



Proceedings of the 35TH PIANC WORLD CONGRESS 2024

Cape Town, South Africa, 29 April – 03 May 2024

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EDITORIAL TEAM

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Foreword

To our delegates, esteemed authors and valued attendees,

Welcome to a celebration of progress and innovation in international waterborne transportation, embodied in the 35th PIANC World Congress 2024, held in the pulsating heart of Cape Town, South Africa. The theme of this year's gathering, ***"Future Ready Waterborne Transport – Unlocking Africa"***.

The theme addressed the work necessary in creating a sustainable maritime sector. The Congress included a good selection of presentation of technical papers in the consulting, contracting, research and development space within the waterborne transportation sector.

Our profound gratitude is extended to all of you who participated and to the primary host, PIANC, along with our Platinum Partner, Transnet National Ports Authority. As the key player in the South African ports and coastal sector, and representative of South Africa within PIANC, their partnership and the support of all our sponsors was instrumental in orchestrating this great event. Their involvement, combined with the support of the PIANC members from across the globe, exemplifies the collaborative spirit at the core of the International Waterborne Transportation community.

The Congress consisted of a main plenary session and parallel technical sessions daily. For parallel technical sessions over 300 abstracts were submitted by authors from over 150 Organisations in 41 countries, to share latest research and developments under the various sub themes. A big thank you to all those that submitted their abstracts for consideration and who registered to present their paper.

The technical committee had a difficult task of selecting around 280 abstracts that was converted into high quality peer-reviewed technical papers for oral presentation at the Congress.

We owe a debt of gratitude to every individual and institution that submitted their pioneering works. The important task of selecting abstracts and reviewing final technical papers fell upon our devoted technical committee, leading to the submission of technical papers that made up a high-quality Congress programme. All papers published in these proceedings, were subjected to a peer-review process involving at least 2-3 reviewers. The range of sub-themes —Overcoming Africa's waterborne transport challenges, Dredging (in the framework of port and navigation projects), Logistics & Infrastructure, Ports, Marinas and small craft harbours, Environment and Inland Navigation — reflects the fabric of the international waterborne transport sector.

As you delve into this proceedings booklet, may it not only offer a deep dive into the myriad facets of the waterborne transport landscape but also inspire you with our industry's dedication to pioneering a more sustainable, efficient, and interconnected world.

Warmest regards,

Mr. Magenthran Ruthenavelu

Congress Chairperson
PIANC SA

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DREDGING

35th PIANC World Congress, 29 April – 23 May 2024, Cape Town, South Africa
 Paper Title: A Holistic Port Basin Expansion Dredging Design Approach for Port Victoria, Seychelles
 Authors Names: Y Kistner, M Rossouw, R van Ballegooyen & M Retief,

A Holistic Port Basin Expansion Dredging Design Approach for Port Victoria, Seychelles

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As part of the Port Victoria Rehabilitation and Extension project, deepening and expansion of the port basin is required to accommodate larger container vessels and fuel tankers. This paper summarises the approach that was followed to derive the dredging, reclamation and spoil disposal solution that will allow for safe navigation of the design vessels, while keeping the environmental impact of associated construction works within acceptable limits. Firstly, key design components, inputs requirements and interdependencies between these were identified. Subsequently, a nautical study was conducted, dredging extents were established, a likely dredge, reclamation and spoil description was developed and the impacts of the dredging-related activities on the surrounding environment were assessed. The dredge design was ultimately captured in drawings, technical specifications and a Dredge Management Plan.

Keywords: dredging, port basin, navigation, dredge spoil, Seychelles, Port Victoria

Introduction

Seychelles is an archipelagic island country situated in the Indian Ocean near the equator. Despite its remote location, the island has a strong economy, boasting one of the highest nominal per capita GDPs amongst African nations. Key to the country's economic prosperity is Port Victoria, Seychelles' primary international sea-freight terminal. The port is base to an industrial-scale fishery (tuna), generating a major part of the country's revenue-earning exports of produce. It also handles the bulk of the country's imports, including fuel, cement and general cargo (mostly containerised). Cruise ships also call at the port.

The Commercial Port, where international freight is handled, has a 370m long quay, referred to as the Mahé quay. The quay infrastructure is severely deteriorated and at risk of structural failure [9]. Furthermore, the quay does not have the structural capacity for shore-based quay cranes that are required to serve modern container vessels.

The port basin has depths near the berth ranging between -10m and -12m Chart Datum (CD), severely restricting access to Panamax-sized and larger container vessels.

The Seychelles Port Authority (SPA) is undertaking the Port Victoria Rehabilitation & Extension project to address the existing spatial and infrastructural limitations of Port Victoria and its potential effect on Seychelles' economy [1]. The initial expansion goals included:

- Increase the quay length to 600 m.
- Reclaim land through a 40m seaward offset from the old cope line to accommodate the increasing container throughput demand.
- Deepen and expand the port basin areas to accommodate container vessels and fuel tankers with static draughts of up to 14 m.

This paper focusses on the dredging and associated works required to accommodate the larger vessels, with the aim to summarise the holistic design approach, highlight key design interdependencies and reflect on some lessons learnt. Figure 1 shows the extent of the basin area which includes the berthing pockets, turning circle and connection to the entrance channel. The basin is surrounded by the man-made Ile du Port and Ile de Romainville, as well as the fishing port.



Figure 1 Port Victoria basin area under consideration, relative to the new quay wall and other areas of interest

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Design Approach

The aim of the deepening and expansion of the Port Victoria basin is to accommodate larger container vessels and fuel tankers than the current capability of the port, while keeping the environmental impact of dredging and associated construction works within acceptable limits. To achieve this aim, the following design components were identified and executed:

- Perform a navigation study and dynamic mooring analysis to establish safe depths and horizontal extents of the port basin and berth pockets for the proposed design vessels.
- Establish the dredge design extents of the port basin to limit construction and operational risks.
- Develop a description of the dredging works, including associated dredge material spoil and reclamation works.
- Assess the potential impact of dredging, reclamation and spoil disposal activities on the environment through numerical modelling.

Ultimately, the design was captured in tender documents, including a Dredge Management Plan, drawings and technical specifications.

Figure 2 highlights the interdependencies between the main design components along with key inputs required from supporting studies to inform the respective design components.

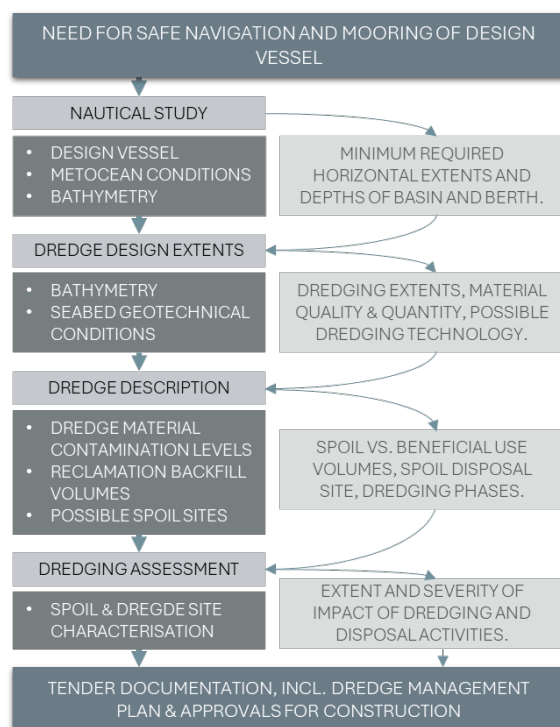


Figure 2 Port Victoria basin design components and key inputs required (left) with key outputs of design components (right).

Nautical Study

The nautical study was required to establish the extents of the port basin area that will allow for safe navigation and mooring of the design vessels.

