, as a result of high levels of pollution and other human impacts, with corresponding impacts on both human well-being and ecological function (Infinity Environmental 2023). Recommendations from this Water Quality Remediation Plan include improvement in inflow water quality (particularly from the Potsdam Wastewater Treatment Works) but also targeted dredging of portions of the system. The purpose of the proposed dredging is to attempt to improve hydrodynamic functioning of the estuarine system and (optionally) to remove, dewater and dispose of (offsite) the organic, nutrient-rich fine sediment. This organic 'sludge' originates from the catchment and from poorly treated effluent. This organic rich sediment is reported to be up to 2 m thick in some places, and, because it is oxygen poor, contributes to the poor water quality and odour in the lagoon (Infinity Environmental 2023). Indeed, the report notes that "proposed dredging is predicted to have a substantial ecological benefit for the health of the lagoon and is recommended for implementation" (Infinity Environmental 2023).

In theory this dredging may also serve to improve hydrodynamic function of the system, by facilitating better tidal exchange and therefore, salinity-induced estuarine circulation, as well as potentially resulting in tidal-amplification (van Maren et al. 2015). These potential benefits are, however, highly site specific, and difficult to 'test in field' and therefore require numerical modelling studies to assess the impacts of these anthropogenic modifications on system function. To this end, Infinity has appointed Anchor Environmental Consultants (Pty) Ltd (Anchor) to conduct a hydrodynamic dispersion modelling study to assess potential impacts that proposed dredge options may have on the lower Diep Estuary. The results of this hydrodynamic modelling study is also used here to inform an Estuarine Impact Assessment study and management options required to achieve certain desired ecological outcomes.

1.2 Terms of Reference

This Report presents the setup, validation and results of the hydrodynamic dispersion model, as well as an Estuarine Impact Assessment and includes:

- A baseline description of the affected environment, with particular focus on hydrological and hydrodynamic function of the estuary under various environmental conditions (i.e., seasonal flow);

- A detailed discussion of the set-up, validation and assumptions/limitations of the model, as well as outputs of modelled impacts on estuarine tidal flux, and resulting impacts on basic water quality resulting from dredging; and,
- An interpretation of the outputs/findings of the modelling studies as part of an Estuarine Impact Assessment, which considers potential impacts on the estuarine environment that may arise during the project life cycle.

1.3 Project description

There are two proposed dredge options under consideration:

1. The '**dredge and move'** option. This is a limited dredge, which focuses on potentially improving hydrodynamic functioning in the lower reaches of the system through the creation of a scour channel. It is proposed that up to 30 000 m^2 of material will be dredged to create a channel of ~20 m width, to a depth of 1 m below land levelling datum (LLD) and side slopes with a 1:5 slope (Infinity Environmental, Pers. Comm. 2025). The proposed is for this material to be moved to create 'flats' 0.5 m above LLD in the intertidal zone, rather than removed completely.

   This proposed intervention includes the creation of a berm upstream of the small island at the Wooden Bridge, using 600 m^3 of dredged material, to potentially concentrate flows west of the island and increase flow velocities.

2. Optionally, the dredging may also involve the separation, dewatering, and offsite disposal of the organic sediment fraction of the dredged material ('**dredge, clean and move**') (Figure 1-1). If this option is implemented, dredged material will be cycloned to separate clean sand from organic silt and fine sediment, which will then be pumped into geotextile tubes for dewatering on the open park area adjacent to Marine Drive (Figure 1-1). The site is currently an open grassy recreational space. After dewatering, the dried organic sediment would be disposed of off-site. The volume of material for offsite disposal is estimated at 6000 m^2, which would be transported by road to a licensed landfill site at Vissershok. The sand recovered from the cyclone will be placed back into the lagoon adjacent to the dredge channel ('enrichment'), raising the bed level by 400 mm.

   Communications from Infinity Environmental (2023) and Gerrit Basson and team at ASP Tech indicate that the residual inputs into the estuary from this runoff are likely to be very low, and the residence time (time that these nutrients will remain in the system) will also be very short since the mouth is predominantly open.

Activity	Estimated Duration (Months)	Months											
		1	2	3	4	5	6	7	8	9	10	11	12
Permitting and Site Establishment	3												
Dredging Works	4-6												
Dewatering and Disposal	6-8												
Demobilisation and Reinstatement of Site	3												

Figure 1-1. (Top) Anticipated dredge project schedule (Luke Fouche pers. Comm. 2024). (Bottom) The proposed dewatering site shown in blue.

1.4 Data sources

The Diep Estuary is a well-studied system, and a good deal of effort has been undertaken recently to collect data pertaining to water quality and quantity. Data used in this report have been drawn from the following sources:

- A site visit undertaken in November 2023 to confirm the state and ecological functioning of the estuary in the area surrounding the proposed dredging, as well as other technical reports and general published literature (including Hutchings & Clark 2010, Gihwala & Hutchings 2021, Gammon & Clark 2022).
- The Water Quality Remediation Plan for the Milnerton Lagoon (Infinity Environmental 2023) and the Diep River Estuarine Management Plan (EMP) (City of Cape Town and Infinity Environmental 2022) are key documents detailing the management requirements for the system.
- Freshwater flow inputs into the head of the estuary are derived from two sources – the general catchment, and the Potsdam Waste Water Treatment Works (WWTW):

  - The long-term daily catchment flows (for the period 1968/01/01 to 2022/04/29) used in this report were provided by Gerrit Basson and his team at ASP Tech. These flows were generated from the catchment by hydrological rainfall-runoff model (SHETRAN, see Infinity Environmental (2023).
  - Catchment flow data from 2022/04/30 to 2024/11/07 were sourced from the Department of Water and Sanitation (DWS) gauging station G2H042. This station lies outside of the estuarine functional zone and does not capture the full flow of other tributaries entering the estuarine system. However, it was used as a basis for estimating the flows over the modelled period (2024), based on the historical relationship with the modelled SHETRAN data.
  - Data for the Postdam WWTW (from 2012/07/01 to 2025/09/31) were sourced from the City of Cape Town.
- In situ data for salinity and water levels within the estuary were collected through the deployment of AquaTroll instrument at Woodbridge Island for March-June 2024, and August-November 2024. The data collected included salinity and water depth (m). In situ sediment quality data were provided by Infinity Environmental and PRDW.
- Table Bay hourly tidal data was supplied by the Hydrographic Office of the South African Navy**.**
- Bathymetric data were sourced from the September 2024 survey of the system by Tritan Survey (Pty) Ltd.
- The proposed dredging and enrichment site and volumes was provided by the consulting engineering team (Gus Hojem and his team from PRDW).
- South African Estuary Information System by the South African Environmental Observation Network (SAEON, various dates).
- South African National Biodiversity Assessment 2011, 2018, 2020 (Van Niekerk, L. & Turpie, J.K., various dates).
- Wind and rainfall data were sourced from ERA5, the 5th generation reanalysis data set produced by European Centre for Medium-Range Weather Forecasts (accessed on 2024/11/08) DOI: 10.24381/cds.adbb2d47 (Hersbach et al. 2023).

The level of available data for each section in this report varies both spatially, temporally and in the level of confidence. Within each section of this report, reference/historical data are sought, reported on and then compared to present day data (or, where present day data were lacking, the most up to date data available).

1.5 Assumptions and limitations

The assumptions and limitations of this study are outlined below:

- The study is based on details provided by the client as they pertain to planned dredge area, volumes, duration etc.

- There are some limitations in the calibration of the model as there are no current measurements available within the estuary. However, tidal simulations are well represented in the model, and modelled water levels were successfully calibrated against in situ data available for March-June 2024, and August-November 2024. Given that water movement in the system is driven primarily by tides and freshwater flux, the overall set-up of the model is considered satisfactory.

- The lack of a functional flow gauging station at the river mouth meant it was not possible to use in situ flow measurements at the head of the estuary. Furthermore, upstream validation efforts were severely limited with the lack of continuous and reliable historic flow data throughout the watershed.

- Data for freshwater inflow into the head of the estuary from various catchment level sources (kindly provided by Gerrit Basson and his team at ASP Tech) was only available up to 2022. As such, the measured DWS inflow data was used as a ‘proxy’ inflow, which means that the modelled Delft3D inflow data may not capture the full freshwater inflow to the system.

- The modelled sediment quality is based on data from 2022 (six samples), 2023 (three samples) and 2024 (three samples) provided to Anchor by the PRDW and Infinity teams (see details in Section 4.5.4). Based on this data, only non-cohesive sand fraction was included in the modelling study.

- This model does not account for wave forcing as it pertains to movement/transport of sediment at the mouth of the system. However, as water level values are well represented by the model (see details in Section 4.7), the mouth dynamics are considered to be suitable for modelling purposes without the inclusion of wave forcing.

- The calculation of the critical shear stress assumes a constant density of 1000 kg/m^3(see details in Section 4.8.3). While this assumption does not always hold true in estuarine systems; it aligns with the initial conditions for the model and is deemed suitable for the calculation. The Shields’ parameter (which represents the ratio between shear stress to gravitational forces) as used to calculate the critical shear stress was set at typical non-cohesive sediment value of 0.05 (van Rijn 2020).

2 LEGISLATIVE CONTEXT

2.1 Estuary management

This section provides an overview of legislation and policy applicable to management of estuaries in South Africa and specifically to the Diep Estuary. South African policy and law as pertinent to estuaries has been summarised in detail elsewhere (Van Niekerk & Taljaard 2007). A summary of the most relevant policies is presented in Table 2-1.

Estuary management falls mainly under two national government departments: the Department of Water and Sanitation (DWS), responsible for water resources, and the Department of Forestry, Fisheries and the Environment (DFFE), responsible for other estuarine management aspects including land use and living resources. Environmental management in most instances is devolved to provincial level through the relevant provincial department responsible for environmental matters. Management and conservation of marine living resources is an exception in this respect, with responsibility for coastal and estuarine management issues residing with the DFFE. At a local (municipality) level, municipal councils pass municipal by-laws that cannot conflict with provincial and national laws (Anchor 2008). Policy and legislation which affects estuaries directly can be roughly divided into that affecting (a) water quality and quantity, (b) land use and infrastructure development, and (c) living resources (Taljaard 2007, Van Niekerk & Taljaard 2007).

Chapter 4 of the National Environmental Management: Integrated Coastal Management Act 24 of 2008 (ICMA) aims to facilitate the efficient and coordinated management of all estuaries, in accordance with the National Estuarine Management Protocol (ICMA Section 33) (promulgated in 2013, with amendments finalised in 2021 as per Government Gazette Vol 672, Notice No. 44724, 2021) and estuarine management plans for individual estuaries (ICMA Section 34). The purpose of the National Estuarine Management Protocol is to manage South Africa's estuaries in accordance with the national vision for estuarine management, which requires that "estuaries...are managed in a sustainable way that benefits the current and future generations".

The Diep River Estuarine Management Plan (EMP) was developed by the Coastal Management Branch of the City of Cape Town in 2022 following the standards specified in the National Estuarine Management Protocol. It consists of a Situation Assessment Report and the Management Plan itself, which sets out the Vision and Objectives for the Diep Estuary and identifies the management action and objectives required to meet these key objectives (City of Cape Town and Infinity Environmental 2022).

The Western Cape Government has also released a Coastal Management Policy which includes a suite of goals, objectives and strategies designed to achieve sustainable coastal development in the Western Cape. These are closely aligned with the National Coastal Management Policy and are organised within a number of themes. Various goals within each of these themes are of relevance to the management of the Diep Estuary and are detailed in Table 2-2.

Table 2-1. Summary of national policies which affect estuarine management, water quality and quantity in estuaries in general, landing use, development and resource use in the estuarine environment.

White Paper (= Policy)	Bill or Act (= Law)	Lead agent	Implications
National Estuarine Management Protocol (as amended 2021)	National Environmental Management: Integrated Coastal Management Act, 2008 (Act No. 24 of 2008)	DFFE	The National Environmental Management: Integrated Coastal Management Act requires that estuaries be managed in a co-ordinated and efficient manner, in accordance with a National Estuarine Management Protocol through the development and implementation of estuarine management plans (EMPs). The EMPs seek to achieve greater harmony between ecological processes and human activities while accommodating orderly and balanced estuarine resource utilisation. The national vision for estuarine management is that "the estuaries of South Africa are managed in a sustainable way that benefits the current and future generations".
Water quality & quantity			
White Paper on National Water Policy for SA (1997)	National Water Act 36 of 1998	DWS	Defines the environmental reserve in terms of quantity and quality of water; provides for national, catchment and local management of water
White Paper on Integrated Pollution and Waste Management for South Africa (2000)	Marine Pollution (Control and Civil Liability) Act (1981)	DFFE	Provides for the protection of the marine environment from pollution by oil and other harmful substances, the prevention and combating of such pollution, and the determination of liability in certain respects for loss or damage caused by the discharge of oil from ships, tankers and offshore installations.
	Integrated Coastal Management Bill (2007)	DFFE	Provides for the control of dumping of substances in the sea (including estuaries) (replaces the Dumping at Sea Control Act (1980) as amended).
Land use & management			
	Integrated Coastal Management Bill (2007)	DFFE / DEA&DP	Ownership of the seashore (includes the water and land between the low-water mark and the high-water mark in tidal rivers such as the Goukou Estuary) is vested in the State; currently used to control recreational boating activities in estuaries (replaces the Seashore Act (1935) as amended)
	Environmental Conservation Act (1989)		Most of the provisions of this Act have been repealed by NEMA, apart from the regulation on Sensitive Coastal Areas.
	National Heritage Resources Act (1999)	DFFE	Provides for managements of national heritage resources (including landscapes and natural features of cultural significance, and for participation of communities in the identification, conservation and management of cultural resources
White Paper for Sustainable Coastal Development in South Africa (2000)	National Environmental Management: Integrated Coastal Management Bill	DFFE	Provides for integrated coastal and estuarine management in South Africa, and sustainable development of the coastal zone, defines rights and duties in relation to coastal areas; includes a National Estuarine Management Protocol for South Africa, and requires that estuarine management plans be developed and implemented for all estuaries

White Paper (= Policy)	Bill or Act (= Law)	Lead agent	Implications
White Paper on Spatial Planning and Land-use Management (2001)	Local Government: Municipal Systems Act (2000)	Department of Provincial and Local Government (DPLG)	Requires each local authority to adopt a single, inclusive plan for the development of the municipality intended to encompass and harmonise planning over a range of sectors such as water, transport, land use and environmental management.
White Paper: Mineral and Mining Policy for South Africa (1998) White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity (1998)	Mineral and Petroleum Resources Development Act (2002)	Department of Energy (DE)	Deals with environmental protection and management of mining impacts, including sand and coastal mining.
Protected areas			
	National Environmental Management: Protected Areas Act (2003)	DFFE	Provides for the protection and conservation of ecologically viable areas representative of South Africa's biological diversity and its natural landscapes and seascapes; and for establishment of a national register of national, provincial and local protected areas, describes the different types of protected areas that can be declared which may also apply to estuaries (repeals Section 43 of the Marine Living Resources Act (1998)).
	World Heritage Convention Act (1999)	DFFE	Provides for the incorporation of the World Heritage Convention into South African Law, and for the recognition and establishment of World Heritage Sites in South Africa
	National Environmental Management: Biodiversity Act (2004)	DFFE	Provide for the conservation of biological diversity, and regulates sustainable use of biological resources
Use of living resources & MPAs			
Marine Fisheries Policy for South Africa (1997)	Marine Living Resources Act (1998)	DFFE	Regulates living resource use within marine and estuarine areas, mainly through licensing.

Table 2-2. Summary of provincial acts/policies which affect estuarine management, water quality and quantity in estuaries in general, landing use, development and resource use in the estuarine environment.

Act/Ordinance	Lead agent	Implication
Municipal Ordinance (Cape) (1974)	DEA&DP	Grants local authorities in the province of the Western Cape the power 'to drain storm water into any natural water course'.
Land Use Planning Ordinance (1985) as amended	DEA&DP	Provides for the establishment of the Western Cape Nature Conservation Board. Most planning applications received by the provincial department are in terms of this Act including applications for departure, rezoning or subdivision and appeals against planning decisions taken by a municipality.
Western Cape Planning and Development Act (1999)	DEA&DP	Provides guidelines for the future spatial development in province of Western Cape.
Nature Conservation Ordinance (1974)	Western Cape Nature Conservation Board (WCNCB)/ CapeNature	Provides for the establishment of provincial, local and private nature reserves and the protection of indigenous species of flora and fauna. Protected and endangered species of flora and fauna are listed in schedules to the ordinance. It is administered by the Western Cape Nature Conservation Board (WCNCB) and grants certain powers to the WCNCB.

2.2 Estuary water quantity and quality requirements

Currently, conservation in estuaries is achieved through a number of different legislative Acts including ICMA, the Marine Living Resources Act 18 of 1998 (as amended) (MLRA), the National Environmental Management: Protected Areas Act (Act No.57 of 2003) (NEM:PAA), and the National Environmental Management: Biodiversity Act (Act No. 10 of 2004) (NEM:BA). With the exception of the ICM Act, all of the acts listed above are able to provide explicit protection for living and non-living resources below the high-water mark only (viz. the MLRA) or above the high-water mark only (the rest).

Maintenance of an adequate supply of freshwater to estuaries is provided for under the National Water Act (NWA) (Act 36 of 1998). This Act also requires a specific water use licence for any development within the 1:100-year flood line. All development in this zone is actively discouraged, due to the predicted changes in climate and associated possibility of increased flood events. In addition, the Estuarine Functional Zone (EFZ), as delineated by a 5 m above mean sea level (MSL) contour as proxy indicator, restricts certain activities within an estuary without prior Environmental Authorisation as per the 2014 Environmental Impact Assessment Regulations (GNR 985) under NEMA (1998).

The White Paper on National Water Policy for SA (1997) promotes efficiency, equity and sustainability in the use of water resources through its slogan "some, for all, for ever". The policy explicitly recognises the environment as a legitimate user of water and makes provision to protect the environment from overexploitation of water resources. The NWA makes provides the legal framework for this policy, making provision for a water "Reserve" required to meet basic human needs as well as provision of water in the required quantity and quality to support aquatic ecosystems and to protect the natural functioning of a water resource. The latter portion of the reserve is known as the Environmental Reserve.

The published classes and resource quality objectives of water resources stipulate that the Diep Estuary is to be maintained at a minimum D Ecological Category (DWS 2019) (Table 2-3). This indicates that there has been a large shift in natural processes and ecosystem functions from the natural condition (Van Niekerk et al. 2019). The worst assessed category were invertebrates, with a rating of Critically Modified “F”, and four categories classed as “E” Severely Modified, and includes water quality, macrophytes, fish, and the physical environment (Table 2-3 and Table 2-4). Finally, the three categories with the “best” overall rating are hydrology and birds, both with a score of “C”: Moderately Modified, and Hydrodynamics, with a score of “B”: Near Natural with Few Modifications (Table 2-3 and Table 2-4). Although overall 2018 score represents a degraded system, there has been a negative shift in the system since then (see Section 3.4.1), with substantial deteriorations in water quality in recent years, and a near-complete collapse in the fish community (see Section 3.6.3).

Table 2-3. Ecological health categories assigned to Estuaries.

Condition (% of pristine)	Present ecological state	General Description
≥91%	A	Unmodified, approximates natural condition: The natural abiotic processes should not be modified. The characteristic of the resources should be determined by unmodified natural disturbance regimes. There should be no human induced risks to the abiotic and biotic processes and function.
76--90	B	Near natural with few modifications: A small change in the natural habitats and biota may have taken place, but the ecosystem functions are essentially unchanged
61-75	C	Moderately modified: A loss and change of the natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
41-61	D	Heavily modified: A large shift in natural processes and ecosystem functions and/or loss of habitat, biota have occurred.
21-41	E	Severely modified: The loss of natural habitat, biota and basic ecosystem functions is extensive.
≤20	F	Critically Modified: Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural abiotic processes and associated biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.

Water quality objectives (in terms of hydrology, flows, hydrodynamics, physico-chemical parameters as well as bacteria and phytoplankton.) are the key components of this management and are summarised in Table 2-5 below.

Table 2-4. Ecological categories associated with individual components of the Diep Estuary as of 2018 (Van Niekerk et al. 2019).

NBA 2018 Condition Status:			
Present Ecological State (2018)	D	Microalgae	D
Hydrology	C	Macrophytes	E
Hydrodynamics	B	Invertebrates	F
Water Quality	E	Fish	E
Physical habitat	E	Birds	C

Table 2-5. Diep Estuary Water Quality Objectives (adapted from City of Cape Town and Infinity Environmental (2022).

<table>
<tr><th>Indicator</th><th>Water quality objective RQO</th><th>Threshold of potential concern</th></tr>
<tr><td>Flow</td><td>Maintain freshwater inflow adequate to maintain water quality and habitat suitable for flora and fauna. Specifically, ensure that Mean Monthly Runoff (MMR) and Mean Annual Runoff (MAR) meet the following parameters as a percentage of natural / reference values:
<table>
<tr><td>Months</td><td>Oct</td><td>Nov</td><td>Dec</td><td>Jan</td><td>Feb</td><td>Mar</td><td>Apr</td><td>May</td><td>Jun</td><td>Jul</td><td>Aug</td><td>Sep</td><td>Annual</td></tr>
<tr><td>MMR/MAR (% Nat)</td><td>80 %</td><td>80 %</td><td>80 %</td><td>93 %</td><td>100 %</td><td>100 %</td><td>80 %</td><td>80 %</td><td>80 %</td><td>80 %</td><td>80 %</td><td>80 %</td><td>80 %</td></tr>
</table></td><td>Total freshwater inflow should not drop below 0.3 m^3/s or 0.8 Mm^3 / month.</td></tr>
<tr><td>Salinity</td><td>Average salinity in lower estuary (Milnerton Lagoon) = 20, maximum = 35</td><td>Average salinity in lower estuary (Milnerton Lagoon) < 15, maximum > 35</td></tr>
</table>

3 DESCRIPTION OF AFFECTED ENVIRONMENT

3.1 Overview

An "estuary" or "estuarine system" has been defined as "a body of surface water that (a) is permanently or periodically open to the sea; (b) in which a rise and fall of the water level as a result of the tides is measurable at spring tides when the body of surface water is open to the sea; or (c) in respect of which the salinity is higher than fresh water as a result of the influence of the sea, and where there is a salinity gradient between the tidal reach and the mouth of the body of surface water.'' The Diep Estuary is classified by the 2018 National Biodiversity Assessment (NBA) as a 'Heavily Modified' system, meaning that a large shift in natural process and ecosystem function and/or loss of habitat and biota have occurred.

The hydrodynamic function and characteristics of an estuary is affected by several key drivers. As estuaries form the interface between the marine and freshwater environment, oceanic factors can play a significant role in the hydrodynamic and biogeochemical characteristics of a system. These oceanic influences include sea level variations from tides and weather effects (i.e., storm surges), as well as water quality parameters such as salinity (the most important in this case), temperature, dissolved oxygen and nutrient concentrations. In a similar fashion, the quantity and quality of freshwater entering the system (and changes thereof) is critical in shaping form and function. Channel morphology and sediment structure (which is often determined by freshwater inflow) as well as external influences on the system such as wind, rain, air temperature, insolation and evaporation, also affect the manner in which the water circulates and mixes within the estuarine system.

A detailed Situation Assessment for the Diep Estuary is presented in Infinity Environmental (2023) as well as the Diep River Estuarine Management Plan (City of Cape Town and Infinity Environmental 2022) and is not repeated in full here. However, some aspects critical to the model set up (including mouth state and salinity profiles) are summarised below. Note that while no detailed surveys on biodiversity have been conducted since 2021, it is assumed that the situation has deteriorated further, based on the deteriorating water quality parameters.

3.2 Catchment, climate and hydrology

The catchment of the Diep Estuary system is approximately 1 495 km^2, and falls within the City of Cape Town, West Coast and Cape Winelands District Municipalities (Infinity Environmental 2023). The Diep River catchment and the main tributaries of the Diep River are the Mosselbank, Swart and Riebeek Rivers (DWS 2017) (Figure 3-1). While the catchment falls within the Fynbos Biome, the predominant land use within the catchment is agriculture, with urban residential and industrial development in the area immediately surrounding the estuary (DWS 2017).

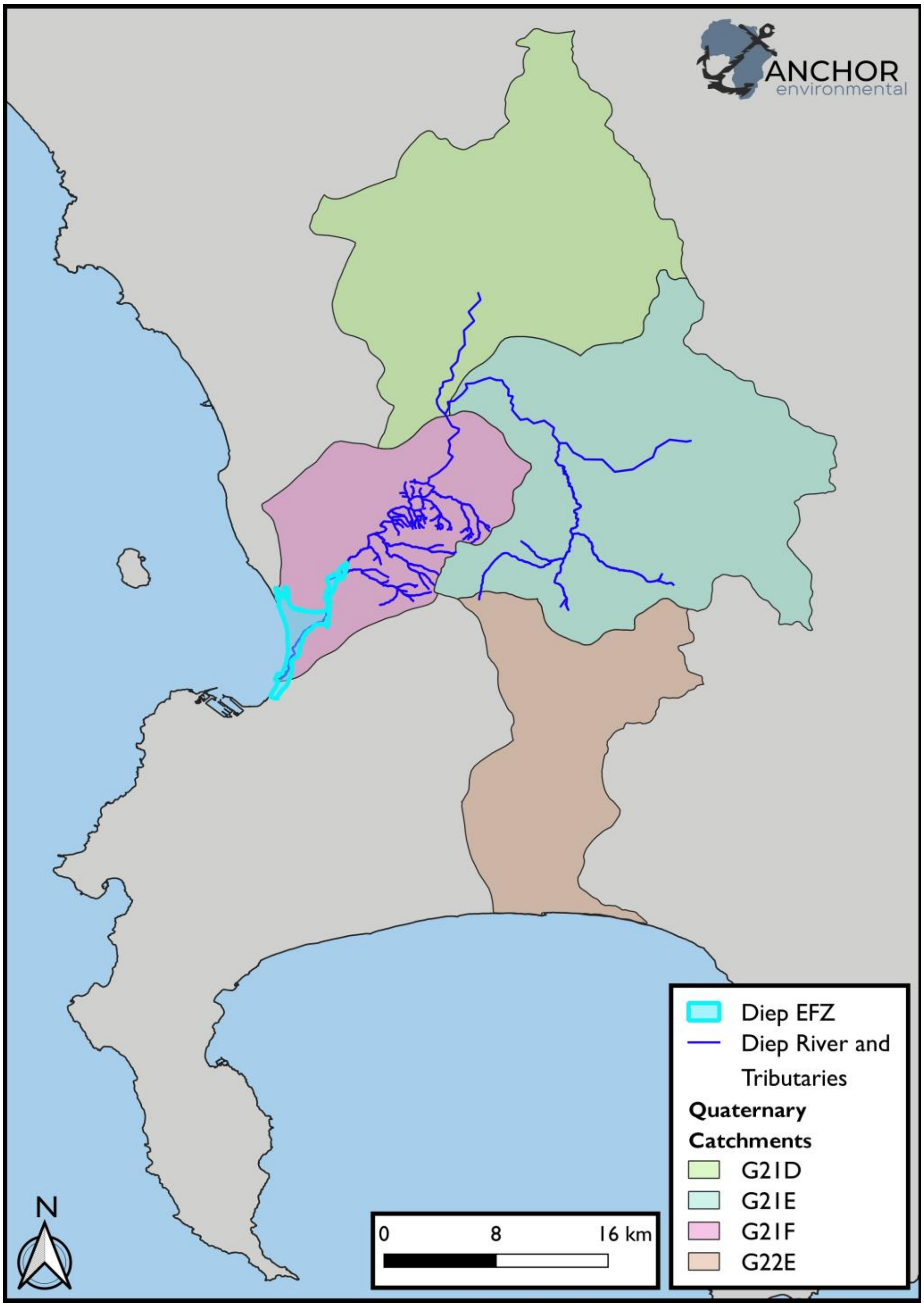

Figure 3-1. Quaternary catchments of the Diep River System.

Hydrology in the catchment is strongly seasonal — the Diep Estuary is situated within the cool temperate Western Cape, an area characterised by winter rainfall and dry summers (Figure 3-2). While the mean annual precipitation for the catchment is approximately 500-600 mm (Jackson et al. 2008), long term data show variability between years, with clear evidence of the 2015-2017 Western Cape drought evident in the lower average rainfall over each of these three years relative to 'wetter' years (2023, for example) (Figure 3-2).

