Richards Bay effluent pipeline

D A Lord and N D Geldenhuys

The relative magnitude of the Richards Bay pipeline, the considerable funding, research, and monitoring input through the Marine Pollution Research Programme of SANCOR, and the format for planning and design of marine pipelines created by this effort, led to this publication

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Cover: Richards Bay from the air showing city and industrial centre
(Photograph by C Best, NRIO)

SYNOPSIS

Adequate provision for waste disposal is an essential part of the infrastructure needed in the development of Richards Bay as a deepwater harbour and industrial/metropolitan area.

Having considered various options for waste disposal, with due regard to the major producers of waste material and effluent in the area as well as the waste characteristics, a marine pipeline was chosen.

Basic prerequisites for marine disposal of wastes through a pipeline include identification of effluent characteristics and of the critical constituents of each discharge, assessment of the marine environment, establishment of discharge criteria, design of pipeline to meet criteria, and monitoring.

Aspects of major concern identified in the effluent are the large volume of byproduct calcium sulphate (phosphogypsum) which would smother marine life, high concentrations of fluoride highly toxic to marine life, heavy metals, chlorinated organic material and colour.

Surveys and studies of the marine environment were undertaken to assist in the siting and design of the pipeline and to provide baseline information for assessing the environmental impact of the project.

The design of the pipeline was largely determined by the discharge criteria for various constituents in the effluent. It was decided that the wastes should be separated into a dense and a buoyant mixture at or close to the source, and that each mixture should then be discharged through a separate pipeline and diffuser system to give optimum dilution. The line for the buoyant mixture relies on deeper water for optimum dilution as the effluent rises through the water column, whereas the line for the dense mixture relies more on high velocity discharge and wave agitation in shallower water.

Approval of the concept of the pipeline facility and its operation was subject to rigid monitoring requirements, including regulatory monitoring as well as intensive monitoring to determine the environmental impact of the effluent.

ACKNOHLEDGEHENTS

The contributions and comments received from the members of the Richards Bay Effluent Pipeline Research Co-ordinating Committee (see Appendix I for membership) are gratefully acknowledged. Thanks are also due to Mr 0 A van der Westhuysen (SANCOR) for his valuable advice and to Mrs H Ridder for her invaluable assistance in the preparation of this document.

Most of the research discussed was undertaken under the auspices of the CSIR with substantial financial support from the Department of Environment Affairs. A contribution from the Mhlatuze Water Board towards the cost of producing this publication is highly appreciated.

SINOPSIS

Toereikende voorsiening vir die wegvoer van afval is 'n noodsaaklike deel van die infrastruktuur benodig vir die ontwikkeling van Richardsbaai as diepwaterhawe en industriele/metropolitaanse gebied.

Na oorweging van verskeie moontlikhede vir afvalverwydering, met inagneming van die vernaamste produsente van afvalstowwe en uitvloeisel in die gebied asook die eienskappe van die afvalstowwe, is daar besluit op 'n seestortpyp.

Die basiese voorvereistes vir die wegvoer van afvalstowwe deur middel van 'n seestortpyp is onder andere bepaling van die eienskappe van die uitvloeisel asook die kritiese bestanddele van die stowwe wat vrygelaat word, evaluering van die mariene omgewing, vasstelling van kriteria vir die uitvloeisel, die ontwerp van die stortpyp om aan die" kriteria te voldoen en gereelde kontrole.

Die groot hoeveelheid kalsiurasulfaat (fosfogips) wat mariene lewe kan versmoor, die hoe konsentrasies fluoried wat uiters giftig is vir mariene lewe, swaarmetale, gechloreerde organiese materiaal en die kleur is uitgeken as die mees problematiese aspekte van die uitvloeisel.

Opnames en studies van die mariene omgewing is uitgevoer met die oog op riglyne vir die ligging en ontwerp van die stortpyp asook die verkryging van basiese inligting om die projek se uitwerking op die omgewing te kan bepaal.

Die ontwerp van die stortpyp is in hoe mate bepaal deur die kriteria vir die storting van verskillende bestanddele van die uitvloeisel. Daar is besluit dat die afvalstowwe by of naby hul bron geskei moet word in twee mengsels, naamlik 'n digte en 'n drywende mengsel, en dat die mengsels dan deur afsonderlike pype en spreistelsels gestort word om optimale verdunning te verkry. Met die pyp vir die minder digte mengsel word staat gemaak op dieper water om optimale verdunning te verkry deurdat die uitvloeisel in die waterkolom styg, terwyl met die pyp vir die digte mengsel, wat in vlakker water 1§, vir die doel staat gemaak word op 'n hoer uitlaatsnelheid en golfaksie.

Goedkeuring van die stortpypfasiliteit en die wyse waarop dit gebruik word is onderworpe aan die nakoming van streng kontrolevereistes, wat insluit monitering om aan wetlike standaarde te voldoen sowel as intensiewe monitering van die mariene oragewing om die uitwerking van die uitvloeisel daarop te bepaal.