The design vessels for this study were a Post-Panamax container vessel with a maximum draught of 14 m and a Capesize tanker with an overall length of about 250 m. Tankers of this size typically have laden draughts of 15 m or more. The client indicated that the limiting factor is a draught of 14 m and as such the studies further assumed that the tanker would enter the port only when semi-laden.

Design wind, wave and current conditions were required as input to the navigation study. Long term wind data was available from the Seychelles International Airport (8km from the seaport). However, no long-term wave and current measurements were available near the port. Therefore, numerical wave and hydrodynamic flow modelling studies were conducted, using the Deltares Delft3D modelling suite, to establish the design wave and current conditions in the area of interest. These modelling studies used:

- Measured wind data from the airport.
- 28-Year offshore wave hindcast data from the National Centres for Environmental Prediction [2].
- Bathymetry information based on the British Admiralty Chart 227 [12].

Based on the above, a nautical study was conducted in accordance with the Design Guidelines for Harbour Approach Channels [5]. The study comprised the following components:

- The required vertical dimensions of the approach channel and basin were conceptually determined and subsequently refined by means of a vertical ship motion response study using WAVESCAT. WAVESCAT considers the vertical response of vessels to vessel speed (squat) and wave impact (heave, pitch and roll) to determine the Response Amplitude Operators for the six critical keel-points on the hull of the design vessels, ultimately establishing the underkeel clearance requirements.
- Similarly, the conceptual horizontal extents of the approach channel and basin were determined and subsequently refined by means of ship navigation simulations. Fast- and real time ship navigation studies were conducted with Force Technology's Simflex4. Figure 3 shows an example of the design container vessel track while entering the port under calm conditions with tug assistance.

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- A dynamic mooring analysis (using QUAYSIM and WAVESCAT, both tools developed by the CSIR) was conducted to determine the moored ship motions and associated mooring line and fender reaction forces. The moored ship motion responses were analysed to confirm the maximum vertical response of a moored vessel at the quay, thereby informing the required depth of the berth pocket [3].
- allowance for 0.3m siltation between dredging exercises.
- potential future siltation of the basin and sounding inaccuracies of 0.1m.
- at the berth pockets, the dredging depth was increased to include the scour protection thickness. The depth was further increased by 0.5m to reduce the risk of damage during maintenance dredging above the scour protection.



Figure 3 Simflex4 vessel navigation in conceptual extents of the Port Victoria basin. Image represents a vessel (dark red outline) entering the port under calm conditions with tug assistance.

Through the nautical studies the minimum depth requirements for safe navigation of the design vessel were established as summarised below:

- Connection between entrance channel and turning circle: -16m CD.
- Turning circle and basin area connecting to the berth pockets: -15.5m CD.
- Berth pockets: -15.3m CD.

Furthermore, a turning circle diameter of 640m is required along with a berth pocket that is 40m wide. The latter was established through a scour protection design (not conducted by the dredge design team) in front of the quay wall.

Basin Dredge Design

The design dredging depth was based on the nautical study requirements, but also included the following as per the Design Guidelines for Harbour Approach Channels [5]:

The horizontal extents of the basin at the design depths extended as required to ensure safe navigation. In addition to these extents, allowance was made for side slopes based on the expected bed material quality.

To quantify the design dredging volumes, the volumetric difference between the existing bathymetric surface and the design dredging depths was calculated using AutoDesk Civil3D. The resulting design dredging volume was approximately 500 000m³.

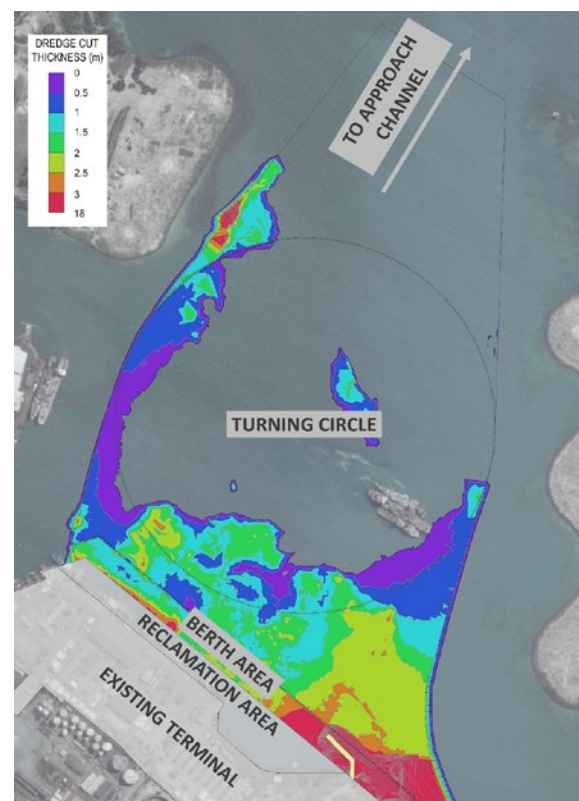


Figure 4 Dredge cut thickness required to achieve basin design dredging depths, based on 2019 bathymetry.

NOTE: The 2019 bathymetry was established through a single beam echosounder bathymetric survey. A multibeam echosounder survey was preferred to allow for identification of seabed obstacles, but suitable craft was not available for mounting of the survey equipment. During the

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survey campaign, tidal levels were recorded at the port. Through comparison of the measured vs. predicted tidal levels, the surveyor [11] identified a gross error in the supplied control point heights of nearly 2m. Using historical tide gauge readings from Point la Rue and the precise levelled tide gauge benchmarks, the surveyor corrected the heights for the control points at the project site, allowing the production of a bathymetric survey with depths correctly represented to Chart Datum (CD). This highlights the importance of verifying supplied control point heights through tide measurements.

From the geotechnical investigation, it is envisaged that most of the dredging material is relatively fine and soft and can be dredged with a Trailing Suction Hopper Dredger (TSHD). However, these dredgers cannot dredge near vertical structures such as quay walls and typically cannot achieve the tolerances expected for dredging in the scour protection area. Therefore, the berth pockets are envisaged to be dredged with a backhoe dredger.

NOTE: The geotechnical investigation relevant to the dredging design focussed on sample collection in the basin area. Ideally, such sampling should be done through rotary core drilling from a jack-up barge and vibrocoring on the seabed. However, due to the limited availability of specialised offshore geotechnical equipment in Seychelles, a non-standard sampling technique was employed. The sampling technique did not allow for undisturbed samples to be collected. Still, sufficient information was obtained, along with the sub-bottom profiling study outcomes, to conclude that the basin material in the dredge cut layer is mostly very fine to fine sediments, with occasional coral outcrops [7][14].

Assuming small or medium sized dredging plant operating in sheltered water with moderate currents, the following vertical dredging depth accuracies are expected to be achieved [10]:

- Trailing Suction Hopper Dredger: $\pm 350\text{mm}$ and $\pm 400\text{mm}$ for silts and soft clays respectively.
- Backhoe Dredger: $\pm 300\text{mm}$ for silts and soft clays.

The following horizontal accuracies are considered achievable [13]:

- Trailing Suction Hopper Dredger: $\pm 0.5\text{m}$ to $\pm 4\text{m}$.
- Backhoe Dredger: $\pm 0.1\text{m}$ to $\pm 0.5\text{m}$.

Considering the average expected dredging inaccuracies in addition to the minimum design dredging extents, a more realistic dredging volume of roughly $620\,000\text{m}^3$ can be expected. This volume could however fluctuate between the minimum design volume and an even higher volume, depending on the exact conditions during dredging.

Conceptual Construction Plan

Dredging cannot be considered in isolation from a plan for use or disposal of the dredged material. With Seychelles being a signatory to the London Convention (1972), material to be dredged was sampled from the basin to determine if it is contaminated in any way that would limit its potential beneficial uses or means of disposal. The sampled sediment quality data indicated that although some of the basin material to be dredged is contaminated by metals, polycyclic aromatic hydrocarbons and butyltins, the level of contamination is lower than the relevant sediment quality guidelines [4][6]. This suggests there is little likelihood that these chemicals pose a toxic risk to sediment-dwelling or aquatic organisms in the water column during dredging or dredge spoil disposal activities.