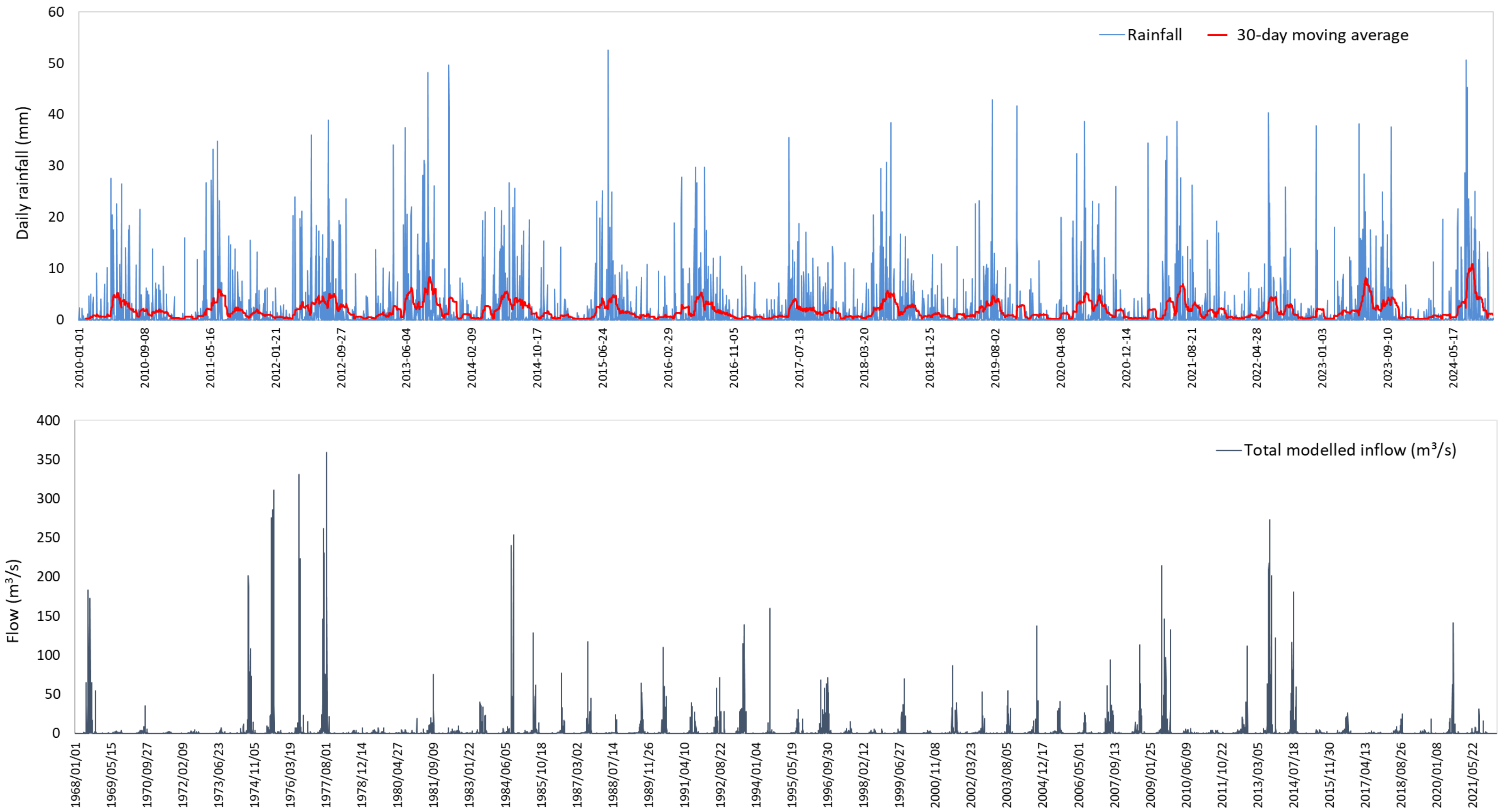

Figure 3-2. (Top) Daily precipitation averaged over 1-hour increments with a 30-day running average from 2010-2024 (data from ERA5 for Cape Town). (Bottom) Simulated Diep River flows from 1968-2022 (Infinity Environmental 2023).

The hydrological functioning within the Diep Estuary catchment has experienced substantial anthropogenic change. Flows entering the catchment have reduced significantly from the natural levels of 60.8 million cubic metres per year (Mm^3/a) to present levels of 37.3 Mm^3/a (a 39% reduction), mainly as a result of agricultural abstraction of water (Clark 2018). Modelled inflow data for the Diep Estuary (Infinity Environmental 2023) as well as flow data measured at DWS gauge G2H042[1] show a cyclical pattern in the natural flushing of the estuary by floods (floods larger than 50 m^3/s) from the Diep River catchment (Figure 3-2 and Figure 3-3). Modelled data show no floods over 50 m^3/s for 1969-1973 (five years), and again from 2015-2019 (four years) i.e., there appears to be some historical precedence for years with no floods to scour the system (Figure 3-3). However, historically, large floods have followed these periods of lower peak flows (for example, in 1974 there were nine days where flows exceeded 50 m^3/s, and of those, flows exceeded 100 m^3/s three times) (Figure 3-3). In contrast, after four years of no modelled flows >50 m^3/s from 2015-2019, there was only two days of flows >50 m^3/s in 2020 (of which, one was >100 m^3/s) (Figure 3-3). While modelled data only extends to 2022, there is a flood peak of >50 m^3/s in measured gauge data in 2023 (four events), which likely translates to similar flows at the head of the estuary (Figure 3-3).

Of particular interest here is that there are eight days of flows >50 m^3/s in measured gauge data in 2024 (compared to four in 2023, and two in 2020) (Figure 3-3). This represents a significant flood event, which scoured the estuary in some areas (Gus Holm, pers. Comm. 2024).

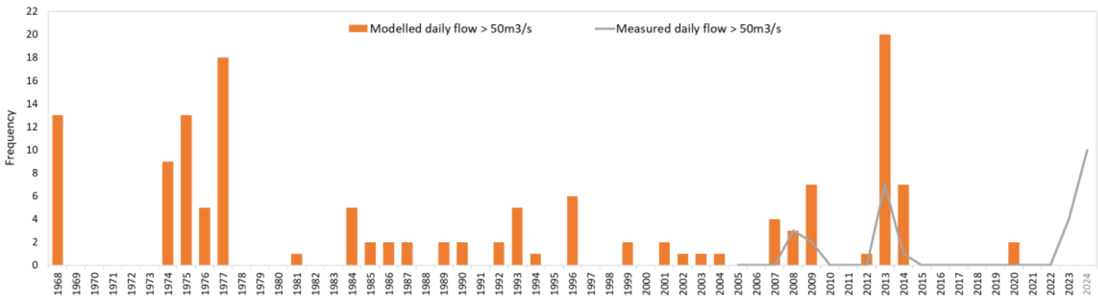

Figure 3-3. Annual frequency of modelled (Infinity Environmental 2023) and measured (DWS flow gauge G2H042) flow days exceeding 50 m^3/s (the flow required to flush the estuary).

The estuary flows are supplemented by 20.7 Mm^3/a of treated wastewater from the Potsdam WWTW (Figure 3-4 and Figure 3-5). Indeed, during periods of low flow (i.e., the dry summers), the WWTW discharge makes up most of (if not all of) the freshwater inflow at the head of the estuary (Figure 3-5). The Potsdam WWTW has been granted environmental authorisation to increase its treatment capacity from 47 000 m^3/day to 100 000 m^3/day, which, if fully utilised, would increase supplementary flows by an additional 10.3 Mm^3/a (Infinity Environmental 2023).

[1] This is the closest gauge to the head of the Diep Estuary; note however that there are other tributaries lower down the catchment whose flow is not captured in this data set.

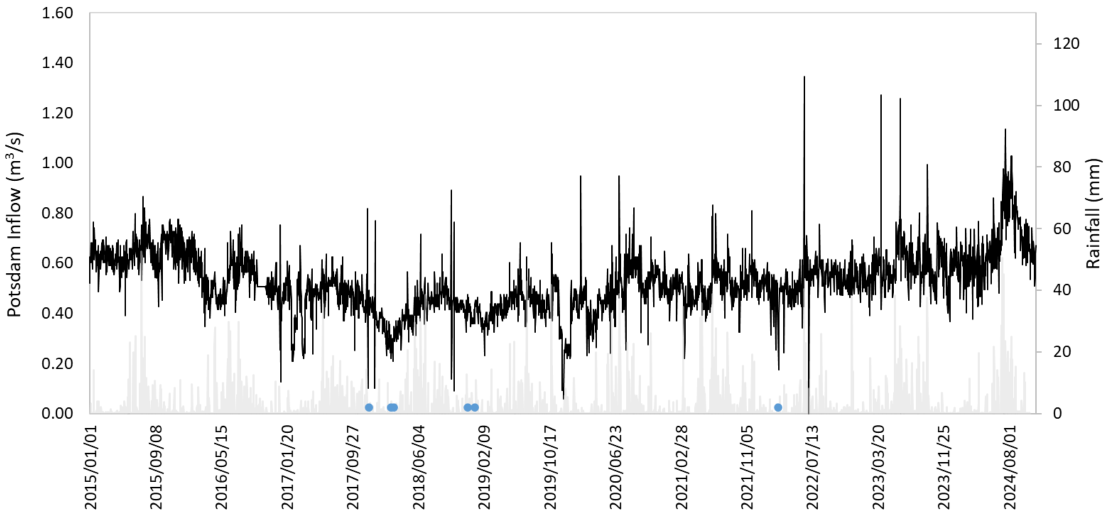

Figure 3-4. Potsdam WWTW inflow (data from the City of Cape Town 2024, shown in black) from January 2015-November 2024, with rainfall (derived from ERA 5 analysis, shown in grey). The blue dots indicate dates when the mouth was closed/was almost closed in available satellite imagery (Google Earth 2024).

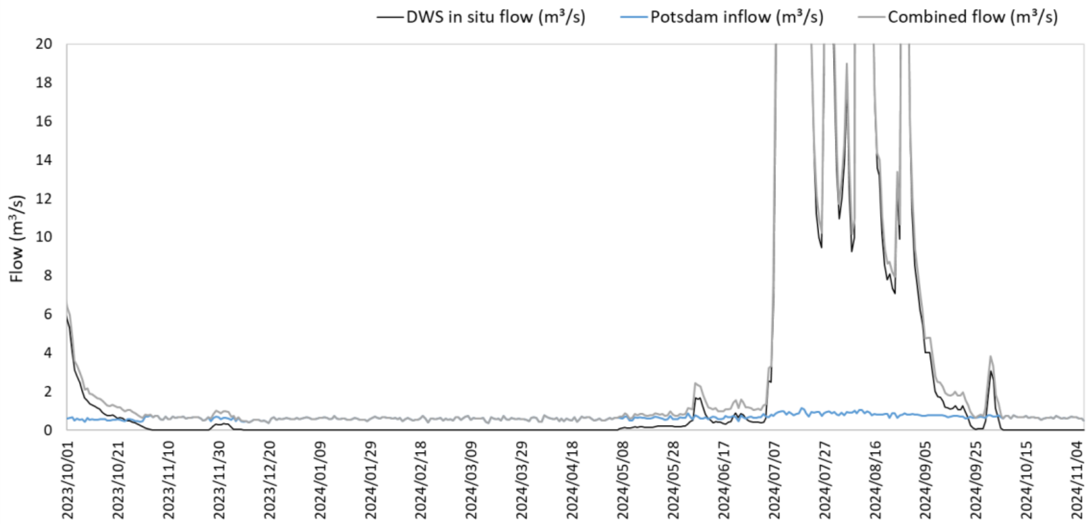

Figure 3-5. An example of how the Potsdam WWTW freshwater effluent (blue line) makes up most of, and in some cases, all of, the freshwater flow entering the Diep Estuary during dry summer seasons (periods of low flow). The DWS flow data is from gauge G2H042.

3.3 Hydrodynamics and mouth state

The lower reaches of the Diep Estuary (i.e., the Milnerton Lagoon) are canalised, with the banks stabilised by road embankments and bridges. This development constraints the natural movement of the mouth to the north and south, as would be the case prior to development (i.e., in its reference state) (Infinity Environmental 2023). Under reference conditions, the mouth would also close during the dry summer months of low rainfall inflow; however, the inflow from the Potsdam WWTW has historically been sufficient to keep the mouth open on an almost permanent basis (City of Cape Town and Infinity Environmental 2022, Infinity Environmental 2023). During some periods (such as in the dry summer seasons of 2017-2018), the Potsdam WWTW inflow has not been sufficient, and the mouth has closed (examples are presented in Figure 3-6). These dates often coincide with periods of low rainfall and/or low Potsdam flow (Figure 3-6). The 2022 EMP notes that a "permanently open mouth state is preferred to avoid accumulation of nutrients and pathogens in the estuary", and that there is an increased likelihood of mouth closure during drought conditions, which needs to be accounted for under climate change planning (City of Cape Town and Infinity Environmental 2022).

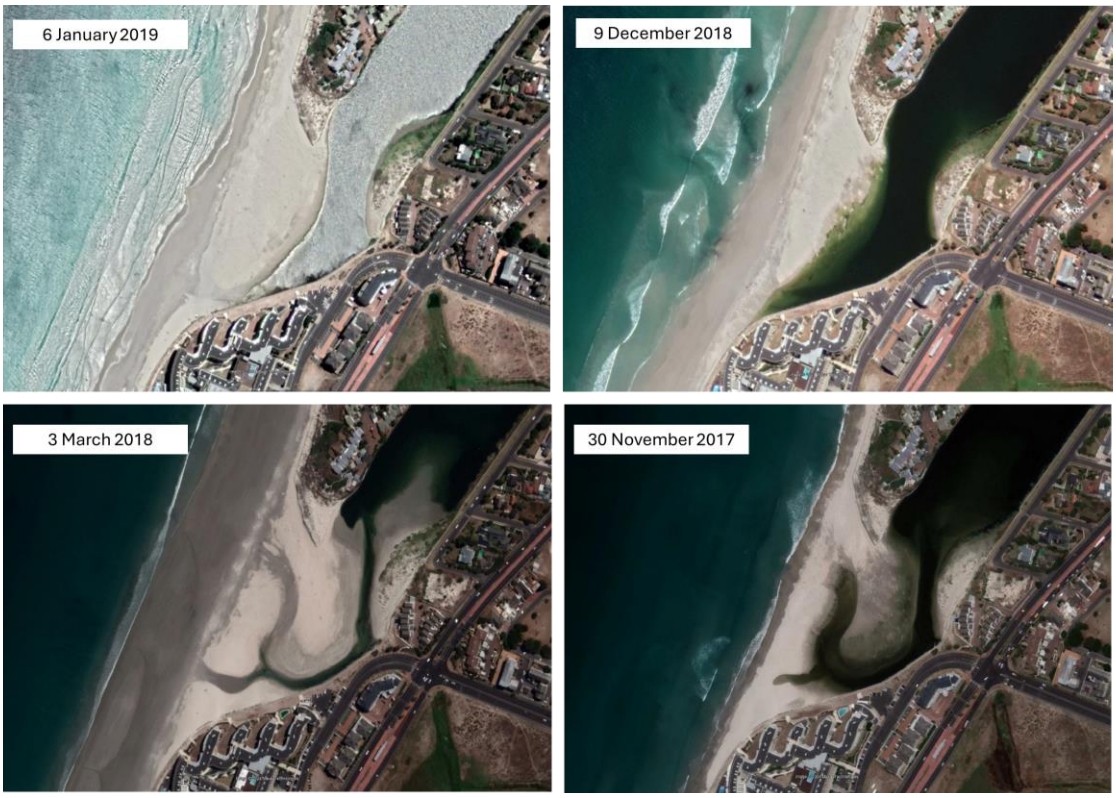

Figure 3-6. The closure of the lagoon mouth is evident in satellite images on 30 November 2017 and 9 December 2018 (images courtesy of Gus Hojem, 2024).

3.4 Water quality

3.4.1 General overview

There have been significant changes in water quality within the Diep Estuary over the years, and the system no longer "functions in a completely natural fashion" (City of Cape Town 2016, Viskich et al. 2016). These changes include large shifts in salinity within the system, as well as increases in nutrient and microbial pollution. The primary source of microbial and nutrient pollution in the Diep River can be traced to agricultural runoff in the greater Diep River catchment, discharge of the Potsdam WWTW effluent water into the system, and a number of large stormwater drains that discharge directly into the Diep Estuary.

Faecal indicator bacteria (i.e., *Escherichia coli* (*E. coli*) and intestinal enterococci) can be used as a bacterial indicator of faecal pollution arising from sewage as well as from livestock and domestic animals. The presence of faecal pollution may indicate the presence of pathogens responsible for infectious diseases (City of Cape Town and Infinity

Environmental 2022). Due mainly to the treated effluent entering the Diep River from the WWTW, *faecal bacteria levels* in the Diep Estuary are high and increasing (City of Cape Town and Infinity Environmental 2022). This suggests that the effluent is not being sufficiently treated before it is discharged. Sewer spills, overflows and illicit discharges into the stormwater system are also a problem (City of Cape Town and Infinity Environmental 2022).

Also associated with the influx of effluent and stormwater are the high nutrient levels in the Diep Estuary. Phosphorus and nitrogen input into rivers and estuaries can result in nutrient enrichment and eutrophication. Inorganic nitrogen levels in the Diep Estuary exceeded the Resource Quality Objective (RQO) for nitrogen, and appear to have worsened over the last decade, which has been attributed to upstream inputs (City of Cape Town and Infinity Environmental 2022). The 2016/2017 drought also had a major impact on nitrogen levels, as the intermittent closing of the estuary mouth resulted in stagnant conditions. Linked to these elevated inorganic nitrogen levels are "Unacceptable" ammonia concentrations in the lower estuary in recent years. Indeed, as a result, the City has erected signboards close to the development site stating that the water within the estuary is "polluted", and "unfit for swimming, playing or drinking" (Figure 3-7) (City of Cape Town 2020, Payne et al. 2023).

Figure 3-7. Stagnant conditions observed in the lower Diep Estuary in February 2022 (top left and right). A signboard erected by the City of Cape Town on the banks of the lower Diep Estuary cautions users about the polluted water (bottom) (Payne et al. 2023).

Associated with this organic loading from anthropogenic sources is a decrease in dissolved oxygen (DO) in the system. This is an ongoing issue — sampling undertaken on 5 August 2022 indicated that the water was warm and very poorly oxygenated (0.41-4.49 mg/L), with highest oxygen readings at the mouth of Milnerton Lagoon with progressive decline further upstream (Gammon & Clark 2022). The DO concentration decreased substantially during October and November 2024 to 3.47 mg/L (a ~50% decrease in DO).Indeed, DO levels measured at the Otto du Plessis bridge are low (generally < 4 mg/l since 2014 and 0 mg/L since January 2024), reflecting the organic pollution load from upstream sources (City of Cape Town and Infinity Environmental 2022).

Measured data for March-June 2024 at Woodbridge Island shows that DO levels fluctuate substantially, between 0 mg/L and 28.6 mg/L (Figure 3-8). DO peaks are followed almost immediately by a substantive decline to 0 mg/L, which is indicative of high levels of organic loading (eutrophication) (Figure 3-8).

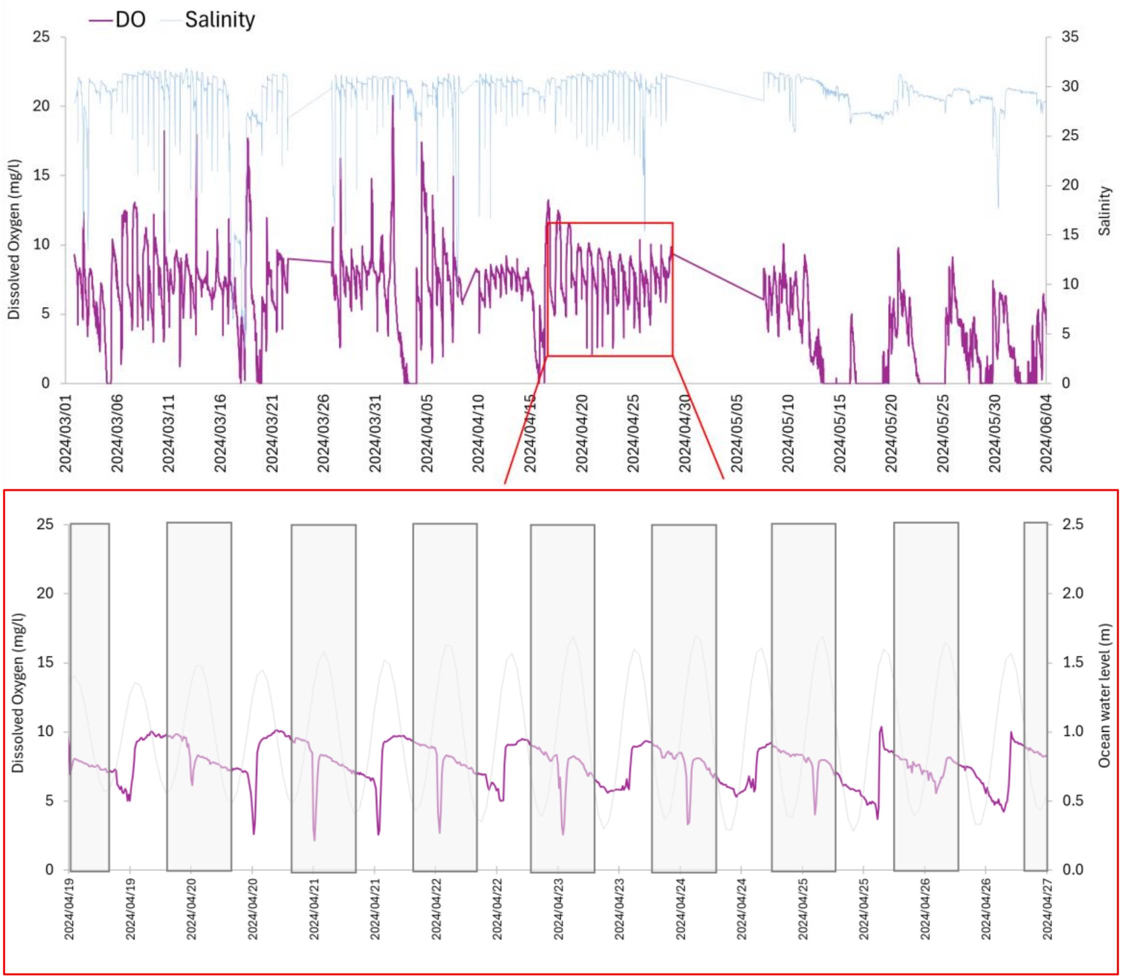

Figure 3-8. (Top) Dissolved oxygen (mg/L, shown in purple) against salinity (blue) for the deployment period of an AquaTROLL near Woodbridge Island (data provided by Infinity Environmental). The depth is not specified. (Bottom) Detailed diurnal patterns in DO (purple) across a relatively stable period of measurements. The grey shaded areas indicate night hours. Tides in Table Bay are shown in light grey (note that there is a tidal lag up the estuary).

The DO fluctuations do show a diurnal pattern — increased photosynthetic activity in the system during daylight hours results in increased oxygen levels, which decrease again during the night (daytime low oxygen levels of 2-5 mg/L, and nighttime levels of 1-4 mg/L) (Figure 3-8). However, there are substantive, and very rapid decreases in DO levels at or just after slack tide towards low tide, an effect magnified under neap tide conditions. At low tide, most of the estuary comprises low oxygen freshwater from the WWTW. Oxygen levels increase very rapidly as the tide turns and pushes in again, with more oxygenated oceanic water (Figure 3-8). This indicates that this tidal forcing, whilst small, is of critical importance to oxygen levels of the system. Should the mouth be permitted to close, it is likely that do levels would decrease very quickly to 0 mg/L, and it is uncertain if renewed tidal flushing alone will be sufficient to reverse the trend.

While low, DO levels in the lower estuary are higher than in the upper estuary, presumably due to tidal flushing. Reduced DO in the lower estuary over the past few years is correlated with increased ammonium nitrogen: total inorganic nitrogen ratios as well as increased reporting on hydrogen sulphide odours in this area, all indicative of high chemical and biological oxygen demand that exceeds oxygen availability (Infinity Environmental 2023).

3.4.2 Salinity

Salinity refers to the dissolved salt content in seawater. Typical temperate ocean salinities range between 33–36, but the input of fresh water from large rivers can result in slightly reduced salinities near river mouths. Estuaries are typically much more variable, and salinity can range from zero when freshwater input is high, to 35 when the estuary is filled with sea water, and can even become hypersaline (>35) as a result of evaporation when the estuary mouth is closed. Anthropogenic influences on salinity in estuaries can originate from water abstraction and/or wastewater discharges into the catchment, which, depending on the volume discharged, can result in short-term decreases or increases in salinity in the estuary. More serious impacts can be caused by hypersaline discharges from, for example, reverse osmosis plants. Typical water quality problems which may be associated with abnormal salinity levels include growth deficiencies, lowered reproduction, changes in water pumping rates (e.g. in filter feeding organisms or for respiration), changes in moulting patterns and mortalities of marine and estuarine biota.

Salinity is strongly linked to estuary health, and low salinities have been linked to major changes in the faunal composition of the Diep Estuary (Viskich et al. 2016). For example, sandprawn populations have declined dramatically, and they are known to burrow deeper to reach their preferred salinity (>16), which has knock-on effects for waterbirds and fish which feed on these invertebrates, as well as bait collectors (Viskich et al. 2016). In addition to being food for higher trophic groups, sandprawns are also known to improve water and sediment quality in estuaries, so their loss has even wider impacts (Pillay & Branch 2011). Many species of benthic invertebrates are no longer found in the estuary, and freshwater-associated species have become more dominant (see Section 3.6.2) (Gihwala et al. 2021). The Diep Estuary used to fulfil an important role as nursery habitat for larval and juvenile fish, which are now much less abundant (see Section 3.6.3) (Viskich et al. 2016, Gammon & Clark 2022). Freshwater, high-nutrient conditions that are increasingly observed in the estuary may lead to the proliferation of Cyanophytes (blue-green algae) and other microalgae, some of which are toxic (Infinity Environmental 2023).

In the past, the Diep Estuary mouth would close periodically during summer (see Section 3.3). With the addition of high evaporation rates, a reverse salinity gradient would develop, with hypersaline conditions observed at the vlei part of the estuary near Otto du Plessis bridge. This pattern can be observed in the 1954 and 1974 data (see Figure 3-9), and was reported to be important in structuring the fauna in the system (Viskich et al. 2016).

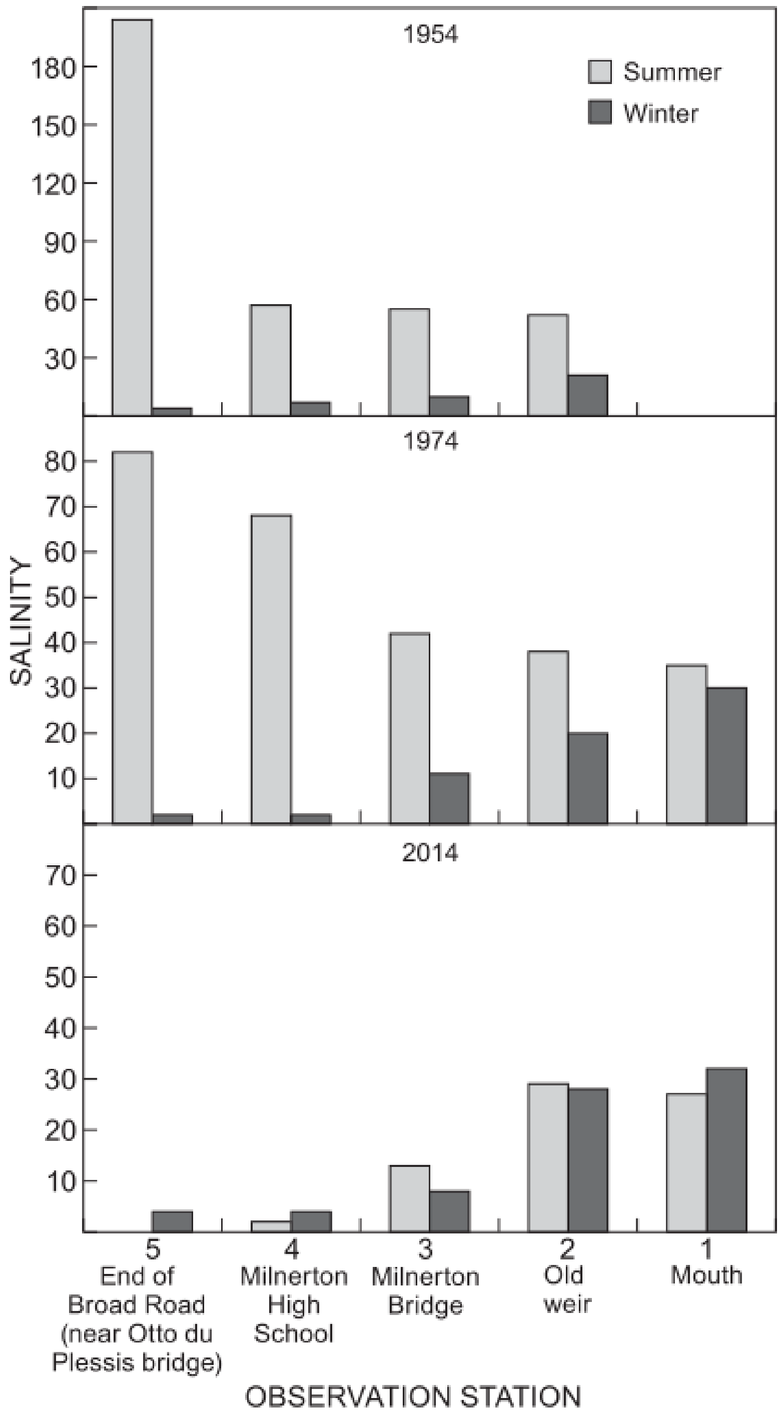

Figure 3-9. Salinity measurements taken at observation stations (names and numbers shown) in Milnerton Lagoon during winter and summer, in 1954 (Millard & Scott 1954), 1974 (Weil unpublished data) and 2014 (Viskich et al. 2016). The 1954 bar graph shows the average salinity taken in each season during the period 1948–1953. Source: Viskich et al. (2016).

In recent years, the discharge from the Potsdam WWTW into the estuary has maintained flow levels such that the estuary mouth has remained open almost permanently, but also that salinity has been majorly reduced compared to the salinity levels recorded in 1954 and 1974 (Figure 3-9) and relative to reference condition (Table 3-1), with little seasonal change. Currently, summer flows consist mainly of effluent from the WWTW (Viskich et al. 2016), and the system is increasingly freshwater dominated. Data for 2001-2010 showed significant salinity penetration in the lower and middle reaches of the Diep Estuary, with values regularly going above 30 PSU in the lower reaches. The average salinity was 14 at the Otto du Plessis bridge (DWS 2017).