TABLE OF CONTENTS

Page

SYNOPSIS .... (iii)

ACKNOWLEDGEMENTS .... (iii)

SINOPSIS .... (iv)

BACKGROUND 1
- Historical 1
- Description 1
- Land use planning and development 2
- Harbour development 2

INDUSTRIAL DEVELOPMENT AND WASTE DISPOSAL 4
- Industries 4
- Waste disposal : Philosophy and options 6

THE USE OF THE SEA FOR WASTE DISPOSAL 7
- Effluent volumes and characteristics 8
- Environmental constraints 8
- The sea in the vicinity of Richards Bay 9

THE RICHARDS BAY PIPELINE 16
- Environmental considerations 16
  - Phosphogypsum disposal 16
  - Effects of fluoride on locally occurring organisms 16
- Engineering design 18

DESCRIPTION OF THE SCHEME 19

MONITORING 19

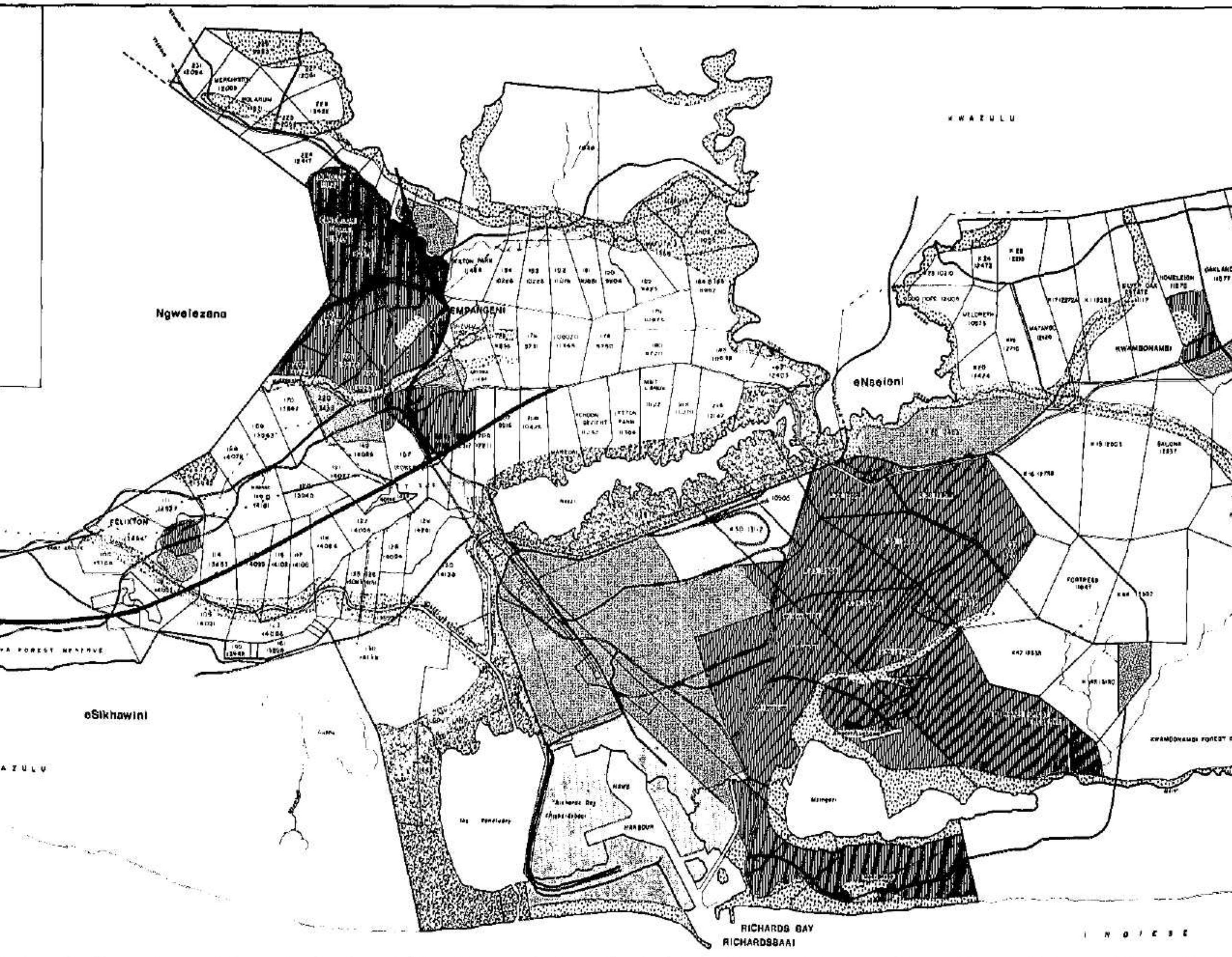
CONCLUSION 21

INSTITUTIONS INVOLVED IN MARINE POLLUTION RESEARCH IN SOUTH AFRICA 22

APPENDIX I 23

LIST OF PUBLICATIONS 24

RECENT TITLES IN THIS SERIES 26



KWAZULU
Ngwelezana
EMPANGENI
eNseleni
KWAMBONAMBI
FELIXTON
eSikhawini
RICHARDS BAY
RICHARDSBAAI
HARBOUR

BACKGROUND

Historical

The town of Richards Bay is situated on the east coast of South Africa, approximately 160 km north-east of Durban, and was named after Sir Frederick William Richards. Although the area was already known to the Portuguese mariners in the 15th Century as Rio^dos-Peixos (River of Fish) Richards was the first person to map Richards Bay as such when in 1879, while involved in survey work along the coast, gave his name to the area occupied by the Mhlatuze estuary.

The decision by the State in 1965 to develop a deep-water harbour at Richards Bay meant a change in the character of the area from a tiny holiday and fishing village to a modern industrial/harbour complex. This development was necessary due to the need to provide an additional rail connection between the coast and the Pretoria/Witwatersrand/Vereeniging industrial complex and to provide deep-water port facilities for export of minerals and other commodities which would enable South Africa to compete favourably on the international markets.

Description

Richards Bay is situated on a large coastal plain, underlain by unconsolidated and porous sands. The coastal plain varies in altitude from sea level to 60 m and in width from 3 km to 20 km.

