REQUIREMENTS FOR A MONITORING PROGRAMME TO DETECT ENVIRONMENTAL IMPACTS OF COFFER DAM MINING AND SHORELINE ACCRETION ON THE MARINE ENVIRONMENT

In identifying and assessing environmental impacts it is important to acknowledge that change is not necessary unnatural nor is it due to human disturbance alone (Green 1979, 1993). An impact should not therefore be characterised as being the difference in some measure at a particular site before and after a disturbance only. An impact should be characterised as being the relative difference between changes at a disturbed site (*i.e.* the change from before to after a disturbance) compared with changes that have occurred in a similar undisturbed (or control or reference) site (Underwood 1992, 1993, 1994). In other words there must be some change from before to after a disturbance and such change must be different from what occurred in undisturbed control areas. To achieve this it is necessary to study communities in impacted and reference sites prior to (provided that this is of course possible) and after an impact has occurred. If such conditions are not met, the interpretation of the impact will be compromised (Underwood 1996).

Having established the basic protocol required for an impact assessment, several decisions have to be taken with regard to how one should proceed with the research or monitoring program. The most important of these include how much monitoring should be undertaken (intensity, frequency and duration), what in terms of community parameters should be monitored and, if monitoring is continued through to the recovery stage, when can a site be declared fully rehabilitated. Central to all of these is the question of how much change or disturbance matters. Two sorts of mistakes are inherent in monitoring programs because of the need for statistical analyses. Type I error occurs where results of a monitoring program suggest that there has been an environmental changes when there has not. Type II errors occur when there has been an environmental change but the monitoring program fails to detect it. The most common reason for the occurrence of Type II error is a sampling program that it poorly designed or one that is not comprehensive enough (i.e. insufficient samples) (Underwood 1996). Assuming that the whole point of a monitoring program is to illicit managerial response in the event that there is an impact, Type I error should become self-correcting (further investigation is likely to expose the error). (It may however result in a waste of money, time, resources, reputations and possible loss of economic activity). In contrast Type II error elicits no response. The cost is in terms of the environment - environmental degradation continues unnoticed.

In terms of environmental management, precautionary principals require that more attention be paid to Type II error, such that this is unlikely to occur (Mapstone 1995; Underwood 1996). The only realistic trade-off is to increase the probability of the Type I error until costs of errors (the cost of responding to a non-existent environmental threat) are likely to be unacceptably high. Then trade back the rate of the Type I error in return for more resources for sampling. The potential costs to society through crying wolf - mistakenly declaring there to be an environmental change because of a Type I error - can be reduced provided proper resources are made available to detect real changes (i.e. to have a small probability of Type II error).

To quantify the full impact of the proposed coffer dam mining or accretion of Mitchell's Bay on the marine environment, all affected habitats and/or communities should be monitored before, during and after mining. However, prior research has indicated that this is impractical, impossible or simply unnecessary. Monitoring should rather focus on what are likely to be the most sensitive, significantly affected and/or representative species, communities, habitats and resources. The proposed mining areas comprises intertidal sandy beach and rocky shore habitat, as well as subtidal sandy and rocky habitats. A suite of standard, and widely accepted techniques have been developed for the monitoring of benthic communities associated with these habitats, and it is proposed that these be adopted for this study. These techniques include both univariate and multivariate statistical analyses. Vertebrate communities, specifically birds and fish, associated with surf-zone habitats require a different approach. Previous studies have shown that these highly mobile animals are generally not significantly affected by beach mining operations. Monitoring of these populations is therefore considered unnecessary.

The final question that needs to be resolved, is how long should a habitat appear to be restored before it can be declared restored? It is now widely accepted that when assessing recovery following a disturbance event, the classic scientific approach of testing a null hypothesis is not really valid (Dixon & Garrett 1992; McDonald & Erickson 1994; Underwood 1996). The classic approach is an attempt to reject or disprove the "null" hypothesis, which assumes that two populations are identical. The alternative hypothesis, that the two populations are not identical, can only be accepted if the probability that any differences detected are due to chance alone is less than 5%. In deciding whether an impact has occurred, this approach is perfectly acceptable, as it largely eliminates the probability of declaring a false positive i.e. that an impact has occurred when this is not the case. However, when we are assessing recovery, this is not the case. We have accepted that an impact has occurred (otherwise we would not be monitoring recovery), and we now wish to establish an end point at which we can declare recovery complete. The approach proposed as an alternative to the classic significance testing is known as the test for bioequivalence. The approach is to define two areas to be bioequivalent if, for example, the mean density of a particular organism or organisms on the impacted site exceed a predefined percentage (R say 80%) of the mean density on the reference site for a defined time interval. Conversely, a site is said to be impacted or disturbed until the selected variable(s) exceed(s) the predefined level over a defined time interval. This procedure is commonly used in testing the equivalence of drugs (Kirkwood 1981; Westlake 1988) and is becoming more popular in other biological sciences (Dixon & Garret 1992; McDonald & Erickson 1994). It has recently been successfully applied in assessing recovery of deepwater invertebrate macrofauna following remote mining (Clark 2014), as well as beach macrofauna following seawall mining and shoreline accretion in southern Namibia (Pulfrich et al. 2015). Full details of the test are contained in McDonald & Erickson (1994).

One of the greatest merits of this approach is that it recognises (a) that systems are naturally variable and (b) that one does not always have "adequate" baseline data for the assessment of the significance of a particular impact. It also recognises that while physico-chemical factors are an important determinant of the structure of biotic communities, other biological factors (such as timing of recruitment and variations in recruitment success which, to some extent are linked to the abundance of adults in neighbouring areas, as well as competition and predation) also play an important role in structuring biotic communities, which can vary greatly in both space and time even when biophysical conditions remain constant (see for example Hall 1994; Kenny & Rees 1994, 1996; Herrmann et al. 1999; Ellis 2000; Schratzberger et al. 2004a).

The predefined percentage is necessarily site- or situation-specific, but the value of 80% seems to have attained fairly wide acceptance (McDonald & Erickson 1994; Underwood 1996). Similarly, the number of successive intervals over which this value should be achieved is site- and situation-specific but also depends on the sampling interval. It is proposed that sampling of sandy beach invertebrates, and rocky intertidal benthic communities be conducted annually. Selected parameters include measures of the abundance and/or biomass of the communities or certain key species in each case, as well as a measure of the diversity of the community as a whole (e.g. Shannon-Weiner Diversity), and that the value of R must exceed 80% in each case for at least three to five years before a site can be considered to have recovered. For the purposes of this study, the term recovery would thus be defined as: "the re-establishment of ecological function through colonisation of previously mined areas by marine faunal communities that can be considered to be functionally equivalent to those that exist in comparable undisturbed sites, taking into account natural variability, as judged by the fact that they are at least 80% similar in terms of their species composition, abundance and biomass, measured over a period of at least 3-5 years". The bioequivalence tests should also be supplemented with standard multivariate graphical and statistical tests (e.g. hierarchical cluster analysis, multidimensional scaling, ANOSIM) for which no bioequivalent alternatives exist. Levels of significance for these tests should be set at 95%.

A graphic depicting how such a process may play out in the case of the assessment of mining impacts, as presented in Clark 2014) is shown in Figure 1 below. The blue and purple line represents the average number of individuals, biomass or species at a suite of stations at reference sites outside of the mining area, and a second group in close proximity to the area being mined (Discharge), but potentially affected by other mining-related activities, respectively (in the example the 'indirect' effect was the discharge onto the beach of a sediment slurry of fine tailings from an on-site processing plant to aid with accretion). The red line represents average abundance at a suite of stations in an area that is subject to mining during the course of the study. The dots on each line represent average values derived from discrete samples collected, in the example, at quarterly intervals (every 3 months) at these respective sites. The horizontal dotted lines indicate abundance/biomass/no. species for all the reference sites averaged across the full time period of the study, and the 80th percentile for these sites. Sampling at all sites commenced 2 years before mining started and continued until it was established that the biota at the reference sites in close proximity to the impact site (Discharge) and at the mined sites (Impact) had recovered to a level where the average abundance/biomass/no. species (dotted red line) had recovered within the 80th percentile for the reference stations (blue shaded area). Note that in this diagram abundance at the reference station in close proximity to the impact site (Discharge) dropped during the construction phase but recovered again shortly thereafter.

In light of the above, an impacted site would be considered recovered or "functionally equivalent" if the data measured over a period of at least three years falls between the 20th and 80th percentiles of the reference and baseline data. Should the pre-mining and reference site data show extremely high variability, the more conservative approach of using the 25th to 75th percentile can be adopted.