Table 3-1. Salinity model for the Diep Estuary (DWS 2017).

State	Reference			2017		
Physical driver	The Estuary was deeper, and saline water could penetrate further upstream. Base flows were lower.			At present the estuary is shallower and the tidal influences are more restricted. Base flow ranges are elevated.		
	Closed	**Open, brackish**	**Open, freshwater dominated**	**Closed**	**Open, brackish**	**Open, freshwater dominated**
Lagoon	40	30	5	40	15	1
Otto du Plessis bridge	20	5	0	15	0	0

Recent monitoring data from the City shows that the average salinity in the Lagoon during the dry season over the period 2017-2020 was fresher (average of 15.3) than for 2021-2023 (average 21.6) (Figure 3-10). This may be because of more frequent mouth closures in the 2017-2020 monitoring period, which coincided with periods of very low flow and fewer flood events compared to the 2021-2024 period (see Figure 3-2, Figure 3-3 and Figure 3-4). These closures likely instead resulted in lower salinity at the mouth during the dry season, as saline inflow from the ocean was stopped, but there was continued general inflow from the Potsdam WWTW (this is challenging to confirm without reliable information about mouth closure occurrence and duration). While the average salinity at the mouth increased to an average of 21.6 in the period 2021-2023, this did not translate to an increase in saline penetration further upstream at Woodbridge Island, likely because of the increasing freshwater inflow from the Potsdam WWTW (Figure 3-10 and Figure 3-4).

New salinity data for March-June and August-November 2024 from AquaTROLL instruments situated at Woodbridge Island and further upstream near the golf course were used to assess the salinity levels in the estuary (Figure 3-11). All of these sites are considered to be part of the 'Milnerton Lagoon' as defined for the Resource Quality Objectives (RQOs) (see Section 2.2, Table 2-5).

The March-June 2024 data indicate that average salinity in the estuary was 13.2 at site US1 and 10.6 at site DS (Figure 3-11 and Figure 3-12), meaning that the salinity does not meet the RQO of > 15 (see Section 2.2). These data also illustrate that while salinity at these sites did fluctuate somewhat with the tides, this fluctuation was minimal, and tidal forcing does not appear to have been strong enough to regularly flush the system (Figure 3-12).

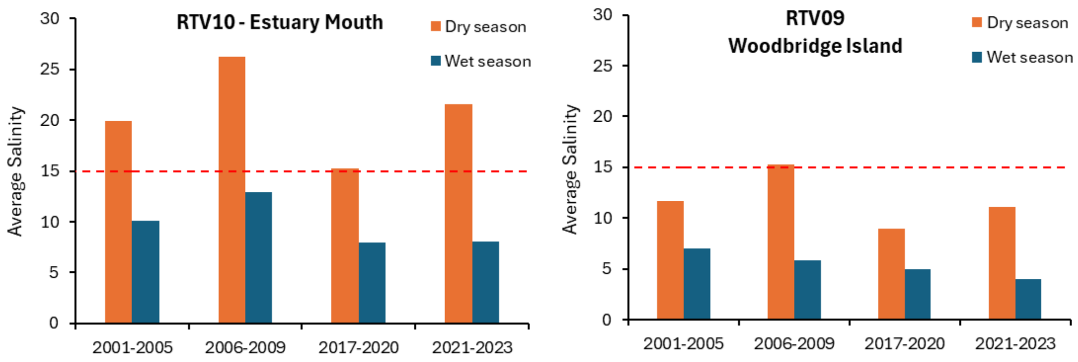

Figure 3-10. Average dry season (1 October-15 April) and wet season (16 April-30 September) salinity from sampling sites on the Diep Estuary (Note that average salinity was calculated from conductivity and temperature data). Source: City of Cape Town 2024 Open Data Portal.

Figure 3-11. Locations of three AquaTROLL instruments situated within the Diep Estuary in 2024 (WB = 'Woodbridge Island', DS = 'Downstream' and US1 = 'Upstream').

The data from the AquaTROLL situated closer to the mouth at Woodbridge Island (WB, see Figure 3-11) for March-June 2024 also shows minimal fluctuation in salinity in the lower estuary, rarely dropping below 21 during this period (Figure 3-12). The average salinity in the lower estuary over this period was 29.1, with a few occasions, mainly linked to high precipitation events, when salinity did decrease (Figure 3-12).

The data from the AquaTROLL located at Woodbridge Island (WB) from spring (August to November) 2024 show a very different pattern (Figure 3-13). Large precipitation events in August 2024, associated with peaks in flow, resulted in major reductions in salinity that lasted over a week, after which the estuary reverted to tidal fluctuations in salinity between ~ 1-30 (Figure 3-13). There is a clear link between precipitation and salinity — high precipitation events coincide with periods of lowered salinity at Woodbridge Island. Although the average salinity in the lower estuary was still below 15, these data represent a better 'flushing' of the system, which will likely have a positive knock-off impact on estuary health (Figure 3-13). This change may be linked to the major flooding which occurred during July 2024 (see Figure 3-5), which scoured the estuary, allowing better flushing and tidal forcing upstream.

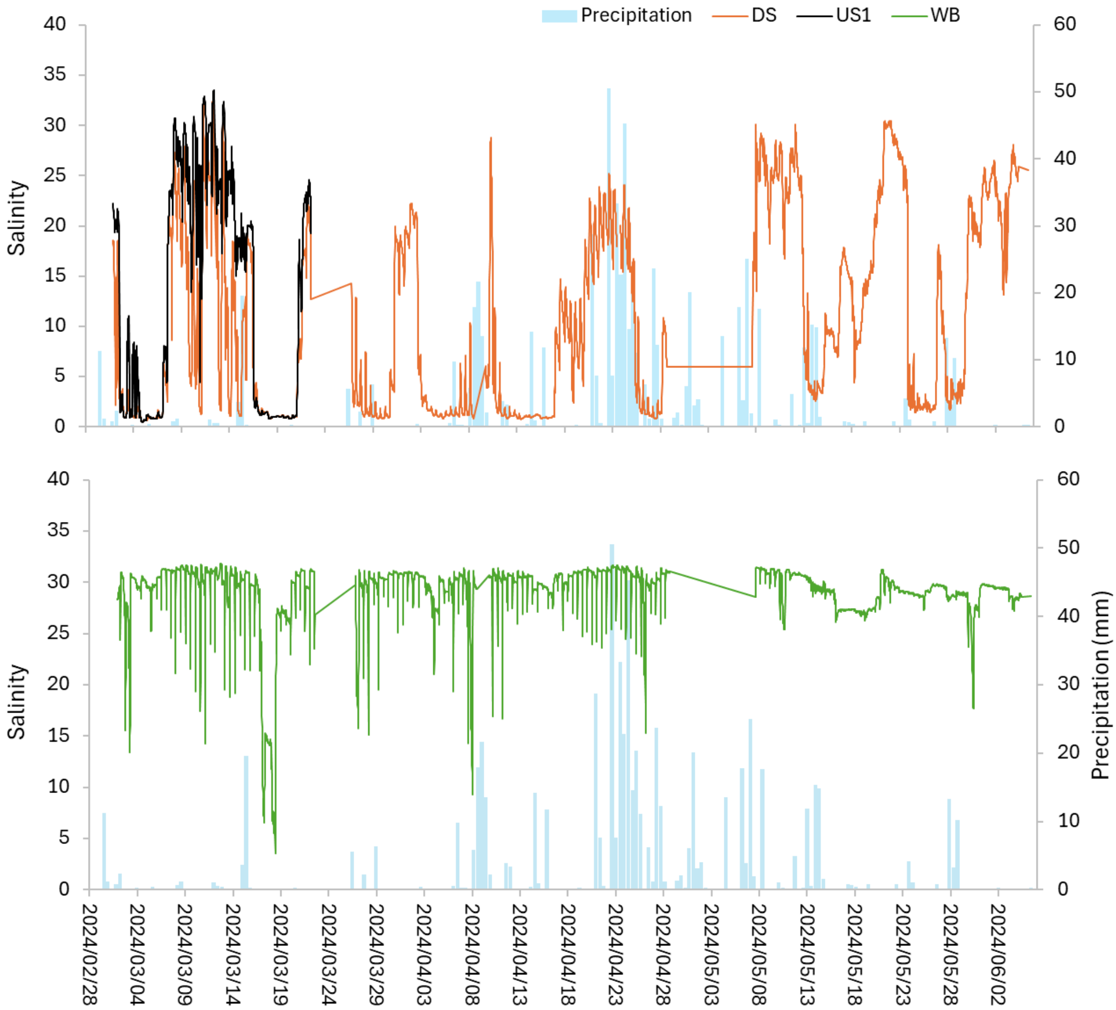

Figure 3-12. Salinity data for March to June 2024 from three AquaTROLL instruments situated within the Diep Estuary (see Figure 3-11 for sites), as well as ERA5 precipitation data for Cape Town.

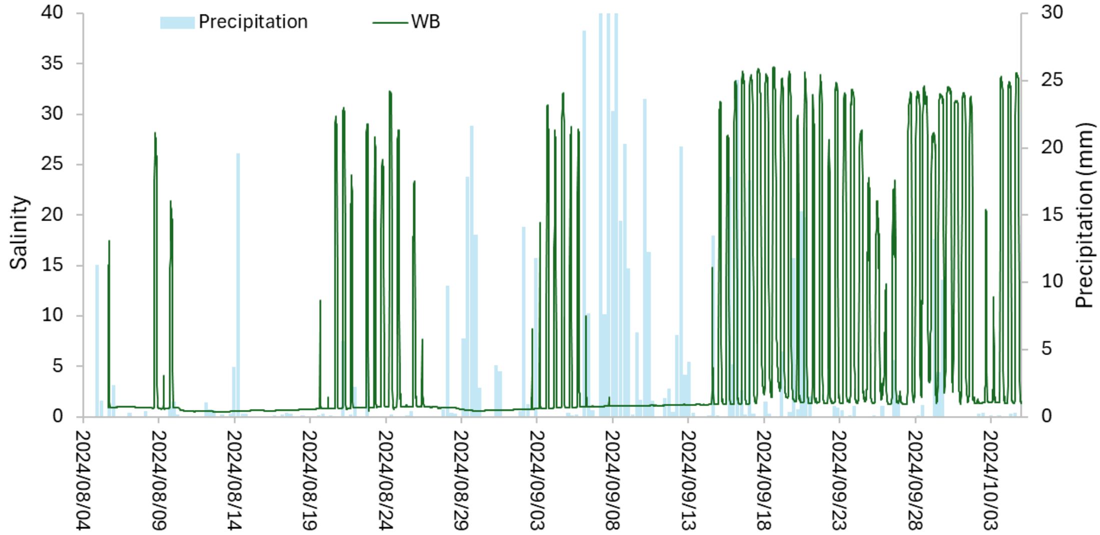

Figure 3-13. Salinity data for August to October 2024 from an AquaTROLL instrument situated in the lower Diep Estuary at Woodbridge Island, with ERA5 precipitation data for Cape Town.

3.5 SEDIMENT

3.5.1 PARTICLE SIZE DISTRIBUTION OR GRANULOMETRY

Estuary sediments are derived from terrestrial and marine sources; weathering, biological and marine processes interact with hydrodynamic and geomorphological processes creating distinct spatial and temporal differences in the size composition and distribution of sediments. This heterogeneous distribution of sedimentary characteristics has both ecological and physico-chemical implications in estuaries. Fine sediments tend to accumulate in regions where there is minimal hydrodynamic disturbance. Conversely, coarse sediments typically remain in high energy regions where current, tidal and wave disturbances are prevalent. Understanding sedimentary characteristics provides valuable insight into the diversity and distribution patterns of benthic macrofaunal communities. Benthic macrofauna respond to differences in sediment properties either as larvae or adults and are thus strongly associated with the sedimentary composition of their habitat (Gray 1974, Etter & Grassle 1992, Bergen et al. 2001, Ellingsen 2002, Anderson 2008).

Particle size analysis of sediments in the Diep Estuary in 2021 indicated that sand was the main component of sediments in the system, with the proportion of mud increasing with distance upstream from the mouth (Figure 3-14 and Figure 3-16) (Gihwala et al. 2021). Mean percentage sand composition ranged between 77-97% of the total sediment particle size distribution, with sites in the vicinity of Woodbridge Island (sites 3-5) having comparatively less sand and a greater mud composition (Figure 3-16). This study reported that these results contained higher proportions of fine sediment in comparison to those reported in earlier surveys by Hutchings & Clark (2010) and CSIR (2015).

Sampling in December 2022 by Tritan Survey and November 2023 and September 2023 by PRDW found slightly greater sand composition near Woodbridge Island, ranging from 86-99% sand (Figure 3-14 and Figure 3-17), suggesting that some of the finer sediments in this area may have been mobilised since the 2021 sampling, most likely due to flooding in 2023 (Gus Hojem, Pers. Comm. 2024). Higher mud content is generally associated with decreased hydrodynamic flow resulting from biotic (e.g., marginal vegetation) or anthropogenic obstructions (Infinity Environmental 2023).

Figure 3-14. Milnerton Lagoon within the Diep Estuary and the location of sediment (1-20) and macrofauna (1-12) sampling sites along system, from June 2021 (Gihwala et al. 2021).

Figure 3-15. Location of sites sampled for sediment granulometry in December 2022, November 2023 and September 2024 by Tritan Survey and PRDW.

These sediment particle size analyses do not appear to 'capture' the levels of sludge present in the system — Infinity Environmental (2023) reports that the lower Diep Estuary is covered in a layer of organic, nutrient-rich fine sediment, or sludge, that originates from the catchment and from poorly treated effluent. This sludge is oxygen-poor and contributes to poor water quality and odour in the estuary.

This sludge has accumulated due to the long absence of natural flushing of the estuary by large floods. The most recent estimates of the sediment and sludge depth is a mean level of +0.2 metres above sea level (masl) in the lower estuary (downstream of the Woodbridge Island bridges) and a mean level of +0.4 masl upstream of the Woodbridge Island bridges (Infinity Environmental 2023). Probes were used to estimate the depth of the sludge, which was up to 2 m thick in some sections of the estuary in December 2022/January 2023. The total volume of sludge in the estuary was estimated at 136 550 m^3 (Infinity Environmental 2023).

3.5.2 ORGANICS AND POLLUTANTS

Apart from granulometry, organic content of the sediment can similarly influence macrofaunal distribution and diversity and plays a part in the accumulation of trace metals and other anthropogenic contaminants (Austen & Widdicombe 2006, Martins et al. 2013). Organic matter derived from either marine or terrestrial origins is also an essential food source for benthic macrofaunal communities and affects the ecological health of the marine ecosystem as a whole.

Contaminants such as metals and organic toxic pollutants are predominantly associated with fine sediment particles (mud and silt). This is because fine grained particles have a relatively larger surface area for pollutants to adsorb and bind to. Higher proportions of mud, relative to sand or gravel, can thus lead to high organic loading and trace metal contamination. Disturbance to the sediment (e.g. dredging) can lead to re-suspension of the mud component from underlying sediments, along with the associated organic pollutants and metals.

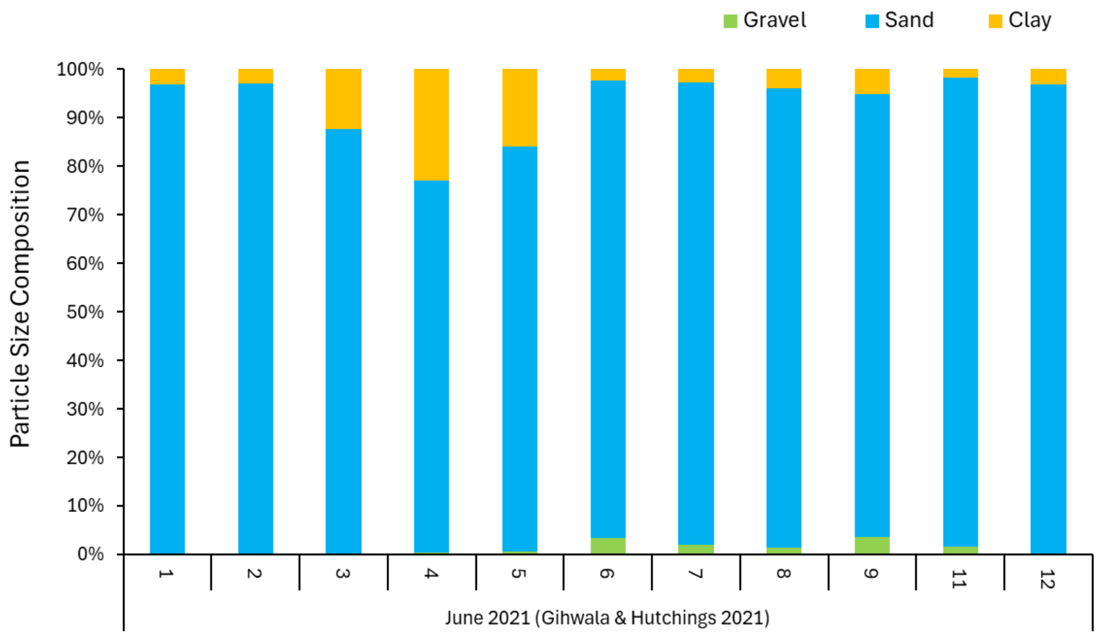

Figure 3-16. Mean cumulative percentage contribution of sediment particle grain size fractions (gravel, sand and mud) sampled at 20 transects on the Diep Estuary on 10-11 June 2021 (Gihwala & Hutchings 2021). See Figure 3-14 for sites.

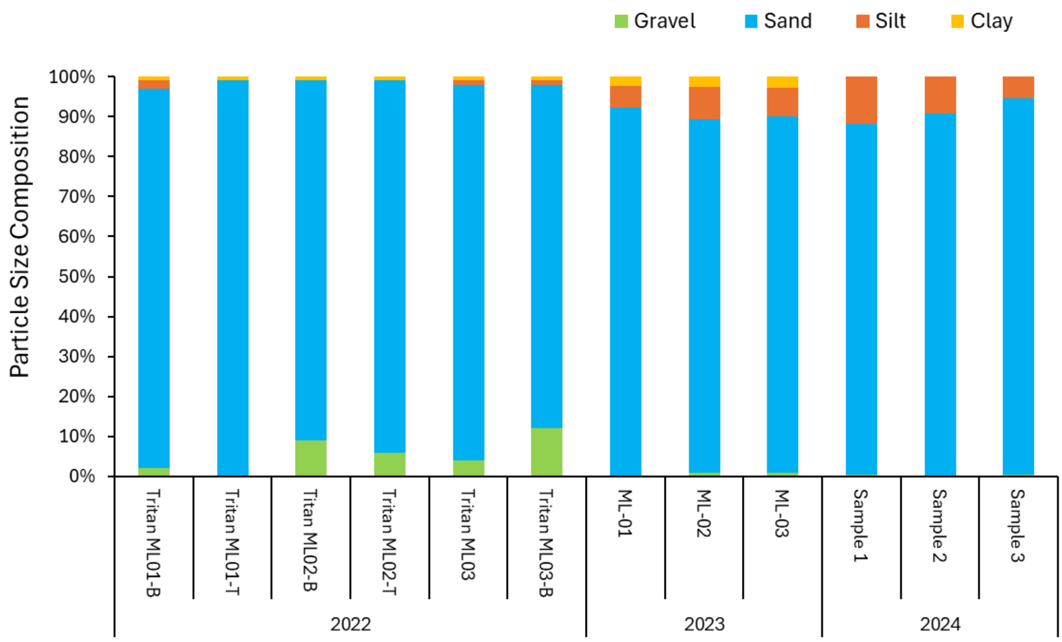

Figure 3-17. Mean cumulative percentage contribution of sediment particle grain size fractions (gravel, sand, silt and clay) sampled at sites (see Figure 3-15) on the lower Diep Estuary in December 2022, November 2023 and September 2024 (data courtesy of Gus Hojem and Jeremy Rose, 2024).

Total organic carbon (TOC) and total organic nitrogen (TON) accumulates in the same areas as mud as most organic particulate matter is of a similar particle size range and density to that of mud particles (size <60 µm) and settles out of the water column together with the mud. Hence TOC and TON are most likely to accumulate in sheltered areas with low current strengths, where there is limited water movement and hence limited dispersal of organic matter. The accumulation of organic matter in the sediments doesn't necessarily directly impact the environment, but the bacterial breakdown of the organic matter can (and often does) lead to hypoxic (low oxygen) or even anoxic (no oxygen) conditions. Under such conditions, anaerobic decomposition prevails, which results in the formation of sulphides such as hydrogen sulphide (H_2S). Sediments high in H_2S concentrations are characteristically black, foul smelling and toxic for most living organisms.

The results of the 2021 survey by Gihwala et al. (2021) indicated lower concentrations of TOC and TON within the lower Diep Estuary in comparison to further upstream, except for the sites in the vicinity of Woodbridge Island (which had higher mud content) and at the Otto du Plessis Bridge (Figure 3-18). Samples from these sites held high inter-sample variability in TOC and TON, with some samples having extremely high organic content, particularly those with finer and darker sediments (Gihwala et al. 2021). The percentage mud in the 2021 samples was significantly positively correlated with both TOC and TON (Gihwala et al. 2021).

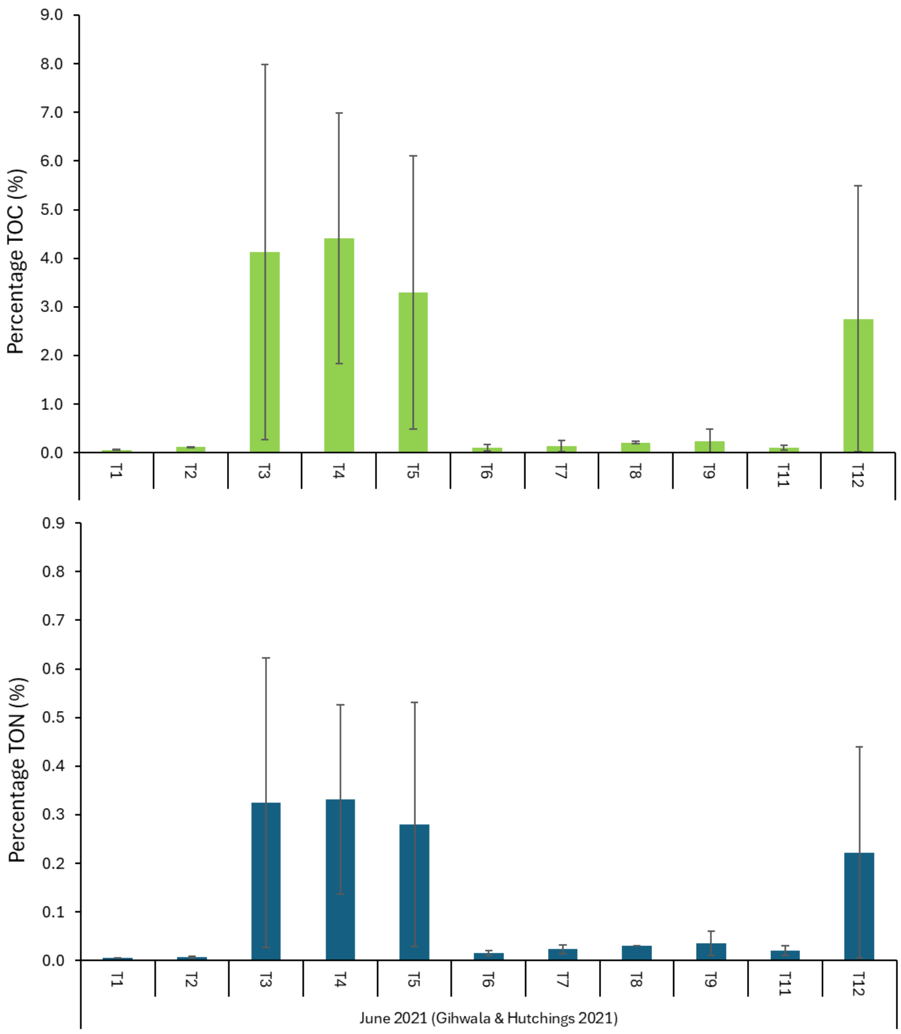

Figure 3-18. Mean percentage of Total Organic Carbon (TOC) and Total Organic Nitrogen (TON) sampled at 20 transects within the Diep Estuary (downstream of the Otto Du Plessis bridge) in June 2021 (adapted from Gihwala et al. 2021).

As stated above, metals are strongly associated with the cohesive fraction of sediment (i.e. the mud component) and with TOC, and this is indeed the case in the Diep Estuary. Four trace metals (arsenic (As), cadmium (Cd), nickel (Ni) and zinc (Zn)) measured along the Diep Estuary in June 2021 exceeded the South African and international sediment quality guidelines (Gihwala et al. 2021). Enrichment factors indicated substantial increases in Cd, Fe and Zn concentrations within the Diep Estuary over the past 32 years. In general, the majority of the trace metals measured in the sediments of the Diep Estuary have become enriched compared to historical surveys. Additionally, the average trace metal concentrations for Cd, Ni and Zn within the Diep Estuary were relatively high in comparison to other local and international estuaries (Gihwala et al. 2021). This is a reason for concern, as such elements are typically elevated by anthropogenic activities and are known to have ecotoxicological effects.

3.6 Biodiversity

3.6.1 Riparian/fringing vegetation

The lower estuarine area below the Woodbridge Island bridge is highly disturbed, with the only remaining "natural vegetation" of environmental significance downstream of the Woodbridge comprising a thin strip of dunes between the Woodbridge Island development (which itself is classified as "transformed habitat of no known conservation significance") and the beach itself. There is also a semi-vegetated dune towards the mouth of the estuary on the south bank. Typical species of this dune vegetation includes *Blombos Metalasia muricata, Osteospermum moniliferum* (previously Chrysanthemoides monilifera) and *Thesium species* interspersed with arum lilies (DWS 2017). Submerged/aquatic macrophytes within the lower estuary include *Ruppia* species, *Stuckenia pectinata*, filamentous algae Cladophora/Enteromorpha and the invasive water hyacinth (DWS 2017).

The estuarine channel upstream of Woodbridge Island is dominated by freshwater species. The banks of the serpentine area of the estuary are dominated by invasive grasses that encroach onto the open water and thrive under the eutrophic, fresh conditions.

3.6.2 Benthic systems

The invertebrate fauna of the Diep Estuary have been well studied, and include sandprawns *Kraussillichirus kraussi* or *Upogebia africana*, benthic macrofauna communities, and the invasive reef-building polychaete *Ficopomatus enigmaticus*.

Sandprawns are considered "ecosystem engineers" i.e., species that create, significantly modify, maintain or destroy habitat, causing physical changes to abiotic or biotic materials around them (Pillay et al. 2007b). Sandprawns undertake ecosystem engineering by virtue of the bioturbation created by their burrows. These invertebrates have been shown to influence community structure, water flow patterns, sediment biogeochemistry and nutrient exchanges between burrows and the overlying water column (Pillay et al. 2007b a, Moyo et al. 2018) (Figure 3-19).

Figure 3-19. Sandprawns such as *Kraussillichirus kraussi* (left) can create irregular sediment topography (right). Photos: Prof. Charles Griffiths (left) and Venter et al. (2020) (right).

Sandprawns have also been shown to have a positive effect on water quality in urban estuaries, principally by reducing chlorophyll-a concentrations in the water column and maintaining benthic-pelagic coupling (Venter 2019, Venter et al. 2020). The presence and abundance of sandprawns in the lower to mid reaches is an indicator of estuarine function, with both presence and absence indicative of substrate type and condition, physical disturbance and pollution within a system. However, marked declines of sandprawns and shifts in their distributions within the system have been reported as a consequence of the apparent deterioration in water quality, particularly lower salinity (Viskich et al. 2016). As sandprawns, along with the commensal species that share their burrows, constitute important food resources for fish and bird species, these declines have consequences for the trophic functioning of the system (Pillay & Branch 2011, Viskich et al. 2016).

Benthic macrofauna comprise all invertebrate animals that occur in or on sediments and can be retained on a 1.0 mm sieve (i.e., are usually visible with the naked eye) (Figure 3-20).

Figure 3-20. Examples of benthic macrofauna from the West Coast of South Africa, including crabs (A), amphipods (B and C) and isopods (D).

They are a fundamental part of the estuarine food web and are important as processors of organic particles. These organisms are frequently monitored as bio-indicators to detect changes in the health of marine environments. This is because most of them are relatively sessile and cannot easily avoid contaminants (as mobile biota can), nor are they carried passively by ocean currents (as may happen to planktonic organisms).

Additionally, they are relatively easy to sample quantitatively, and they exhibit a range of tolerances to environmental stress and pollution (Warwick 1993, Dutertre et al. 2013). Furthermore, they are scientifically well-studied, compared to other sediment-dwelling components (e.g. meiofauna and microfauna), and taxonomic keys are available for most groups. In addition, benthic community responses to a number of anthropogenic influences have been well documented. Investigations regarding benthic macrofauna community structure and dynamics are important when formulating models and quantitative predictions about the functioning of soft-bottom marine systems (Dunn et al. 2013).

There have been significant changes to the benthic macrofauna communities in the Diep Estuary over time, specifically, a dramatic decline in species richness, and an increase in freshwater species (Viskich et al. 2016, Gihwala et al. 2021). The earliest survey by Millard & Scott in 1954 recorded 47 species in the lower estuary, while surveys by Weil in 1974 (unpublished data) and Viskich et al. in 2014 found 23 species each (Millard & Scott 1954, Viskich et al. 2016). Most recently, a survey by Gihwala et al. in July 2021 recorded just six different taxa (Gihwala et al. 2021). The results of these surveys suggest that species richness has been on a downward trajectory for decades.