The coastline in this vicinity is characterised by a steep eroding sandstone cliff-face and a strip of one to four dune ridges parallel to the coast. These coastal dunes contain rich deposits of heavy minerals such as ilmenite, rutile and zircon which are presently being exploited. The coastal dunes support a particularly dense, indigenous forest which is dependent on the high rainfall. This vegetation is very sensitive to disruption and is supported by a remarkably shallow topsoil over the loose sand of the dunes.

A distinct feature of the hydrology of the area is the Mhlatuze River system and its associated floodplain and delta system. The lower section of the river, which is subject to severe flooding, has been almost completely canalised to allow for cane cultivation on the floodplain. The former estuary has been developed into a separate harbour and a sanctuary area, separated by an embankment and tidal gate. Several freshwater lakes, the largest of these being Lakes Msingazi, Cubhu and Nsezi, are also prominent in this area and provide an important part of the freshwater supply for the region. The coastal plain is underlain by a major aquifer which is very susceptible to local ground water contamination.

The sanctuary supports a particularly rich fauna, especially waterbirds. This area includes the southernmost breeding populations of hippo whilst crocodiles also occur in the lower reaches of the Mhlatuze and the sanctuary. Many species of snakes are found, and marine and freshwater fish species are abundant.

The climate is subtropical with average temperatures ranging between 13°C and 29°C and average annual rainfall of 1 350 mm- This combination of temperature and rainfall is very favourable for plant growth but the resultant relative humidity can at times be fairly uncomfortable. Average values range between 67% and 84%.

Land-use planning and "development

The future spatial development of the area should be seen against the background of an evolving metropolitan area where industrial development and modern harbour facilities of Richards Bay are playing an important role in the national and regional economy. Closely related to this is the rapid urbanization of the area. Therefore, whereas the region was previously utilised for agriculture, forestry and rural settlement, the situation is now rapidly changing to urbanization and industrialization associated with Richards Bay.

This is undertaken within the framework of the Richards Bay Urban Development Plan and also the more recent Richards Bay/Empangeni Draft Guide Plan (see Figure 1).

The industrial component of 2 400 ha forms a major part of the land-use framework and this is related to the importance attached to Richards Bay in fulfilling a national and regional function in accommodating primary industries directed at the national and international markets. In addition large areas of land and water have been reserved as nature areas and open spaces whilst the town centre and residential areas were designed to create a parklike atmosphere.

Harbour development

The catalyst and major factor in the growth of this area is obviously the new harbour in the large natural lagoon at the mouth of the Mhlatuze River. Its development involved the division of the lagoon into two sections by a 4 km causeway or berm-wall. To the north-east of this berm unrestricted harbour and industrial development was to proceed, whilst to the south-west of the berm the bay was to be left undeveloped, and to be kept as a nature reserve, but only after the creation of a new mouth to the sea and the diversion of the Mhlatuze River into the sanctuary. This subdivision of the Richards Bay estuary was completed in 1976 and is shown in figure 2.

The harbour first became operative in 1976 and is still being developed. At present the major export is coal, 34,7 million tonnes being exported in 1984 which is expected to increase to 80 million tonnes in the medium term. A variety of other types of cargo are also handled at other quays, including exports such as phosphoric acid, aluminium ingots, rutile, zircon, titatium slag and pig iron, and imports such as alumina, petroleum, coke, sulphur, and general cargo.