The non-contaminated status of the dredge material confirmed that it can be used for the purpose of backfilling behind the planned new quay wall. However, based on the required backfill material volumes, there would be a surplus of dredge material after backfilling that would require disposal.

Based on the volume of dredged material to be spoiled and the quality thereof, a dredge spoil disposal site was selected. The selection process comprised several iterations as a result of evolving characterisation of dredge material, changing engineering designs (and spoil volumes) and inputs from local parties. The site selection process comprised a multi-criteria assessment of the on-land and offshore disposal sites considered, and included:

- Environmental considerations (i.e. seabed and benthic impacts, dispersive nature of the site, proximity to marine protected areas like the St Anne Marine National Park, etc.).
- Beneficial use impacts (visual impacts, interference with recreation and/or fishing activities and interference with port operations and other marine traffic).
- Technical considerations (distance of spoil site from dredge areas, possible infrastructure requirements to contain dredge spoil, possible ground improvement activities required and coordination between dredging and quay wall construction activities).

Based on the above considerations, the ex-quarry adjacent to the airport (approximately 10km from the port basin) was selected as the disposal site, with the discharge of return flows into the dispersive marine environment adjacent to the site. The port, where dredging and reclamation would occur, is present in Figure 5 along with the selected spoil

disposal site, indicating the proximity to the St Anne Marine National Park and shallow coral reef areas.



Figure 5 Port Victoria (dredge basin and reclamation area), the selected spoil disposal site and the St Anne Marine National Park.

The intention was that the quay wall will be constructed in two phases to allow continuous operation of the port during the construction works. Firstly, the southern end of the quay will be constructed and reclaimed, while the existing quay in the north remains operational. The construction in the northern area will follow completion of construction of the southern area.

Since there is no space for temporary stockpiling of dredged material, the phased quay wall construction approach implies that dredging of the basin will also be phased. Ultimately it is the contractor's responsibility to derive a suitable construction methodology. However, to inform the dredging assessment, a plausible dredging sequence was derived considering the dredging, backfill and disposal volumes, associated sites and the likely dredging technology to be employed. A critical assumption was that the first phase will consist of only dredging for reclamation, while the second phase would entail dredging for reclamation as well as for disposal. This would mitigate the risk of over-disposal of dredged material during the first phase resulting in insufficient dredged material available for reclamation during the second phase.

Dredging Assessment

A dredge modelling study was undertaken to characterise the impact of dredging, disposal and reclamation activities on the environment. The assessment considered the most likely dredge

description and a representative range of environmental conditions that included both monsoon seasons.

Using the Deltares modelling suite, a coupled wave-hydrodynamic model was set-up that encompassed the area of interest in terms of potential dredging impacts. This three-dimensional barotropic model included wind-, wave- and tidally driven currents and mixing processes. The model was set up to represent the following sediment loadings:

- Dredging related sediment loadings such as propeller wash, suspension of sediments at the dredge head/bucket and hopper overflow (lean mixture overboard).
- Return flows from the quay wall and dredge spoil disposal site into the marine environment.

Two fractions of fines were modelled, representing sediment loading due to dredging activities (clayey silt) and return flows (predominantly clay). This approach provided a diagnostic capability to determine which of these two vectors of impact are of greatest concern and consequently would need to be mitigated or more closely managed during construction. The sediment loadings modelled assumed restrictive limits on hopper overflows and the assumption of well managed return flows from the backfill operations at the quay wall and from the dredge spoil disposal site.

The key vectors of potential impact in the modelling study were deemed to be:

- Elevated water column turbidity due to sediments suspended by dredging-related activities, potentially leading to visual dredge plumes (aesthetic impacts) and reduced light infiltration through the water column, ultimately inhibiting growth (chronic impact) of marine organisms.
- Sedimentation of dredging-related fines on the seabed that could result in smothering (acute impact) of corals and seagrasses.

Thresholds of potential concern related to these impacts needed to be identified for the analysis and presentation of the modelling results. However, literature pertaining to earlier dredging campaigns in the Seychelles is both limited and contains few detailed references to environmental monitoring and dredging performance criteria. The adopted thresholds of concern in the modelling assessment and resultant Dredge Management Plan were therefore predominantly based on an extensive review of international literature and prior experience in similar dredging projects.

The outcome of the dredge assessment was that during the first dredging phase, the dredging and

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reclamation impacts are limited to the port area, with a risk of acute impacts on the corals over a very limited area on the western shore of Ile de Romainville. During the second dredging phase, that includes dredge spoil disposal at the ex-quarry site, visual impacts are predicted to occur in the vicinity of Point La Rue and alongside the airport. Similar, but less extensive chronic impacts on corals and seagrasses are predicted for the second phase, in comparison with the first phase.

Figure 6 indicates the predicted extents of a) aesthetic impacts and b) acute impacts on corals and seagrasses resulting from elevated water column turbidity caused by dredging, reclamation and dredge spoil disposal activities during Southeast Monsoon conditions. Both results indicate that impacts are mainly limited to the port basin and areas surrounding the dredge spoil disposal site.

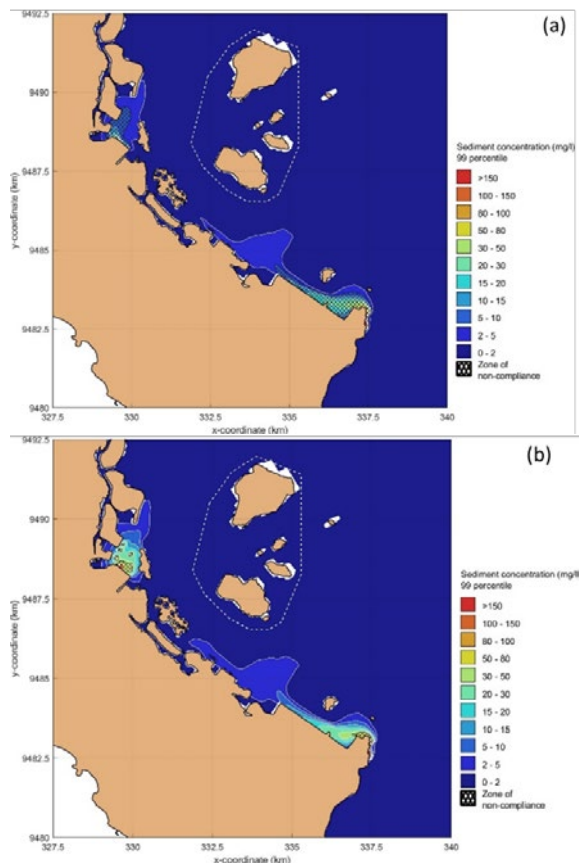


Figure 6 a) Aesthetic impacts and b) acute impacts on corals and seagrasses from elevated water column turbidity caused by dredging, reclamation and dredge spoil disposal activities undertaken during Southeast Monsoon conditions. Hatched areas indicate where the thresholds of concern are exceeded.

The only realistic mitigation measure to limit the impact of dredging and associated activities is to limit the total suspended sediment concentrations in

the return flows from the reclamation and dredge spoil disposal areas. Alternatively, the dredging rate, and therefore the rate of sediment release into the environment, could be reduced. There is scope within the dredging and construction programme for this to occur, however this is likely to significantly increase costs.

Given that the thresholds of concern adopted for the study are not site-specific, an adaptive management approach has been recommended in the Dredge Management Plan that allows for these thresholds to be adjusted based on knowledge acquired during the execution and monitoring of the dredging activities.