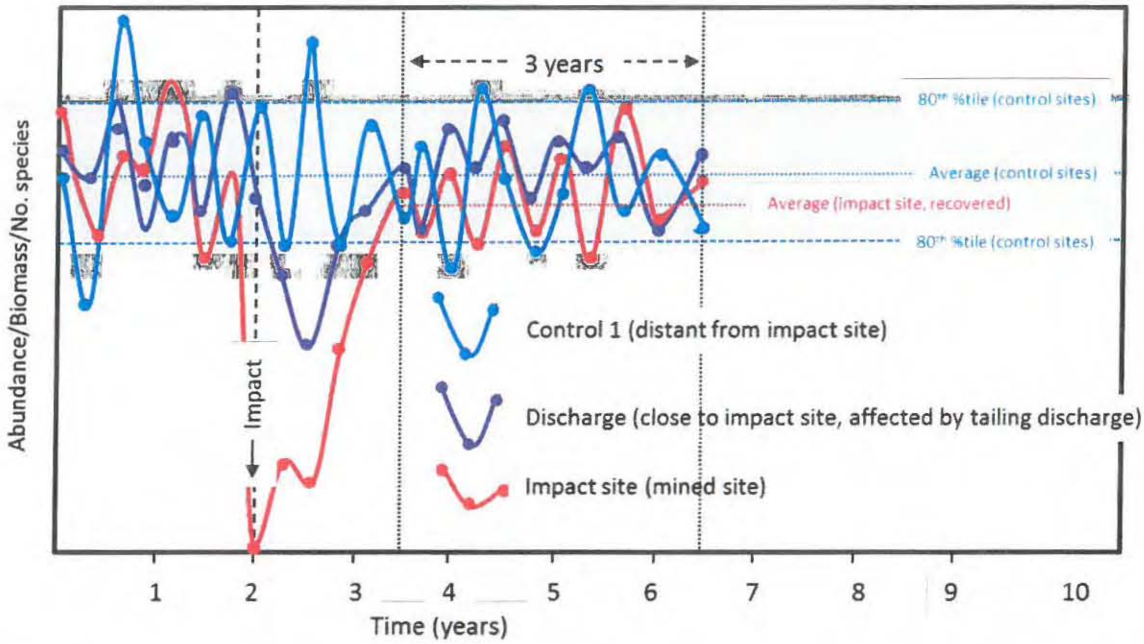

Figure 1: Graphic demonstration of procedures for monitoring environmental impacts and recovery. See text for details. Source: Clark (2014)

PROPOSED MARINE MONITORING PROGRAMME TO BE IMPLEMENTED BY WEST COAST RESOURCES

1. Objectives of the Marine Monitoring Studies

The research objectives that need to be addressed in properly assessing the impacts of coastal mining operations on marine benthic communities are defined below:

Sandy Beach Habitats

- Assess the species diversity and abundance of sandy beach macrofaunal communities at selected sites to be impacted by mining operations and compare these with macrofaunal community composition and structure on relatively undisturbed beaches.
- Once mining commences, quantify the effects of mining operations on the distribution and composition of beach macrofaunal communities. Where the area may already have been impacted by past mining operations, quantitatively assess the relative changes in beach macrofaunal communities as a result of future mining impacts against established benchmarks.
- Assess the physical characteristics, specifically the beach slope, sediment particle size composition and swash characteristics of these beaches.
- Quantify changes in the physical characteristics of the impacted beaches, and monitor changes in the diversity and abundance of beach macrofaunal communities as a consequence of mining disturbance and determine the rate of recovery of these communities after the cessation of mining operations.

Rocky Intertidal Habitats

- Assess the species diversity and abundance of rocky intertidal communities at selected sites potentially impacted by mining operations and compare these with benthic community composition and structure on relatively undisturbed shores.
- Once mining commences, quantify the effects of mining operations on the distribution and composition of intertidal rocky-shore communities.
- Monitor changes in the impacted rocky intertidal communities relative to undisturbed sites and determine the rate of recovery of these communities after the cessation of mining operations. Observed changes in rocky intertidal biota should been evaluated in context with the influences of natural sedimentary cycles on rocky habitats along the Namaqualand coastline.

2. Proposed Approach

The marine monitoring programme put forward here is based broadly on the recognised BACI design described previously to identify and assess the environmental impacts of the proposed mining. However, it also sets out to establish a robust pre-mining baseline along a stretch of the Namaqualand coast where quantitative data from sandy beach and rocky intertidal and shallow subtidal habitats are sorely lacking. The principal objective of this proposal is to focus effort on intertidal sandy beaches and rocky shores at sites targeted for cofferdam mining or beach accretion using sites in equivalent habitats within the proposed Namaqualand Marine Protected Area as suitable undisturbed 'controls'. Due to the inherent difficulties of undertaking subtidal surveys along a stretch of coastline characterised by rough sea conditions, the quantitative monitoring of subtidal reefs is excluded from the monitoring programme at this stage. The collection of sufficient reliable subtidal data is labour intensive, costly, and typically prone to failure due to the necessary reliance on suitable weather windows during which to conduct the diving operations. Nonetheless, it is strongly advised that some form of semi-quantitative survey be undertaken at Mitchell's Bay prior to the commencement of mining operations. Furthermore, additional requirements for subtidal monitoring may ensue following discussions with stakeholders holding abalone ranching permits in the project area. Details of such surveys can be compiled on request as and when required.

The recommended sampling approach for the quantitative collection of community data in each of the habitat types is detailed below.

Sandy Beach Macrofauna

During a meeting with DEA: O&C, their researchers were of the opinion that collecting pre-mining baseline data on invertebrate macrofaunal communities from the target beaches, should be given higher priority than establishing a structured BACI experimental approach at only a few impact sites[1]. The inherent risk in taking this approach is that the current DEA staff/opinions may change over time, and criticism may in future be received from key stakeholders that WCR have no programme in place to demonstrate recovery of communities directly impacted by their mining operations. To show due diligence and demonstrate recovery of beaches on cessation of mining it is recommended that a combined approach be adopted for the monitoring of beach macrofaunal communities in WCR's licence areas, namely:

- Establishing a once-off pre-mining baseline comprising two sites on each of the following beaches:
  - Visbeenbaai
  - Stokbreekbaai
  - Langklipbaai
  - Mitchell's Bay
- A BACI approach be adopted to monitor impacts and recovery at Visbeenbaai, using the beaches at the Spoeg River mouth (30°28.196´S; 17°21.485´E) and at Moon Bay (30°48.061´S; 17°32.936´E), within the Namaqualand MPA as controls. The selected beaches would be sampled biannually. However, in the case of the Spoeg River mouth beach, it is important to first establish (by means of suitable hydrodynamic modelling) that the beach will in no ways be affected by redistributed sediments from mining operations involving shoreline accretion in Mitchell's Bay. The extent of sediment redistribution and deposition to the north and south of Mitchell's Bay as well as the extent offshore needs to be more accurately established for the proposed accretion scenarios.

[1] This opinion was based on the lack of biodiverity data from the area in combination with existing knowledge of the recovery rates of macrofaunal communities following beach mining operations of different scales.

Beach faunal community sampling would be carried out using established sandy-beach sampling techniques. At each identified sampling site three transects, perpendicular to the shore and spaced 5 m apart, would be surveyed from above the drift line to the lowest point of the swash during spring low tide. Ten stations would be positioned along each transect line at equal horizontal intervals across the beach face. At each station, three 0.1-m^2 quadrat samples would be excavated to a depth of 30 cm, and the sediments rinsed in a 1-mm mesh sieve bag. All macrofauna retained in the sieves would be preserved in 96% alcohol, and identified to the lowest taxonomic level possible. Dry biomass of all fauna would be obtained by drying the specimens at 60°C for 24 hours. Macrofaunal densities would be expressed as the number of individuals per square metre, and the biomass as $g.m^{-2}$.

A variety of physical parameters will also be measured at each site. These will include wave height and period, surf-zone width, beach profile and water table depth. Sediment samples will be collected from Station 1 (the drift line), Station 5 (mid-shore) and Station 10 (spring low water mark). In the laboratory, the sediment samples will be passed through a series of graded sieves to determine the grain-size composition. Graphic methods will be used to obtain the mean particle diameter, sorting and skewness of the sediments. These physical data will be used to calculate the dimensionless fall velocity (or Dean's value, Ω) and to rate each site in terms of wave exposure. Using the dimensionless fall velocity an indication of the beach morphodynamic state will be provided.

A further consideration is to set up poles for fixed-point photography on the rocky headlands to the north of each target beach. Such techniques are easy and comparatively inexpensive to set up and photographs taken regularly from such points (e.g. by the on-site Environmental Control Officer or Environmental Manager) can provide valuable data on natural vs. mining-induced sediment movement. Accurate cataloguing of the captured images is, however, vital.