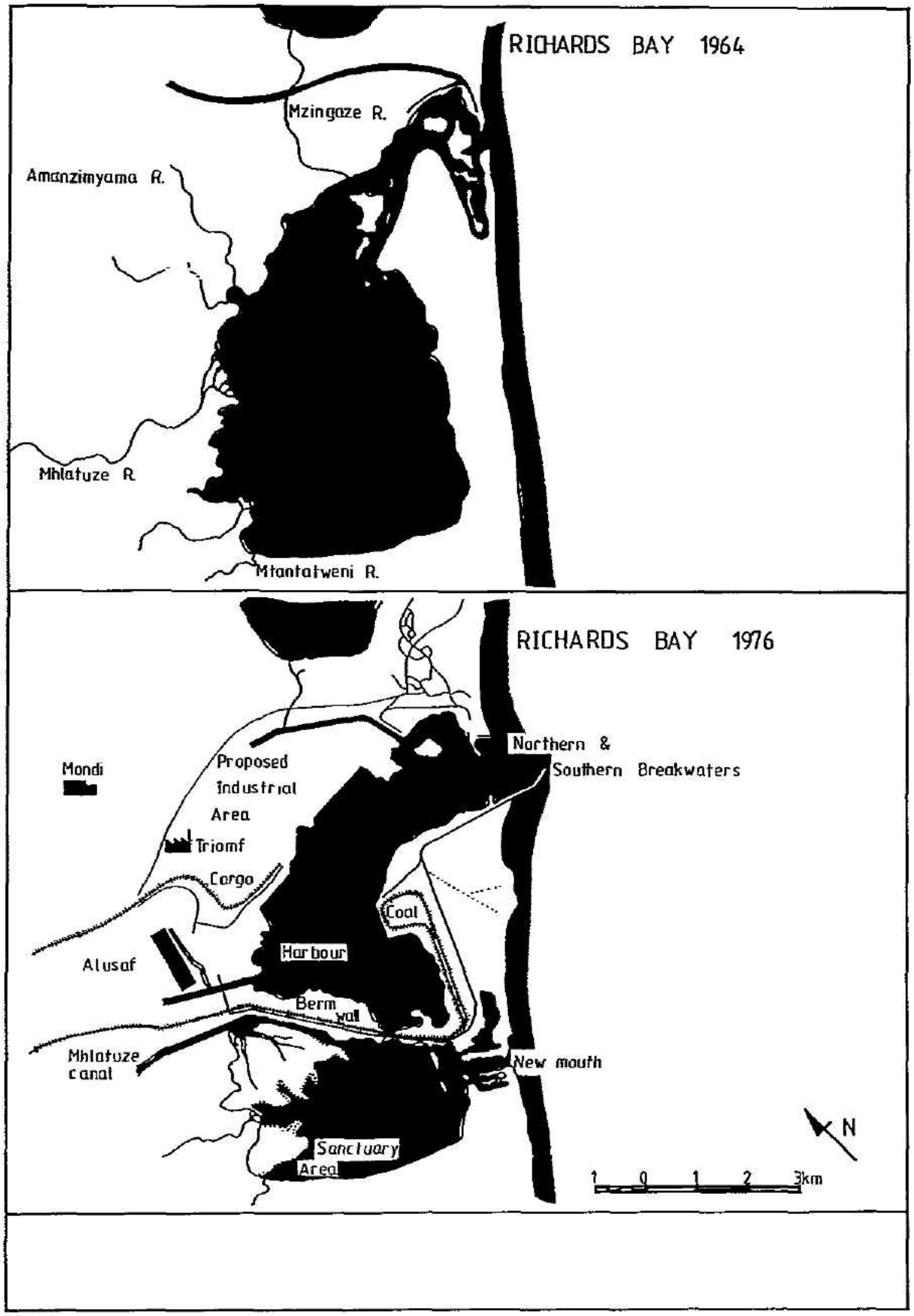


Figure 2: *The subdivision of the Richards Bay estuary (1964-1976)*

INDUSTRIAL DEVELOPMENT AND WASTE DISPOSAL

Industries

The emphasis at Richards Bay is on industrial development. The major feature of the area is consequently provided by the heavy industries, of which there are already several in Richards Bay and environs. Approximately 60 associated service and general industries are also established in the industrial township. The following major industries are in operation in the area.

Aluminium smelter:

The Alusaf primary smelter is one of the first industries established in Richards Bay and is located at the western end of the harbour. An indication of the size of this plant is the electricity consumption of 325 megawatt. The annual production capacity is 175 000 tonnes of aluminium.

Phosphoric acid and fertilizer factory:

The Triomf phosphoric acid plant is one of the important import/export orientated industries in this region. Raw materials include large quantities of phosphate rock from Phalaborwa and approximately 350 000 tonnes of sulphur which are imported annually. The main product is phosphoric acid solution which is used in the manufacture of granular fertilizers and mono-ammoniumphosphate powder. The bulk of the phosphoric acid is exported whilst approximately 10 % is used in South Africa for the manufacture of phosphatic fertilizers and animal feeds.

The effluent from this plant consists of 9 470 tonnes/day of byproduct calcium sulphate, (which is called phosphogypsurn) containing 32% free water, and 7 560 nrVd of effluent water containing fluorides at 92 tonnes/day. The chemical composition of the untreated effluent is presented in table I, while estimated effluent volumes are indicated in table V.

Table I : Chemical Composition of Untreated Phosphoric Acid Effluent

	mg/l
Mercury	less than 0,001
Copper	32,5
Cadmium	0,00364
Lead	1,062
Zinc	0,716
Iron	2,429
Chromium	0,198
Cobalt	0,257
Nickel	0,187
Magnesium	2,641
Fluoride (as F)	8000
pH = 1,6	

Pulp and paper mill:

The Mondi Paper Company commenced manufacture of pulp and paper during 1984. The mill will utilise the sulphate or Kraft pulping process and initial production capacity will be 350 000 air dry tonnes per annum of fully bleached pulp. This will be used primarily in South African paper and board mills, but especially during the first ten years of operation there will be extra capacity for the production of export pulp-Estimated characteristics of the effluent are indicated in table II, while estimated effluent volumes are shown in table V.

Table II : Estimated Characteristics of pulp mill effluent

	mg/l
Dissolved organic matter (lignin, acetic acid, sugars, etc.)	1 400 – 2 000
Dissolved inorganic matter (Na, Ca, Cl, etc.)	1 700 – 2 300
Total dissolved solids	3 100 – 4 300
Suspended solids (fibre and insoluble salts)	30 – 100
COD (hardwood and softwood)	1 000 – 2 000
BOD	350 – 600

pH = 3 – 7
T°C = 40 – 50
Colour = 3 100 platinum units

Borough of Richards Bay.

Although it is not an industry as such, the fact that the Municipality takes responsibility for the treatment of sewage from industries and housing developments within its boundaries, makes it liable as an industry in terms of the Water Act.

Although several smaller industries are situated in this area, the effluent is dominated by the contributions of domestic origin and the effluent has the following general characteristics (table III). Effluent volumes are shown in table V

Table III : Borough of Richards Bay effluent

	mg/l
Settleable solids	6,0
Suspended solids	200,0
Permanganate value	50,0
COD	450,0
Ammonia - Nitrogen (as N)	30,0
Ortophosphate (as P)	6,5
pH = 7,1	

Heavy mineral recovery:

This involves mining of the coastal dunes north of Richards Bay for rutile, zircon and ilmenite by means of a floating dredger. Large-scale processing occurs at the nearby smelter and 90 % of the production is exported. This activity occurs outside of the area of jurisdiction of the Mhlatuze Water Board.

Waste disposal : Philosophy and options

As mentioned previously, in terms of the long-term spatial development of the country, the role of Richards Bay as a future metropolitan area and industrial growth point has been clearly identified. Considerable effort has been expended to achieve these goals and a number of large industries are already located in the area.