Only six species out of a potential 69 taxa were recorded across all three surveys between 1954 and 2014: *Capitella capitata*, *Ficopomatus enigmaticus*, *Scolelepis squamata*, *Kraussillichirus kraussi*, *Melita zeylanica* and *Hymenosoma orbiculare* (Viskich et al. 2016). Of these, only the polychaete *C. capitata* and the brachyuran *H. orbiculare* were observed in the 2021 study. *C. capitata*, which is characteristic of highly polluted and degraded environments, dominated all samples and constituted 79% of the abundance. Furthermore, more than half of the macrofauna samples did not contain any macrofaunal organisms at all, with the samples from upstream of 1.5 km from the mouth being especially depauperate (Gihwala et al. 2021).

Species that have increased in abundance include insects (primarily freshwater species). Two alien invertebrates not previously reported from the system have also been introduced (Viskich et al. 2016). These changes certainly reflect the changing water quality profile of the system (see Section 3.4).

In the Diep Estuary, large reefs of the invasive reef-building polychaete (or coral/tube worm) *F. enigmaticus* have formed under the bridges to Woodbridge Island (Viskich et al. 2016). This species is known to have both socio-economic and ecological impacts on invaded systems through the building of large calcareous reefs (Bezuidenhout & Robinson 2020). However, *F. enigmaticus* has also been shown to improve water quality as a filter feeder (Bruschetti et al. 2008, Piccardo et al. 2024).

3.6.3 FISH

Estuaries are considered critically important nursey habitat for fish. Indeed, the Diep Estuary represents some 10% of the nursery area for fish on the West Coast, including species such as the white steenbras *Lithognathus lithognathus* (Jackson et al. 2008, Viskich et al. 2016).

However, there are clear declines in fish species richness over time, from 12 species reported by Millard & Scott (1954) to five reported by Viskich et al. (2016). Of these five species, the most abundant was the opportunistic southern mullet or harder *Chelon* *richardsonii*, which moves between estuarine and marine environments (Lamberth et al. 2010, Viskich et al. 2016, Whitfield 2019). In addition, two alien species were reported in Viskich et al. (2016): the highly invasive mosquito fish *Gambusia affinis*, and banded tilapia *Tilapia sparrmanii*, while just three of the original native species were still present in in the system in 2014. These two alien fish species are usually associated with freshwater systems, despite being found in the lower estuary (Viskich et al. 2016).

These changes are likely linked to changes in water quality, specifically increased ammonia levels linked to malfunctions in the Potsdam WWTW, as well as substantially reduced dissolved oxygen concentrations, which regularly drop below the 2 mg/l threshold for the survival of aquatic species. While many estuarine-associated species are adapted to hypoxia, an increased frequency of low oxygen events (anoxia) has almost certainly negatively impacted benthic fish communities (Lamberth et al. 2010). Indeed, stagnant, low oxygen conditions were the likely cause of a large fish kill reported by the City of Cape Town on 3 March 2022. About 500 dead fish, consisting of juvenile mullet species, were removed from the mouth of the Diep Estuary (Infinity Environmental 2023).

Poor water quality has also been linked declines and shifts in behaviour in benthic invertebrates, such as the burrowing sandprawn *Kraussillichirus kraussi*. Benthic invertebrates are a major food source for many fish species, with some fish species also relying on commensal or mutualistic relationships with burrowing invertebrates (Viskich et al. 2016). Consequently, there has been a complete loss of benthic goby species *Caffrogobius saldanha*, *Psammogobius knysnaensis* and *C. nudiceps*, as well as drastic declines in the number of juveniles of important linefish species such as white steenbras *Lithognathus lithognathus* and white stumpnose *Rhabdosargus globiceps* (Viskich et al. 2016, Infinity Environmental 2023). Indeed, only five individual fish from three species were caught during in seine and gill net fish surveys conducted in August 2022 — harders *Chelon richardsonii*, banded tilapia *Tilapia sparrmanii* and sharptooth catfish *Clarias gariepinus* (Gammon & Clark 2022). The banded tilapia and sharptooth catfish are alien species and only very small harders were caught. In contrast, surveys in 2010 caught several species including silverside *Atherina breviceps*, gobies *Caffrogobius nudiceps*, round herring *Gilchristella aestuaria*, harder *C. richardsonii*, Mozambique tilapia *Oreochromis mossambicus*, banded tilapia *T. sparrmanii* and Eurasian carp *Cyprinus carpio* ((Hutchings & Clark 2010)) — given that most of these native species were absent from the 2022 sampling events, this appears to indicate an almost entirely collapse of fish populations in the system.

3.6.4 BIRDS

Birds are mostly long-lived animals (6-15 years+) and as such are good indicators of long-term changes in the health of the environment. They are particularly susceptible to disturbance by human presence and infrastructural development (e.g. housing development), and changes in food supply (e.g. pelagic fish and intertidal invertebrates).

The Diep Estuary system (including Rietvlei) is considered one of the most important areas for water birds in the region and is recognised as an Important Bird and Biodiversity Area (IBA) by Birdlife International (an IBA is an area identified using an internationally agreed set of criteria as being globally important for the conservation of bird populations). Rietvlei has also been ranked sixth out of the 65 coastal wetlands in the southwestern

Cape and ranks sixth or seventh out of 42 estuaries in South Africa based on their conservation value for waterbirds (Ryan et al. 1988, Turpie 1995).

While most of the information of bird abundance and species richness for the area is focused on Rietvlei, rather than the lower estuary, various sources have reported kelp gull *Larus dominicanus*, Hartlaub's gull *Chroicocephalus hartlaubii*, common tern *Sterna hirundo* and Cape shoveler *Spatula smithii*, as well as predominantly freshwater species such as red-knobbed coot *Fulica cristata* and African darter *Anhinga rufa*, and others (Millard & Scott 1954, Viskich et al. 2016). Coordinated Waterbird counts (CWAC) surveys were conducted at two sites in the lower Diep Estuary between 1985 and 2009, and resulted in sightings of 76 waterbird species over this time period (Infinity Environmental 2023).

CWAC surveys have been conducted at two sites in the lower Diep Estuary in proximity to Woodbridge Island since 1985; however, the last survey was conducted in 2009 (a species list is provided in Table 3-2). Site visits undertaken by Anchor in December 2020 and February 2022 confirmed that the estuary is an important feeding and roosting area for many bird species, including greater *Phoenicopterus roseus*, white-breasted cormorants *Phalacrocorax lucidus* and pied avocets *Recurvirostra avosetta*. A list of species encountered in the vicinity of the lower Diep Estuary are presented in Table 3-3 below. Many bird species appear to use the exposed tidal mudflats as sites for roosting and foraging (Payne et al. 2023) (Figure 3-21). During the November 2023 site visit, groups of predominantly piscivorous waterbirds were noted on the sandbanks upstream of Woodbridge Island.

Table 3-2. Historical records of bird species observed in the lower Diep Estuary (CWAC data; 1985-2009).

Species Name	Taxonomic name	Species Name	Taxonomic name
African Black Duck	*Anas sparsa*	Grey-headed Gull	*Chroicocephalus cirrocephalus*
African Darter	*Anhinga rufa*	Hadada Ibis	*Bostrychia hagedash*
African Fish Eagle	*Haliaeetus vocifer*	Hartlaub's Gull	*Chroicocephalus hartlaubii*
African Jacana	*Actophilornis africanus*	Hybrid duck	*Anas hybrid*
African Marsh Harrier	*Circus ranivorus*	Intermediate Egret	*Ardea intermedia*
African Oystercatcher	*Haematopus moquini*	Kelp Gull	*Larus dominicanus*
African Sacred Ibis	*Threskiornis aethiopicus*	Kittlitz's Plover	*Charadrius pecuarius*
African Snipe	*Gallinago nigripennis*	Lesser Flamingo	*Phoeniconaias minor*
African Spoonbill	*Platalea alba*	Little Egret	*Egretta garzetta*
African Swamphen	*Porphyrio madagascariensis*	Little Grebe	*Tachybaptus ruficollis*
Bank Cormorant	*Phalacrocorax neglectus*	Little Stint	*Calidris minuta*
Black-crowned Night Heron	*Nycticorax nycticorax*	Little Tern	*Sternula albifrons*
Black-headed Heron	*Ardea melanocephala*	Malachite Kingfisher	*Corythornis cristatus*
Blacksmith Lapwing	*Vanellus armatus*	Mallard Duck	*Anas platyrhynchos*

Species Name	Taxonomic name	Species Name	Taxonomic name
Black-winged Stilt	*Himantopus himantopus*	Marsh Sandpiper	*Tringa stagnatilis*
Cape Cormorant	*Phalacrocorax capensis*	Pied Avocet	*Recurvirostra avosetta*
Cape Shoveler	*Spatula smithii*	Pied Kingfisher	*Ceryle rudis*
Cape Teal	*Anas capensis*	Purple Heron	*Ardea purpurea*
Cape Wagtail	*Motacilla capensis*	Red-billed Teal	*Anas erythrorhyncha*
Caspian Tern	*Hydroprogne caspia*	Red-knobbed Coot	*Fulica cristata*
Common Greenshank	*Tringa nebularia*	Reed Cormorant	*Microcarbo africanus*
Common Moorhen	*Gallinula chloropus*	Ruff	*Calidris pugnax*
Common Ringed Plover	*Charadrius hiaticula*	Sanderling	*Calidris alba*
Common Sandpiper	*Actitis hypoleucos*	Sandwich Tern	*Thalasseus sandvicensis*
Common Tern	*Sterna hirundo*	South African Shelduck	*Tadorna cana*
Crowned Cormorant	*Microcarbo coronatus*	Spur-winged Goose	*Plectropterus gambensis*
Curlew Sandpiper	*Calidris ferruginea*	Three-banded Plover	*Charadrius tricollaris*
Domestic Duck	*Anas platyrhynchos*	Unidentified Duck	*N/A*
Egyptian Goose	*Alopochen aegyptiaca*	Unidentified Tern	*N/A*
Giant Kingfisher	*Megaceryle maxima*	Unidentified Wader	*N/A*
Glossy Ibis	*Plegadis falcinellus*	Water Thick-knee	*Burhinus vermiculatus*
Great Crested Grebe	*Podiceps cristatus*	Western Cattle Egret	*Bubulcus ibis*
Great White Pelican	*Pelecanus onocrotalus*	Western Yellow Wagtail	*Motacilla flava*
Greater Crested Tern	*Thalasseus bergii*	White-breasted Cormorant	*Phalacrocorax lucidus*
Greater Flamingo	*Phoenicopterus roseus*	White-fronted Plover	*Charadrius marginatus*
Greater Painted-snipe	*Rostratula benghalensis*	White-winged Tern	*Chlidonias leucopterus*
Grey Heron	*Ardea cinerea*	Wood Sandpiper	*Tringa glareola*
Grey Plover	*Pluvialis squatarola*	Yellow-billed Duck	*Anas undulata*

Table 3-3. Bird species observed in the lower Diep Estuary in December 2020 and February 2022.

Common name	Species	Common name	Species
Greater flamingo	*Phoenicopterus roseus*	Common tern	*Sterna hirundo*
White-breasted cormorant	*Phalacrocorax lucidus*	Sandwich tern	*Thalasseus sandvicensis*
African oystercatcher	*Haematopus moquini*	White-fronted plover	*Charadrius marginatus*
Grey heron	*Ardea cinerea*	Pied avocet	*Recurvirostra avosetta*
Black-winged stilt	*Himantopus himantopus*	Curlew sandpiper	*Calidris ferruginea*
Red-winged starling	*Onychognathus morio*	Pied kingfisher	*Ceryle rudis*

European starling	*Sturnus vulgaris*	Great egret	*Ardea alba*
Cape teal	*Anas capensis*	Little egret	*Egretta garzetta*
African black duck	*Anas sparsa*	Egyptian goose	*Alopochen aegyptiaca*
Yellow-billed duck	*Anas undulata*	Kelp gull	*Larus dominicanus*
Cape shoveler	*Spatula smithii*	Hartlaub's gull	*Chroicocephalus hartlaubii*

Figure 3-21. Waterbirds using the lower estuary intertidal banks for foraging and roosting (February 2022).

4 FAR-FIELD HYDRODYNAMIC AND SEDIMENT MODELLING

4.1 Introduction

The role of hydrodynamic modelling is to develop a mathematical representation of a system, accounting for diverse and complex drivers, to answer questions around water quality, circulation patterns and management requirements. Given the particular questions and concerns around the lower Diep Estuary (tidal flushing and the impacts thereof on salinity and ecology), it is critical that water dynamics be resolved through the water column to fully assess stratification characteristics along the estuary. To address these questions, the system and proposed dredging activities were modelled using the sediment transport and morphological capability of the Delft3D modelling system, and in particular, the Delft3D-FLOW system (FLOW is the hydro-morphodynamics package of the integrated Delft3D modelling suite).

4.2 Scenarios modelled

Far-field modelling was used to simulate the extent, duration and behaviour of saline intrusion (as a proxy for estuarine circulation) within the Diep Estuary under a range of environmental conditions (different seasons and freshwater flow regimes) and impact scenarios (prior to dredging and with dredging). The modelling assumes a continuous field for all properties within the modelled fluid field, thus enabling high accuracy without computational cost of small element sizes within the grid.

Given the known seasonality in flow and hydrodynamic behaviour of the system (Section 3.2), these refence states were simulated for a dry "low flow" period and a wet, "high flow" period, based on inflow data. As such, for the current study, two simulation periods were modelled:

- Dry season: 15 March 2024 to 30 April 2024.
- Wet season: 15 July 2024 to 31 August 2024.

Each of these simulation periods (high flow and low flow) were modelled independently with a two week "run-up" period to stabilise the hydrodynamics. The scenarios modelled included the following:

- A baseline (i.e., present day) wet and dry season scenarios to assess the saline intrusion and stratification dynamics in the estuary as it currently stands (i.e., prior to dredging). A portion of the scenario overlapping with available situ AquaTROLL water depth and salinity data were used to validate the Delft3D model.

- A dry season scenario, and a wet season scenario (both with dynamic mouth function) to assess the saline intrusion and stratification dynamics in the estuary with the proposed dredging and sandbank enrichment (as per Section 4.6).

- A dry season scenario, and a wet season scenario (both with dynamic mouth function) to assess the saline intrusion and stratification dynamics in the estuary with the proposed dredging and sandbank enrichment, as well as placement of a berm upstream of Woodbridge Island (as per Section 4.6).

4.3 MODEL DESCRIPTION

The modelling was performed with the Delft3D-FLOW three-dimensional hydrodynamic model. Delft3D-FLOW is a multi-dimensional hydrodynamic and transport simulation software package which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing on a boundary fitted structured rectilinear or curvilinear grids (Deltares 2020a). The computational grid employed is an irregularly spaced, orthogonal grid in the horizontal and a sigma-coordinate grid in the vertical.

Delft3D-FLOW allows for the coupled solution of the hydrodynamic momentum equations, fluid state and advection-diffusion equation for properties such as heat, salinity, and other conservative tracers by means of the Alternating Direct Implicit (ADI) scheme. Additionally, to improve accuracy a k-ε turbulence model is employed. Hydrodynamic condition outputs include velocities, water elevations, density, salinity, vertical eddy viscosity and vertical eddy diffusivity. Due to the complexity of the physical processes involved, the Delft3D-FLOW computer modelling suite has been set up for the Diep Estuary and applied to simulate the tidal forcing, salinity intrusion, freshwater inflow at the head of the estuary and transport of sediment. The model requires, as input, well-defined input data such as wind speed, wind directions, water salinities as well as atmospheric information. Furthermore, all these datasets need to be co-existing, that is, they all need to be measured during the same time period and at sufficient temporal resolution.

The Delft3D-FLOW sediment module was used to simulate the behaviour of sediment within the system before and after the proposed dredging. The Sediments Process component of the FLOW model permits the specification of cohesive and non-cohesive sediment characteristics, the critical shear stresses for sedimentation and erosion (for cohesive sediments) and the initial sediment at the bed (Deltares 2020a).

4.4 COMPUTATIONAL GRID, BATHYMETRY AND OBSERVATION POINTS

The computational grid set-up for the hydrodynamic simulations was positioned to encompass the Diep Estuarine Functional Zone just upstream of the Otto du Plessis bridge and contains two horizontal domains (Ocean and Estuary)[2] . The ocean grid consists of three open boundaries, an offshore water-level boundary (with tidal forcing) along with two cross-shore Neumann boundaries. Initial salinities 35 were applied to all ocean grid forcing boundaries. The estuarine grid consists of one total discharge open boundary to represent freshwater inflows with a salinity of 1. To ensure mathematical stability and computational efficiency, each simulation period included a two-week run up period. Flushing time post runup was observed to accurately sync to the tidal cycles after 4 days and the 2-week runup was deemed satisfactory for this model. Coupling of

[2] A grid point in Delft3D is defined by an m and n value; it is the area that is encompassed by two numerical grid lines. Numerical computations for water level, concentration of constituents, salinity and temperature are applied to the centre of the grid points. Horizontal and vertical velocities are computed at grid edges (Deltares 2020a).

the two boundaries was done through a domain decomposition boundary located at the interface between the two grids (Figure 4-1). The grids were designed so that the cells are relatively uniform throughout the domains while having a local refinement in the estuary mouth and river system (Figure 4-1). The local refinement is limited to ~10 x 10m.

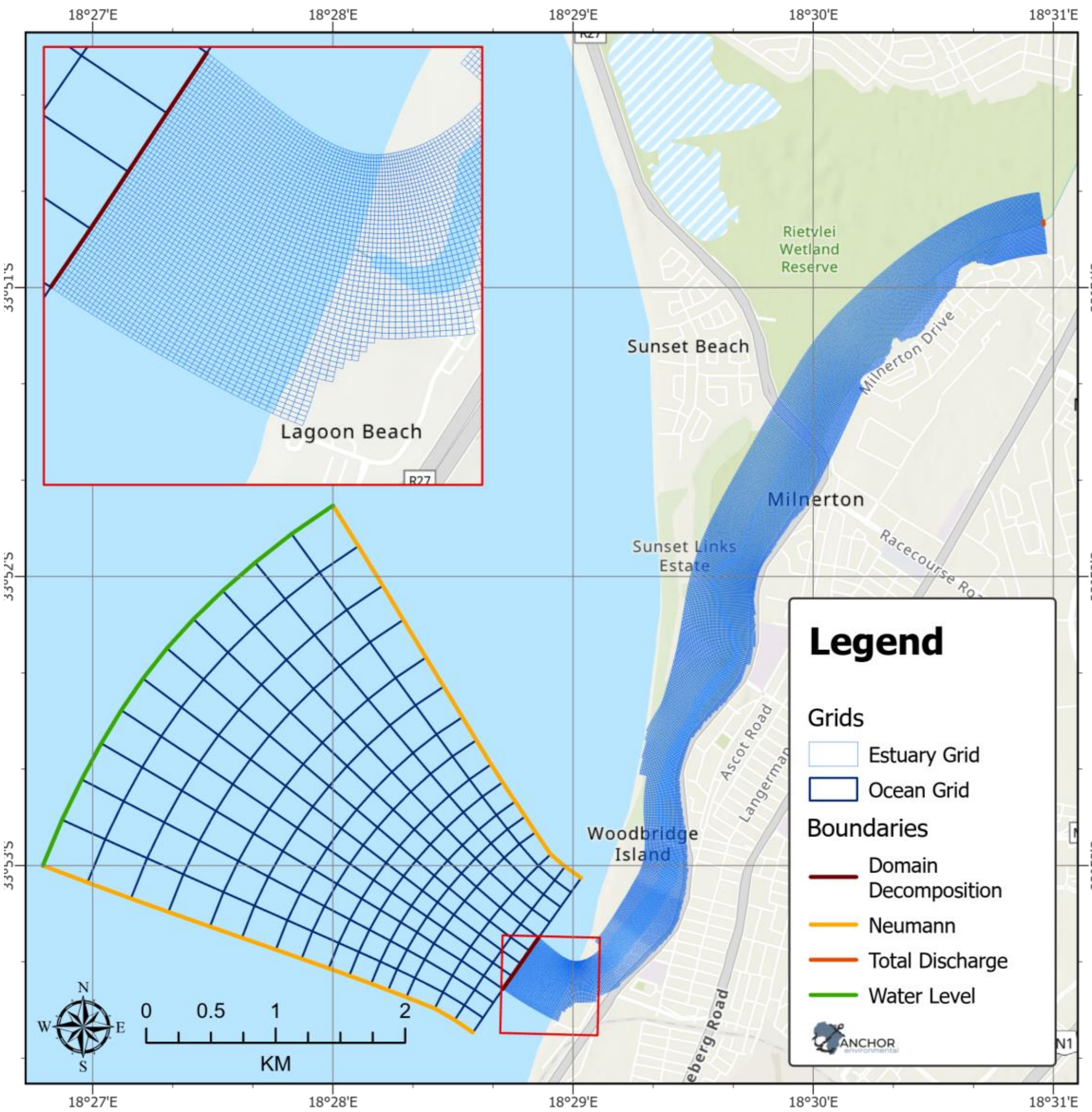

Figure 4-1. Computational grid of the region of interest. The grid is separated into two distinct domains to accommodate the higher resolution required for detailed estuarine geometries.

Due to the relatively shallow depth, the model consists of 10 sigma layers spaced between the surface and the seabed each comprising 10% percentage of the local water depth[3]. By distributing the depth into sigma layers, higher vertical resolutions are achieved for areas of interest (Mellor & Blumberg 1985, Deltares 2020a).

[3] Each sigma layer is a percentage of the real local depth at a point. For example, if the real depth is 100 m then a sigma layer of 10% would be 10 m. Logically, all the percentages in the sigma layer should add to 100%.

Bathymetric data at the required computational resolution was interpolated using the QUICKIN toolset from the Delft3D software suite (Deltares 2020b). This bathymetry data was extrapolated via triangular interpolation from a geospatially referenced channel bathymetric survey of the system, standardised to mean sea level (MSL), undertaken by Tritan Survey (Pty) Ltd in September 2024.

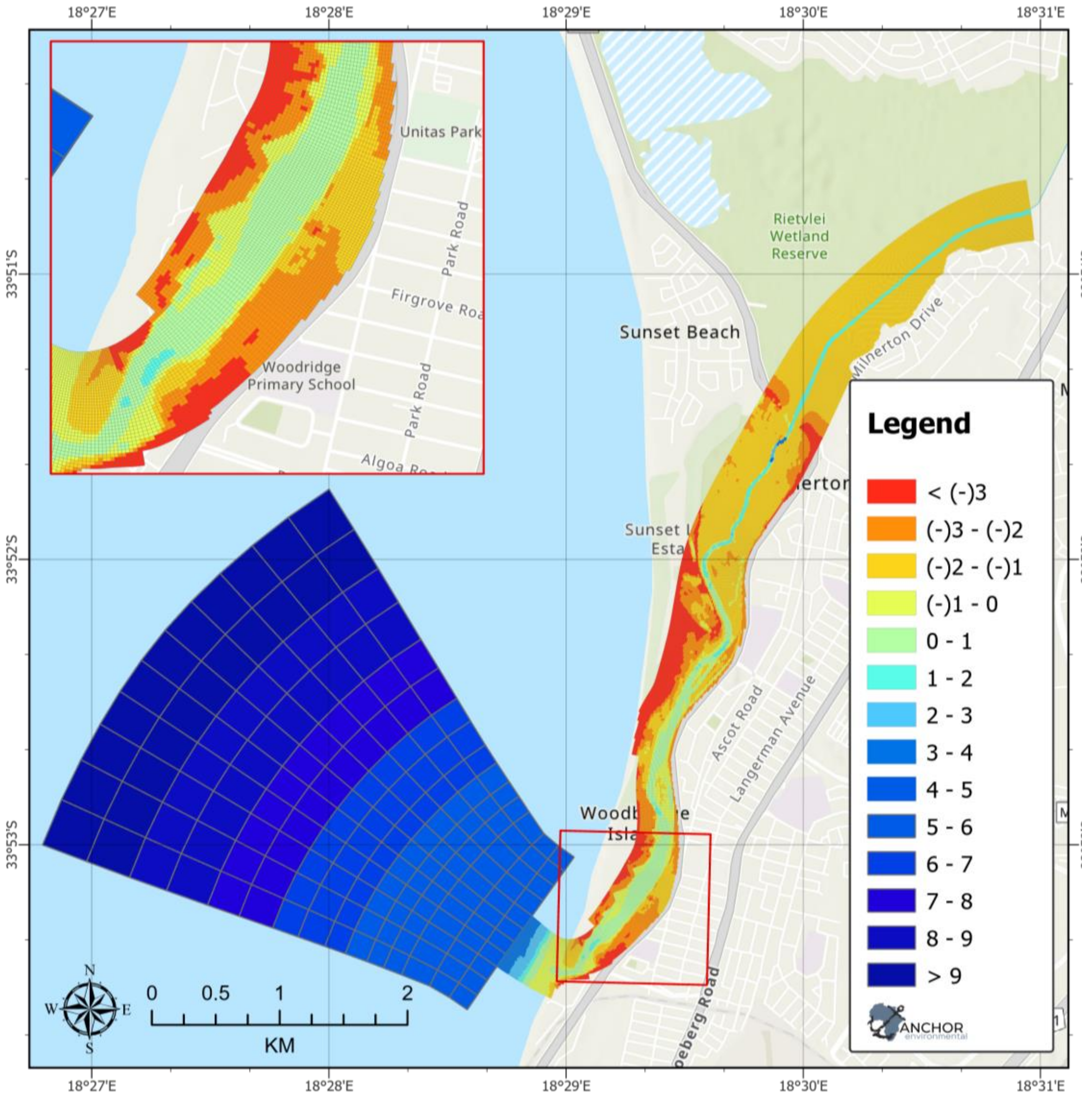

Figure 4-2. Interpolated bathymetry of the computational grid based on survey data undertaken by Tritan Survey (Pty) Ltd (post flood bathymetry). Blue represents deeper regions and red represents the shallower regions.

4.5 PROCESSES INCLUDED IN THE MODEL AND BOUNDARY CONDITIONS

4.5.1 TIDAL FORCING

The model domain outside of the estuarine area was small enough to follow the modelling approach outlined by Roelvink & Walstra (2004) where water level conditions are specified on the offshore boundary and fully developed flow on the lateral boundaries. Indeed, previous studies have shown that these tidal constituents are sufficiently accurate to give an account of the water level variations due to tides in Table Bay (Van Ballegooyen et al. 2006, Diedericks & Smit 2013).

Therefore, the predicted tide for Table Bay using ten tidal constituents according to the analysis of Rosenthal & Grant (1989) was applied on the offshore boundary of the model, assuming no phase lags. The amplitude and phase of each tidal constituent is presented in Table 4-1. Typical Table Bay oceanic salinity values (36) were prescribed on all open boundaries.

The modelled versus predicted tidal levels for Table Bay are presented in Figure 4-3. Measured tidal data was sourced from the Hydrographic Office of the South African Navy. As is evident, the modelled tidal data closely aligns with the measured tidal data (Figure 4-3).

Table 4-1. Tidal constituent data for Table Bay.

Constituent	Amplitude (m)	Phase (deg.)
O1	0.0155	262.73
P1	0.0198	146.96
K1	0.0585	140.36
μ2	0.0164	70.01
N2	0.1098	84.53
M2	0.5000	94.16
S2	0.2169	115.86
K2	0.0631	109.77
M4	0.0045	176.34
MS	0.0014	259.48

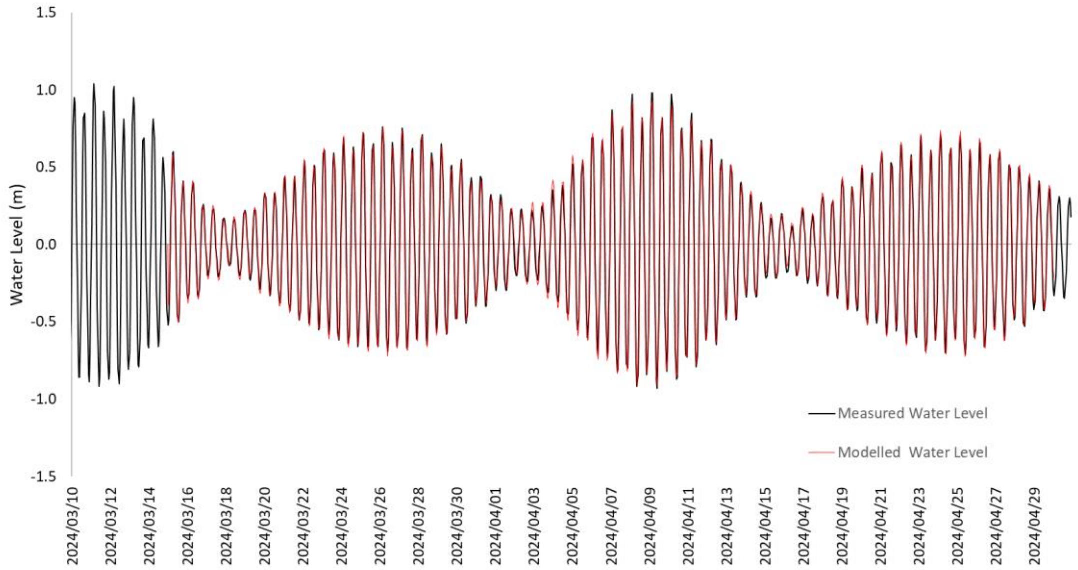

Figure 4-3. The predicted (red) and the measured (black line, courtesy of the South African Hydrographic Office) oceanic tidal data for Table Bay.