Rocky Intertidal Macrobenthos

The proposed cofferdam mining operations at Visbeenbaai, Koingnaasbaai, Stokbreekbaai and Langklipbaai will be targeting the beaches within these bays and any impacts on adjacent rocky shores are likely to be indirect and resulting from redistribution of eroded sediments. In the case of Mitchell's Bay where rocky closure berms may be constructed across the mouth of all or a part of the bay, rocky shores would be directly impacted by construction materials. Should the accretion scenario be adopted for Mitchell's Bay, all rocky shores within the bay (and possibly some distance to the north and south of the bay) would be obliterated by accreting sediments.

Two approaches are proposed for monitoring mining effects on intertidal rocky-shore communities.

- Indirect impacts resulting from the redistribution of sediments are monitored at sites located to the north and south of each of the following target beaches:
  - Visbeenbaai (North: 30°09.349´S, 17°12.724´E; South: 30°10.271´S, 17°13.345´E)
  - Stokbreekbaai (North: 30°14.647´S, 17°14.910´E; South: 30°15.808´S, 17°15.430´E)
  - Langklipbaai (North: 30°22.195´S, 17°17.791´E; South: 30°22.807´S, 17°18.450´E)

As comparable control sites it is intended to sample two long-term monitoring sites within the proposed MPA near the Groen River mouth: Moon Bay (30°48.639´S, 17°33.235´E) and Moon Bay Granatina (30°48.891´S, 17°33.251´E). These sites are currently also being monitored (using the same sampling approach as proposed below) by researchers from DEA: O&C. Further sites established by DEA: O&C at Rooiklippies and Brazil near Kleinzee might provide additional 'control' data. These would, however, not be sampled as part of this programme. It is intended that data collected as part of WCR's programme be used to complement O&C's sampling programme.

- At Mitchell's Bay where mining will involve either beach accretion or the construction of rock berms, a more intensive sampling grid should be established covering rocky shores of varying wave exposure (exposed, semi-exposed and sheltered). Four sampling sites are proposed, the location of which can only be fixed once the final mining approach has been finalised. Control sites will be the same as described above.

The selected sites would be sampled annually at approximately the same time each year. As researchers from DEA: O&C have expressed an interest in expanding their sampling to include Mitchell's Bay, it is hoped that sampling commitments can be shared to the mutual benefit of all concerned. For example, sampling in Mitchell's Bay as part of the current programme could be undertaken in August-October, with the same sites sampled by DEA: O&C in February-May to provide information on temporal variability.

The macrobenthos of rocky intertidal areas would be sampled in four 0.5-m^2 quadrats along each of five replicate transects laid perpendicular to the shore between the mean low water spring and mean high water spring marks. The quadrats are divided into a regular 50x50 mm grid pattern giving 171 intersecting points in a 1 x 0.5 m frame. The individual species occurring in the algal canopy would be recorded under each intersecting point as primary and secondary cover, as would be rare species and mobile organisms within the quadrat. The point counts would be used to calculate the mean percentage cover of all species (both mobile and sessile), and the counts of individual mobile organisms to calculate densities within the quadrat area. Data on mean percent cover and abundance for the community as a whole, individual species and trophic groups would then be compared.

3. Scheduling of Surveys

The intertidal beach and rocky-shore surveys have to be undertaken over a spring tide period when the tides are low enough to permit access to the low shore. Because the amplitude of any given spring tidal movement can vary considerably during the course of a year, the timing of surveys is crucial if accurate and reliable data are to be collected. Consequently, surveys must be scheduled over spring tides when the height of the low tides above chart datum (= Lowest Astronomical Tide) is at a minimum. A 'rule of thumb' for intertidal surveys is that data is only collected when the height of the low tide is 0.25 m or less, above chart datum. As natural variables such as oceanic swell and wind-induced waves will affect the predicted tidal levels, it is all the more critical that surveys are conducted during the lowest possible tides. The lowest spring tides during the year usually occur between February - June and in some years between August - October. Commencement of the monitoring programme will be determined by the mine plan.

Ideally monitoring should be conducted seasonally, although the limitations of inadequately low spring tide levels negates this approach. Biannual monitoring at selected sites should, however, be given consideration. At all other sites monitoring should be conducted on an annual basis starting a minimum of two years prior to that in which mining commences, and continuing until impacted communities have recovered to acceptable levels as defined in the monitoring programme requirements outlined above. It is recommended that annual sampling be conducted at approximately the same time each year (March-June and/or August-October) to eliminate any seasonal variations.

4. Survey Team and Duration

The first once-off survey of the six beaches could be undertaken over a 6-day period (excluding travelling time from Cape Town) by a team of 5 people, of which two would be scientists/technicians and the remainder could be students or relatively unskilled workers with an interest in developing capacity in environmental sampling. Subsequent monitoring surveys of a single impact and two control sites would require 3-4 days.

The 12 rocky shore sites could be sampled by two specialists during the same 6-day period in which the beaches are sampled.

5. Proposed Outputs

Data will be analysed using both univariate and multivariate statistical tests to establish the extent of any mining impacts on the affected communities, and (where applicable) to monitor the rate of post-mining recovery. Various univariate tests will subsequently be used to examine the influence of mining disturbance on variability in community structure. Univariate parameters to be analysed will include abundance and biomass (all species combined as well as separate analyses for principal species), species diversity (Shannon-Wiener Diversity), and percentage cover. Multivariate analyses to be performed will include cluster analysis, multidimensional scaling, ANOSIM (analysis of similarity) and PERMANOVA. Where historical datasets are available these will be used during the analyses in order to establish if temporal and/or spatial trends in response to the mining impacts are evident.

The results and conclusions of the surveys will be submitted in the form of two written reports:

- A Baseline Survey Report for sandy beaches providing species lists, and abundance and biomass values (where appropriate) for macrofaunal components at the sampling sites. Sensitive and threatened locations and species would be identified, and the health and integrity of the invertebrate macrofaunal biodiversity of the project area discussed.
- A Baseline Survey Report for rocky shores providing species lists and abundance values (where appropriate) for floral and faunal components at the sampling sites. Sensitive and threatened habitats and species would be identified, and the health and integrity of the rocky intertidal benthic biodiversity of the project area discussed.

The reports will include an executive summary, will address all of the objectives relevant to establishing the baseline conditions, re-assess the sampling programme and make specific recommendations for revisions or improvements to reflect changes in the mining plan or adjustments to the monitoring approach. The methods employed and final results will be of sufficient detail and technical authority to adequately identify and address any significant impacts as a result of the proposed mining operations on beach and rocky-shore communities. An electronic draft document (in Microsoft Word® and Adobe Acrobat®) of each report, will be submitted to WCR for comment.

The final research reports will be peer-reviewed by an acknowledged and independent specialist in the field concerned before final submission. This is recommended to ensure that aspects in the research approach have not been accidentally overlooked or results misinterpreted, thereby guaranteeing that the final reports are objective, correct and of the highest professional standard.

All relevant comments received from WCR and the external reviewer(s) will be incorporated into the documents, and a final documents will be submitted to WCR.

6. Assumptions

Should this proposal be successful, it is assumed that:

- WCR will assist with the application of any required security clearances for the survey teams.
- WCR will make arrangements for, and cover the costs of, self-catering accommodation for the survey teams when on site.
- WCR will assist with the local sourcing of beach sampling assistants.
- Liaison in connection with this project will be conducted telephonically or via E-mail. No budgetary allowances have been made for meeting.

7. Proposed Budgets

The detailed costs for the proposed monitoring surveys of rocky intertidal communities and sandy beaches are shown in ZAR in the Table below.

VAT at 14% would be payable on these amounts if billed within South Africa.

This budget is valid for 90 days from submission and applies to the baseline monitoring programme only.

The following project milestones and schedule of payments for the project are proposed:

Field Survey Component:

- First Invoice: R 65,670 upfront payment for field survey on signing of contract;
- Second Invoice: R 197,010 on completion of field survey;
- Third Invoice: R 87,120 on completion of macrofaunal analysis.

Baseline Reports:

- Final Invoice: R 140,800 on submission of Survey Reports.

Item	Unit Cost		Number	Units	Item Cost
Personnel					
Project manager & co-ordinator	R 5,800	per day	9	days	R 52,200
Technical Manager	R 4,400	per day	8	days	R 35,200
Research Assistants (2 persons)	R 4,200	per day	16	person days	R 67,200
Field workers (x3)	R 2,200	per day	18	days	R 39,600
Travel costs					
Two 4x4s	R 5	per km	4000	km	R 20,000
Subsistence (7 persons)	R 2,450	per day	8	days	R 19,600
Equipment & Consumables	R 5,000	per unit	1	unit	R 5,000
Macrofaunal Sample Analysis					
- Analysis of macrofaunal samples (12 sites x 10 stations x 3 replicates)	R 200	per sample	360	samples	R 72,000
- Analysis of sediment samples (12 sites x 3 stations)	R 200	per sample	36	samples	R 7,200
Data analyses and reporting					
Rocky Shores	R 6,000	per day	8	days	R 48,000
Sandy Beaches	R 6,000	per day	8	days	R 48,000
Professional Reviewer	R 6,400	per day	5	days	R 32,000
Sub-Total					R 446,000
Administrative Costs	10%				R 44,600
Total					**R 490,600**

REFERENCES

Bowman MF, Bailey RC (1997) Does taxonomic resolution affect the multivariate description of the structure of freshwater benthic macroinvertebrate communities ? Can. J. Fish. Aquat. Sci., 54: 1802-1807.