The major consideration in the initial planning was for the provision of the necessary infrastructure such as rail, road, sea and air communication, as well as water and power supplies. Waste disposal from the major industries was also considered as an integral part of this infrastructure. The various alternative systems which were considered, along with their major advantages and disadvantages, are summarised in table IV.

Table IV : Waste disposal options

Option	Advantages	Disadvantages
Conventional full treatment on land	Potential for future re-use of effluent, nor use of the sea for disposal.	Expensive. Inability to treat extra large volumes of specific wastes (e.g. ca 2 million t/a of phospo-gypsum) Effects of leachate from disposal sites. Effect on recreation and conservation of treated effluent to streams (integrated surface water system consisting of short canals, sanctuary, lakes, and harbour).
Disposal of wastes at sea from barges	Wastes could be disposed of without any land or shore pollution.	Expensive. Weather dependant.
Deep sea pipeline	Proximity of ocean. Relative high assimilative capacity of ocean. Less expensive than other options.	Pollution of marine environment in vicinity unless carefully designed and operated.

All factors being considered, the decision was taken to provide a regional wastewater facility in the form of a submarine pipeline which would discharge into deep water.

THE USE OF THE SEA FOR HASTE DISPOSAL

Marine pipelines rely on three important characteristics of the sea in order to reduce and eliminate any effects of a discharge. The first of these and the more important is the very rapid initial dilution and subsequent dispersion that takes place when a buoyant (i.e. less dense than seawater) effluent is discharged. The second feature is the ability of the sea to decompose naturally certain wastes. The third is the fact that the sea contains vast quantities of salts to which sea life is adapted but which would be very harmful in fresh water-Throughout history, the sea has been used for the disposal of treated and untreated wastes. In many cases, uncontrolled discharge has resulted in serious degradation of environmental quality, yet in others, little or no significant effect has been measured. It is noteworthy that examples of the latter have usually occurred where good planning and design have taken place, and where sound control and detailed monitoring are being practised. Inherent in the planning and design of a modern pipeline facility are the following basic prerequisites:

- identification of effluent characteristics from the various sources
- identification of critical constituents or constraints of each discharge
- assessment of marine environment (physical, chemical, biological)
- determination of discharge criteria
- design of pipeline to meet discharge criteria
- monitoring.

Summary of effluent volumes and characteristics

Table V indicates the effluent types and volumes which will utilize the pipeline initially.

Table V : Effluents in the Richards Bay pipeline

Source	Triomf Fertilizers	Mondi Paper Co.	Richards Bay Municipality	Alusaf	Total
Volume(m^3/d) Initial Future	 25 800 25 800	 90 000 160 000	 5 000 45 000	 20 000 20 000	 140 800 250 800
Main constituents	gypsum (6 440 t/d) fluorides (92 t/d) heavy metals	organics (COD,TDS,SS) colour	organics (COD,SS)	fluorides	

Environmental constraints

In utilizing the pipeline option, the following were seen as the environmental constraints which had to be considered (Table VI).

9 Table VI :

Environmental constraints of effluent

Item	Concern
Gypsum	Large volume, cloud effect (aesthetics and clogging of fish gills), smothering effect on ocean floor.
Fluorides and heavy roetaIs	Acute toxicity and sub-lethal effects on biota
Biodegradable organic materials	High oxygen demand
Chlorinated organxcs	Effect on biota, accumulation in the food chain
Colour	Aesthetics and reduced light penetration.

The Sea in the Vicinity of Richards Bay

The main oceanographic features which influence the dilution of effluent from a pipeline on the seabed are the ambient current and any density stratification of the seawater column. A flowing current will not only supply clean replenishment water, but will also increase turbulent mixing of the effluent while a stratified sea will inhibit mixing.

Various research groups were involved in undertaking surveys of the marine environment and associated research and modelling which would assist in the design of the pipeline and to assess the environmental impact of the effluent. These groups are listed in Table (VII).

Table VII : Research groups involved

Name of Group	Activity
National Research Institute for Oceanology, CSIR	Physical oceanographic features, coastal engineering, sedimentology
National Institute for Water Research, CSIR	Biological and chemical studies of marine and estuarine environment, bio-assays studies
Oceanographic Research Institute	Biological studies with emphasis on ichthyofauna
Sea Fisheries Research Institute DEA	Literature survey, scientific advice

A review and evaluation of all available relevant physical data for the area, as well as hydrographic, seismic and side-scan sonar surveys were undertaken by the National Research Institute for Oceanology (NRIO). The Richards Bay area is not one of high currents and, although currents of 65 cm/sec have been measured, calm periods (which are considered to be those when current velocities are less than 2 cm/sec) occur up to 40 % of the time. Consequently average current strengths in the area are low, at 8,5 cm/sec. The dominant current directions are ENE (current flows towards the ENE) and W. The currents flowing ENE are stronger. However, westward flowing currents occur more frequently.

This area is one of considerable wave action. Data collected since 1968 show that 90 % of wave heights recorded are between 0,5 m and 2,0 m, with the majority of wave periods being short, falling between 8 and 13 seconds. All observed wave directions fall within the sector South to East, with the predominant direction SE.

Baseline ecological studies were also undertaken by the National Institute for Water Research (NIWR) and the Oceanographic Research Institute (ORI) to provide a datum from which possible ecological effects after commissioning of the project could be evaluated.