4.5.2 Wind forcing

In general, wind plays an important role as a forcing mechanism determining the surface layer current speed, direction and mixing in the water column (Diedericks & Smit 2013). Wind time series are specified for the whole model domain. Following previous models, the wind used in this model was sourced from the ERA5 dataset based on hourly wind data measured at Milnerton.

ERA5 stands as a fifth-generation atmospheric reanalysis product, covering global climate data from January 1940 to the present day. ERA5 operates globally on a 31 km grid, utilising 137 atmospheric levels. Updated daily at noon UTC, the reanalysis product runs at a horizontal resolution of 0.25 degrees. The creation of ERA5 involved the integration of historical and observational data sets through an Integrated Forecasting System Cy41r2. This study focused on hourly surface wind (10 m above the surface) running for the entirety of January 2024 till November 2024.

Key data is summarised in Table 4-2, while time series plots of the wind speed and wind direction and wind roses for the simulation periods are summarised in presented in Figure 4.8 and Figure 4.9.

Table 4-2. Average and maximum wind speeds and predominant directions (measured clockwise where 0 or 360 is true north).

Simulation Period	Average wind speed (m/s)	Predominant wind direction (0:360)	Maximum wind speed (m/s)	Predominant direction of strongest wind (0:360)
Low flow (Dry) season February 2024 to March 2024	5.2	140	12.4	134
High flow (Wet) season July 2024 to August 2024	5.3	340	11.8	290

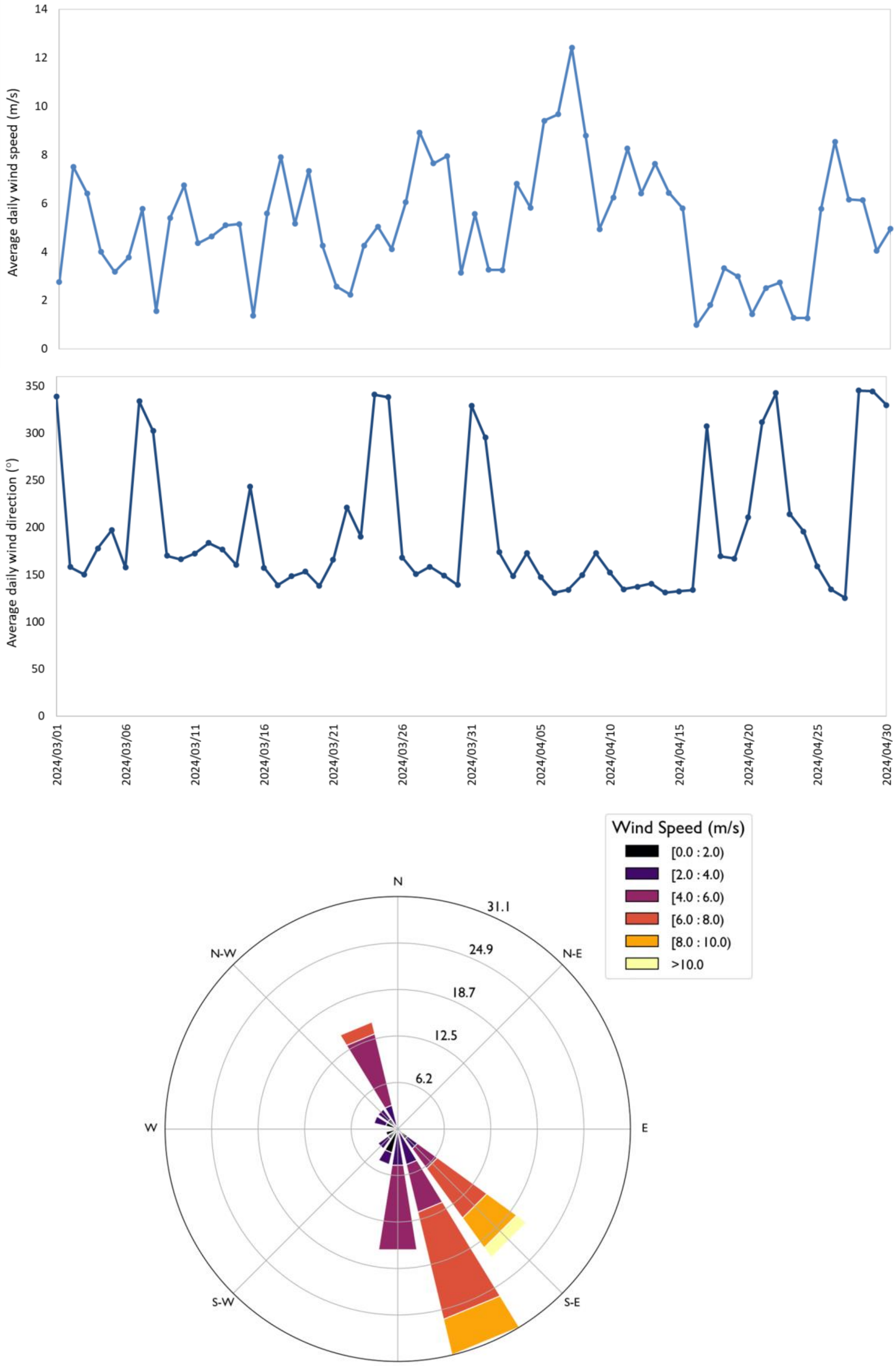

Figure 4-4. (Top) Wind speed (m/s), (middle) wind direction (0:360) and (bottom) wind rose for the modelled low flow season (February 2024 to March 2024).

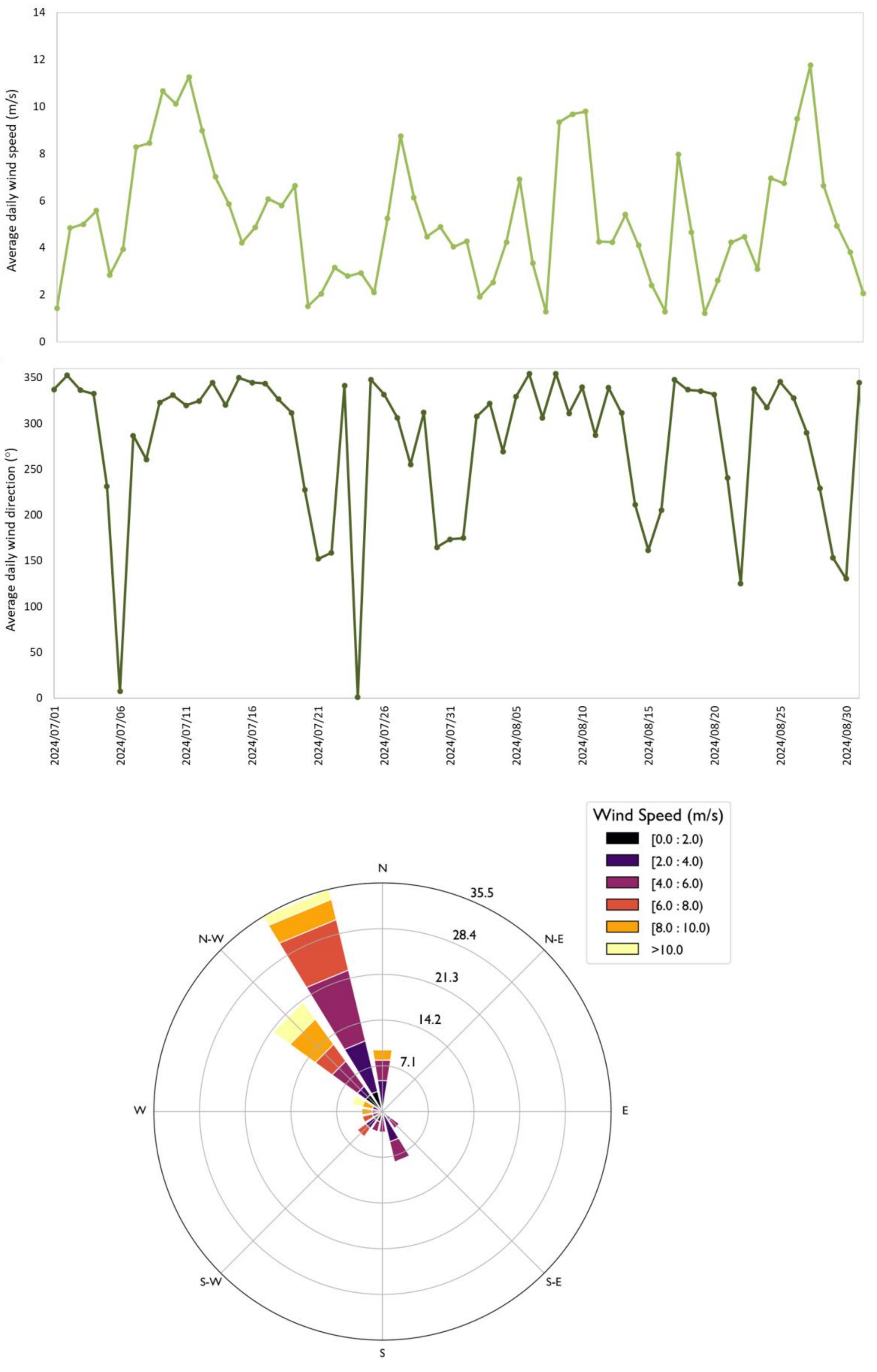

Figure 4-5. (Top) Wind speed (m/s), (middle) wind direction (0:360) and (bottom) wind rose for the modelled high flow season (July 2024 to August 2024).

4.5.3 FRESHWATER INFLOW

Freshwater inflows greatly affect the salinity profile of the estuary. Therefore, a good understanding of freshwater inflows is critical to accurate hydrodynamic modelling of the Diep system, specifically in terms of salinity impacts. In principle, storms in the winter months bring large volumes of freshwater into the estuary that flush out the system and create an almost entirely freshwater environment. Lower rainfalls in summer introduce less freshwater into the estuarine system and allow saline intrusion further upstream, with highest salinities at the estuary mouth decreasing upstream. As discussed in Section 3.2, the Potsdam WWTW discharge makes up most of (if not all) the freshwater inflow at the head of the estuary during periods of low flow (i.e., the dry summers).

The flow data produced by Gerrit Basson and team (see Infinity Environmental 2023) had acceptable congruence with the DWS flow gauge data (DWS flow gauge G2H042) for the 2021/2022 period (Figure 4-6). Given this congruence, and as there was no modelled data beyond 2024 available, the DWS flow data was scaled using power laws and manually adjusted to align with this study's objectives (Figure 4-6) — note that this means that the modelled Delft3D inflow data may not capture the full freshwater inflow to the system.

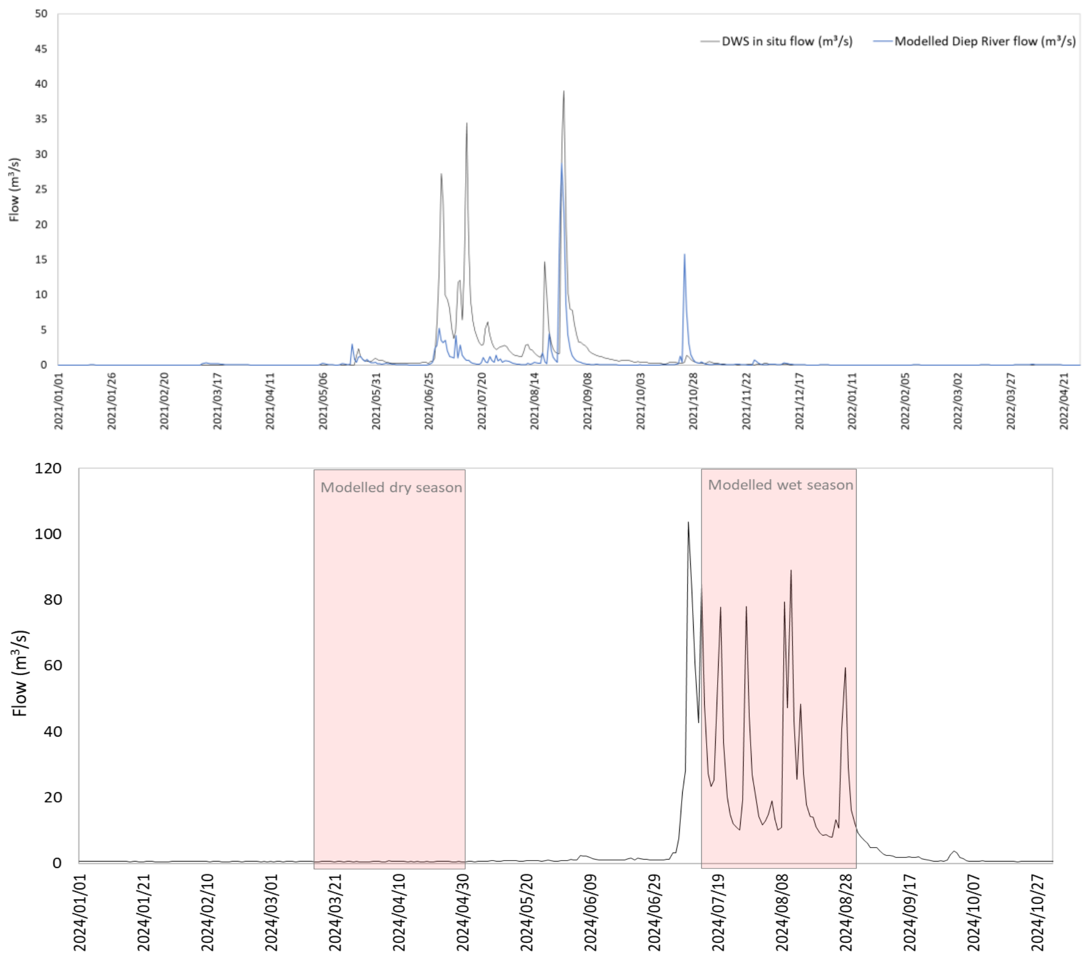

Figure 4-6. (Top) Measured freshwater inflow (G2H042; shown in black) and modelled freshwater inflow at the head of the estuary (data courtesy of Gerrit Basson; shown in blue). The data presented here are for the most recent 'overlap' between measured and modelled data. (Bottom) modelled freshwater inflow at the head of the estuary (data DWS flow gauge data + Potsdam flow data, see Section 3.2). Modelled 'wet season' and 'dry season' periods are indicated in red.

4.5.4 Sediment transport

The Delft3D-FLOW hydrodynamic-morphology software module was used to simulate a dynamic mouth, to better represent estuarine response to flow and tide (Lesser et al. 2004, Van Ledden et al. 2004) In this assessment, the model was applied in fully three-dimensional-horizontal mode. The in-situ measurements across different sites and over multiple years–contained >90% sand and gravel (as per Section 3.5). Therefore, non-cohesive sediments were assumed to be the primary contributor to hydrodynamics and benthic morphology. As this assessment is primarily concerned with the hydrodynamic effectiveness of the estuary pre and post dredging the cohesive sediment was found to have a minimal impact on the hydrodynamics and only the sandy sediments (D50 = 0.35 mm) were modelled. A typical manning's roughness of 0.026 (coarse sand) was chosen for the modelled channel (Arcement & Schneider 1989).

Table 4-3. Input parameters for non-cohesive fraction (sand)

Parameter	Value
Medium Sand	
Median non-cohesive sediment diameter (D50)	0.35 mm
Specific density	2650 kg/m
Dry bed density	1600 kg/m3
Manning	0.026
Volume of sand returned	24 000 m3

4.6 Dredging plan

Details about the proposed dredge plan, and plan for sediment enrichment back to the estuary (to create an intertidal flat, as well as the option to create a berm upstream, see Figure 4-7) for inclusion in the modelling study were provided by the project engineers (PRDW). A summary is presented in Table 4-4 below (see Section 1.3).

Table 4-4. Dredge and sediment enrichment plan (from PRDW) included in the modelling study.

Parameter	Value		
Dredging (see Figure 4-7)			
Dredge Area	40 000 m3		
Dredge Volume	30 000 m3		
Volume to be removed from site	6 000 m3 (approx.)		
Volume of sand returned	24 000 m3		
Dredging depth	-1.1 metres (Updated the dredge depth to allow for sedimentation and depths deeper than this are found along the scour path. The previous studies considered -1 metre dredge depth to remove all contaminated sediment).		
Dredge Slopes	1:4		
Enrichment (intertidal flat) (see Figure 4-7)			
Depth	-1.1 m to 1.63 m	Volume	21 000 m3
Enrichment (upstream berm) (see Figure 4-7)			
Depth	0.09 m to 1.5 m	Volume	3 300 m3

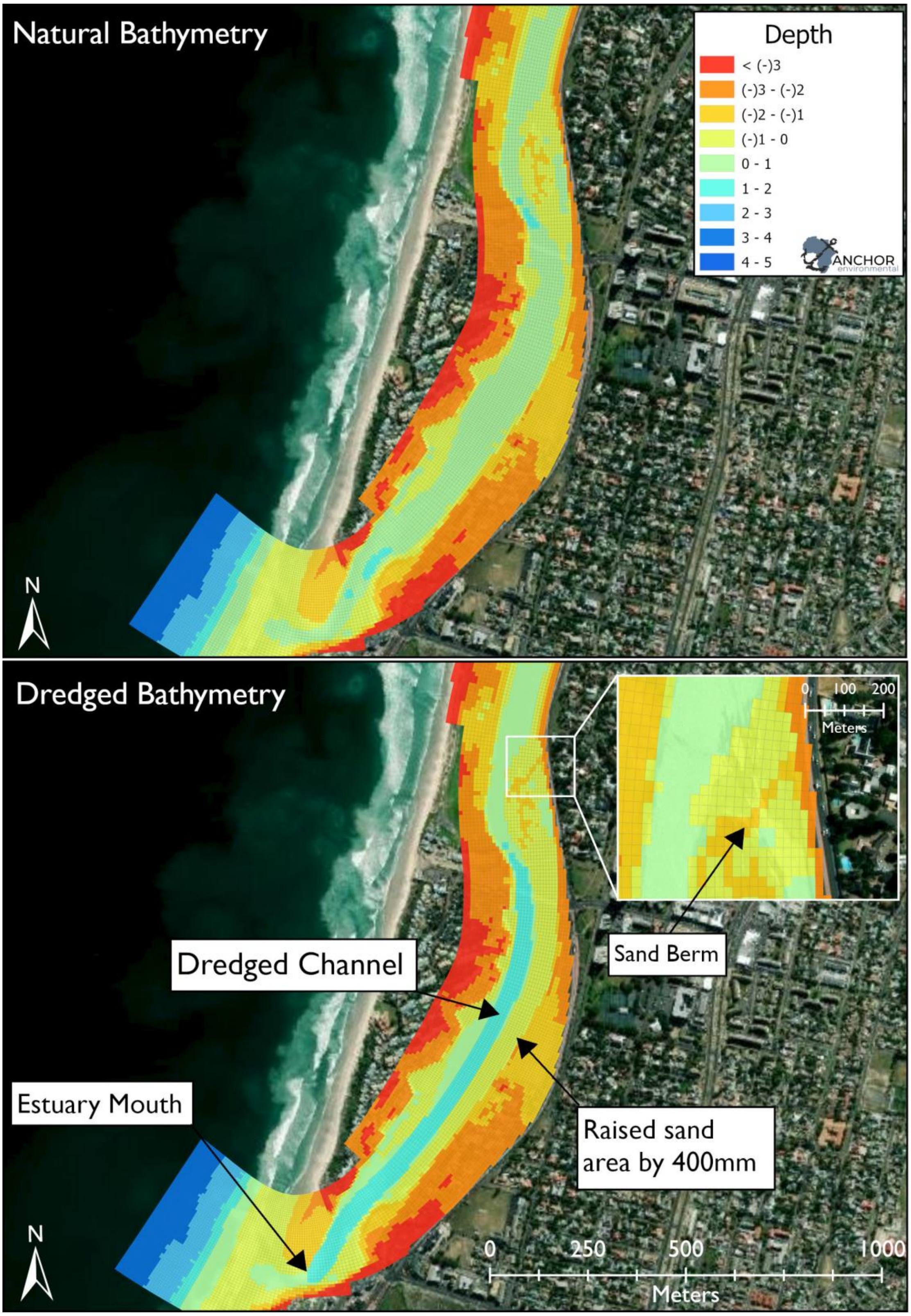

Figure 4-7. Modelled dredge area and area of sand enrichment to form an intertidal flat and an upstream berm (PRDW).

4.7 Model validation

4.7.1 Overview and methodology

Validation of the model against measured/observed data was conducted by means of an error analysis to verify the proposed model as robust and accurate. This validation enables the tuning of the model by means of an improved input data and simulation parameters (such as critical time-step size) to allow for a better representation of the Milnerton Estuary in the hydrodynamic model. For the current study, water level was employed as the scalar field during the validation calculations. Depths obtained from the measured data at a specific time ($\phi_{measured}(t)$) and depths from the simulation results ($\phi_{simulation}(t)$) enables the calculation of a discrete error field at time (t) as:

$$\epsilon_{\phi}^{i}(t) = \frac{\left|\phi_{measured}^{i}(t) - \phi_{simulation}^{i}(t)\right|}{\max\limits_{1 \leq x \leq n}\left|\phi_{measured}^{i}\right|} \times 100$$

where i is a unique discrete location within the domain where measured data is available and n is the total number of locations where measured data is available.

The discrete error field may then be quantified into a useful metric by means of vector norms, namely the l_2-norm and l_∞-norm. Where the following standard definitions are employed,

$$l_2\text{-}norm: \qquad \left\|\epsilon_{\phi}(t)\right\|_2 = \left(\sum_{i=1}^{n} \epsilon_{\phi}^{i}(t)^2\right)^{1/2} / n$$

$$l_\infty\text{-}norm: \qquad \left\|\epsilon_{\phi}(t)\right\|_\infty = \max_{1 \leq x \leq n}\left|\epsilon_{\phi}^{i}(t)\right|$$

These metrics allow for the quantification of the total simulation error at a discrete time providing the weighted average and maximum error respectively. These may then be tuning may be required. Employing a similar approach for an available discrete period of available measured data enables the final calculation of a net and maximum error for the simulation period.

4.7.2 Validation

WATER LEVELS

Simulated tidal patterns were validated against measured tidal depths (see Section 4.5.1), the results of which showed close agreement between the measured and modelled data for open ocean tidal forcing, with a weighted average error of 0.08% and a maximum error of 10.0%, therefore, the tidal phasing is well represented in the modelled data (Table 4-5 and Figure 4-8).

Table 4-5. Delft3D water level and depth validation results.

Validated data	l_2 – norm (Weighted average error)	l_∞ - norm (Maximum error)
Ocean tidal forcing	0.08%	10.0%
Water depth at Woodbridge Island (Wet Season)	0.36%	41.1%
Water depth at the downstream (ds) AquaTROLL deployment site (Dry Season)	0.24%	18.0%

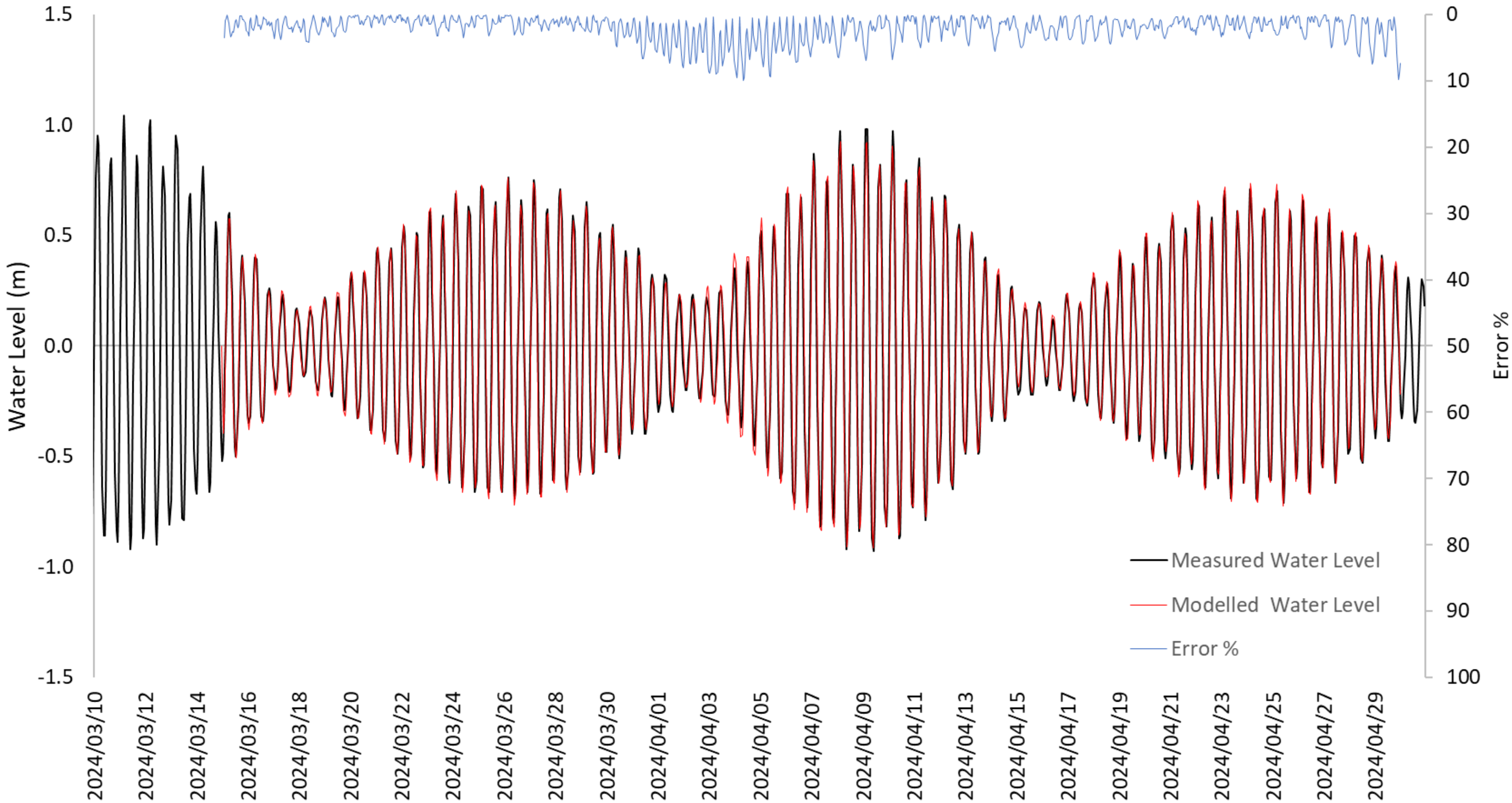

Figure 4-8. Measured (black line) vs. simulated tidal water level around the mean (black line) and error percentage calculation at each time step ($\epsilon_{\phi}^{i}(t)$) (blue line).

Two periods of in situ measurement were used for validation and calibration purposes — an AquaTROLL 200 data logging instrument (at multiple locations) from 1 March 2024 to 4 June , and one AquaTROLL 200 instrument at Woodbridge Island bridge from 5 August 2024 to 5 November 2024 (see details in Section 3.4.2). These instruments provided continuous monitoring of water depth and salinity in the system, and captured both 'dry' periods, with little inflow and high salinities, and 'wet' periods, with high inflows and fresher salinities. The Delft3D water level, depth and salinity results were validated against this in situ data.

Performance of the model during the dry season was considered good with an average error of 0.24% and a maximum error of 18.0% at the downstream AquaTROLL location (Table 4-5 and Figure 4-9). Note that the dry season model simulation runs were undertaken using the post flood bathymetry, after the large flood events in winter 2024 (see Section 3.2), even though the in-situ data was collected prior to these floods (i.e., the pre flood bathymetry). Therefore, some discrepancies are expected between measured and modelled data in the dry season (see Figure 4-9). These discrepancies are of particular note in the salinity data – the measured data show the 'plug' of elevated salinity moving up and down the system without flushing out (see Section 3.4.2 for details), while the modelled post flood results in 'better flushing', with an overall lowered salinity at the site, and the salinity fully flushing out with each tide (Figure 4-10). Given that the model captures water level fluctuations (i.e. the tidal signal) well at this point, it is presumed that tidal forcing is sufficiently captured in the simulation.

It is also clear that salinities become fresh at the AquaTROLL site (at Woodbridge Island) due to tidal forcing, and not necessarily additional freshwater flows — the system becomes fresh at this site in both measured and modelled scenarios as the tidal cycle moved to neap tides, with no corresponding increase in freshwater inflow (Figure 4-10).

The ability of the model to accurately capture the magnitude and duration of flood events, and stabilise again thereafter, is considered a good indication of the overall mathematical stability of the model during the wet season. The wet season simulation period had a weighted average error of 0.36% and a maximum error of 41.1% for water depth at Woodbridge Island, and the overall set-up of the model was therefore considered satisfactory (Table 4-5 and Figure 4-10).

The greatest discrepancy between the measured and simulated data occurred during large flow events i.e., floods (see Figure 4-10). This is not an unexpected result, because the quality of freshwater flow data is crucial to obtaining ideal precision — however, the most accurate freshwater flow rates provided to the model are only measured at DWS gauging stations much further upstream (see Section 4.5.3), which means that there are freshwater inflows unaccounted for in the model. Flood events cause scour in the system and open the mouth, resulting in an overall lowered water level but larger entry for tidal forcing, which the model can replicate in its current iteration. The presence of a dynamic mouth with bathymetric updates provides increases in scour scenarios during a flood event, increasing accurate physical representation (see Figure 4-10). Even though there is evidently some freshwater inflow missing from the modelled scenario, there is enough to match the drop in salinity shown by the in situ instrument (Figure 4-10), which means that the model is replicating the flushing of the system with large freshwater inflows with suitable accuracy.