Clark BM (2014) De Beers Marine Namibia Environmental Monitoring Programme In The Atlantic 1 Mining Licence Area. Strategic Assessment and Review. Report prepared for De Beers Marine Namibia by Anchor Environmental Consultants, 57 pp.

Clarke KR, Warwick RM (1994) Change in Marine Communities - An approach to statistical analysis and interpretation. Natural Environment Research Council, U.K.

Dixon PM, Garrett KA (1992) Statistical issues for field experimenters. Technical Report. Savanna River Laboratory, University of Georgia.

Ellis DV (2000) Effect of Mine Tailings on The Biodiversity of The Seabed: Example of The Island Copper Mine, Canada. In: SHEPPARD, C.R.C. (Ed), Seas at The Millennium: An Environmental Evaluation. Pergamon, Elsevier Science, Amsterdam, pp. 235-246.

Ferraro SP, Cole FA (1990) Taxonomic level and sample size sufficient for assessing pollution impacts on the Southern California Bight macrobenthos. Mar. Ecol. Prog. Ser., 67: 251-262.

Green RH (1979) Sampling Design and Statistical Methods for Environmental Scientists. Wiley, Chichester, 257 pp.

Green RH (1993) Applications of repeated measures designs in environmental impact and monitoring studies. Austr. J. Ecol.,18: 81-98.

Hall SJ (1994) Physical disturbance and marine benthic communities: life in unconsolidated sediments. Oceanography and Marine Biology: An Annual Review, 32: 179-239.

Herrmann C, Krause J Chr, Tsoupikova N, Hansen K (1999) Marine Sediment extraction in the Baltic Sea. Status Report. Baltic Sea Environmental Proceedings, 76. 29 pp.

Kenny AJ, Rees HL (1994) The effects of marine gravel extraction on the macrobenthos: Early post-dredging recolonisation. Marine Pollution Bulletin, 28: 442-447.

Kenny AJ, Rees HL (1996) The effects of marine gravel extraction on the macrobenthos: results 2 years postdredging. Marine Pollution Bulletin, 32: 615-622.

Kent M, Coker P (1992) The description of vegetation in the field. In: Vegetation Description and Analysis. Belhaven Press, London: p45.

Kirkwood TBL (1981) Bioequivalence testing - A need to rethink. Biometrics 37: 589-594.

Mapstone BD (1995) Scalable decision rules for environmental impacts studies: effect size, Type I and Type II errors. Ecological Applications 5: 401-410.

McDonald LL, Erickson WP (1994) Testing for bioequivalence in field studies: Has a disturbed site been adequately reclaimed? Statistics in Ecology and Environmental Monitoring 183-197.

McDonald LL, Erickson WP, Strickland D (1995) Survey design, statistical analysis, and basis for statistical inferences in Coastal Habitat Injury Assessment: Exxon Valdez Oil Spill. In: Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters, ASTM STP 1219. Wells PG, Butler JN and Hughes JS, (Eds.). American Society for Testing and Materials, Philadelphia.

Pulfrich A, Hutchings K, Biccard A, Clark BM (2015) Survey of Sandy-Beach Macrofaunal Communities on the Sperrgebiet Coastline: Consolidated Beach Monitoring Report - 2015. Report to NAMDEB Diamond Corporation (Pty) Ltd., Oranjemund, Namibia. 86pp.

Schratzberger M, Bolam SG, Whomersley P, Warr K, Rees HL (2004) Development of a meiobenthic nematode community following the intertidal placement of various types of sediment. Journal of Experimental Marine Biology and Ecology, 303 (1): 79-96.

Underwood AJ (1992) Beyond BACI: the detection of environmental impact on populations in the real but variable world. Journal of Experimental Marine Biology and Ecology, 161: 145-178.

Underwood AJ (1993) The mechanics of spatially replicated sampling programmes to detect environmental impacts in a variable world. Australian Journal of Ecology, 18: 99 - 116.

Underwood AJ (1994) On beyond BACI: sampling designs that might reliably detect environmental disturbances. Ecological Applications, 4: 3-15.

Underwood AJ (1996) Detection, interpretation, prediction and management of environmental disturbances: Some roles for experimental marine ecology. Journal of Experimental Marine Biology and Ecology 200: 1-27.

Vanderklift MA, Ward TJ, Jacoby CA (1996) Effect of reducing taxonomic resolution on ordinations to detect pollution-induced gradients in macrobenthic infaunal assemblages. Mar. Ecol. Prog. Ser., 136: 137-145.

Warwick RM (1988a) Analysis of community attributes of the macrobenthos of Frierfjord/Langesundfjord at taxonomic levels higher than species. Mar. Ecol. Prog Ser., 46: 167-170.

Warwick RM (1988b) The level of taxonomic discrimination required to detect pollution effects on marine benthic communities. Mar. Pollut. Bull., 19: 259-268.

Warwick RM (1993) Environmental impact studies on marine communities: Pragmatical considerations. Aust. J. Ecol., 18: 63-80.

Westlake WJ (1988) Bioavailability and bioequivalance of pharmaceutical formulations. In: Biopharmaceutical Statistics for Drug Development. Peace KE (Ed.) Marcel Dekker. New York. Pp 329-352.

8

WEST COAST RESOURCES (PTY) LTD

KOINGNAAS AND SAMSONS BAK COMPLEX

ENVIRONMENTAL IMPACT ASSESSMENT REPORT

8. Coastal protection reports

WKSCE 2015/02/RL

August 2016

BF

DMR Ref No: NC0043-MR/102 and NC0044-MR/102

8.1. Coastal protection options

UNITED
BY OUR
DIFFERENCE
WSP

COASTAL PROTECTION OPTIONS FOR BEACH MINING IN THE KOINGNAAS AREA

2015/08/21

West Coast Resources

Quality Management

Issue/revision	Issue 1	Revision 1	Revision 2
Remarks	Draft for comment	Generic berms included. Client comments addressed	
Date	2015/07/29	2015/08/21	
Prepared by	C Soltau H Henning	C Soltau	
Signature			
Checked by		H Henning	
Signature			
Authorised by		G Smith	
Signature			
Project number	19943.R		
Report number	19943/11.2/001		
File reference	11.2		

Coastal Protection Options for Beach Mining in the Koingnaas Area

2015/08/21

Client

West Coast Resources
405 Voortrekker Road
Parow
7500

Consultant

WSP Coastal and Port Engineering Division
Stein House
Brandwacht Office Park, Trumali Street
Stellenbosch
7600
South Africa

Tel: +27 21 883 9260
Fax: +27 21 883 3212

www.wspgroup.co.za

Registered Address

WSP Group Africa (Pty) Ltd
1999/008928/07
WSP House, Bryanston Place, 199 Bryanston Drive,
Bryanston, 2191, South Africa

WSP Contacts

Christoph Soltau
christoph.soltau@wspgroup.co.za

Table of Contents

FIGURES

TABLES

APPENDICES

1 Introduction

1.1 Background

West Coast Resources are re-establishing diamond mining operations in the Koingnaas area on the Namaqualand coast, previously mined by De Beers. As part of their operations, West Coast Resources intend to mine deposits that are located on the beach and extend seaward potentially for several hundred metres. Three sites – Somnaas Bay, Site 68/69, and Rooiwal Bay – have been identified where such mineable blocks exist on the beach and in the sea.

Artificial accretion, or reclamation, of the beaches has been identified as a method to allow these blocks that presently lie seaward of the low-water mark to be accessed for conventional open-cast mining.

Similar beach mining operations have been previously undertaken south of Koingnaas, near the Olifants River, although these have generally been confined to the intertidal beach area. Beach mining operations are presently being undertaken along the coastline near Alexander Bay.

1.2 Purpose

West Coast Resources are commencing with an Environmental Impact Assessment (EIA) for the beach mining operations. As part of this, WSP Africa have been appointed to assist in defining the mining approach in order for it to be fixed and taken forward into the EIA. In particular, beach accretion and coastal protection measures that would be employed during the mining are to be developed to a sufficient level of detail that they can be adopted for assessment in the EIA.

Such coastal protection measures are required for possible mining at three locations:

i. A sandy beach site known as Site 68/69;

ii. A potential diamond deposit on the seabed within Rooiwal Bay;

iii. A generic protection design to be applied at other sites along the coastline.

Designs are to be developed to concept level, recognising that further design work would be required before they can be implemented.