Conclusion

The dredge design for the Port Victoria port basin expansion was captured in the following tender documentation:

- Drawings to capture the minimum basin extents to be achieved through dredging, along with identified seabed or other obstacles in the port basin that should be removed prior to dredging.
- Technical specifications to describe the extent of the works, including dredging, disposal, backfilling, etc. The document provided a description of the seabed characteristics, allowable dredging tolerances and overall quality and health and safety requirements to be incorporated in the construction works.
- A Dredge Management Plan, that was incorporated in the project Environmental Management Plan, detailing requirements in terms of:
 - Dredging control management structures.
 - The development of Environmental Baselines for monitoring activities.
 - Monitoring during dredging, reclamation and disposal activities.
 - Mitigation measures should environmental impact exceed specified thresholds.
 - Specific operations during dredging (e.g. noise, ballast water management, etc.).
 - Post-dredging environmental surveys.

The dredge design described in this paper was not put out to tender for construction. Due to limiting funds, the (SPA) will not be able to undertake the full dredging works at this stage. Thus, the dredging works were separated from the overall port expansion construction works, with the aim to consider a reduced scope in direct consultation with an experienced dredging contractor through a design-build contract [8].

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 Maintenance dredging Risk Minimisation: Beneficial Use Assessments and Implementation of Environmental Windows / Seasonal Restrictions: A Case Study.
 R. van Ballegooyen, Brent Newman and Estelle Swart

Maintenance Dredging Risk Minimisation: Beneficial Use Assessments and Implementation of Environmental Windows / Seasonal Restrictions: A Case Study

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Abstract: The Port Owen Marina, located within the Berg River Estuary on the West coast of South Africa, requires on-going maintenance dredging to ensure its intended functionality. A particular challenge for the Port Owen Marina Authority in sustaining a consistent maintenance dredging effort, has been the environmental authorisation and permitting of proposed maintenance dredging. The consequences of an inconsistent maintenance dredging program is not only a potential loss of functionality of the marina, but also a gradual and ongoing degradation in the quality of the sediments needing to be dredged and possible compromised water quality in the long term. Prior assessments concluded that the discharge of the dredged material into the estuary comprised the most viable option, provided that there was mitigation of potential negative effects by preventing the release of coarser sediments into the estuary and by placing temporal restrictions (i.e., environmental windows and seasonal restrictions) on the proposed dredging activities. This paper provides a detailed re-assessment of beneficial use options and alternatives for dredge spoil disposal based on current best practice and the efficacy of risk reduction measures such as environmental windows and seasonal restrictions.

Keywords: *Maintenance Dredging, Environmental Authorisation, Environmental Windows and Seasonal Restrictions.*

Introduction

Port Owen Marina, in the Berg River Estuary on the West coast of South Africa (Figure 1), requires on-going maintenance dredging to ensure its intended functionality. Not only do the channels need to remain navigable and moorings maintained at sufficient water depth, being a residential marina, there also is an expectation of adequate water quality to avoid negative effects, such as algal blooms, foul smelling water, and fish kills.

A challenge for the Port Owen Marina Authority (POMA) in sustaining a consistent maintenance dredging effort has been Environmental Authorisation and permitting of proposed maintenance dredging activities. Due to the nature of the proposed maintenance dredging operations, both a dredging (Dumping as Sea) and Coastal Water Discharge Permit (CWDP) is required to proceed with the dredging program.

The consequences of inconsistent maintenance dredging is not only a potential loss of functionality of the marina, but also a gradual and ongoing degradation in the quality of sediments needing to be dredged. In the long-term, a reduced flushing potential associated with decreasing water depths could result in compromised water quality in the marina, and perhaps beyond. Thus, it is important to maintain a consistent and ongoing maintenance dredging effort.



Figure 1: Location of the Berg River (upper panel) and Port Owen Marina (lower panel).

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The Port Owen Marina and associated businesses contribute significantly to the total economic value and the delivery of ecosystem goods and services from the Berg River Estuary, and provide employment opportunities. Functional loss resulting from sedimentation in the marina may place property valued at ~R1 billion at potential risk. Allowing the marina to lose its functionality would seriously affect this value, resulting in more immediate losses to property owners due to reduced property valuations and associated longer-term effects on municipal rates and associated tax income.

Maintenance Dredging Challenges

The maintenance dredging required for the Port Owen Marina is challenging since the sediments being dredged comprise a high degree of fines and are often anoxic. The Berg River Estuary is also a sensitive and highly seasonal multi-user environment that, on occasion, experiences eutrophic conditions in its lower reaches that seemingly are exacerbated by inputs from other users (e.g., fish factory effluents, septic tanks, etc.).

Few viable options exist for the disposal of such dredged sediments other than their release into the Berg River Estuary. Prior assessments concluded that the discharge of dredged material into the estuary comprised the most viable option, provided there was mitigation of potential negative effects such as possible sedimentation within the estuary and turbidity and toxicity effects in the water column. In these earlier studies, these potential impacts were proposed to be mitigated by:

- preventing the release of coarser sediments into the estuary, and;
- placing temporal restrictions (i.e., environmental windows and seasonal restrictions) on proposed dredging activities.

Historical Dredging Activities

The two major capital dredging activities that have been undertaken in the Berg River Estuary are:

- dredging to create the new mouth and deepen the channel to -4 m MSL for an approximate 4 km upstream (completed December 1966) and the development of Laaiplek harbour (completed in 1968), and;
- the construction of Port Owen Marina, which commenced in 1983 and was completed in the second half of 1988.

The dredging to create the new mouth and Laaiplek harbour arguably has had a much greater effect on the functioning of the lower Berg River Estuary than has the Port Owen Marina. However, the maintenance dredging requirements of the marina seemingly is the greater of the two.

Since its construction there has remained an ongoing maintenance dredging requirement for the Port Owen Marina. Maintenance dredging was undertaken prior to 2000, however, the exact detail of that dredging remains uncertain. In 2000 and 2001, between 71 000 m³ to 79 000 m³ was dredged and discharged directly into the main estuary channel opposite the western entrance to the marina. Approximately 4.4% to 4.9% of the material dredged settled in the estuary, resulting in a reduction in water depth. It was possible to re-dredge approximately 60% of the settled material, which was then transported via pipeline to an on-land disposal site on the south bank opposite the western entrance channel to the marina. However, this constituted a significant additional effort and expense.

An environmental authorisation in 2009 authorised dredging activities that were undertaken in various areas of the marina from 2010 to 2013. The exact dredge quantities during this period remain uncertain. No dredging took place in 2014. Dredging re-commenced in 2015 and continued until 2019, with dredging occurring in all years except 2018. During this 2015 to 2019 period, an estimated 18 000 m³ to 23 000 m³ of *in-situ* sediments were dredged.

Requirement to use Settling Dams

The experience of coarser sediments settling in channels of the estuary and reducing water depth led to an environmental authorisation (based on a Basic Assessment undertaken in 2009) [9] that required the development and use of settling dams in the maintenance dredging operations. The purpose of the settling dams was to avoid the discharge of coarser material into the estuary. The environmental authorisation stated that dredged material could be released directly to the estuary. However, should more than 3% of the material exceed a grain size of 500 µm, then all dredged material would need to be diverted to settling dams. The intention was that the coarser sediments in the material being dredged would be retained in the settling dams, and the fines subsequently released. The coarser material remaining in the settling dams was then to be trucked to a landfill site.

Sediment surveys suggest that < 2% of the dredged material will comprise sediments having a grain size >500 µm [14]. The surveys also indicated that between 22% to 30% of the material to be dredged comprises sand, and between 69% to 78% comprises mud. If fines are defined to be both mud and very fine sand, the surveys suggest the material to be dredged comprises 85% fines and 15% sand and coarser material. This will be the composition of the dredged slurry if discharged directly into the estuary. If the settling dams are utilised then it is estimated that 50% of fine sand and all coarser

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material will be retained in the settling dams, together with 50% to 100% of the very fine sand. The implication is that only a proportion of the very fine sand and all mud in the material dredged will be released to the estuary from the settling dams. However, significant uncertainty exists around these estimates that are likely to be quite variable depending on the material being dredged and the nature of the dredging operation.