However, as detailed above, the influence of the water quality is primarily of concern during low flow and drought conditions as these periods provide the largest stress on the estuarine environment. Therefore, the Delft3D model developed provides appropriate levels of accuracies and is deemed acceptable for the modelling of the system in question.

It is worth noting that sediment transport through waves was not incorporated into the model. However, throughout the entire simulated duration, the relative hydrostatic pressure difference between the ocean and the estuarine system was sufficient to maintain an open mouth, which is also observed in situ and is considered a valid approximation.

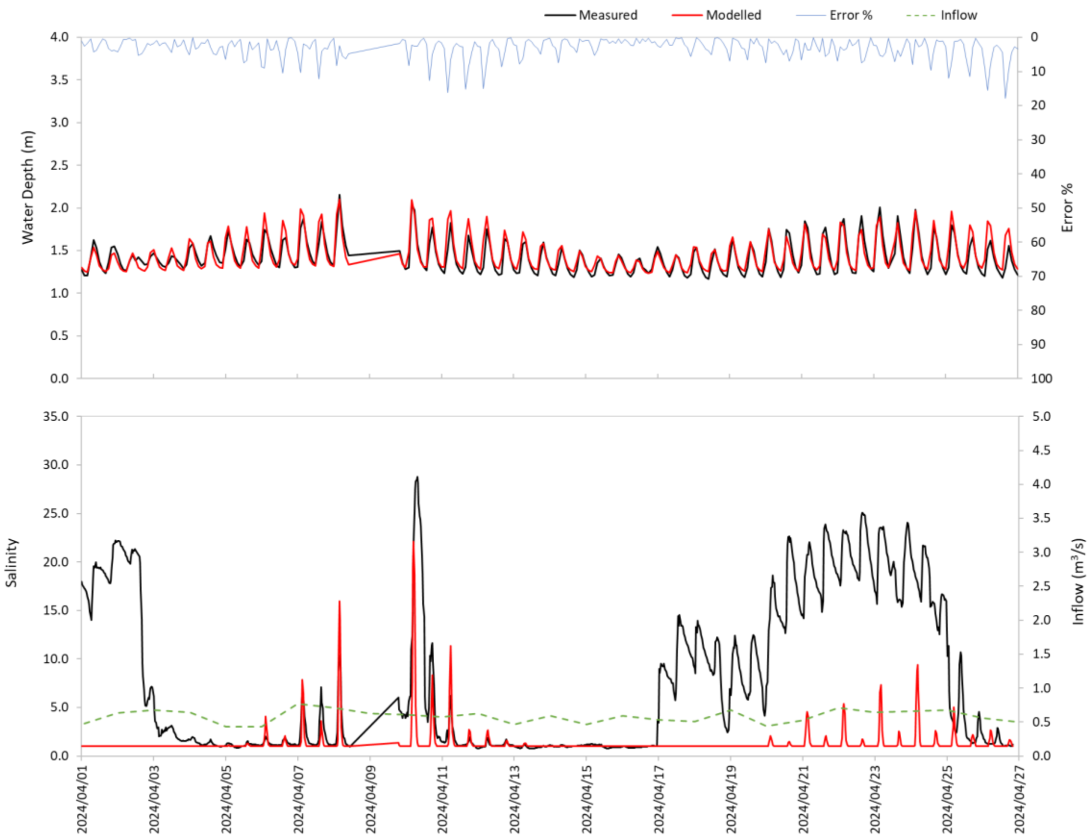

Figure 4-9. Measured (black line) vs. simulated water depth (red line) at the downstream (ds) AquaTROLL deployment site during the dry season for water levels (top) and salinity (bottom). (post-flood bathymetry for both). Note the measured data was collected under pre-flood bathymetry conditions, while model simulations were run under post-flood bathymetry conditions. The error percentage calculation at each time step ($\epsilon_{\phi}^{i}(t)$) is shown for water level (blue line), and the modelled freshwater inflow is shown by the green dotted line.

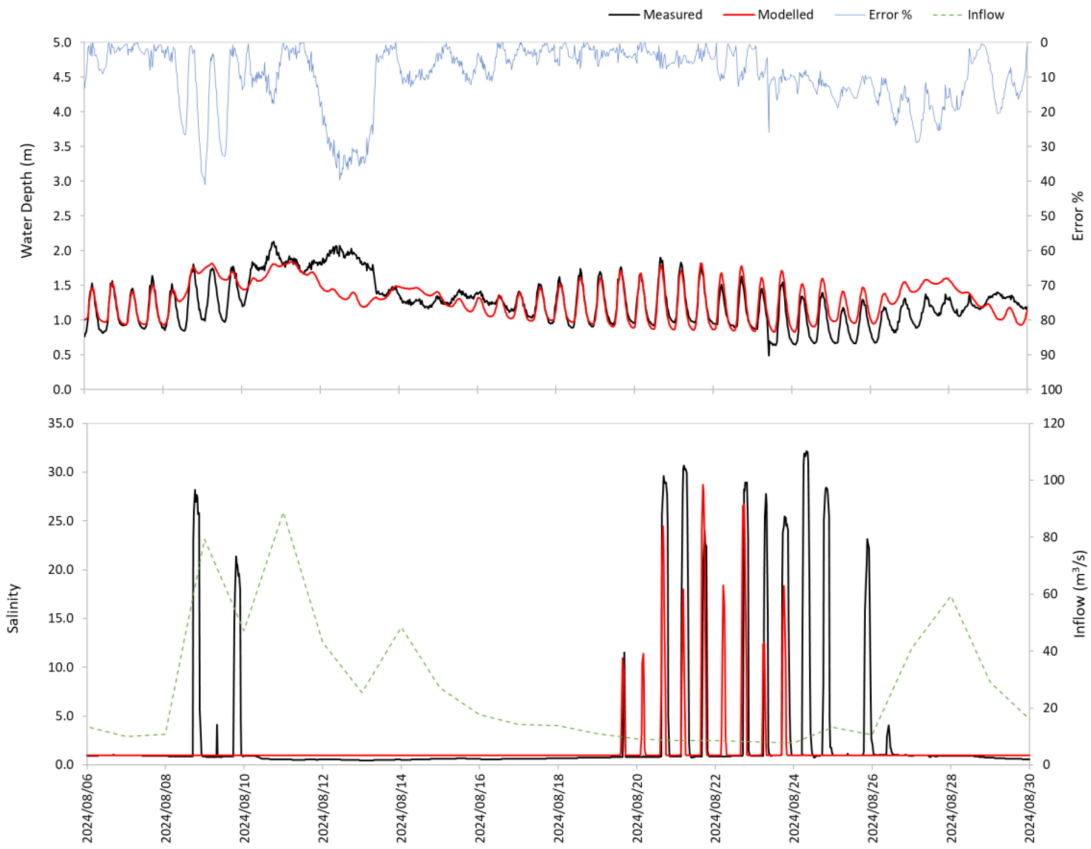

Figure 4-10. Measured (black line) vs. simulated water depth (red line) near to Woodbridge Island during the wet season for water levels (top) and salinity (bottom). Note the measured data was collected, and model simulations were run under post-flood bathymetry conditions. The error percentage calculation at each time step ($\epsilon_{\phi}^{i}(t)$) is shown for water level (blue line), and the modelled freshwater inflow is shown by the green dotted line.

CURRENTS

In this study, we aimed to further validate the model by measuring currents within the estuary using data collected from an ADCP deployed for one day. Given that the ADCP deployment (3-4 April 2025) occurred one year after the model's Summer simulation period (March-April 2024), a critical aspect of the analysis involved tidally matching modelled outputs and the in-situ tidal cycle. Despite the limited deployment duration, the overall measured and modelled velocities were found to be in good agreement (Figure 4-11).

It is important to note that measured ADCP velocities are averaged over three minutes and sampled every nine minutes whereas the modelled velocities are only written every 30 minutes. The temporal mismatch may introduce minor discrepancies in the validation, however, upon comparison of the velocities the general pattern of the velocity magnitude is still preserved. The average velocities from both the measured and modelled data exhibit good agreement at 0.021 m/s and 0.031 m/s respectively. Similarly, the maximum velocities were closely aligned at 0.073 m/s and 0.062 m/s. The comparison of 80th percentile velocities further demonstrated consistency in the validation at 0.035 m/s and 0.043 m/s for measured and modelled data respectively (Table 4-6).

During ebb tide (~22:00 to ~07:00), the correlation between modelled and measured velocities is considered to be acceptable (Figure 4-11). The observed differences noted during this period can be attributed to the complex and dynamic bathymetry in the study area. Changes in morphology, such as abrupt bathymetry gradients, mouth state, and tidal flats may negatively impact the hydrodynamics during simulations. These influences are likely to be magnified over the short time scale represented here. Conversely, during flood tide conditions, the comparison between modelled and measured velocities reveals good agreement (Figure 4-11). These results suggest that the model captures bulk water transportation well and effectively represents the hydrodynamic processes in the study area.

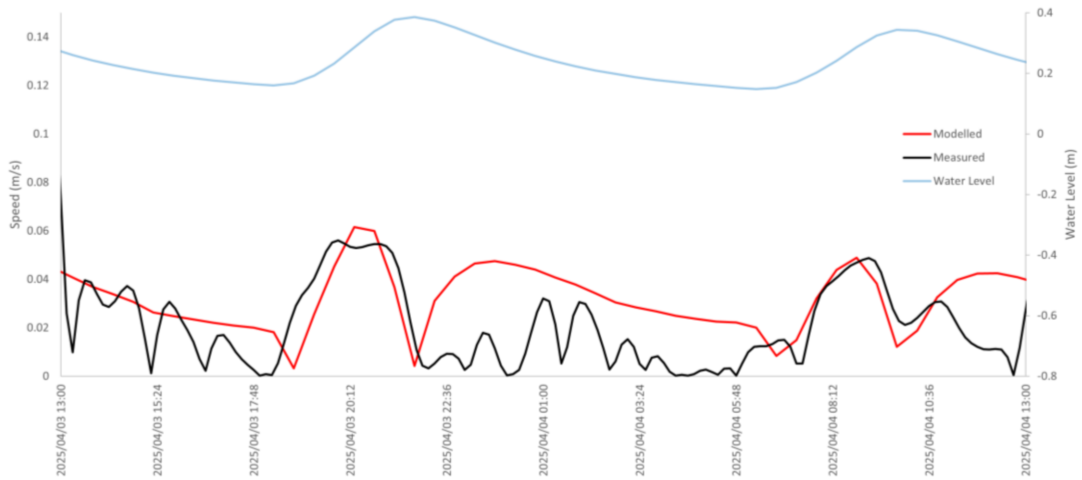

Figure 4-11 Measured (black line) vs. simulated water velocity magnitudes (red line) at the ADCP deployment location. Water Level in the estuary is shown in the blue line. Note the rapid decrease in velocities during the perceived slack tide at the modelled ADCP deployment location (~18:00, ~22:00, 07:00 and 10:00)

Table 4-6 Comparison of statistical parameters of the velocity for the ADCP deployment duration.

Validated velocity magnitudes (m/s)	Measured	Modelled
Average velocity	0.021	0.031
Max velocity	0.073	0.062
80% Percentile	0.035	0.043

4.8 RESULTS

4.8.1 OVERVIEW

Salinity alone does not provide a comprehensive indicator of estuarine health, but it can offer valuable insights into how saline water is transported throughout the system and the rate at which water is exchanged between the estuary and the ocean.

Modelled results suggest that the difference between pre-dredge and post-dredge salinities are minimal at maximum tidal extents (peak high tide and peak low tide). However, the larger post-dredge cross sectional area facilitates larger saline intrusion and saline wedge development in the lower estuary during high energy incoming and outgoing tides (i.e., spring high tides). This can enable increased exchange between saline water and fresh water in the lower estuarine system. The period of greatest concern is when there is minimal freshwater flow and low tidal forcing, which can lead to insufficient tidal exchange to remove deposited sediment and sludge.

4.8.2 SALINITIES

DRY SEASON

Model results shows that dredging does results in increases in salinity in the lower estuary (especially evident in the lower water column, as shown in Figure 4-12). The model also shows that a natural halocline develops readily in the post dredging scenario for the incoming and outgoing tides (Figure 4-13 and Figure 4-14). It is assumed that while dredging allows more water to enter the lower estuary, the net available energy from tidal forcing and freshwater inflow does not carry the saline water further up the estuary, and dredging does not necessarily improve the salinity penetration further upstream (Figure 4-12).

Modelled average salinities in the lower water column near the mouth (0.2 km from the mouth) pre-dredging and post-dredging are 23.8 and 26.5 respectively, yielding an increase of 11.6% (Figure 4-15). In the scenario before dredging, the salinity levels drop to ~1 twice every tidal cycle. This occurs because the freshwater inflow from the Potsdam WWTW is capable of completely replacing the saline water present in the lower system. Conversely, dredging provides a larger volume for saline entrapment and requires more freshwater flow to reduce the salinity to same extent as the pre-dredging scenario.

Further upstream at 2.9 km form the mouth and coinciding with the downstream (DS) AquaTROLL deployment location, the pre-dredging and post-dredging differences in average salinity in the lower water column are much less pronounced at 2.42 and 2.44 respectively (an increase of 0.4%) (Figure 4-16).

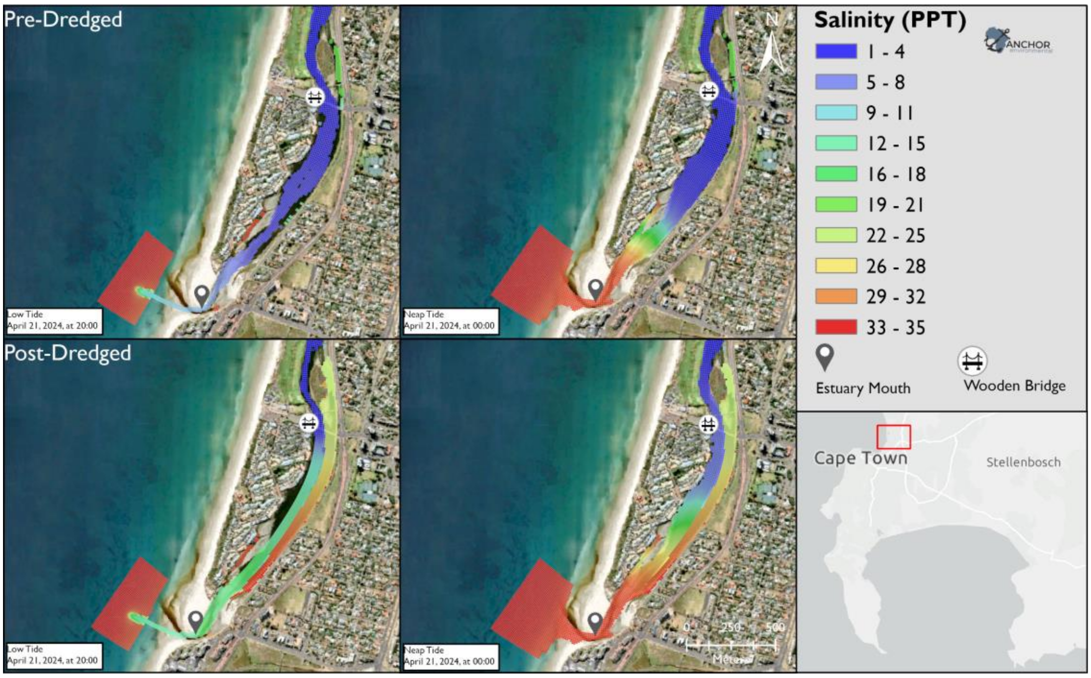

Figure 4-12. Snapshot modelled salinity extent in lower water column (bottom 10%) during low flow season at spring low tide (left column) and neap tide (right column) before dredging (top) and after dredging (bottom). Note that the base image is an image captured by satellite on 12 April 2024, and therefore does not perfectly align with the modelled mouth configuration, and only represents a snap-shot of the tidal cycle.

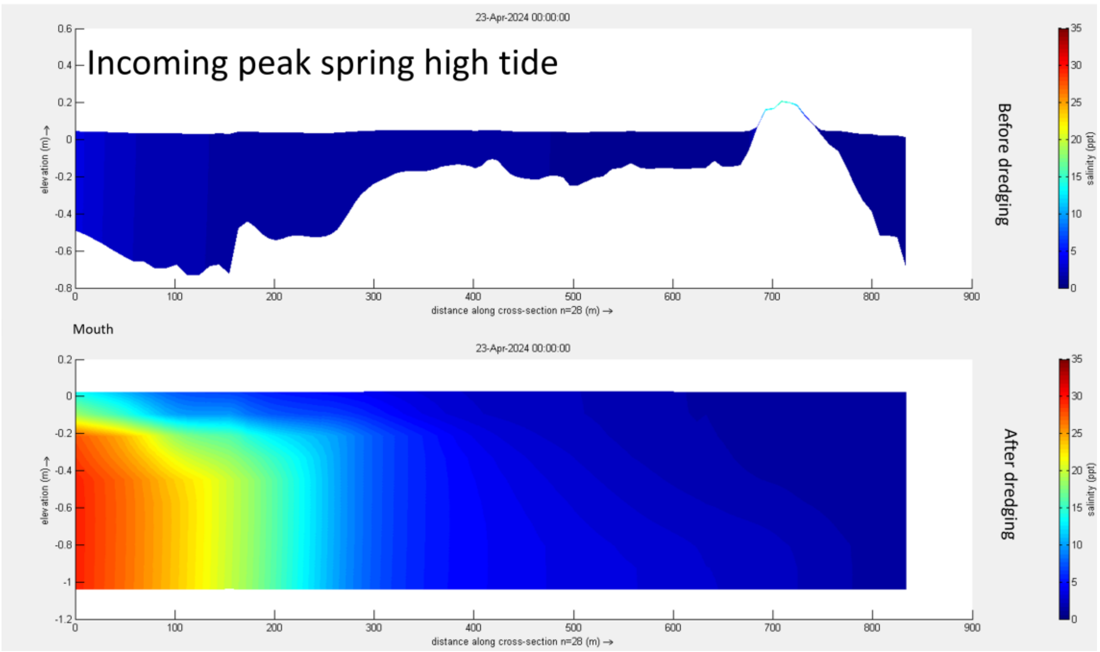

Figure 4-13. Instantaneous snapshot of a salinity profile during the dry season of an incoming peak spring high tide before dredging (top) and after dredging (bottom).

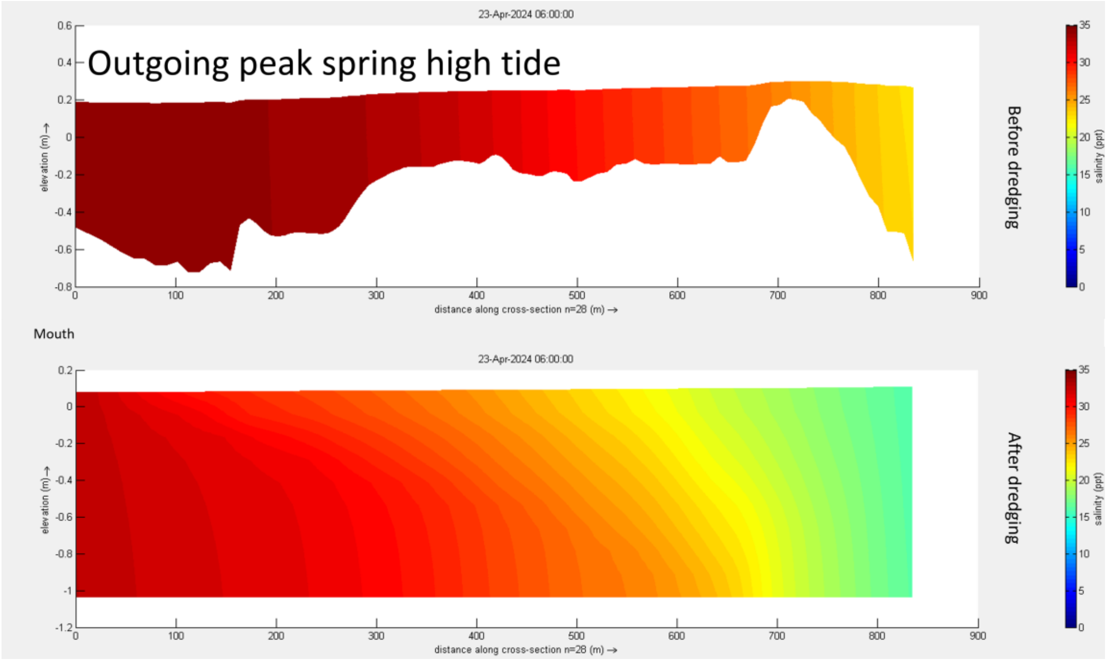

Figure 4-14. Instantaneous snapshot of a salinity profile during the dry season of an outgoing peak spring high tide before dredging (top) and after dredging (bottom).

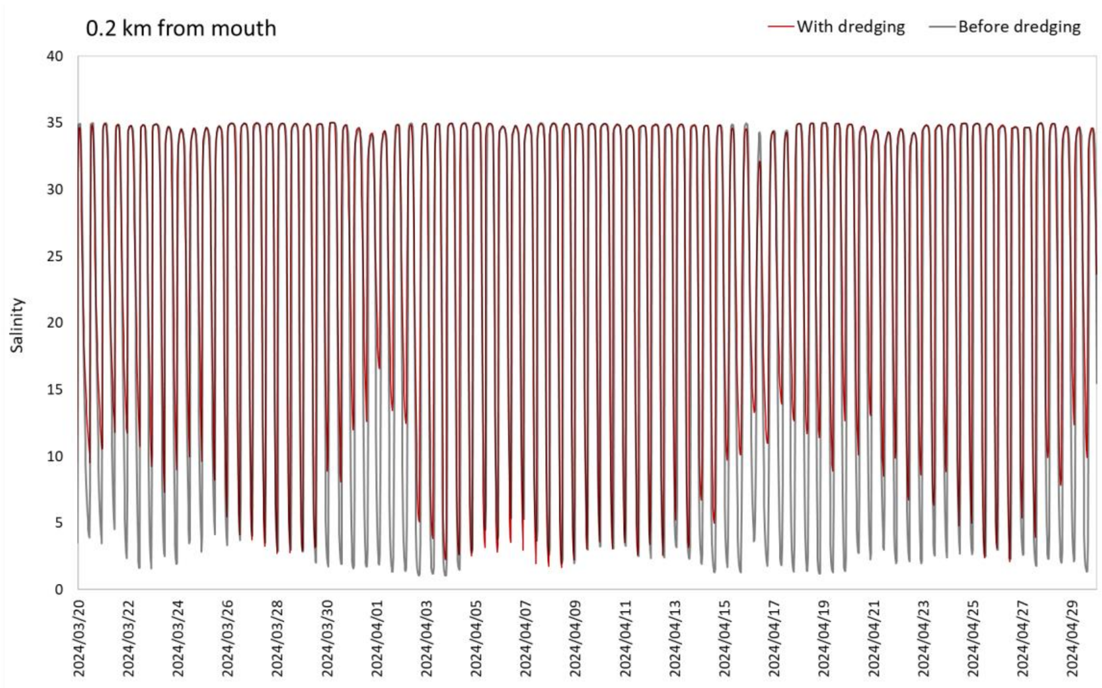

Figure 4-15. Modelled dry season salinity over time with dredging (red line) and before dredging (grey line) at the mouth of the estuary in the bottom layer of the model.

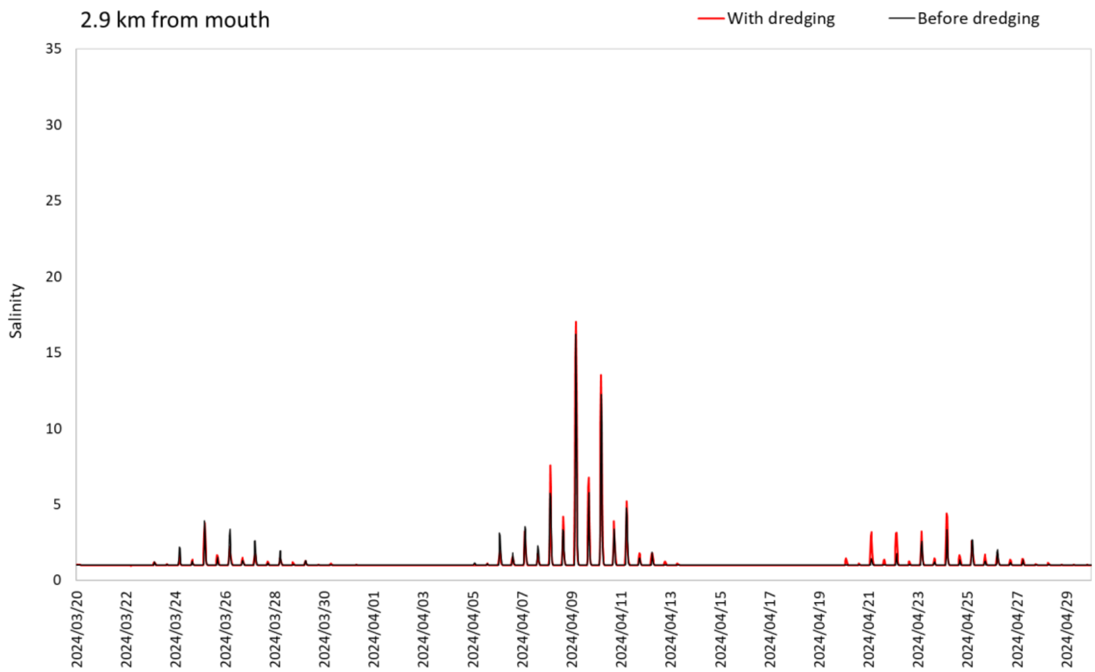

Figure 4-16. Modelled dry season salinity over time with dredging (red line) and before dredging (black line) downstream of the Otto Du Plessis drive bridge coinciding with the AquaTROLL downstream (ds) AquaTROLL deployment location from March-June.

WET SEASON

While there is a constant freshwater inflow from the Potsdam WWTW during the dry season, the wet season simulations are characterised by large freshwater inflows (i.e., flood events, see Figure 4-10). When these large flows are present, the system is entirely fresh (Figure 4-10).

However, model results indicate that, over the period modelled, dredging resulted in a 54% increase in salinity in the lower water column (average of 6.8 after dredging, and 3.1 before dredging) (Figure 4-17). This is likely because the large flood events result in large scale mouth scour and changes to the bathymetry, allowing more saltwater penetration into the system. Despite this, this increased salinity near the mouth is not translated further up the system — indeed, there is no saline penetration at 2.9 km upstream at any point during the wet season (Figure 4-18).

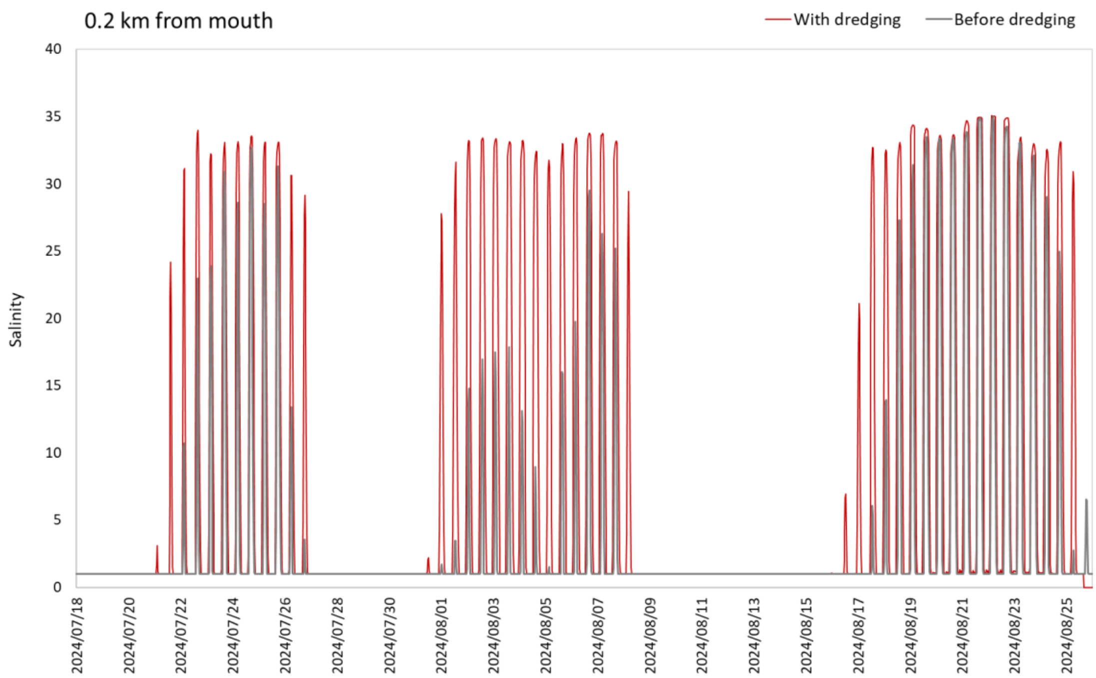

Figure 4-17. Modelled wet season salinity over time with dredging (red line) and before dredging (grey line) at the mouth of the estuary in the bottom layer of the model.