1.3 Study Approach

A wave refraction study was undertaken in order to determine the nearshore wave conditions at the sites. A bathymetric survey was carried out at Site 68/69, as well as at the nearby Somnaasbaai, to provide supporting data for the wave refraction study. A site visit to the area was also undertaken. Background information on the marine and coastal conditions was collated.

Information from the above studies is then employed together with coastal engineering design principles in order to assess a range of coastal protection concepts for both Rooiwal Bay and at Site 68/69. The assessments take into account factors such as:

- The temporary nature of mining;
- The quantity and characteristics of available construction materials (rock, sand);
- Possible phasing of the mining to facilitate recovery of diamonds at an early stage;
- The need to minimise seepage into the mining area;
- Costs of protection measures.

For each site, the most economically and technically viable concept/s are selected and the corresponding design/s developed further. Plan and section illustrations of the concepts are provided, together with an estimate of the quantities and costs, where possible.

A similar approach was followed in order to develop a design for a generic-type of berm that could be applied at any of several locations along the coast.

Drawings of the options are given in larger format in Appendix 1. The bathymetry survey results are included in Appendices 2 and 3 for the Site 68/69 and Somnaasbaai surveys respectively.

2 Description of Coastal Conditions

The Koingnaas area is situated on the West Coast with the investigated sites being exposed to typical West Coast environmental conditions. Prevailing winds, tides, waves and currents are discussed in this section.

The offshore wind and wave conditions were obtained from the National Centres for Environmental Predictions (NCEP) USA. NCEP is part of the US weather services and the National Oceanic and Atmospheric Administration (NOAA). NCEP operate a global wind and wave prediction model from which historic (hindcast) wind and wave data can be extracted at half-degree intervals around the globe. This global model is verified (calibrated) with various wind and wave measurement stations/devices across the world. Past studies have shown that NCEP data is sufficiently accurate along the west coast of southern Africa. This is primarily due to the direction of the deep water waves travelling from the South Western Atlantic and the consistent cold fronts passing along the south of South Africa.

Figure 2.1: Location of NCEP data point relative to the site

The NCEP data point located at S30.50 E17.00 was used for this study – see **Figure 2.1**. This point is approximately 32 km offshore of Rooiwal Bay in a water depth > 150 m.

2.1 Winds

It is not known whether a reliable long-term dataset of wind recordings exists for the Koingnaas area. The NCEP data was used to analyse the wind climate at the site. This data represents 3-hourly averaged conditions. Gusts exceeding the maximum wind speed may occur regularly.

The wind climate has a strong seasonal character, typical of the west coast of southern Africa. Southerly winds dominate in summer and spring, with north-westerly winds being most common in autumn and winter (Figure 2.2). North-westerly winds occur approximately 18% of the time (during the 8-year wind data record) and usually during the Autumn and Winter months. The winter wind speed, however, rarely exceeds 12 m/s (<1% of the data record). Southerly to south-easterly winds occur approximately 64% of the time with typical wind speeds of less than 12 m/s. The maximum wind speed recorded (3 hourly) at the offshore NCEP (S30.50 E17.00) data point was 17.55 m/s (34.11 knots). These high wind speeds of between 16.0-18.0 m/s have been recorded in both winter and summer months, however, they occur less than 0.1% of the time.

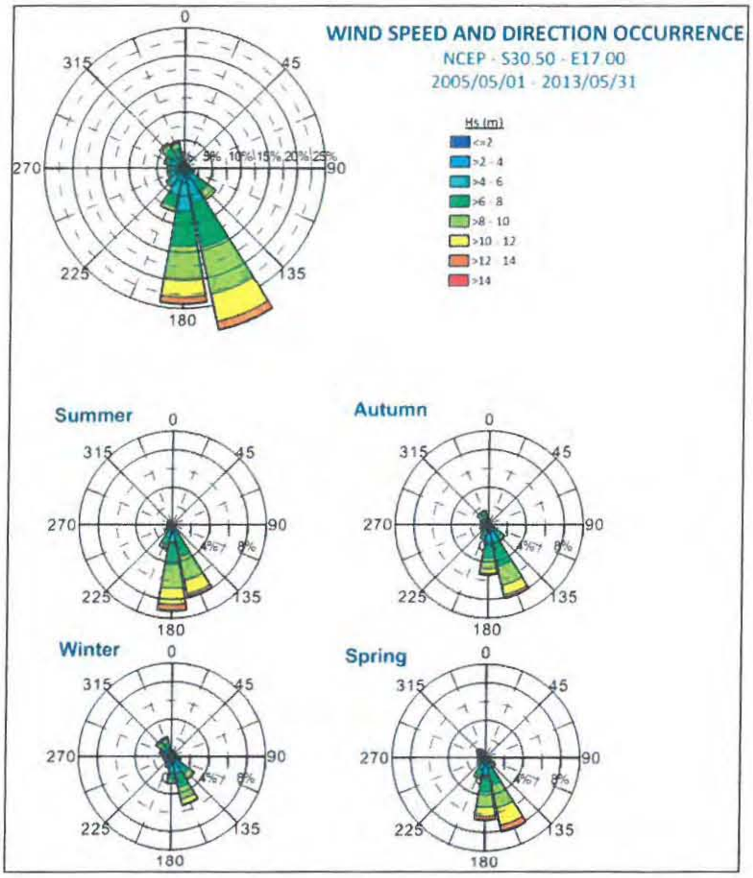

Figure 2.2: Wind speed and direction occurrence rose from NCEP data

2.2 Water Levels

The still water level of the sea is influenced by a number of factors, which are described in the following sections.

2.2.1 Tides

The tides along the South African coastline are semi-diurnal, meaning that two high and two low tides occur per day. Differences between high and low tides are greatest during spring tides, which occur approximately at full and new moon. Differences between high and low tides are least during neap tides, which occur approximately at quarter and three-quarter moon.

Predicted tidal levels are provided by the South African Navy Hydrographic Office (SANHO) for each of the ports on the SA coastline. Port Nolloth is the closest port to the site. The predicted tidal levels for Port Nolloth are as follows (SANHO, 2013):

Table 2.1: Predicted Tidal Levels for Port Nolloth

Parameter	Level (m to MSL)
Highest astronomical tide (HAT)	+1.325
Mean high water springs (MHWS)	+0.985

Mean high water neaps (MHWN)	+0.475
Mean level (ML)	+0.165
Mean low water neaps (MLWN)	-0.145
Mean low water springs (MLWS)	-0.645
Lowest astronomical tide (LAT)	-0.925

The levels are relative to Land Levelling Datum, or Mean Sea Level (MSL), which is 0.925m above Chart Datum at Port Nolloth.

HAT and LAT are the highest and lowest tidal water levels respectively that are predicted to occur under average meteorological conditions and any combination of astronomical conditions. They are unlikely to occur in any given year. However, higher, or lower, conditions can occur as a result of, for example, storm surges.

2.2.2 Storm Surge

Storm surge may significantly increase water-levels at a site. It principally results from two physical phenomena:

- wind set-up;
- atmospheric pressure effects;

Strong onshore (blowing towards the land) winds result in surface water being forced towards the land and "piling-up" against the shoreline. This results in elevated water-levels, called *wind set-up*, which may persist for several hours or even days. Along the west coast, westerly onshore winds that can accompany a winter cold front will result in wind set-up. A wind setup of 0.2 m is estimated for the site for a severe storm.

The cause of most storms is an atmospheric low pressure system. The decreased atmospheric pressure is offset by a rising of the water surface. This increase in water-level is termed the *barometric set-up*. The inverse occurs under atmospheric high pressure systems. The effect is generally small – a 1 millibar (1 hPa) drop in pressure leads to a 1 cm rise in water level. This water level surge is of similar duration to the persistence of the pressure system. An atmospheric pressure set-up of 0.2 m is estimated for the site, based on an average atmospheric pressure of 1017 hPa and a minimum pressure of 999 hPa.

The total storm surge for a typical severe winter storm can therefore be in the order of 0.4 m but can be more severe during extreme conditions.

Apart from the above changes to the still water level, water levels at the shoreline will also vary over short timescales, principally as a result of wave runup on the beach face. This is the high frequency rush of water up and down the beach face. The elevation that wave runup reaches on the beach face increases with increasing wave height. During severe storms, wave runup can result in water overtopping the beach and flooding of low-lying areas.

2.2.3 Sea Level Rise

The total duration of beach mining operations in the area is expected to be short (less than 10 years), and therefore sea-level rise in response to climate change is not considered.

2.2.4 Extreme Water Level

It is proposed that the extreme water level for design purposes is taken as the sum of:

- mean-high water spring tide = +0.985 m
- total storm surge = +0.4 m

Resulting extreme water level = +1.385 m to MSL

The value of 1.385m is similar to the HAT water level. Although unlikely to occur, a severe storm occurring at HAT would result in this level being exceeded. For protective structures that are required to have a longer design life (i.e. longer than 2 years), a higher extreme water level should be used for design.