Although much of the physical oceanographic data have been collected for many years prior to any decision on a pipeline, little biological information was available. By the time a research programme for this purpose had been formulated and implemented in 1981, the offshore and beach environments in the vicinity of Richards Bay had already been severely impacted by dredging activities. These included both the pumping of dredge spoil onto the beaches via extensive pipelines, and the dumping of similar material offshore, from dredgers. The purpose of the research-programme was to assess the chemical and biological status of water and sediments offshore of Richards Bay and on the beaches and was undertaken within the grid of stations indicated in figure 3. The NIWR was requested to perform these tasks, with the objective of being able to use the data for comparison with data collected after discharge began, in order to measure and evaluate the extent of environmental impact. In addition, ORI undertook to study patterns of settlement of various marine organisms on moored offshore platforms, in an experiment to assess the potential of this type of research in environmental impact assessment.

Thus three major research strategies were embarked upon:

- pre~ and post-discharge studies of bacteriology, biological communities, and water and sediment chemistry;

- medium-term studies of settling organisms on offshore platforms, from which samples can also be collected for bio-accumulation studies;

- short-term assessments of gypsum smothering and effluent toxicity.

The following results have been obtained:

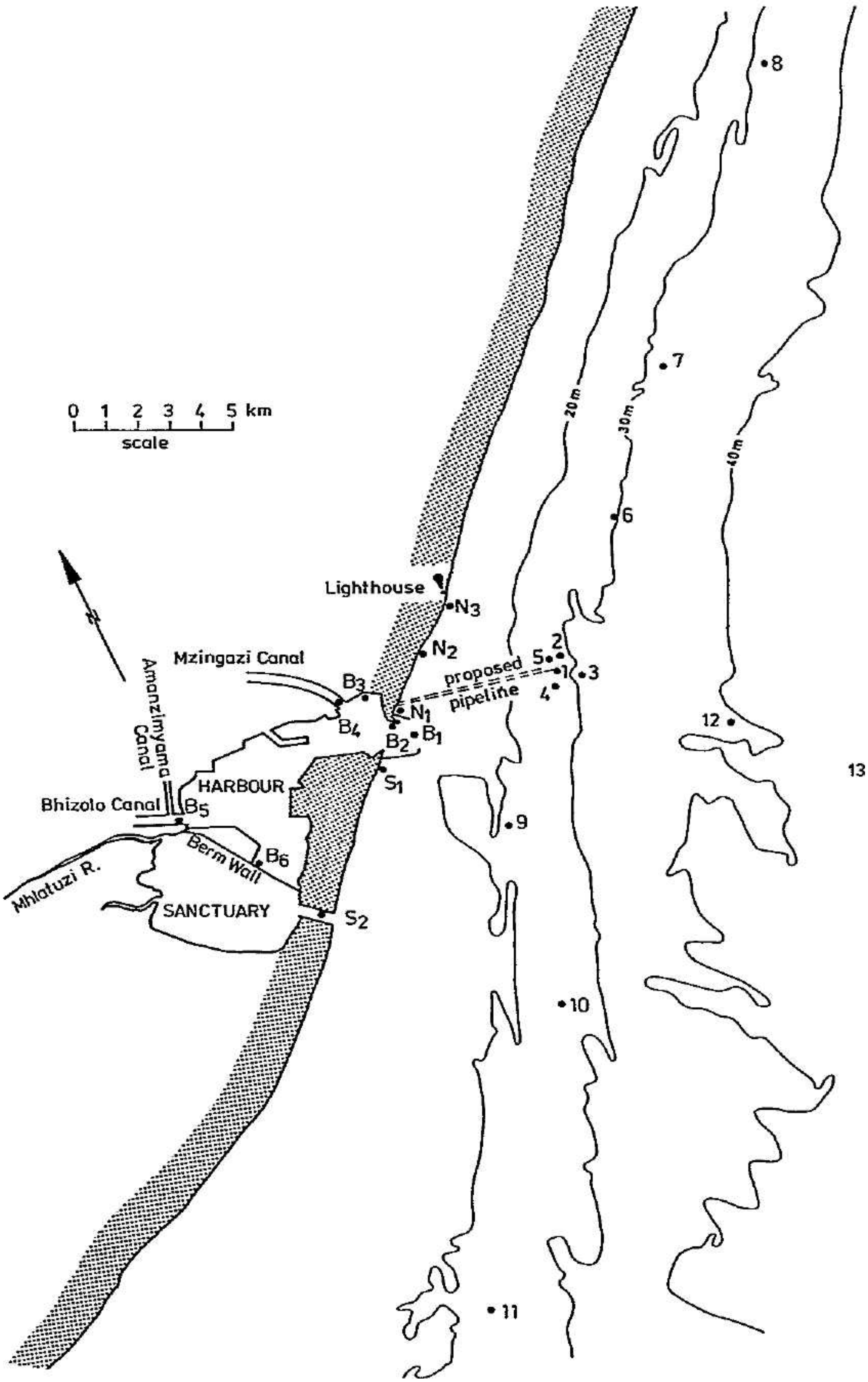


Figure 3: *Location of sampling stations at Richards Bay, also indicating seabed topography*

Bacteriology

Some moderate degree of faecal pollution has been measurable in Richards Bay since 1969. With development this picture remains essentially the same, with a serious increment of sewage occurring at or near station B6 (Figure 3). Little or no contamination of significance has so far affected the northern beaches (except apparently, once in 1981), while the southern beaches may at times be affected by the flow from the sanctuary mouth. No pollution has been found over the sea outfalls site. It can be assumed a reasonably comprehensive background picture now exists against which future changes can be determined.