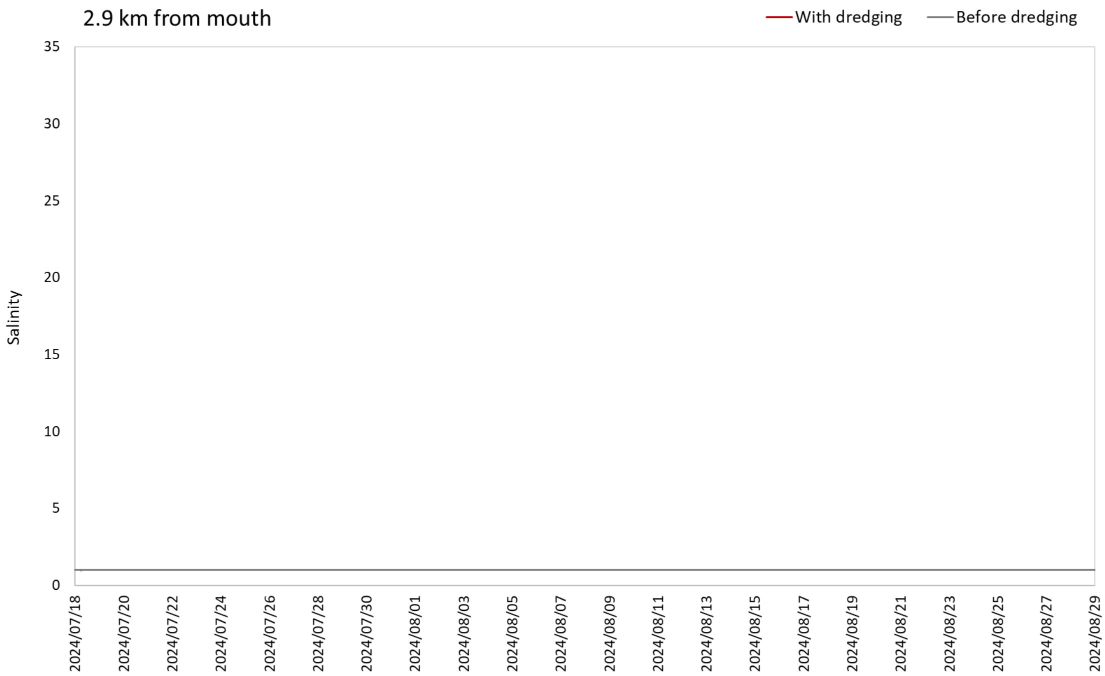

Figure 4-18. Modelled wet season salinity over time with dredging (red line) and before dredging (black line) just downstream of the Otto Du Plessis drive bridge in the bottom layer of the model.

4.8.3 BED SHEAR STRESS

As the modelled sediment was non-cohesive (i.e., as sandy material, rather than muddy) the bed shear stresses were compared against an estimated critical shear stress of 0.10 N/m^2 using the Shields' equation (van Rijn 2020). This shear stress was calculated under the assumption of a constant fluid density and a Shields' parameter of 1000 kg/m^3 and 0.05 respectively (Table 4-7).

Table 4-7 Parameters for calculating an estimation for critical shear stress provided that the density of the fluid remains relatively constant

Parameter	Symbol	Value	Unit
Shields' parameter	θ_{cr}	0.05	-
Sediment density	ρ_s	1600	kg/m^3
Fluid density	ρ_w	1000	kg/m^3
Gravitational acceleration	g	9.81	m/s^2
Sediment diameter	D	0.00035	m
Critical shear stress	τ_s	**0.10**	**N/m^2**

As per:

$$\tau_s = \theta_{cr}(\rho_s - \rho_w)gD$$

The modelled scenarios suggest that freshwater inflow as well as tidal forcing are coupled and interact with bed shear stresses and velocity magnitudes within the dredge channel. During the wet season, these factors interact constructively, leading to higher velocity magnitudes and bed shear stresses before each low tide. For example, (see Figure 4-19 and Figure 4-20) increased freshwater inflow amplifies the outgoing tide resulting in higher peak velocities and shear stresses while the troughs remain unchanged during incoming tide. Conversely, in drier periods the estuarine velocity is primarily driven by tidal forcing. The increased water volume in the dredged channel likely requires more energy to mobilise and consequently, results in lower velocities and bed shear stresses (Figure 4-21 and Figure 4-22).

These data are supported by velocity and bed shear stress percentiles in Table 4-8 and Table 4-9 respectively. In the wet season, velocities percentiles see minimal change in the before-dredging and after-dredging scenarios as freshwater inflow remains the primary driver of sediment transport. However, in the dry season, a consistent large difference in velocity percentiles between the two scenarios is observed, indicating the more pronounced impact of dredging on flow velocities within the dredged channel.

Pre-dredge results for the wet season show that the modelled bed shear stresses only exceed the required critical shear stress at the 90th percentile, indicating that bulk-sediment transport only occurs during high energy scenarios (Table 4-9). Post-dredge scenarios show a consistent reduction in bed shear stresses across all scenarios, suggesting that dredging reduces the intensity of shear stress loading on the bed within the channel. This reduction may have implications for real-world sediment transport and erosion characteristics, potentially resulting in increased deposition within the dredge channel.

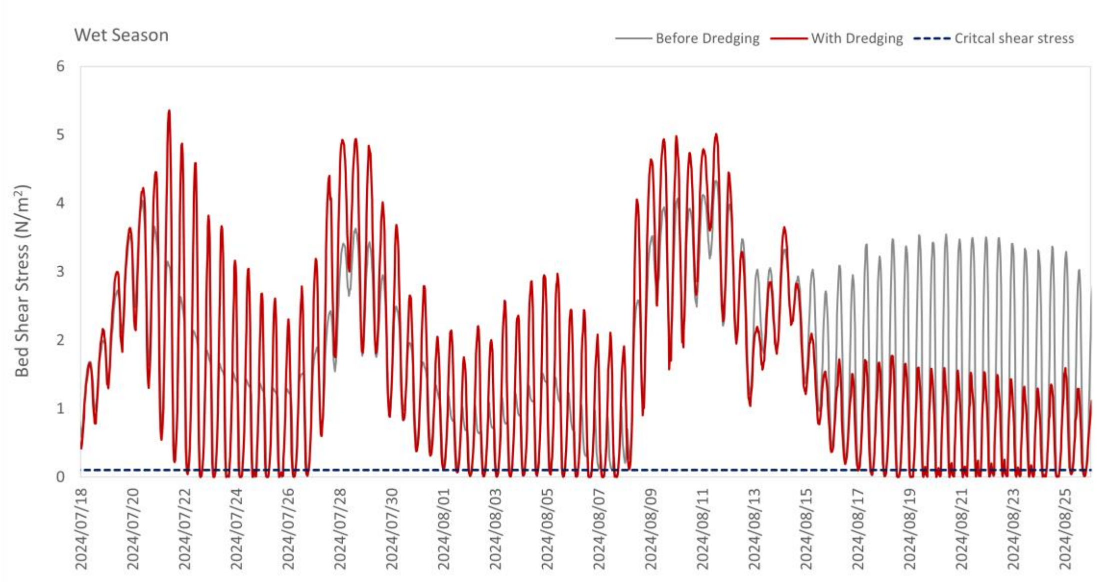

Figure 4-19. Modelled wet season bed shear stress over time with dredging (red line) and before dredging (grey line) in the dredge channel at the bottom layer of the model. The estimated critical shear stress (minimum required shear stress for sediment transport) is represented by the dashed dark blue line.

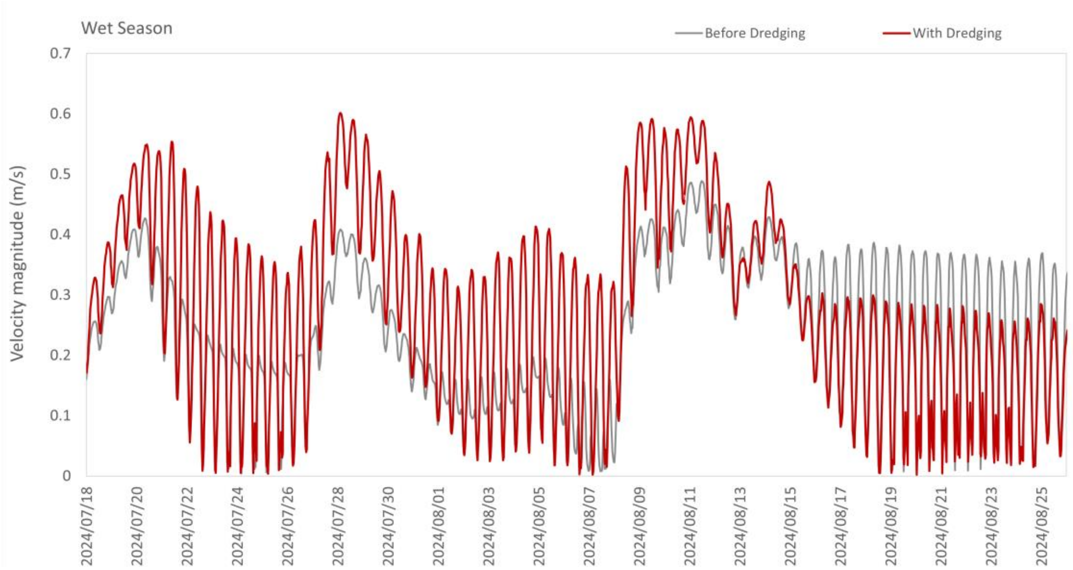

Figure 4-20. Modelled wet season velocity magnitudes over time with dredging (red line) and before dredging (grey line) within the dredge channel at the bottom layer of the model.

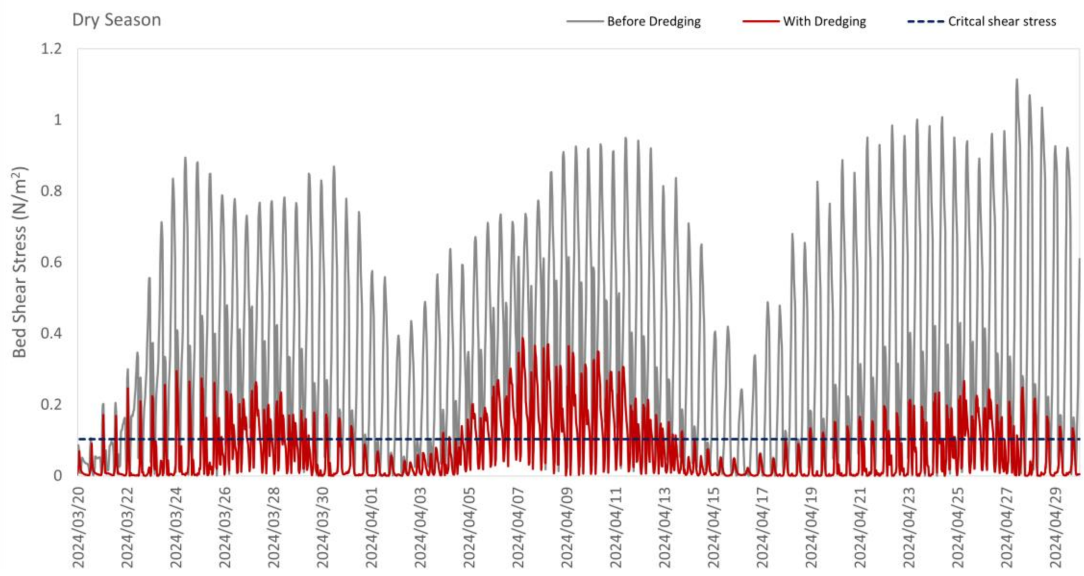

Figure 4-21 Modelled dry season bed shear stress over time with dredging (red line) and before dredging (grey line) in the dredge channel at the bottom layer of the model. The estimated critical shear stress (minimum required shear stress for sediment transport) is represented by the dashed dark blue line.

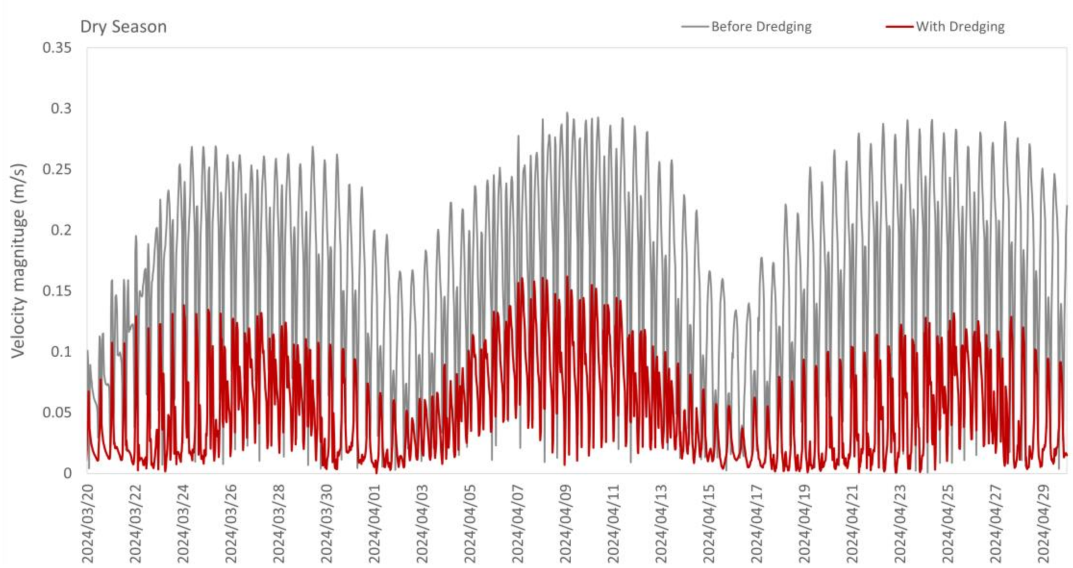

Figure 4-22. Modelled dry season velocity magnitudes over time with dredging (red line) and before dredging (grey line) within the dredge channel at the bottom layer of the model.

Table 4-8. Modelled velocity magnitudes percentiles within the dredged channel measured in m/s.

Scenario	Mode	95th Percentile	90th Percentile	80th Percentile	50th Percentile
Wet Season Before Dredging	0.37	0.04	0.07	0.12	0.24
Wet Season After Dredging	0.25	0.04	0.07	0.15	0.28
Dry Season Before Dredging	0.19	0.03	0.04	0.07	0.16
Dry Season After Dredging	0.01	0.01	0.01	0.01	0.04

Table 4-9. Critical shear stress (Pa) compared against modelled shear stress (Pa) percentiles within the dredged channel. Values above and below the estimated critical shear stress (τ_s) are in green and orange respectively.

Scenario	Critical shear stress (τ_s)	Mode	95th Percentile	90th Percentile	80th Percentile	50th Percentile
Wet Season Before Dredging	0.10	1.43	**0.04**	0.12	0.44	1.47
Wet Season After Dredging		1.35	**0.02**	**0.07**	0.33	1.35
Dry Season Before Dredging		0.11	**0.01**	**0.03**	**0.05**	0.25
Dry Season After Dredging		**0.01**	**0.00**	**0.00**	**0.00**	**0.02**

5 IMPACT ASSESSMENT

5.1 Background

In the estuarine/marine environment a disturbance can be relatively short-lived (e.g., accidental spill which is diluted in the water column below threshold limits within hours) but the effect of such a disturbance may have a much longer lifetime (e.g., attachment of pollutants to sediment which may be disturbed frequently). The assessment and rating procedure described in Appendix I addresses the effects and consequences of this disturbance (i.e., the impact) on the environment rather than the cause or initial disturbance alone. To reduce negative impacts, precautions referred to as 'mitigation measures' are set, and attainable mitigation actions are recommended.

The proposed mitigation measures (for negative impacts) are based on the mitigation hierarchy which allows for consideration of five different levels, which include avoid/prevent, minimise, rehabilitate/restore, offset and no-go in that order. When project impacts are considered, the first option should be to avoid or prevent the impacts from occurring in the first place if possible. If such avoidance is not attainable, the impacts must be minimised as far as possible by the implementation of recommended, applicable mitigation measures.

In this report, there are two types of "dredge activity" assessed 1) the movement of sediment from the channel to the intertidal banks (referred to as '**dredge and move'**) and 2) both the removal of sediment, as well as dewatering and enrichment of the estuary with the clean sediment (referred to as '**dredge, clean and move'**) (as per Section 1.1 and Section 4.6). Impacts assessed in this report associated with these activities fall into two main categories:

1. Construction phase impacts, linked to the dredging activity itself. This includes resuspension of organic matter from sediment, localised turbidity plumes, smothering and noise impacts.

2. Operations phase impacts, which describe the results of the dredging on estuarine form and function over the longer term (i.e., after completion of dredging).

Each of these impacts is likely to affect the associated biota in different ways and at varying intensities depending on the nature of the affected habitat and the sensitivity of the biota. Results of each assessment are presented in Table 5-1 to Table 5-9 and are summarised in Table 5-10.

5.2 Construction phase impacts

5.2.1 Disturbance to and direct mortality of biological communities in the dredged areas

Direct removal of some 30 000 m^3 of estuarine channel sediments as part of either dredge activity option (Section 1.3 and Section 4.6) will lead to direct mortality of fauna associated with those sediments, namely macrofauna and epifaunal species present within the dredge area. The loss of habitat can directly affect the populations of various species, including fish, crustaceans, and benthic organisms (Wilber et al. 2005).

The Milnerton Lagoon benthic macrofauna is very depauperate, with a dramatic decline in species richness over time, and an increase in freshwater species. Of particular concern has been the declines and shifts in behaviour of the burrowing sandprawn *K. kraussi*, which is an ecosystem engineer (see Section 3.6.2). The communities that are present are typical, albeit depauperate, communities that characterise estuaries of the west coast of South Africa. There are no species of particular conservation concern.

While fish are generally considered to be mobile, and will move away from the disturbance, benthic fish species as well as species that are dependent on the estuary for the completion of their life cycle may be disproportionally affected by the proposed dredge activities. However, it is noted that, in tandem with the declines in macrofauna species, there has been a complete loss of species that depend on these invertebrate communities within the system (benthic goby species in particular), as well as drastic declines in the number of juveniles of linefish species that depend on estuarine habitat (white steenbras and white stumpnose) (see Section 3.6.3). Therefore, it seems likely that there are very few fish species of particular sensitivity, conservation concern or commercial importance left in the system that require management.

This potential environmental impact is assessed as having a local, site-specific extent and a high intensity (Table 5-1). There is no difference in impact for either dredge option. Although the majority of the benthic organisms are likely to die or be removed from the dredge areas, this should not have any repercussions at the population levels as communities are likely to recover from other sites in the system relatively rapidly after the impact. The dredge impact duration is expected to occur over the short term (8-12 months) (Table 5-1). Therefore, the overall impact is assessed as being of Low negative significance before mitigation for both dredge options (Table 5-1). There are limited mitigation options available to reduce the intensity or probability of this impact, and therefore the impact remains of Low significance with mitigation for both dredge options (Table 5-1).

Table 5-1. Impact 1: Disturbance to and mortality of estuarine communities in the dredge footprint.

	Extent	Intensity	Duration	Consequence	Probability	Significance	Status	Confidence
Without mitigation - dredge and move	Local 1	High 3	Short-term 1	Low 5	Definite	**LOW**	-'ve	High
Without mitigation – dredge, clean and move	Local 1	High 3	Short-term 1	Low 5	Definite	**LOW**	-'ve	High
Essential mitigation measures: • Constrain spatial extent of impacts to the minimum required. • Ensure equipment is thoroughly rinsed/cleaned prior to use to ensure no transfer of introduced species form other systems.								
With mitigation – dredge and move	Local 1	High 3	Short-term 1	Low 5	Definite	**LOW**	-'ve	High

	Extent	Intensity	Duration	Consequence	Probability	Significance	Status	Confidence
With mitigation – dredge, clean and move	Local 1	High 3	Short-term 1	Low 5	Definite	**LOW**	-'ve	High

5.2.2 Disturbance to estuarine habitat due to dewatering activities

The proposed dewatering methodology (for the '**dredge, clean and move**' option) involves the use of large geotextile "geo-tubes" that will be placed in the grassy recreational space on the eastern side of the estuary body alongside Marine Drive, covering an area of about 0.025 km^2 (see Figure 1-1). There is no functional estuarine vegetation on site, and the entire eastern bank of the estuary in that area is canalised. This means that the area has ceased to have any connectivity with the estuarine water body (for example, it is no longer inundated with tides and hosts no natural estuarine vegetation). Impacts on estuarine habitat resulting from the proposed dewater is therefore considered to be Insignificant, and no mitigation is required (Table 5-2).

Table 5-2. Impact 2: Impact to estuarine habitat due to dewatering process.

	Extent	Intensity	Duration	Consequence	Probability	Significance	Status	Confidence
Without mitigation – dredge, clean and move'	Local 1	Low 1	Short-term 1	Very Low 3	Improbable	**INSIGNIFICANT**	-'ve	High
Mitigation measures: • Not required due to very low significance of impact.								

5.2.3 Noise disturbance of estuarine habitats and species from dredging activities

Noise associated with dredging operations may have an impact on estuarine organisms in the vicinity. Noise generated by dredging activities may include noise associated with service vehicles, vessels, cranes, heavy machinery, generators, etc. Estuarine and marine invertebrates have been shown to be relatively insensitive to low frequency sound, whilst fish appear to be able to tolerate moderate sound levels (Keevin & Hempen 1997).

Waterbirds that use the intertidal flats in the lower estuary for foraging (Section 3.6.4) are expected to avoid the sound source should it reach levels sufficient to cause discomfort. The dredge area and area of sand enrichment will overlap with intertidal areas of known importance to avifauna like greater flamingos, white-breasted cormorants and pied avocets (Section 3.6.4). Note that all of these species are listed as of Least Concern by the IUCN (https://www.iucnredlist.org/). While species of conservation concern (including migrants) were not observed in the lower reaches of the system in the most recent site visits, this does not mean that they may still be present in the system from time to time. Therefore, the extent of the impact may extend beyond the local area (i.e., by affecting how migratory species use the system). While it is likely that these species will completely avoid the lower estuarine/mouth area due to dredging-related noise and vibration (localised impact), the impacts will be of a short-term duration (8-12 months).

The impact for the '**dredge, clean and move**' option is therefore assessed to be of short-term duration, with a Medium significance prior to mitigation (Table 5-3). The '**dredge and move**' option is likely to have lower impacts on estuarine avifauna, simply because the process does not include de-watering and replacement (Table 5-3). After mitigation, the impact of noise and vibration on the estuarine environment for the '**dredge and move**' option is reduced to Very Low significance, while the '**dredge, clean and move**' option remains of Medium significance. (Table 5-3).

Table 5-3. Impact 3: Noise impacts on surrounding estuarine ecology due to dredging, dewatering and sand enrichment activities.

	Extent	Intensity	Duration	Consequence	Probability	Significance	Status	Confidence
Without mitigation - dredge and move'	Regional 2	Medium 2	Short-term 1	Low 5	Probable	**LOW**	-'ve	High
Without mitigation – dredge, clean and move'	Regional 2	High 3	Short-term 1	Medium 6	Probable	**MEDIUM**	-'ve	High
Essential mitigation measures: • Mobile equipment, vehicles and power generation equipment must be suitably maintained during the project. Implement a maintenance plan to ensure all diesel motors and generators receive adequate maintenance to minimise noise emissions and potential pollution events. • Constrain spatial extent of impacts to the minimum required. • Constrain highly disturbing (light, noise) activities to daytime where possible to minimise noise and light disturbance at night. **Recommended mitigation measures:** • Inform all staff about sensitive estuarine species and suitable disposal of waste. • Investigate and employ all feasible measures for reducing noise during dredging.								
With mitigation - dredge and move'	Regional 2	Medium 2	Short-term 1	Low 5	Possible	**VERY LOW**	-'ve	High
With mitigation - dredge, clean and move'	Regional 2	High 3	Short-term 1	Medium 6	Probable	**MEDIUM**	-'ve	High

5.2.4 SMOTHERING OF ESTUARINE FAUNA

Impacts of smothering related to dredging activities will affect most of the lower reaches of the system. For the '**dredge, clean and move**' option, the enrichment of sediment back into the system (see Section 4.6) will result in direct smothering of ~51 000 m^2 of lower estuarine habitat. The '**dredge and move**' option is likely to disturb the same area, and potentially even a greater area overall.

Smothering occurs when sediments are disturbed and settle on the seabed, covering and potentially suffocating organisms (Wilber et al. 2005). Sediments stirred up by dredging activities can settle over large areas, smothering benthic organisms (Wilber et al. 2005, Pineda et al. 2017). This can lead to decreased oxygen levels in the sediment, suffocating organisms unable to escape or tolerate the changes. The impacts of smothering also have cascading effects on entire ecosystems. For example, changes in the abundance or distribution of key species can alter predator-prey dynamics, trophic interactions, and overall ecosystem function (Wilber et al. 2005). Again however, there is evidence that the benthic habitats of the estuary are depauperate, with significant changes in community composition and structure (see Section 3.6). In addition, the estuary is relatively turbid for periods with high flow rates (the wet season, for example), and any communities still present are likely adapted to occasional periods of high sediment load.

The permanently open mouth of the system is likely to reduce the intensity of this impact, as is the generally low receptor sensitivity. While the dredging itself will take place over the short-term (six months, see Section 1.3), and modelling results also indicate almost complete tidal flushing even before dredging during the dry season. Strong freshwater flow (i.e., complete flushing during the wet season, see Section 4.8), means that resuspended materials are likely to quickly leave the system during this time.

Note that no mitigation is possible for smothering linked to the areas of enrichment, and the impact rating remains the same post-mitigation (Table 5-4).

Table 5-4. Impact 4. Smothering of estuarine fauna.

	Extent	Intensity	Duration	Consequence	Probability	Significance	Status	Confidence
Without mitigation - dredge and move	Local 1	High 3	Short-term 1	Low 5	Probable	**LOW**	-‘ve	High
Without mitigation – dredge, clean and move	Local 1	High 3	Short-term 1	Low 5	Probable	**LOW**	-‘ve	High
Essential mitigation measures: • Plan dredging and dewatering activities to minimize the duration and extent of disturbance to water bodies.								
With mitigation - dredge and move’	Local 1	High 3	Short-term 1	Low 5	Probable	**LOW**	-‘ve	High
With mitigation – dredge, clean and move	Local 1	High 3	Short-term 1	Low 5	Probable	**LOW**	-‘ve	High

5.2.5 Water quality impacts related to dredge and dewatering activities

This sedimentation can cloud the water (increased turbidity), reducing water clarity and light penetration and can disrupt the feeding and reproductive behaviours of various species that rely on clear water for survival. This may have negative implications for the primary productivity of microalgae (phytoplankton and microphytobenthos), and for invertebrates and fish. The response of larval fish to turbidity of the water column is generally species-specific (Harris et al. 1999) and estuarine fauna are generally well adapted to high levels of turbidity. However, fine particulate matter may result in the clogging of the feeding and breathing apparatus of certain organisms (e.g., filter feeding invertebrates and the gills of sensitive fish species) (Wenger et al. 2017).

Released sediment can also introduce excess nutrients into estuarine waters (Kahn & Mohammad 2014). Nutrient enrichment can lead to eutrophication, promoting algal blooms and reducing oxygen levels in the water. This can result in fish kills, habitat degradation, and the loss of biodiversity. As discussed in Section 3.5.2, elevated nutrient levels associated with finer particle sizes have been reported by Gihwala et al. (2021) in the proposed dredging area. These nutrients will likely therefore be remobilised into the water column during dredging activities.

Dredging can also release contaminants trapped in sediments, such as heavy metals, hydrocarbons, and other pollutants, into the water column (Eggleton & Thomas 2004). These contaminants can have toxic effects on marine fauna, causing physiological stress, reproductive problems, and even death. As discussed in Section 3.5.2, there are elevated levels of trace metals in the sediments of the system, some of which (As, Cd, Ni, Zn) exceeded the South African and international sediment quality guidelines (Gihwala et al. 2021). Indeed, the average trace metal concentrations for Cd, Ni and Zn within the Diep Estuary were relatively high in comparison to other local and international estuaries (Gihwala et al. 2021). These trace metals will also therefore be remobilised into the water column during dredging activities.

It is important to note that just because a trace metal is present within sediment at a specific concentration does not mean that the metal is in a bioavailable (i.e., harmful) form, nor that the concentration in the sediment translates to a 100% resuspension to a dissolved form. Indeed, it has been suggested by previous sediment transport studies that a small fraction (0.5%) of trace metals bound to benthic sediment enters the water column as dissolved trace metals during large scale disturbance of the sediment such as dredging (Van Ballegooyen et al. 2023). Therefore, while resuspension of trace metals into the water column due to dredging is noted, the magnitude of the impact is likely tempered by lower bioavailability.

The '**dredge and move**' option will likely have the high intensity, immediate impacts on estuarine water quality through sediment disturbance and remobilisation. For this option, the sediment will essentially be redistributed to create 'intertidal' areas along the eastern edge of the lower system. Any organic matter or other containments present in the sediment will therefore be remobilised within the system, and not physically removed — this will likely result in higher intensity short term impacts on water quality, especially in terms of oxygen levels, given that the dredging cannot be planned for times of optimal flushing (i.e., the wet season). This option does not result in any long-term removal of organic material from the lower estuary. The material that remains on the created intertidal flats will be inundated at high tide, likely resulting on continued 'leeching' of organic material to the water column. The impact is therefore assessed as of a medium-term duration (Table 5-5).

The '**dredge, clean and move**' option involves a dewatering process, which involves the use of large geotextile "geo-tubes" that contain the material and filter the water as it permeates through the bag. This water will ultimately flow from the geo-tubes and will re-enter the estuary. The volumes of water re-entering the system will be relatively small and will be released over the course of around eight months (see Section 1.3). It is anticipated that most of the sediments and organic matter present in this dewatering process will be contained within the geo-textile bags. It is also anticipated then that the water re-entering the estuary will be of sufficient quality to not pose a risk to the health of the system in terms of suspended solids and organic material. The impact is therefore assessed as of a short-term duration (Table 5-5).