2.3 Currents

2.3.1 General current conditions

Mechanisms for generation of local currents include the following: offshore currents, tide fluctuations, wind, waves and pressure gradients set up by density differences in the water column (for example temperature differences). The currents generated by tide are insignificant along the open western coastline. In the nearshore zone, wind is a significant mechanism for generating currents. Wave-driven currents are the most important currents in the surf zone. Because of mixing by wave and wind action, density currents are usually not significant in the nearshore zone of the west coast.

2.3.2 Benguela Current

The Benguela Current flows northward along the west coast of southern Africa. While the cold waters of this ocean current affect the coastal climate and fisheries industry, its velocities are generally low and contribute negligibly to currents at the shoreline.

2.3.3 Surfzone Currents

Strong currents can occur in the surfzone (region where waves break) because of the interaction between bathymetric/geographical features and the waves.

Longshore currents are generated when waves break at an oblique angle to the shoreline. They occur on rocky and sandy coastlines. On a beach they result in the alongshore transport of sand. They can result in rapid erosion or accretion of a beach. The direction of a longshore current varies, depending on the wave direction.

Rip currents are a seaward return flow of water. Their velocities are typically sufficiently high to transport sand. The occurrence of rip currents usually results in deep gullies forming close the shoreline, with resultant erosion of the beach opposite the gully.

2.4 Waves

2.4.1 General Wave Climate

Wave conditions around the South African coastline are dominated by the regular passage of cold front weather systems. These low pressure systems generate waves that originate from westerly to southerly directions as the fronts pass from west to east to the south of the country. These are generally high energy wave systems, with peak periods between 9 and 16 seconds (Rossouw, 1989).

Wave conditions near Koingnaas may also be affected by local winds. These winds generate short period (4 s to 8 s) seas that are of comparatively low energy and thus are generally not a critical design consideration. They can affect operational time during marine construction activity.

2.4.2 Wave Data

Offshore wave data were obtained from the same NCEP point as that of the wind data (Section 2.1). Figure 2.3 presents the wave height occurrence roses of the seasonal and annual wave conditions. Waves from the south-west predominate. The median offshore wave height is 2.5 m (50% exceedance), with wave heights exceeding 4.3 m for 5 % of the time (Figure 2.4).

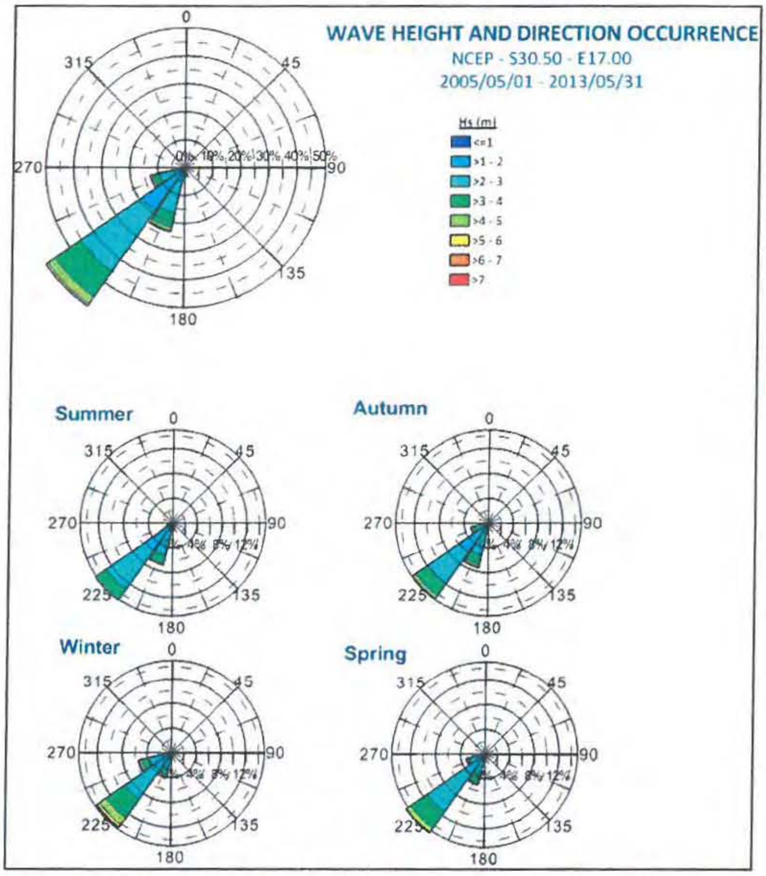

Figure 2.3: Wave height and direction occurrence rose from NCEP data

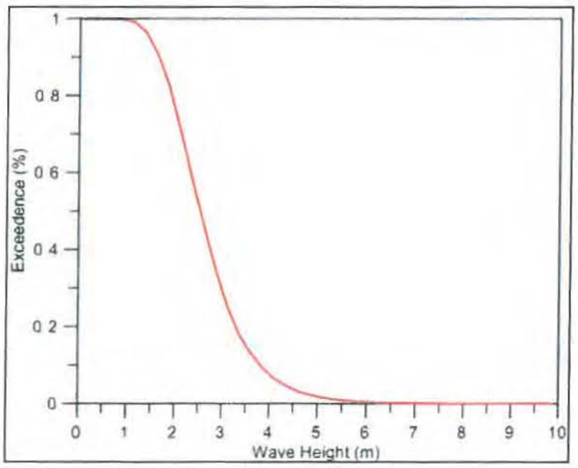

Figure 2.4: Wave height (Hs) exceedance from offshore NCEP data

Figure 2.5 presents the occurrence percentages of the deep sea wave periods. The median wave period is 11 seconds. Wave periods exceed 8 seconds for 95 % of the time. Wave periods of less than 10 seconds are generally seen as wind/sea waves. These are generally associated with smaller wave heights than swell – periods greater than 10 s.

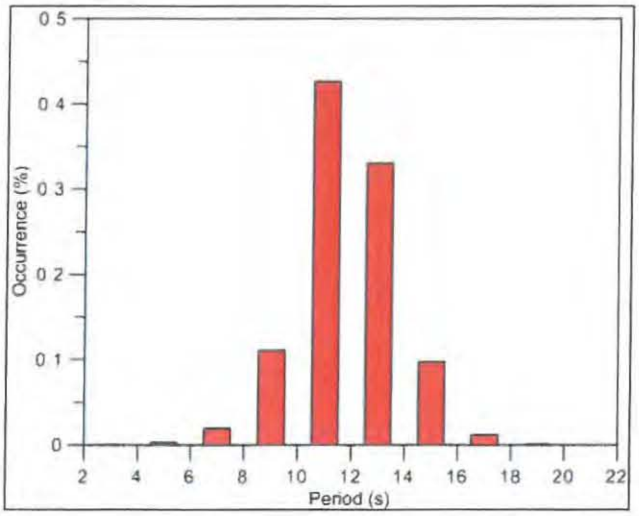

Figure 2.5: Wave period (Tp) occurrence histogram from offshore NCEP data

2.5 Offshore Bathymetry

Offshore bathymetry information was obtained from the British Admiralty chart BA 2078 and South African chart SAN115. Hydrographic soundings for part of the SAN115 area were also provided in digital format by the South African Navy Hydrographic Office.

The offshore seabed slopes very gently from the 200 m depth contour (located more than 60km form the coast) to the 100 m depth contour (located approximately 5 km from shore). From the 100 m depth contour, the seabed slopes steeply to the shoreline.

2.6 Site 68/69 Beach

Site 68/69 consists of a sandy beach approximately 1.8 km long. It is one of few sandy beaches along a predominantly rocky coast. The layout of the site is shown in Figure 2.6.

The southern end of the beach is defined by a rock headland that causes some sheltering and forms an embayment along the southern part of the beach. The Swartlintjiesrivier is located at the southern end of the beach. The coastline becomes rocky at the northern end of the beach.

The seawater intake pumpstation for the Koingnaas processing plant was located near the centre of the beach. A large seepage channel was previously opened along the southern part of the beach and used as seawater source for the intake. This channel has been completely filled with sand, most likely as a result of overtopping by the sea. The target mining blocks are located on the beach north of the pumpstation.