The dredge spoil disposal settling dams were used on all occasions since 2015, except for limited dredging undertaken in 2019 when monitoring of the nature of the material being dredged did not indicate the need to use the dams.

Imposition of Seasonal Restrictions and Environmental Windows.

In addition to the above, seasonal and environmental windows were imposed on the dredging operations. Concern around dredging effects on fish migration and recruitment, together with seasonal changes in the Berg River Estuary receiving environment (high natural turbidity in winter months and increased eutrophication risk in summer months), resulted in a requirement that most of the dredging and sediment disposal must occur between May to July, with an allowance for dredging at low rates during April, August, and September. Such restrictions:

- limit dredging discharges during the peak fish recruitment period from August to October [9]
- avoid dredging in the summer period when waters of the estuary are significantly less turbid due to reduced catchment flows in the dry summer months [12];
- avoid dredging in the late summer period when there exists an elevated risk of eutrophication impacts in the lower estuary [14].

A further major requirement was that the dredged material only be discharged during outgoing tides when the tidal flows exceed 200 m³/s [7]. The intention of this restriction is to ensure as much of the discharged sediments travel downstream and leave the estuary so that they are not advected upstream during incoming tides.

Additional temporal restriction, related mainly to noise impacts and interference with recreational and boating activities in the marina, included no dredging on weekends, and that dredging activities be restricted to daylight hours only.

This placed very onerous restrictions on the dredging activities, particularly the rate of dredging. Reduced dredge volumes run the risk of:

- the maintenance dredging not achieving its goal of removing the backlog of accumulated

sediments to restore the functionality of the marina,

- a gradual and ongoing degradation in the quality of the sediments needing to be dredged, and;
- in the long-term, a potential reduction in the flushing potential of the marina associated with decreasing water depths that could result in compromised water quality within the marina and perhaps further afield.

Based on the impacts [8], an application was made in 2018 to relax the restriction that dredging and discharge of material be largely restricted to winter. Whilst granted, subsequently the Department of Forestry, Fisheries and the Environment: Ocean and Coasts Division (DFFE: O&C) issued a notice to POMA to stop dredging until application had been made for a new Dredging (Dumping at Sea) Permit as well as a Coastal Waters Discharge Permit (CWDP) that took into account changed circumstances that included changed legislation and regulatory authority, a requirement to integrate the POMA maintenance dredging activities into the recently developed Berg River Estuary Management Plan [5], and re-evaluation of the dredging activities to address any residual concerns and ensure adherence to the latest best practise guidelines as required by the latest legislation.

DFFE: O&C indicated a requirement for:

- additional information on the nature of the dredging and dredging volumes generated;
- a more comprehensive assessment of the material to be dredged (grain size, bulking factor, potential metal contamination, oxygen demand, nutrient releases);
- a more detailed technical assessment of alternatives in terms of beneficial use of the dredged material and the alternatives (for disposal of dredge spoil for which there remains no obvious viable beneficial use, and
- the need for a more rigorous impact assessment, especially the dispersal of the sediment plume downriver of the proposed discharge location and possible impacts of the hypoxic/anoxic sediments in the water column.

An additional concern was that significant changes have occurred in the Berg River Estuary [1-6,13] over time, including:

- a significant reduction in freshwater inflow that has resulted in reduced flushing and a possible lower rate of removal of sediments from the lower extremities of the estuary. Nutrients entering the estuary mouth and from a fish factory in the lower estuary are possibly now being advected further upstream than in the

past, potentially adding to eutrophication effects further upstream;

- a large increase in nutrient loads into the lower extremities of the estuary, related primarily to the increased nutrient loading from upstream waters entering the lower estuary, but also due to some potentially significant local inputs such as those from a fish processing plant and possibly from local septic tanks;
- local changes in infrastructure and shoreline developments, the most recent of which are likely to have resulted in only small localised effects.

This resulted in a POMA-commissioned comprehensive assessment being undertaken that that addressed the above issues [14], including a detailed assessment of beneficial use and disposal options for the dredged material. The information generated has been used to inform subsequent applications for a dredging (Dumping at Sea) permit and CWDP that have now both been granted.

Comprehensive Maintenance Dredging Assessment

The comprehensive maintenance dredging assessment undertaken addressed the above issues within a structured framework that included:

- an effort at waste minimisation (*i.e.*, minimisation of proposed maintenance dredged quantities);
- a detailed assessment of beneficial use and disposal options for dredged material;
- a comprehensive assessment of possible impacts of the hypoxic/anoxic sediments in the water column.

Ultimately the best practicable environmental option, *i.e.*, “the option that provides the most benefit or causes the least damage to the environment as a whole, at a cost acceptable to society, in the long term as well as in the short term”, will need to be selected.

In this comprehensive maintenance dredging assessment, it has been demonstrated that if existing protocols are followed then:

- dredging-related discharge into the Berg River Estuary (directly or via the settling dams) is unlikely to result in any significant changes in channel locations, side-slopes, and depths;
- any accumulation of dredging-related sediments in shallower regions downstream of Port Owen Marina, should it occur, is likely to be insignificant compared to potential sediment deposition in these areas related to natural sediment fluxes in the estuary. Furthermore, it is not anticipated there will be any long-term

accumulation in fines of any significance in areas downstream of the marina;

- the sediments dredged from the marina are deemed to be uncontaminated or minimally contaminated at most. Thus, not only is there not expected to be a long-term accumulation of fines in the areas downstream of the marina, but any accumulation that may occur should not be metal contaminated, *i.e.* no different to most other sediments being transported in the Berg River Estuary.
- there is likely to be some level of impact of elevated turbidity and a lowering of the dissolved oxygen concentration in the water column (and possibly elevated dissolved metal and nutrient concentrations in the water column) associated with the discharge of dredging-related sediments into the Berg River Estuary. The spatial extent of these impacts is likely to be determined by a sacrificial zone beyond which the achievable dilution of the dredging effluents exceed 3 to 5 dilutions. However, both the required dilutions and spatial extent of this zone presently remains uncertain. It should be noted that any risks in this regard are likely to be greater for dredged spoil disposal in summer, when flows and sediment loads in the Berg River estuary are naturally lower, and the dissolved oxygen concentration is low and nutrient concentrations high due to upwelling along the coast and possible eutrophication effects in the lower estuary downstream of the marina.

Beneficial Use Assessment

Prior to the beneficial use assessment, a significant effort was undertaken to minimise the dredging required by adopting a minimum requirement for channel widths and depths (Figure 2). This resulted in an initial maintenance dredging backlog ranging between 46 400 m³ to 113 300 m³, assuming the most likely annual rate of sediment accumulation in the marina is 5 000 m³ per annum or possibly as much as 51 400 m³ to 128 300 m³ should a more extreme (but probably less realistic) assumption be made that the annual rate of sediment accumulation in the marina is of the order of 10 000 m³. The annual rate of sedimentation is expected to be quite variable, with historical estimates suggesting a rate of 7 000 m³ per annum.

Based on these estimates of the quantity and quality of material to be dredged, limitations of the dredging equipment available, and likely dredging rates and environmental restrictions, a detailed beneficial use assessment was undertaken based on PIANC guidance documents [10, 11];

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other than the location of the discharge, which could be achieved without disturbing the saltmarsh. However, potential constraints of such an approach are:

- sedimentation in unwanted locations, *i.e.* in the deeper channels of the river or downstream areas (or even back into Port Owen marina) instead of the target areas on the fringes of the salt marshes;
- potential water column impacts (elevated turbidity, possible reductions in dissolved oxygen, nutrient releases) associated with the release of anoxic sediments into the estuary.