Viruses and Coliphages

No viruses were isolated from the samples, and the coliphages census on the stations examined, which included offshore, beach and harbour stations, proved insignificant. It can therefore be concluded that no gross contamination of the Richards Bay marine environment with raw sewage was apparent prior to the submarine outfalls becoming operational.

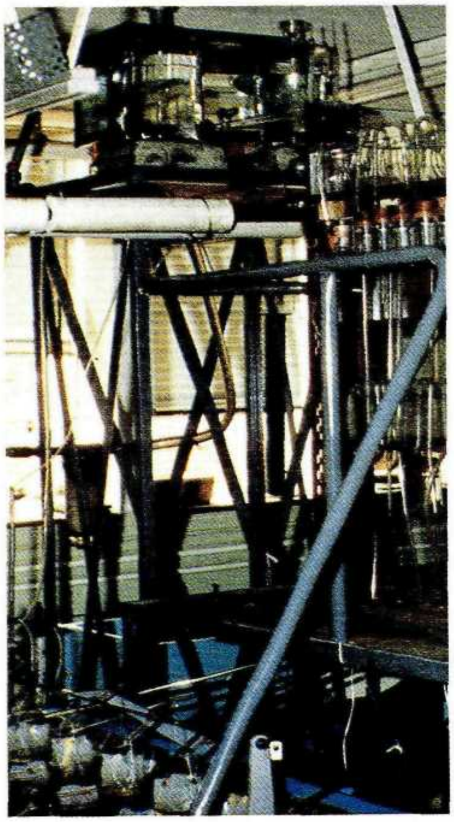
Benthic Macrofauna

Total numbers, number of taxa and diversity were all depressed in samples collected from October 1980 to May 1983, a period when dredge spoil was being dumped in the main study area. The two extremes of sediment type encountered in this study were organically rich mud and clean sand. During the period mentioned above, most samples collected near the pipe end were muddy, while on the most recent cruise for example (August 1985), only one muddy sample was encountered in seventeen stations occupied within a 2 km radius of the pipe end.

Apart from the influence of dredge spoil dumping, natural seasonal variations and inherent patchiness are considered to have played a significant role in characterising the results of the pre-discharge benthic faunal survey. The survey has nevertheless provided a background picture against which changes in the benthos, resulting from the operation of the marine outfalls, may be judged-

Beach Meiofauna

By far the most important influence on beach meiofauna has been dredge spoil dumping on the beaches. Meiofauna were monitored 6, 14 and 23 months after dumping commenced. The data show that nearly all meiofauna were temporarily lost at the point of dumping, but that meiofaunal density increased with increasing distance and time after dumping. The trend was independently indicated by all the major groups in the meiofauna, though they obviously differed in their susceptibility to dumping disturbance.



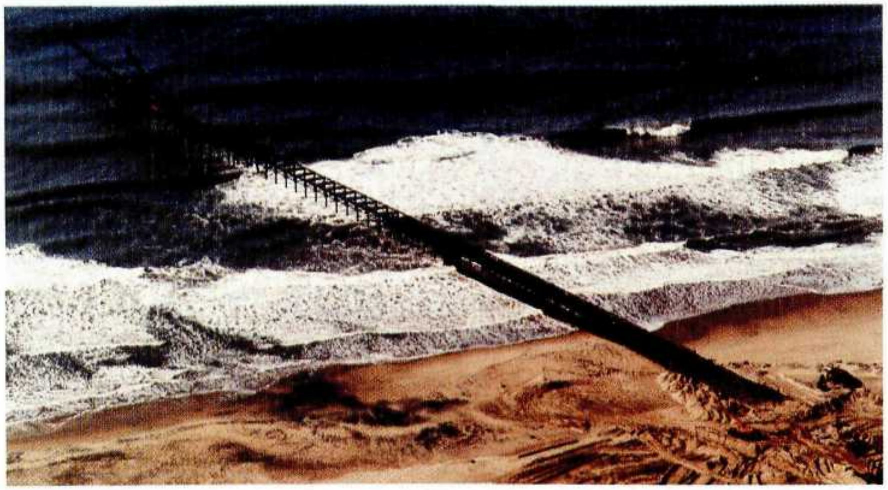
View of the Mhlatuze Water Board's Laboratory
(Photo: supplied by Mhlatuze Water Board)

Toxicity laboratories at NIWR
(Photo: A D Connell, NIWR)

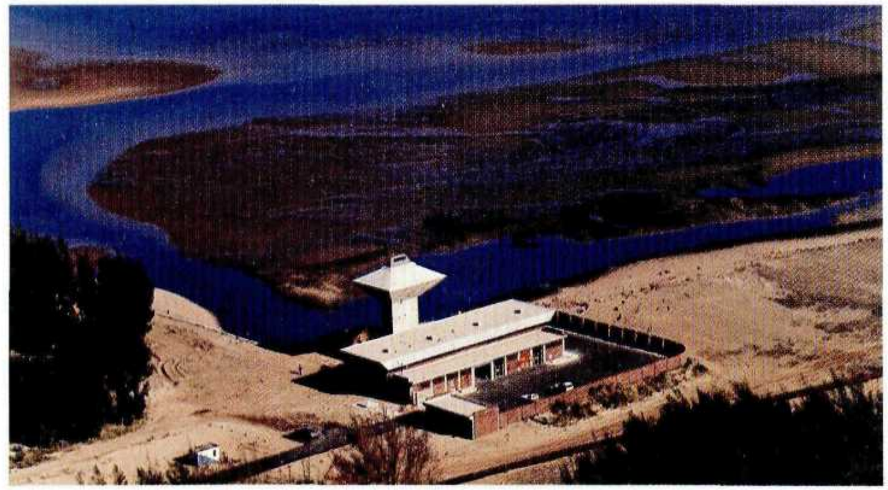
The Mondi Richards Bay effluent treatment plant, showing the twin clarifiers and the reserve holding dam
(Photo: supplied by Mondi Pulp Mills)