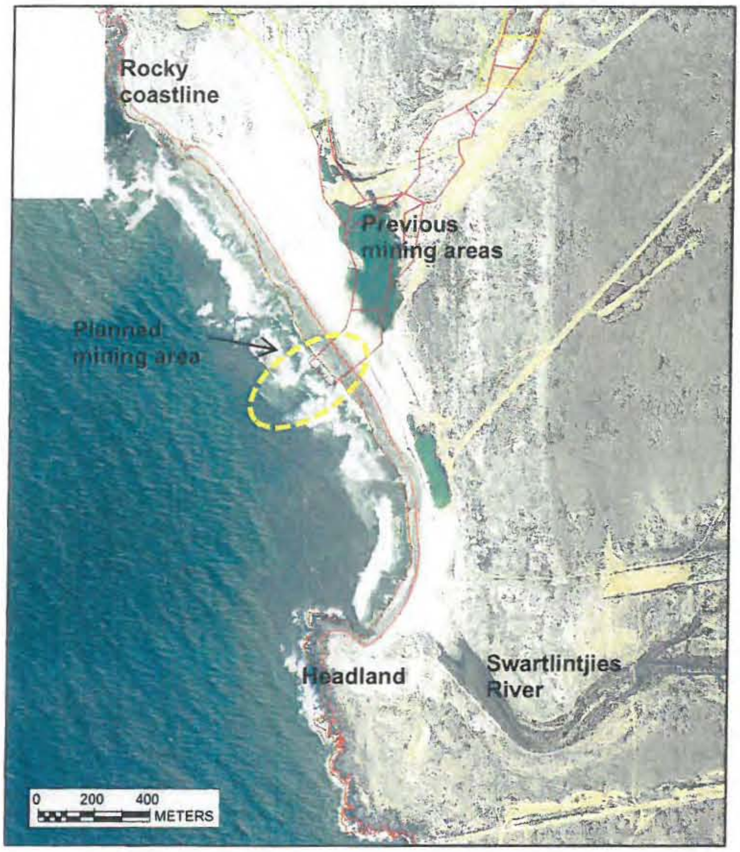

Figure 2.6: Layout of Site 68/69

The beach is gently sloping (estimated slope of 1:20 between high and low-water marks). The southern part of the beach is wide (90m) with low elevation that rises into a vegetated dunefield. Small mobile dunes occur on the northern part of the beach.

Samples from the inter-tidal beach indicate the sand is fine to medium sizes and well sorted. The median (D_{50}) grain size is in the order of 270 microns. The particle size data from the two samples is given in **Table 2.2** below.

Table 2.2: Grain size on Site 68/69 beach

Size (microns)		
	Sample 1	Sample 2
D10	208.5	213.8
D25	236.7	250.1
D50	265.3	274.9
D75	288.2	314.5
D90	352.3	454.4

The beach is exposed to waves from all directions and waves break powerfully close to shore. Only the very southern part of the beach experiences some sheltering as a result of the headland.

The surfzone is typically between 250 m and 400 m wide. It appears that a reef is located in deeper water opposite the northern part of the beach.

2.7 Rooiwal Bay

Rooiwal Bay (Rooiwalbaai) is a small bay located approximately 17 km south of Hondeklipbaai. A layout of the site is shown in Figure 2.7. The main features of the site are the following:

- A narrow sandy beach backed by steep soil cliffs;
- The bay is set deeply into the coastline, indicative of a lack of sand that would otherwise have filled the bay;
- A shallow reef is located in the mouth of the bay – see Figure 2.8 below. Historical bathymetry data indicates water depths of 4 m to MSL over the reef;
- An irregular, deep, channel is present in the northern part of the bay. Water depths here are indicated to exceed 20 m. A second depression occurs in the southern part of the bay;
- The seabed is mainly rock – bedrock, boulders, cobble and gravel. The limited sandcover is restricted to the eastern side at the beach, and in the northern channel;
- A (paleo) channel enters the bay at its northern side. The channel has been previously mined.
- A vegetated dune field traverses east of the bay, in a south-north direction.

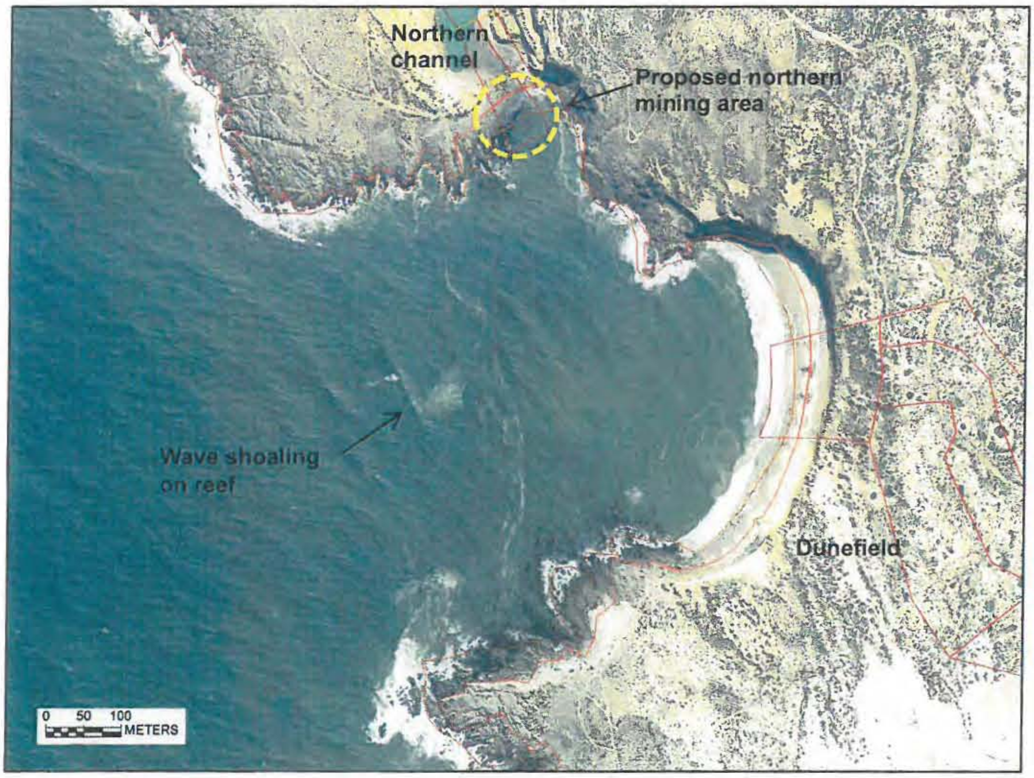

Figure 2.7: Layout of Rooiwal Bay

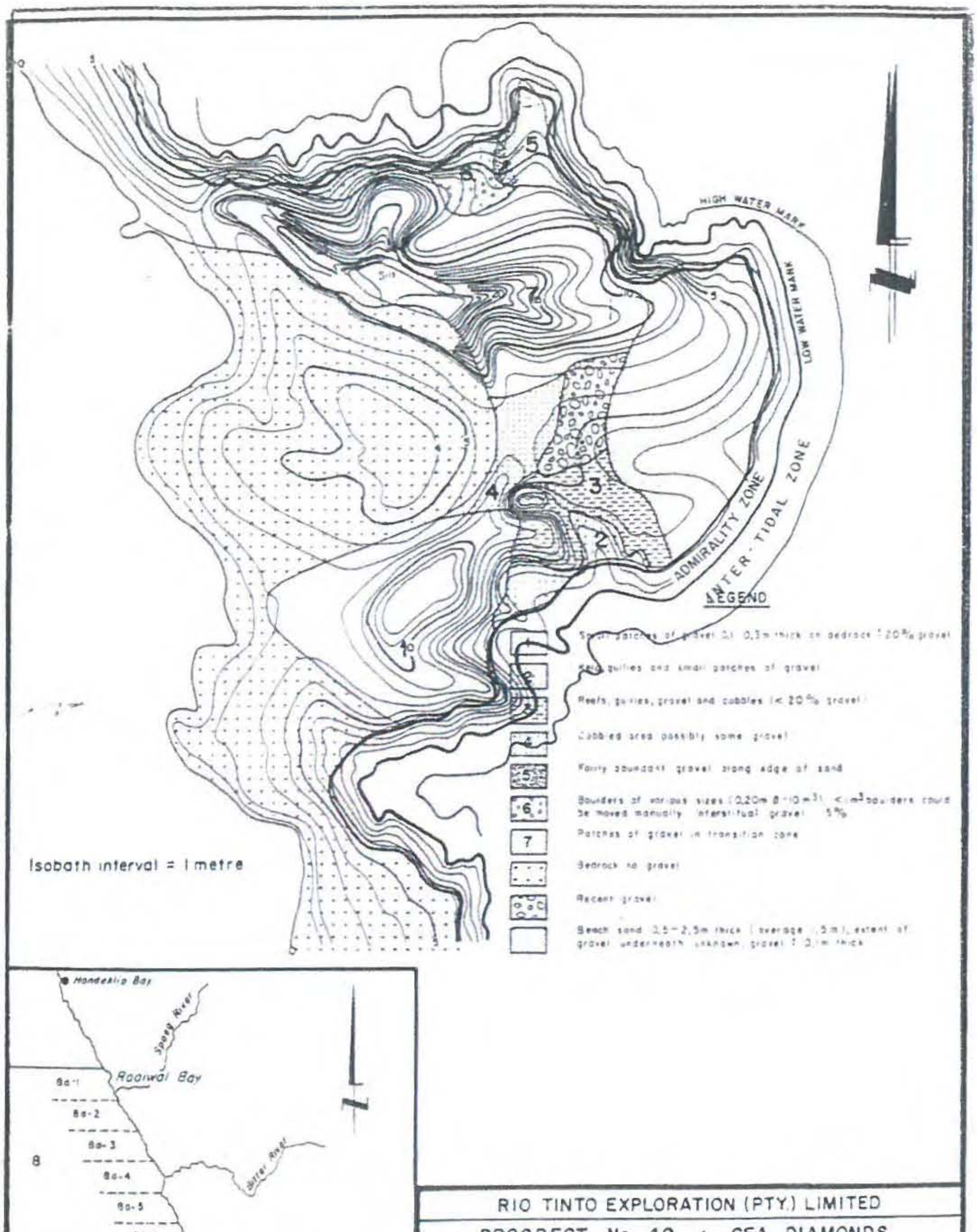

Figure 2.8: Historical bathymetry of Rooiwal Bay

Waves break heavily on the rocky margins of the bay. The reef in the centre of the bay causes waves to shoal and break. This reduces the energy that reaches the beach. The rocky outcrops at the northern side of the beach are exposed to high wave energy that enters the bay over the deep channel in the seabed.