More detailed investigations to assess such potential constraints will take time and such an approach may require additional environmental authorisations that could significantly delay maintenance dredging, with attendant consequences.

Conclusion

The conclusions of the assessment were that dredged spoil disposal options previously considered are less viable than the discharge of dredged material into the estuary.

Although an adaptive management approach has not been formally followed to date, changing environmental authorisations essentially have provided adaptive management outcomes. Given some of the existing uncertainties, a formal adaptive management approach is proposed whereby where there is adequate monitoring of potential impacts. Based on the outcomes of this monitoring the present restrictions can be relaxed or, if necessary, additional restrictions imposed.

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ENVIRONMENT

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Climate Change Risk and Vulnerability Assessments and Adaptation strategies for South African Ports

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Climate Change Risk and Vulnerability Assessments and Adaptation strategies for South African Ports

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Abstract: South Africa's ports play a major role in the country's economy. Should climate-related infrastructure damage or operational disruption occur, this could have severe "knock-on" effects to the wider economy. Consequently, Transnet, since 2010, has been in the process of developing an integrated Climate Change Strategy across its operations, commencing with a preliminary Risk and Vulnerability assessment for all Transnet Operating divisions in 2010, followed in 2014 by a first-level risk and vulnerability assessment for the Transnet National Port Authority to assess potential drivers of climate-change risk to port infrastructure, operational support systems, activities related to safety and long-term sustainability of the eight ports they presently manage. Only once the climate-related changes in these key environmental drivers are adequately understood and characterised at a local scale, is it possible to assess climate change risks in each port with sufficient rigour to ensure that any proposed adaptation measures are both appropriate and economically justified. Presented here is initial progress with a TNPA-funded, multi-year, collaborative effort by a consortium of scientist and engineers from range of local institutions and consultancies in making such a detailed Climate Change Risk and Vulnerability Assessment informing the development of Adaptation strategies for South African Ports.

Keywords: *Climate Change, Risk and Vulnerability Assessment, Climate-Change Adaptation Strategies.*

Introduction

South Africa's ports play a major role in the country's economy and therefore should infrastructure damage or operational disruption occur, this could have severe "knock-on" effects to the wider economy whether due to existing or future climate conditions. Any existing infrastructural and operational vulnerabilities to existing climatic conditions, in most cases, are likely to be significantly exacerbated by the effects of climate change (CSIR, 2014).

Recognising such vulnerabilities, Transnet, since 2010, has been in the process of developing an integrated Climate Change Strategy across its operations. The purpose of the strategy is to manage Transnet's exposure to climate change-related risks, and to address Transnet's responsibilities, both as a corporate citizen and as a State-owned Enterprise, in assisting South Africa to meet its international commitments for carbon emission reductions, climate change mitigation and adaptation, as outlined in the National Climate Change Adaptation Strategy approved by the South African Government in August 2020.

As part of the first phase of development of Transnet's Climate Change Strategy, a preliminary Risk and Vulnerability assessment, was conducted in 2010 [22]. This assessment provided a high-level overview of key risks and opportunities for the Transnet Group as a whole, as well as its individual Operating Divisions such as the National Ports Authority. Aspects such as commercial, physical and even reputational risks were addressed, indicating the importance of a holistic understanding the scope and nature of the potential impacts of Climate Change. Of the risks assessed in the study, the greatest identified risk to Transnet National Port Authority (TNPA) was assessed to be the "physical risks" to port infrastructure and operations, a fact re-affirmed by TNPA identifying this as a Priority 1 risk for South African ports in its 2022 Annual Report. A follow-up study was conducted in 2014 [3], comprising a first-level risk and vulnerability assessment of the potential drivers of climate change and the associated implications for identified port elements (*i.e.*, infrastructure and operational support systems) as well as activities related to safety, operations and long-term sustainability of the eight ports presently managed by TNPA. The approach taken in this study was to assess the risk and vulnerability of port

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infrastructure and operations to changes in key drivers under existing climatic conditions, as well as two potential future climate change scenarios. From this study it became clear that, to ensure a sufficiently robust assessment of the risks associated with climate change for the eight TNPA-managed ports, will require a sufficiently rigorous assessment of how climate change will play out not only for the greater region but specifically within each port. Only once the climate-related changes in the key environmental drivers (i.e., changes in statistical distributions of winds, sea levels, waves currents, etc.) are adequately understood and characterised at a local scale, will it be possible to assess the climate change risks in each port with sufficient rigour to ensure that any proposed adaptation measures are both appropriate and economically justified.

Since these earlier studies, significant progress has been made in predicting future climate change scenarios as well as in the capability to down-scale and model the likely climate-change related shifts in temperature, rainfall, winds, sea level, waves, currents; water quality, sediment transport and ecosystems affecting South African ports infrastructure and operations.

This paper summarises early progress in a TNPA-funded, multi-year, collaborative study by a CSIR led consortium comprising the CSIR, the University of the Witwatersrand, the South African Weather Services and WSP Group Africa, designed to address such issues. The main emphasis of the collaborative study is to provide a more rigorous assessment climate-related changes in key environmental drivers affecting port infrastructure and operations, a pre-requisite for undertaking a

risk and vulnerability assessment that adequately informs the selection of adaptation strategies.

Such strategies include the design of suitably resilient infrastructure and port operations, as well as risk management systems to better manage risks associated with climate change.

Approach

The key goals of the overall study are to:

- provide a sufficiently rigorous assessment of the expected changes in atmospheric and ocean forcing likely to occur under appropriately selected future climate change scenarios;
- down-scale these climate-related changes in forcing to accurately represent local conditions both external and within the ports (i.e., characterise locally the shifts in key drivers affecting the construction and maintenance of both present and future port infrastructure and operations);
- use this information to provide a better informed and more rigorous assessment of Risk and Vulnerability to port infrastructure and operations posed by climate-related changes in identified key drivers, and ;
- based on the updated Risk and Vulnerability Assessment, undertake the selection and co-production with TNPA of appropriate adaptation strategies for each of the South African ports managed by TNPA.

The project structure adopted to address these key elements is provided in Figure 1. This paper reports on the progress to date in executing these key project elements.

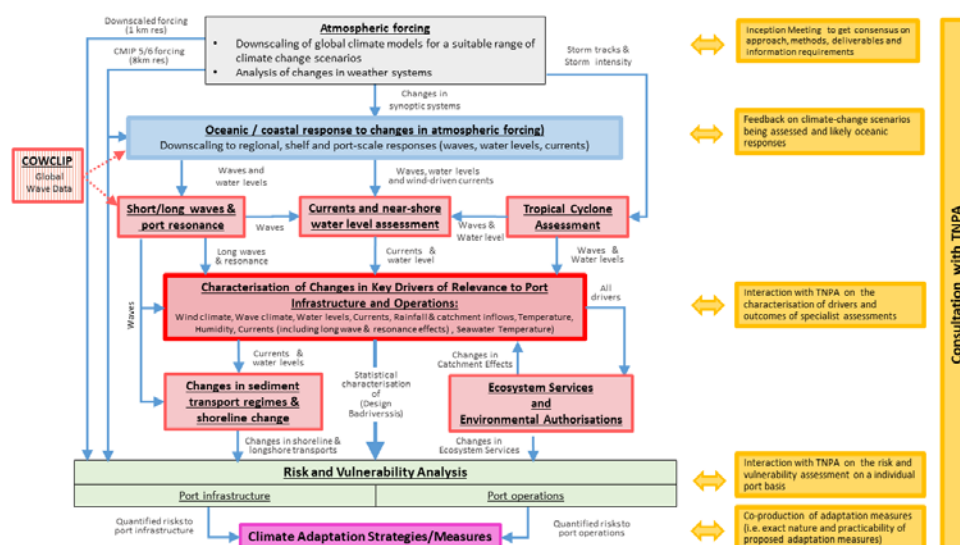


Figure 1: The key elements of the Risk and Vulnerability Assessments and development of Adaptation Strategies, indicating the data and information dependencies between the key project elements and the required consultation to ensure robust and agreed upon outcomes.