There is some risk that sediment disturbance and remobilisation of organic material will have implications for oxygen level in the system. While low oxygen levels do occur within the system (due to organic enrichment), it is important to ensure that additional low oxygen events are suitably managed (and preferably prevented). It is proposed that oxygen monitoring take place in the lower reaches of the system for the duration of the dredging process to monitor these impacts, with control sites upstream of Woodbridge Island. Should the 95th percentile Dissolved Oxygen (DO) levels in the lower system fall below 10% of the control sites, additional management actions may be required (such as oxygenation).

The project engineers have stated that dredging cannot be scheduled for the wet season, which is characterised by almost complete tidal flushing, and strong freshwater flow, with complete flushing (see Section 4.8), during which resuspended materials are likely to quickly leave the system. While the dredging itself will take place over the short-term (six months, see Section 1.3), modelling results indicate that there is limited tidal exchange with water in the lower estuary (even before dredging) in the dry season. Indeed, there are potential risks that dredging may result in increased deposition of organic material in the dredge channel in the dry season (Section 4.8.3); however, these are likely to be mitigated by the increased tidal flushing (Section 4.8.2), provided that the mouth stay open.

Table 5-5. Impact 5: Impacts on estuarine water quality.

	Extent	Intensity	Duration	Consequence	Probability	Significance	Status	Confidence
Without mitigation - dredge and move'	Local 1	High 3	Medium-term 2	Medium 6	Probable	**MEDIUM**	-'ve	High
Without mitigation – dredge, clean and move'	Local 1	High 3	Short-term 1	Low 5	Probable	**LOW**	-'ve	High

Essential mitigation measures:

- Plan dredging and dewatering activities to minimize the duration and extent of disturbance to water bodies.
- For land-based activities that may result in erosion, contractors are to install erosion control barriers such as silt fences, sediment traps, drainage channels or sediment curtains to minimise sediment runoff into the water during the proposed activities. This is pertinent if construction is to take place during the wet season.

	Extent	Intensity	Duration	Consequence	Probability	Significance	Status	Confidence
Monitoring requirements • Dissolved Oxygen (DO) monitoring take place in the lower reaches of the system, with control sites upstream of Woodbridge Island. Should the 95%ile DO levels in the lower system fall below 10% of the control sites, additional management actions may be required (such as oxygenation).								
With mitigation - dredge and move'	Local 1	High 3	Medium-term 2	Medium 6	Probable	**MEDIUM**	-'ve	High
With mitigation – dredge, clean and move'	Local 1	High 3	Short-term 1	Low 5	Probable	**LOW**	-'ve	High

5.2.6 WASTE GENERATION AND DISPOSAL

The problem of litter entering the environment has escalated dramatically in recent decades, with an ever-increasing proportion of litter consisting of non-biodegradable plastic materials. South Africa has laws against littering, both on land and in the coastal zone, but they are seldom rigorously enforced. Objects which are particularly detrimental to aquatic fauna include plastic bags and bottles, pieces of rope and small plastic particles. Large numbers of aquatic organisms are killed or injured daily by becoming entangled in debris or as a result of the ingestion of small plastic particles (Gregory 2009, Wright et al. 2013). These materials, being largely plastics, may be transported by currents for long distances out to sea or around the coast. The impact on certain forms of marine life by floating or submerged solid materials cannot be overstressed. Most at risk are seabirds and fish, including possibly rare or even endangered species.

Poor management of the dredging and dewatering operations site can also have impacts on water quality. For example, uncontrolled runoff of sewage and other organic wastes is harmful to biota due to high concentrations of nutrients which stimulate primary production that in turn leads to changes in species composition and changes to biodiversity, toxicity effects and impacts on water quality parameters like oxygen (Cloern 2001). Dredging will also involve the presence of vehicles on the intertidal areas of the estuary. Spills or improper disposal of waste associated with the full project operation on site can lead to water contamination, posing risks to aquatic life and human health. Pollutants can bioaccumulate in the food chain and have long-lasting impacts on ecosystems.

In order to reduce this, all domestic and general waste generated during construction must be disposed of responsibly. All reasonable measures must be implemented to ensure there is no littering and that construction waste is adequately managed. Staff must be regularly reminded about the detrimental impacts of pollution on aquatic species, and suitable handling and disposal protocols must be clearly explained, and sign boarded. The 'reduce, reuse, recycle' policy must be implemented. This impact is rated as Medium without mitigation and is reduced to Very Low with appropriate mitigation actions (for all dredge options) (Table 5-6).

Table 5-6. Impact 6: Waste generation and improper disposal.

	Extent	Intensity	Duration	Consequence	Probability	Significance	Status	Confidence
Without mitigation – both options	Regional 2	Low 1	Long term 3	Medium 6	Probable	**MEDIUM**	-ve	High
Essential mitigation measures: • Inform and train all staff about sensitive estuarine species and the responsible disposal of construction waste. This training must be integrated into toolbox talks or onsite awareness sessions to ensure that waste management practices are understood and followed diligently. Additionally, contractors must prepare a method statement outlining specific waste management procedures, which must be approved by the resident engineer before construction activities commence. • Suitable handling and disposal protocols must be clearly explained, and sign boarded. • Reduce, reuse, recycle. • Waste disposal at licensed landfill sites by qualified contractors is mandatory, with proof of disposal submitted to the appointed Environmental Officer. Waste management certification must be obtained, and detailed records of all stored and disposed waste, including quantity, nature, and fate, must be maintained for auditing purposes. • Adequate sanitary facilities and ablutions must be provided for all personnel throughout the project area. Enforcement of facility usage and cleanliness is crucial.								
With mitigation – both options	Local 1	Low 1	Long term 2	Low 5	Improbable	**VERY LOW**	-ve	High

5.3 Operational impacts

5.3.1 Impacts of dredging on magnitude of the tidal prism

Model results for both the low flow and high flow scenarios indicate that the dredging increases tidal exchange between the study area and the ocean, with more high salinities (~35) in the lower system, and a small (~11%) increase in average salinity in the lower estuary in the dry season, and a larger (~54%) increase on average during the wet season (Section 4.8.2). This increased salinity is indicative of tidal flushing — there is more ocean water pushed into the lower system by the tides (in particular, at spring high tide) after dredging.

Under dry season conditions, the model results show that it takes more energy to 'move' the saline water back out on outgoing tides and replace it with freshwater after dredging than before. This demonstrates that tidal forcing is more important to the function of the estuarine exchange than the freshwater inflow during the dry season. In other words, the Potsdam flow, which dominates the freshwater inflow in the dry season, is not strong enough to 'push' the seawater back out of the mouth after dredging (see Section 4.8.2). The large flood events that occur during the wet season (and specifically, the modelled 2024 floods) result in large scale mouth scour and changes to the bathymetry, allowing more saltwater penetration into the system (Section 4.8.2).

This improvement in tidal flux (as demonstrated by saline inflow) does not appear to increase modelled upstream saline intrusion (see Section 4.8.2) and any positive impacts appear to be limited to the lower reaches of the system.

In the case of this fresher dominated system, increased salinity would ideally result in a more brackish system, which would better support estuarine communities (such as sandprawns). This would also potentially result in potential improvements in water quality, improved habitat for benthic organism and fish, with positive cascading impacts up the food chain.

However, based on the modelling results presented here, it is unlikely that the predicted general increase in salinity with dredging will result in a change to the Estuarine Health Score of the system. Instead, model results suggest that dredging will result in marginal improvements in the tidal prism and increased average salinity in the lower reaches of the system. The extent of the impact is limited to the lower reaches of the system, and the effects are anticipated to last over the medium term (based on Infinity Environmental 2023). Therefore, the impact is assessed to be a Low, positive impact for both dredging options (Table 5-7). Note however that neither dredging option will address all of the challenges faced by the Milnerton Lagoon — for long term, high significance positive impacts to be realised, the problems with the upstream inflow water quality must be addressed.

Table 5-7. Impact 7: Impacts of proposed dredging on magnitude of the estuarine tidal prism.

	Extent	Intensity	Duration	Consequence	Probability	Significance	Status	Confidence
Without mitigation - dredge and move'	Local 1	Medium 2	Medium-term 2	Low 5	Probable	**LOW**	+'ve	High
Without mitigation – dredge, clean and move'	Local 1	Medium 2	Medium-term 2	Low 5	Probable	**LOW**	+'ve	High
There is no feasible mitigation to enhance the direct positive impacts of dredging on the on magnitude of the estuarine tidal prism								

5.3.2 Impacts of a deeper channel at the mouth of sludge settlement and flushing

The proposed dredging of a new, narrow cannel towards the mouth in the lower reaches of the system may concentrate any 'sludge' that has been transported down the system. Instantaneous velocities are likely to be lower within the deeper parts of the channel, relative to the shallower banks (because velocities immediately decrease in wider, deeper areas) (see Section 4.8.3) (Schumann & Brink 2009). The presence of this deeper channel may therefore result in the concentration of fine, organic rich sludge into this channel, especially in the dry season (see Section 4.8.3).

However, the enhanced tidal prism may also more readily flush out accumulated material through the mouth (with the overall larger volume flow rate in dredged area). Note however that this improvement will only likely be realised in the lower portions of the system towards the mouth (given that there are limited impacts on tidal prism forcing further upstream, see Section 4.8). Therefore, the proposed dredging may result in a Very Low positive impact on estuarine health over the medium term for both dredging options (Table 5-8).

It is imperative that the channel be maintained at this depth to ensure continued function (and associated benefit) over time (Table 5-8). The key recommendation here is that inflow water from the catchment as well as various point sources (including the Potsdam WWTW) must be improved to realise a significant improvement in estuarine health over the long term.

Table 5-8. Impact 8: Impacts of a deeper channel at the mouth of sludge settlement and flushing.

	Extent	Intensity	Duration	Consequence	Probability	Significance	Status	Confidence
Without mitigation - dredge and move'	Local 1	Low 1	Medium-term 2	Very Low 4	Probable	**VERY LOW**	+'ve	Low
Without mitigation – dredge, clean and move'	Local 1	Low 1	Medium-term 2	Very Low 4	Probable	**VERY LOW**	+'ve	Low
Recommendations to enhance the positive impact: • It is imperative that the channel be maintained at this depth. • The mouth must be kept open at all times.								
With mitigation - dredge and move'	Local 1	Low 1	Medium-term 2	Very Low 4	Probable	**VERY LOW**	+'ve	Low
Without mitigation – dredge, clean and move'	Local 1	Low 1	Medium-term 2	Very Low 4	Probable	**VERY LOW**	+'ve	Low

5.3.3 IMPACTS OF NEW EXPOSED MUDFLAT INTERTIDAL AREAS RESULTING FROM SAND REPLACEMENT

Under both dredging options, dredged sediment will be moved/put back into the estuary once dewatered to create an artificial sandflat along the eastern bank. Some 24 000 m^3 will be returned to the system, raising the bed level by 400 mm. This will result in increased sand in intertidal areas, which may mean that more intertidal mud/sandflat area is exposed at low tide in the lower estuary. Assuming that the sand is colonised by benthic macrofauna, this has the potential to expand the feeding area available to waders and other waterbirds which feed on the intertidal mud/sandflats. Furthermore, exposure to air will likely facilitate oxygenation of these sediments. This has the potential to have a positive impact on estuary water quality.

These impacts are likely to be very localised to the lower estuary and of low intensity, resulting in a Very Low positive significance with Low confidence for both dredging options (Table 5-9). By improving the quality of the inflow water into the estuary, which will have large positive impacts on estuary health, the value of the additional tidal flat area will be much greater, as they will likely support a much greater diversity of macrofauna and waterbirds. This impact is rated as having a High positive significance with improved water quality (Table 5-9).

Table 5-9. Impact 9: Impacts on estuarine health linked to new intertidal areas resulting from sediment enrichment.

	Extent	Intensity	Duration	Consequence	Probability	Significance	Status	Confidence
Without mitigation - dredge and move'	Local 1	Low 1	Medium-term 2	Very Low 4	Definite	**VERY LOW**	+'ve	Low
Without mitigation – dredge, clean and move'	Local 1	Low 1	Medium-term 2	Very Low 4	Definite	**VERY LOW**	+'ve	Low
There is no feasible mitigation to enhance the direct positive impacts of new intertidal areas resulting from sediment enrichment.								

5.4 NO-GO ALTERNATIVE

The No-Go alternative represents the baseline against which the project related impacts are assessed. The no-go option would entail maintaining the current status quo, i.e. no dredging activities in the lower Diep Estuary.

The Construction Phase impacts assessed above (Section 5.2) are all assessed as of negative significance, with generally short- to medium- term durations and significances ranging from Insignificant to Medium after mitigation. Therefore, the no-go option would mean that none of these negative Construction phase impacts occur.

However, the no-go option also means that the positive impacts assessed for the Operational Phase (Section 5.3) (rated as Low to Very Low positive impacts) that may occur once dredging is completed will not be realised. The realisation of these positive benefits is contingent on the implementation of the required mitigation measures, and provided that the mouth is kept open.

5.5 PRE-REQUISITES FOR PROJECT SUCCESS

Dredging activities cannot be performed in isolation; rather, necessary pre-requisites need to be met to ensure efficient allocation of resources and implementation of environmental management programmes.

The quality of inflow from the catchment has been identified as a critical determinant of the overall health of the estuarine system. Monitoring efforts have identified consistent deterioration in estuarine water and sediment quality over several years primarily led by the decrease in inflow water quality (see Section 3.4 and Section 3.5). Therefore, improvement of inflow water from the catchment and various point sources (including the Potsdam WWTW) is imperative to improve estuarine health over the long term.

It is imperative that the mouth be kept open at all times. Any mouth closure will lead to a drop in tidal forcing which, which combined with the lower bed sheer stress, will likely lead to the settling of organic matter from upstream to the sediment, as well as dramatic decreases in oxygen level due to the poor quality of the freshwater inflow.

5.6 Summary of potential impacts

Identified potential impacts that may be experienced during the construction or operational phases, before and after mitigation, are summarised in Table 5-10.

Table 5-10. Summary of potential construction and operational phases of the proposed dredging, dewatering and enrichment activities on the lower Diep Estuary.

Phase	Impact identified	Consequence	Probability	Significance	Status	Confidence
Construction phase	Impact 1a: Disturbance to and mortality of estuarine communities in the dredge footprint - dredge and move.	Low	Definite	**LOW**	-'ve	High
	After mitigation - dredge and move.	Low	Definite	**LOW**	-'ve	High
	Impact 1b: Disturbance to and mortality of estuarine communities in the dredge footprint - dredge, clean and move.	Low	Definite	**LOW**	-'ve	High
	After mitigation - dredge, clean and move.	Low	Definite	**LOW**	-'ve	High
	Impact 2: Impact to estuarine habitat due to dewatering process - dredge, clean and move.	Very Low	Improbable	**INSIGNIFICANT**	-'ve	High
	Impact 3a: Noise impacts on surrounding estuarine ecology due to dredging, activities - dredge and move.	Low	Probable	**LOW**	-'ve	High
	After mitigation - dredge and move.	Low	Possible	**VERY LOW**	-'ve	High
	Impact 3b: Noise impacts on surrounding estuarine ecology due to dredging, dewatering and sand enrichment activities - dredge, clean and move.	Medium	Probable	**MEDIUM**	-'ve	High
	After mitigation – dredge, clean and move.	Medium	Probable	**MEDIUM**	-'ve	High
	Impact 4a. Smothering of estuarine fauna from dredging, activities - dredge and move.	Low	Probable	**LOW**	-'ve	High
	After mitigation - dredge and move.	Low	Probable	**LOW**	-'ve	High
	Impact 4b. Smothering of estuarine fauna from dredging, dewatering and sand enrichment activities - dredge, clean and move.	Low	Probable	**LOW**	-'ve	High
	After mitigation - dredge, clean and move.	Low	Probable	**LOW**	-'ve	High
	Impact 5a: Impacts on estuarine water quality- dredge and move.	Medium	Probable	**MEDIUM**	-'ve	High

Phase	Impact identified	Consequence	Probability	Significance	Status	Confidence
Construction phase (Cont.)	After mitigation - dredge and move.	Medium	Probable	MEDIUM	-'ve	High
	Impact 5b: Impacts on estuarine water quality- dredge, clean and move	Low	Probable	LOW	-'ve	High
	After mitigation - dredge, clean and move.	Low	Probable	LOW	-'ve	High
	Impact 6: Waste generation and improper disposal – both options.	Medium	Probable	MEDIUM	-ve	High
	After mitigation – both options.	Low	Improbable	VERY LOW	-ve	High
Operational phase	Impact 7a: Impacts of proposed dredging on magnitude of the estuarine tidal prism - dredge and move.	Low	Probable	LOW	+'ve	High
	Impact 7b: Impacts of proposed dredging on magnitude of the estuarine tidal prism - dredge, clean and move.	Low	Probable	LOW	+'ve	High
	Impact 8a: Impacts of a deeper channel at the mouth of sludge settlement and flushing - dredge and move.	Very Low	Probable	VERY LOW	+'ve	Low
	After mitigation – dredge and move.	Very Low	Probable	VERY LOW	+'ve	Low
	Impact 8b: Impacts of a deeper channel at the mouth of sludge settlement and flushing - dredge, clean and move.	Very Low	Probable	VERY LOW	+'ve	Low
	After mitigation - dredge, clean and move.	Very Low	Probable	VERY LOW	+'ve	Low
	Impact 9a: Impacts on estuarine health linked to new intertidal areas resulting from sediment enrichment - dredge and move.	Very Low	Definite	VERY LOW	+'ve	Low
	Impact 9b: Impacts on estuarine health linked to new intertidal areas resulting from sediment enrichment – dredge, clean and move.	Very Low	Definite	VERY LOW	+'ve	Low

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Impact assessment

Sixteen potential impacts were identified and assessed for the proposed '**dredge and move'** activities (i.e., the movement of sediment from the channel to the intertidal banks) and the proposed '**dredge, clean and move'** activities (i.e., the removal of sediment, as well as dewatering and enrichment of the estuary with the clean sediment) as described in Section 1.1 and Section 4.6 in the lower reaches of the Diep Estuary. Both construction phase impacts and operational impacts were assessed.

Of the ten construction phase impacts, there were six impacts of Low negative significance (either reduced to Very Low, or remaining at a Low significance with mitigation), and one impact assessed to be Insignificant, requiring no mitigation. There were three identified impacts of Medium significance before mitigation, one of which were reduced to Very Low significance post-mitigation, and three which remained as of Medium significance with mitigation.

All identified impacts during the operational phase (i.e., after completion of dredging) were assessed to be positive, meaning that they improved environmental conditions of the system in question. These impacts were either of Low positive significance, or Very Low positive significance. Note the low confidence rating for these Very Low positive impacts.

6.2 Mitigation and monitoring

There are as series of recommended mitigation measures that should be taken to avoid, minimize, or offset adverse impacts, or enhance positive impacts, identified during the Impact Assessment. They include:

- Any equipment to be used in the estuary must be thoroughly rinsed/cleaned prior to use to ensure no transfer of introduced species from other systems.
- All feasible measures for reducing noise during dredging should be investigated and employed. Mobile equipment, vehicles and power generation equipment must be suitably maintained during the project. A maintenance plan must be implemented to ensure all diesel motors and generators receive adequate maintenance to minimise noise emissions and potential pollution events.
- Highly disturbing (light, noise) activities should be constrained to the daytime where possible to minimise noise and light disturbance at night.
- The spatial extent of impacts must be constrained to the minimum required. Dredging and dewatering activities should be planned to minimize the duration and extent of disturbance to water bodies.
- For land-based activities that may result in erosion, contractors are to install erosion control barriers such as silt fences, sediment traps, drainage channels or sediment curtains to minimise sediment runoff into the water during the proposed activities. This is pertinent if construction is to take place during the wet season.
- All staff must be informed and trained about estuarine species and the responsible disposal of construction waste. This training must be integrated into

toolbox talks or onsite awareness sessions to ensure that waste management practices are understood and followed diligently. Additionally, contractors must prepare a method statement outlining specific waste management procedures, which must be approved by the resident engineer before construction activities commence.

- Suitable handling and disposal protocols must be clearly explained, and sign boarded. A reduce, reuse, recycle policy must be drafted and adhered to.
- Waste disposal at licensed landfill sites by qualified contractors is mandatory, with proof of disposal submitted to the appointed Environmental Officer. Waste management certification must be obtained, and detailed records of all stored and disposed waste, including quantity, nature, and fate, must be maintained for auditing purposes.
- Adequate sanitary facilities and ablutions must be provided for all personnel throughout the project area. Enforcement of facility usage and cleanliness is crucial.
- Improvement of inflow water from the catchment and various point sources (including the Potsdam WWTW) is imperative to improve estuarine health over the long term.
- It is imperative that the channel be maintained at this depth and the mouth be kept open at all times.

Monitoring requirements include that Dissolved Oxygen (DO) monitoring take place in the lower reaches of the system, with control sites upstream of Woodbridge Island. Should the 95%ile DO levels in the lower system fall below 10% of the control sites, additional management actions may be required (such as oxygenation).

6.3 Conclusions

Based on the modelling results presented here, it is unlikely that dredging will result in a significant improvement in tidal forcing in the Diep Estuary as a whole, and it is unlikely that the dredging activities will result in a change to the Estuarine Health Score of the system. Model results for low flow scenario (i.e., worst-case) indicate that the dredging increases tidal exchange between the estuary and the ocean, with more high salinities (~35) in the lower system bottom waters (a small (~10%) increase in average salinity in the lower estuary and a larger (~54%) increase on average during the wet season). This improvement in tidal flux (as demonstrated by saline inflow) does not appear to increase modelled upstream saline intrusion, and the positive impacts will therefore be limited to the lower reaches of the system. Therefore, the impact is assessed to be a Low, positive impact. It is imperative that the channel be maintained at this depth to ensure continued function (and associated benefit) over time.

The large flood events that were included in the modelled wet season were relatively unusual across the available hydrological time scale (see Section 3.2), and caution must be taken when applying this scenario as 'representative' of future wet seasons. It is likely that during the years of no flow days > 50 m^3/s, the system will behave as a 'dry season' system, regardless of the time of year. This is of particular concern in the face of decreased catchment flows due to climate change.

There may be some additional positive impacts to the system that are associated with the proposed activities, especially for the dredge, dewater and enrichment option. While these are assessed with low confidence, they may offer additional impacts of very low positive significance. For example, the new, narrow dredged cannel in the lower reaches of the system may concentrate any 'sludge' that has been transported down the system, where the enhanced tidal prism will more readily flush it out through the mouth (with the overall larger volume flow rate in the dredged area). Assuming that the sand is colonised by benthic macrofauna, this has the potential to expand the feeding area available to waders and other waterbirds which feed on the intertidal mud/sandflats. In addition, the creation of larger tidal flats adjacent to the dredge area will be exposed at low tide, along with any deposited material. Exposure to air may facilitate oxygenation of these sediments. There is a risk however, that the lower bed shear stress within the dredge channel may result in a higher likelihood that organic material may settle out onto the bed under low flow scenarios.

These model results and associated assessment suggest that dredging will not address all of the challenges faced by the Milnerton Lagoon The quality of inflow from the catchment has been identified as a critical determinant of the overall health of the estuarine system — for long term, high significance positive impacts to be realised, improvement of inflow water from the catchment and various point sources (including the Potsdam WWTW) is imperative to improve estuarine health over the long term.

It is imperative that the mouth be kept open at all times. Any mouth closure will lead to a drop in tidal forcing which, which combined with the lower bed shear stress in the dredge channel, will likely lead to the settling of organic matter from upstream, as well as dramatic decreases in oxygen level due to the poor quality of the freshwater inflow.

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8 APPENDIX I

Impact Assessment Methodology

The significance of all potential impacts that would result from the proposed project is determined in order to assist decision-makers. The significance of an impact is defined as a combination of the consequence of the impact occurring and the probability that the impact will occur. The significance of each identified impact was thus rated according to the methodology set out below:

Step 1 – Determine the consequence rating for the impact by determining the score for each of the three criteria (A-C) listed below and then adding them. The rationale for assigning a specific rating, and comments on the degree to which the impact may cause irreplaceable loss of resources and be irreversible, must be included in the narrative accompanying the impact rating:

Rating	Definition of Rating	Score
A. **Extent** – the area over which the impact will be experienced.		
Local	Confined to project or study area or part thereof (e.g. limits of the concession area)	1
Regional	The region (e.g. the whole of Namaqualand coast)	2
(Inter) national	Significantly beyond Saldanha Bay and adjacent land areas	3
B. **Intensity** – the magnitude of the impact in relation to the sensitivity of the receiving environment, taking into account the degree to which the impact may cause irreplaceable loss of resources.		
Low	Site-specific and wider natural and/or social functions and processes are negligibly altered	1
Medium	Site-specific and wider natural and/or social functions and processes continue albeit in a modified way	2
High	Site-specific and wider natural and/or social functions or processes are severely altered	3
C. **Duration** – the time frame for which the impact will be experienced and its reversibility.		
Short-term	Up to 2 years	1
Medium-term	2 to 15 years	2
Long-term	More than 15 years (state whether impact is irreversible)	3

The combined score of these three criteria corresponds to a Consequence Rating, as follows:

Combined Score (A+B+C)	3 – 4	5	6	7	8 – 9
Consequence Rating	Very low	Low	Medium	High	Very high

Example 1:

Extent	Intensity	Duration	Consequence
Regional 2	Medium 2	Long-term 3	High 7

Step 2 – Assess the probability of the impact occurring according to the following definitions:

Probability – the likelihood of the impact occurring	
Improbable	< 40% chance of occurring
Possible	40% - 70% chance of occurring
Probable	> 70% - 90% chance of occurring
Definite	> 90% chance of occurring

Example 2:

Extent	Intensity	Duration	Consequence	Probability
Regional 2	Medium 2	Long-term 3	High 7	Probable

Step 3 – Determine the overall significance of the impact as a combination of the consequence and probability ratings, as set out below:

		PROBABILITY			
		Improbable	Possible	Probable	Definite
CONSEQUENCE	Very Low	INSIGNIFICANT	INSIGNIFICANT	VERY LOW	VERY LOW
	Low	VERY LOW	VERY LOW	LOW	LOW
	Medium	LOW	LOW	MEDIUM	MEDIUM
	High	MEDIUM	MEDIUM	HIGH	HIGH
	Very High	HIGH	HIGH	VERY HIGH	VERY HIGH

Example 3:

Extent	Intensity	Duration	Consequence	Probability	Significance
Regional 2	Medium 2	Long-term 3	High 7	Probable	HIGH

Step 4 – Note the status of the impact (i.e. will the effect of the impact be negative or positive?)

Example 4:

Extent	Intensity	Duration	Consequence	Probability	Significance	Status
Regional 2	Medium 2	Long-term 3	High 7	Probable	HIGH	-'ve

Step 5 – State the level of confidence in the assessment of the impact (high, medium or low).

Impacts are also considered in terms of their status (positive or negative impact) and the confidence in the ascribed impact significance rating. The prescribed system for considering impacts status and confidence (in assessment) is laid out in the table below. Depending on the data available, a higher level of confidence may be attached to the assessment of some impacts than others. For example, if the assessment is based on extrapolated data, this may reduce the confidence level to low, noting that further ground-truthing is required to improve this.

Confidence rating	
Status of impact	+ ve (beneficial) or – ve (cost)
Confidence of assessment	Low, Medium or High

Example 5:

Extent	Intensity	Duration	Consequence	Probability	Significance	Status	Confidence
Regional 2	Medium 2	Long-term 3	High 7	Probable	HIGH	-'ve	High

The significance rating of impacts is considered by decision-makers, as shown below. Note, this method does not apply to minor impacts which can be logically grouped into a single assessment.

INSIGNIFICANT: the potential impact is negligible and will not have an influence on the decision regarding the proposed activity.

VERY LOW: the potential impact is very small and should not have any meaningful influence on the decision regarding the proposed activity.

LOW: the potential impact may not have any meaningful influence on the decision regarding the proposed activity.

MEDIUM: the potential impact should influence the decision regarding the proposed activity.

HIGH: the potential impact will affect a decision regarding the proposed activity.

VERY HIGH: The proposed activity should only be approved under special circumstances.

Step 6 – Identify and describe practical mitigation and optimisation measures that can be implemented effectively to reduce or enhance the significance of the impact. Mitigation and optimisation measures must be described as either:

- Essential: must be implemented and are non-negotiable; and
- Best Practice: must be shown to have been considered and sound reasons provided by the proponent if not implemented.

Essential mitigation and optimisation measures must be inserted into the completed impact assessment table. The impact should be re-assessed with mitigation, by following Steps 1-5 again to demonstrate how the extent, intensity, duration and/or probability change after implementation of the proposed mitigation measures.

Example 6:

	Extent	Intensity	Duration	Consequence	Probability	Significance	Status	Confidence
Without mitigation	Regional 2	Medium 2	Long-term 3	High 7	Probable	HIGH	-'ve	High
Essential mitigation measures Xxxx Xxxxx								
With mitigation	Local 1	Low 1	Long-term 3	Low 5	Improbable	**VERY LOW**	– ve	High

Step 7 – Prepare a summary table of all impact significance ratings as follows:

Phase	Impact identified	Severity	Probability	Significance	Status	Confidence
xxxxxx	Impact 1: xxx	Medium	Improbable	**LOW**	–ve	High
	With mitigation	Low	Improbable	**VERY LOW**		High
	Impact 1: xxx	Very Low	Definite	**VERY LOW**	–ve	Medium
	With mitigation	Very Low	Improbable	**INSIGNIFICANT**	–ve	Medium

Indicate whether the proposed development alternatives are environmentally suitable or unsuitable in terms of the respective impacts assessed by the relevant specialist and the environmentally preferred alternative.

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environmental