3 Overview of Beach Reclamation Methods for Mining

An overview is given in this section of methods that are used for reclamation or to accrete beaches for mining purposes.

3.1 Beach Accretion with Sand

Several methods are practiced by Namdeb to accrete beaches and protect mining excavations near Oranjemund in southern Namibia, see Figure 3.1. These utilise the large volumes of sand that are available:

i. Massive sand berms, or seawalls, are constructed with earthmoving machinery in order to accrete the beach and protect the mining excavation. The crest of these seawalls is typically at 7 m above MSL, and is 20 m to 30 m wide. Large sand volumes are required to construct the seawalls and to maintain them. Sand is constantly eroded from the seawall by wave action. The rate of erosion, and thus replenishment, increases as the walls are built further into the sea.

ii. Dredgers are used to strip the overburden sand and discharge the slurry onto the beach, where the deposition of sand results in accretion. Wave action distributes the sand along the coast. The rate of accretion is dependent on the dredging rate. Dredging is a cost effective accretion method if large volumes must be moved. However, a pond must be created and maintained for the dredger to float in. A constant supply of water is required to replace that pumped out with the sand. Supply of this water by pumping can be costly if natural seepage is limited.

iii. Conveyors are also being used to move sand, and coarser material, from further inland onto the beach. The front of the conveyor is moved or extended seaward as the accretion occurs. Wave action distributes the material along the coast. This method is effective if the source of sand is a large stockpile or dump, as little additional earthmoving machinery is required.

Figure 3.1: Beach accretion methods (left to right) - seawalls, dredger discharge, conveyor

Sand can be a suitable material for beach accretion when:

- Plentiful supply is available
- Haulage distances are short
- The mining operation already requires extensive stripping of sand overburden

A drawback of using sand is that is that it is easily transportable by the sea – large volumes are required in order to achieve accretion, and frequent replenishment is required to replace the sand lost during storms. Furthermore, the accreted shoreline rapidly will attain a new equilibrium shape, due to alongshore movement of sand. This can result in accretion in areas where it is not required, or desired.

This is illustrated in Figure 3.2, which shows that the entire coastline needed to be accreted in order to achieve accretion at the desired location. The consequence of this is that the volumes of sand needed are much greater, which increases the cost of the mining operation, and that the impact area of the accretion is beyond the boundaries of the mining operation.

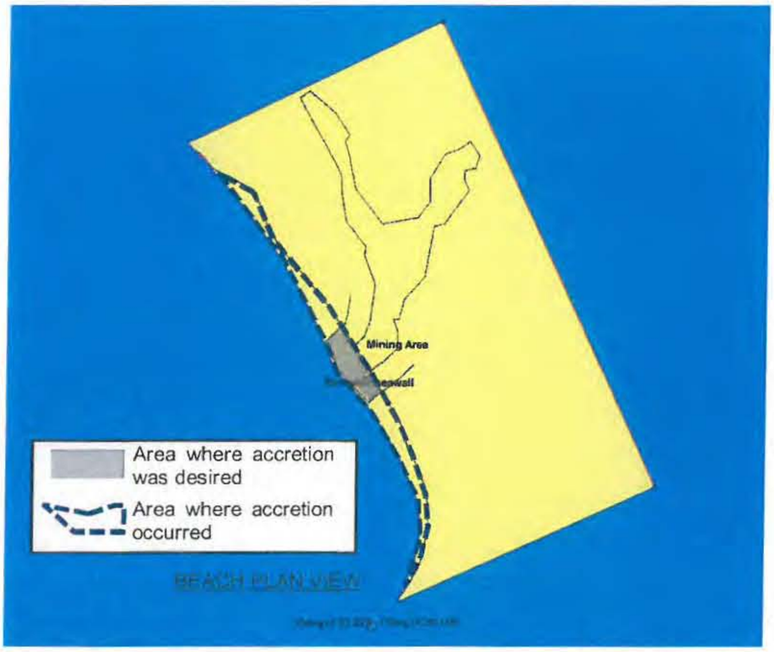

Figure 3.2: Model simulated case of shoreline accretion with sand

3.2 Rock Berms

Rock is typically used to construct revetments and breakwaters for coastal protection. A typical cross-section for such structures is shown in Figure 3.3. The structure usually consists of an outer layer of large armour rock, or concrete armour units. Subsequent rock layers – under layer, core – typically consist of progressively smaller material.

The size/mass of the rock required for the armour layer is a function of several factors of which the predominant is the prevailing wave conditions. Larger (heavier) rock is required in order to absorb and dissipate the energy of larger waves.

A structure that is located in deeper water will be exposed to higher waves than a structure located in shallower water. A structure located landward of the breaker line (i.e. in the surfzone) will be exposed to low wave energy, as energy is dissipated during breaking. During periods of higher water levels, such as high tides or storm surges, the breaker line shifts and such a structure may then be located at or outside the breakerline. The structure is then exposed to higher wave energy.

The term "berm" is used here to describe a rock mound serving to protect an open excavation from the sea.

Rock breakwaters are typically designed to be permeable. However, for reclamation of a mining area, a rock berm would need an impermeable core, or at least one that restricts seepage.

A berm would usually be constructed seaward from the shore by end-tipping the core material from trucks. Once a sufficient section of core is built, it would be covered with the larger armour layer. If the armour material is also small, it would be also be end-tipped, with an excavator used to dress the slope to the correct profile. If the armour material is larger, the individual rocks would be lifted and placed into position by an excavator or crane. Concrete armour units would be placed by crane due to their mass and the requirement to accurately place them to the correct packing density. A crane is required for placing armour units in water deeper than a few metres, as excavators are unable to reach the required distances.

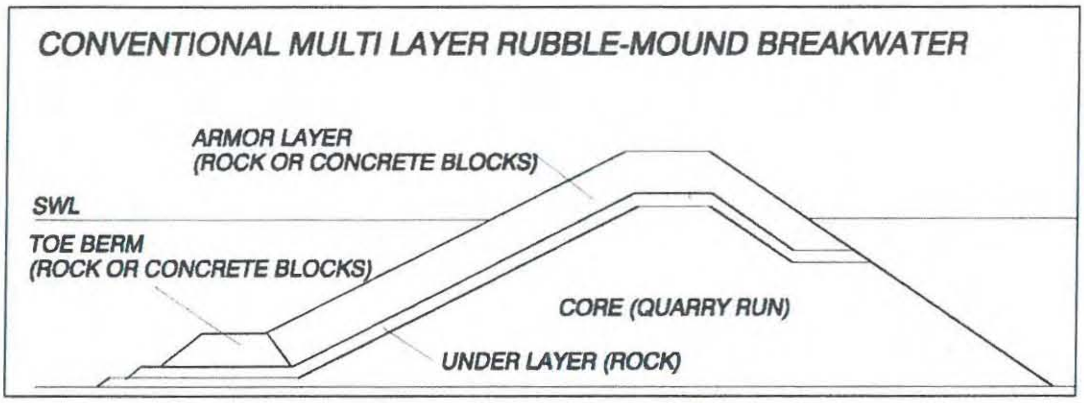

Figure 3.3: Cross-section of typical rubble mound breakwater (CEM, 2001)

A simple rock rock berm has been used near Alexander Bay to protect mining excavations from the sea – see Figure 3.4.

Figure 3.4: Rock berms used to reclaim mining area on the beach near Alexander Bay

3.3 Alternative Methods

Sand filled geotextile bags (also called geobags, sandbags, and several other proprietary names) have become popular for temporary beach stabilisation and protection works. Some applications are illustrated in Figure 3.5.