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Risk and Vulnerability Assessment Framework

As noted in the introduction, an initial review (WSP, 2010) of the key risks and opportunities for the individual Operating Divisions (such as the National Ports Authority) and the Transnet Group as a whole, identified the greatest risk to be due to "physical risk". This led to the more detailed risk and vulnerability assessment undertaken in 2014 (CSIR, 2014) that focussed solely on such "physical risks". Specifically issues such the development of port infrastructure and ongoing port operations and shipping on GHG emissions were excluded from this study.

This study undertook a risk and vulnerability assessment for the eight ports presently managed by Transnet, under the following three scenarios:

- Scenario A: Existing conditions, *i.e.*, a no climate change scenario;
- Scenario B: A sea level rise of 0.5 m and a 10% increase in all other drivers considered, and
- Scenario C: A more extreme sea level rise of 1.0 m and a 20% increase in all other drivers considered.

The results of two of these scenarios are presented in Figure 2.

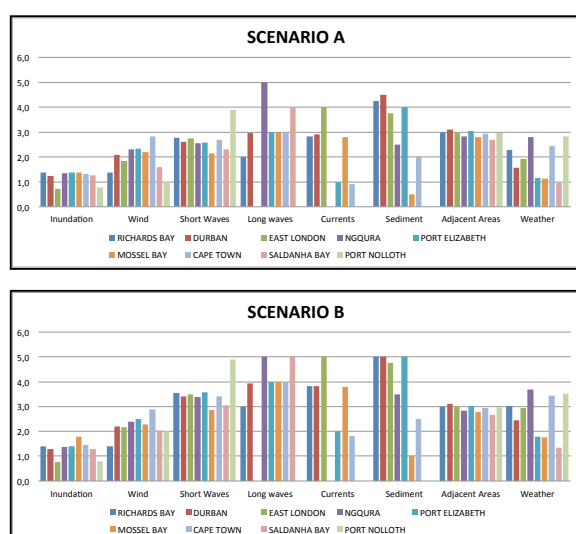


Figure 2: Vulnerability rating of ports under Scenario A (no climate change) and Scenario B (moderate climate change) [3].

Issues around changes in sediment transport regimes, together with changes in wave climate, are highlighted as constituting the major risks to ports in terms of climate change. It is for this region that the detailed modelling proposed for the present study focusses on the detailed down-scaling of climate-related changes in large-scale forcing to inform resultant changes in the key drivers of waves, water levels and sediment transport.

A more recent global assessment provides context to these results [6], particularly in terms of multi-hazard risks due to climate change. The study reports a particular vulnerability of South African east coast ports to such multi-hazard risks associated with climate change.

Early guidance on risk and vulnerability assessments was provided by PIANC [11], that was followed by a more comprehensive guidance document in 2020 [12]. Subsequently additional guidance was provided by PIANC on climate change risks [15] and resilience of port infrastructures [13, 14]. The study undertaken for TNPA in 2014 [3] included the first three of the key elements identified in PIANC guidance document for "Climate Change Adaptation Planning for Ports and Inland Waterways" [12], namely:

- The identification of key infrastructure and operations at risk due to climate change, the exact nature of the vulnerabilities and required adaptation and resilience objectives;
- The robust and detailed characterisation risk parameters (wind, waves, currents, *etc.*) at the local port scales both under present and future climatic conditions;
- A risk analysis based on an agreed upon approach, that included identification of hazards, detailed characterisation of the risks, *i.e.*, the nature of impact, the vulnerability to such impacts and the likelihood and consequence of such impacts.

Excluded from this initial study was the identification and assessment of the likely efficacy and desirability of adaptation measures and associated adaptation pathways. The study did not explicitly consider adaptation measures due to insufficient rigour in the characterisation of many of the risk parameters at the local port scale, the very issue that the present study seeks to address.

The risk and vulnerability method proposed for the present study largely mirror that of the initial 2014 assessment, with some minor modifications and enhancements to ensure consistency with more recent similar assessments [6].

Atmospheric Forcing

The objectives of this component of the study are:

- the identification of a range of climate change scenarios under likely emissions scenarios that need to be considered and the effect that such changes will have on large-scale atmospheric circulation;
- the detailed characterisation of key weather systems such as cut-off lows and cyclones that presently, or will in future, pose significant threat to existing port infrastructure and

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operations, and how these weather systems will change under future climate change;

- downscaling of global climate model outputs for the selected climate change scenarios to provide high resolution characterisations of local conditions at each of the ports. This information is required for both direct hazard assessment (e.g., highly variable wind conditions affecting operations in the Port of Cape Town and flooding effects on the Port of Durban), as well as inputs to the other study components.

Based on a ranking of Coupled Model Intercomparison Project Phase 6 (CMIP6) global climate models in southern Africa [8], an ensemble of the three best performing global climate models (GCMs), namely FGOALS-g3, MPI-ESM1-2-HR and NorESM2-LM, has been selected for the development of methodologies to track both cut-off lows and tropical cyclones, as well as investigating the frequencies and intensities of these weather phenomena in future. A tracker previously developed and utilized for the identification and tracking of cut-off lows over southern Africa in reanalysis data and climate change projection scenarios [5], is being used to determine cut-off low attributes such as frequency of occurrence and geographical location under both present and future climates. A similar effort is being undertaken for the tracking of tropical cyclones [5, 9, 10], under existing and future climate scenarios. The findings of this analysis, once available, will be utilised in detailed modelling of tropical cyclones at the relevant east coast ports.

Downscaling efforts include the characterisation of down-scaled winds, temperature and rainfall that will directly inform the Risk and Vulnerability Assessment. For example, extreme rainfall events are projected to increase in their frequency of occurrence over eastern South Africa, including at the ports of Durban and Richards Bay.

However, more important is that the downscaled atmospheric drivers from this component of the study will inform the modelling undertaken in the remaining project elements, particularly the characterisation of changes in local winds, water levels and wave conditions that, in turn, will influence strongly the sediment transport regimes and the natural systems (and associated ecosystem services) in the ports. It is planned to generate 8 km resolution wind data for the planned regional wave and water level modelling to be undertaken for this study.

Statistical downscaling of extremes is planned, based on measured data for the ports and well as measured data from the South African Weather

Services. This downscaling will commence once all relevant measured data have been collated.

Regional Wave and Water level modelling.

The characterisation of wave and water level climates under both present day and future climate conditions is important, particularly insofar as providing joint probabilities of occurrence of high wave conditions and increased water level due to wind-driven flows (storm surges).

The data to be used in these regional model simulations include:

- wave boundary conditions for the low mitigation greenhouse gas emission scenario, SSP5-8.5 from two climate models forced by EC-Earth3 and ACCESS-CM2 for the period 1961–2100, and
- 8 km resolution downscaled atmospheric forcing data from the same two models.

This modelling study presently is in its early stages of implementation. The planned model outputs are important inputs into higher resolution modelling to be undertaken within the immediate environs of the ports and as well within the ports (see section on Nearshore and Port Wave Modelling).

The legacy forecasting systems from this endeavour are likely to form an integral part of the risk management systems to be embedded in adaptation strategy pathways being developed as part of this study.

Nearshore and Port Wave Modelling.

Waves and water level changes (storm surges) arguably pose the most important and persistent risks for port infrastructure and operations.

High resolution nested SWAN models for each of the ports have been setup and refined to a resolution of approximately 20m in each of the 8 port regions. Test frameworks and events have been run for offshore wave and wind events. An example of the high-resolution output from a nested grid for the port region of the port of Cape Town is shown in Figure 3.

Once the outputs from the regional wave modelling for existing and future climate change scenarios are available, the models will be used to generate the statistical analyses that can be used as the “design basis” for assessing the risk of both present and future climate.

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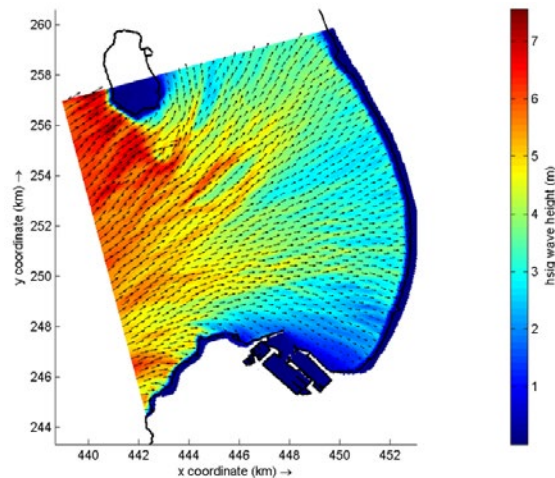


Figure 3: An example of high-resolution SWAN wave model output for the port of Cape Town showing significant wave height, and peak wave direction (vectors).

Also planned are wave penetration studies for the Ports of Richards Bay Durban and Cape Town, using the Mike 21 Boussinesq Wave model to assess whether wave conditions will get worse inside ports under climate change.

Challenges associated with the effects of long waves exist in the Ports of Saldanha, Cape Town and Ngqura. Therefore, it is important to quantify the long wave effect to determine if these will be exacerbated by climate change. Presently, running of long waves frameworks are complete for these 3 ports. Figure 4 provides a comparison of measured and modelled long wave conditions obtained applying the Port of Cape Town framework.

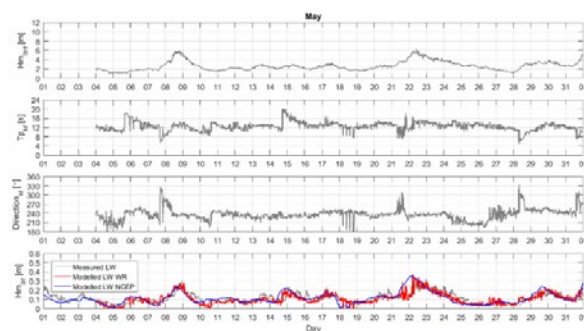


Figure 4: A comparison of measured and modelled long wave parameters applying the Slangkop and NCEP hindcast data for the month of May 2018.

Tropical cyclones assessment

Tropical Cyclones (TC) can generate severe wave conditions, as was the case with TC Imboa off Richards Bay in February 1984 when a significant wave height of approximately 8 m was recorded off the port. Although rare events, TC's pose high risk

events ports. TC activity is not uncommon to the region north of Richards Bay. Given the rarity of such events, South African ports are likely to be ill-prepared should such events occur more frequently.

Based on predictions from the tropical cyclone tracker utilised to assess existing and future climate change scenarios, model simulation will be undertaken to determine water levels and wave conditions extremes associated with such events. The information generated will be used to quantify the risk and vulnerability of both existing and future port infrastructure and operations for the two most severe tropical cyclones events identified for future climates.

Sediment Transport Regime Assessments

The primary influences from climate change on sediment transport regimes are related to changes in water level and wave conditions (both in extremes and average climate conditions). The resultant climate-related changes in sediment transport regimes could result in:

- erosion/accretion effects of ports on neighbouring shorelines due to wave sheltering effects and/or changes in sand supply;
- altered maintenance dredging (e.g., changes in the accumulation of sediments in sand traps, due to changing longshore sediment transport) [4, 16] and associated beach nourishment requirements [18];
- Increased erosion or sedimentation within ports due to changes in hydrodynamic conditions within the port [20]
- Changes to the stability of sandy shorelines within ports (the south bank of the Richards Bay port entrance which is managed by a series of groynes) [17];
- the integrity of environmentally sensitive habitat within ports (i.e. the Central Sandbank in Port of Durban) [21];

The intention is to quantify, as best possible:

- potential changes in sediment transport regimes and associated impacts as described above for the most likely climate change scenarios, and
- possible adaptation and/or mitigation measures that are likely to require significant modification of existing dredging and sand-bypassing activities.

To achieve the above requires an understanding of the natural transport regimes as modified by existing dredging, sand-bypassing, shoreline management and catchment flow management activities. Thus, in addition to information on existing sediment transport regimes, required is a robust characterisation of existing (capital and

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maintenance) dredging and shoreline management activities.

The review of such activities is largely desktop but will be supplemented by a limited modelling effort for ports where there exist major concerns. This is expected to include one or more of the Ports of Durban, Richards Bay and Ngqura.

Currents And Near-Shore Water Level

For most of the east coast ports, wave- and wind driven flows, and even the influence of the Agulhas Current on occasion, make for potentially challenging conditions at the port entrances. This was particularly true for the Port of Durban prior to the widening of the port entrance channel.

Climate change is expected to result in changes in large-scale ocean circulations, that together with changes in the wave climate, could change both the flows and water quality over the adjacent shelf and in the vicinity of port entrances. While predicted increases in mesoscale activity in the Agulhas Current [2] could influence inshore currents [1, 7], by far the greatest effect on navigation is expected the wave-and wind-driven flows at the port entrances [19]. These risks associated with climate change will be assessed once the changes in wave-and wind-driven flows have been more robustly characterised for the climate change scenarios considered in this study.

Ecosystem Services and Environmental authorisations.

A key factor in future port development and existing operations is the utilisation of the ports by other users as well as ecosystem services derived from the port environments. Ports can no longer operate without acknowledging and incorporating societal and environmental considerations in their planning and management. There exist uncertainties (changing baselines and vectors of change), associated with the effects of climate of port ecosystems that hamper assessments undertaken to achieve environmental authorisation for proposed port developments.

A broad review of the current and likely future ecosystem services derived from natural infrastructure in ports (inclusive of those that benefit port operations) as well as current and likely future threats to these services, will be undertaken. This will be based on the predicted climate-related changes in key drivers such as changing water levels, changing catchment stormwater and sediment inflows and to the ports, erosion and inundation of habitats, amongst others.

Updated Risk and Vulnerability Assessment

An updated risk and vulnerability assessment will be completed based on the more robust characterisation of the key drivers generated by this study. Depending on the type of risks identified and the associated uncertainties, the most appropriate and cost-effective adaptation measures are likely to include changes in one or more of the following:

- infrastructure design,
- port operations,
- management systems,
- maintenance activities; and
- general behaviours.

Given the inherent uncertainty in the assessed risks and likely efficacy of proposed adaptation measures,⁷ it is best to adopt an adaptation pathway which itself can change and adapt to new knowledge or evidence over time. It may also prove cost-effective to undertake short-term measures to buy time. More expensive or longer-term solutions can then be adopted, designed and implemented as data availability and understanding (e.g. of local rates of change) improve. Furthermore:

- no- or low-regret solutions that deliver benefits irrespective of how the climate changes, and
- nature-based solutions that capitalise on nature's resilience,

can play an important role in accommodating uncertainty.

It is planned to identify and develop adaptation strategies in a co-production mode with TNPA, ultimately resulting in an adaptation strategy based on identified adaptations measures, their likely efficacy and whether they are deemed cost-effective.

Project Legacy

The project will conclude with quantitative, probabilistic estimates of the main risks over time, and the formulation of suitable adaptation options for each key risk identified. This is expected to include a "design basis" for climate change that can be utilised in future design and or detailed assessment of proposed developments within the Transnet ports. Whilst, in general, risk is best managed by including resilience to climate-change resilience in the design of port infrastructure and operations, a likely legacy of the project is an improved measurement and predictive modelling capability to actively manage risk to port operations and shipping.

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