Temporary jetty for installation of pipeline
(Photo: D A Lord, UPE)

Temporary jetty through surfzone
(Photo: D A Lord, UPE)



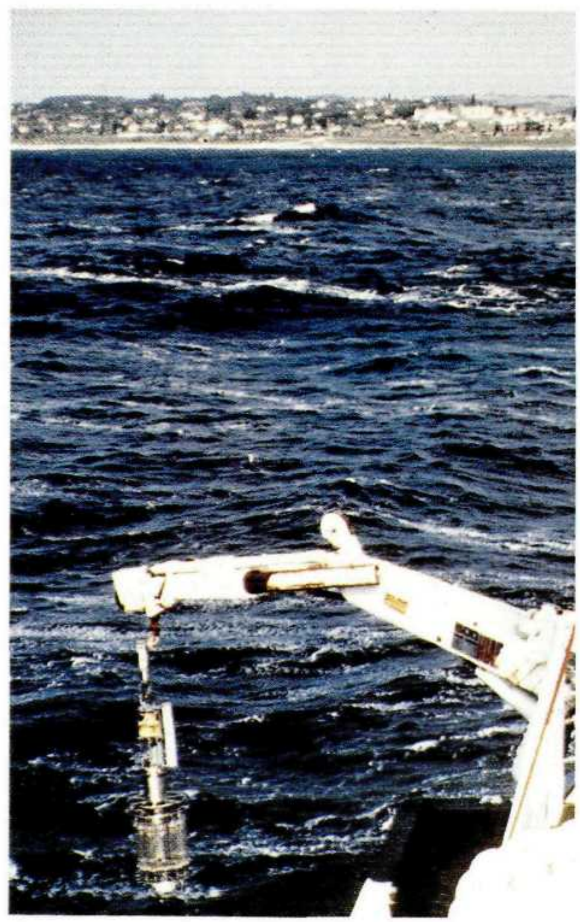
Temporary jetty through the surf zone during construction
(Photo: supplied by Mhlatuze Water Board)



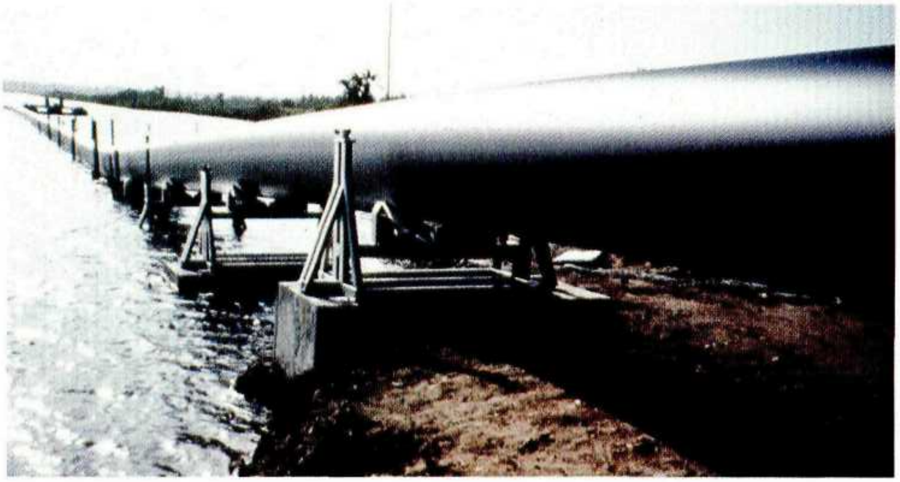
Aerial view of the main Pumpstation showing the seawater intake from Richards Bay Harbour for primary dilution of effluent
(Photo: supplied by Mhlatuze Water Board)

An aerial view of the Mondi Richards Bay pulp and linerboard plant
(Photo: supplied by Mondi Pulp Mills)

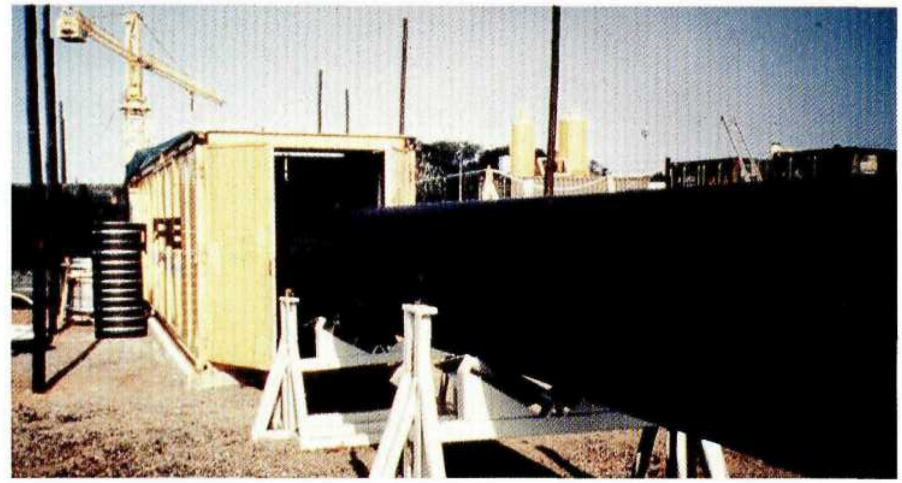
RV Meiring Naudé
(Photo: A D Connell, NIWR)



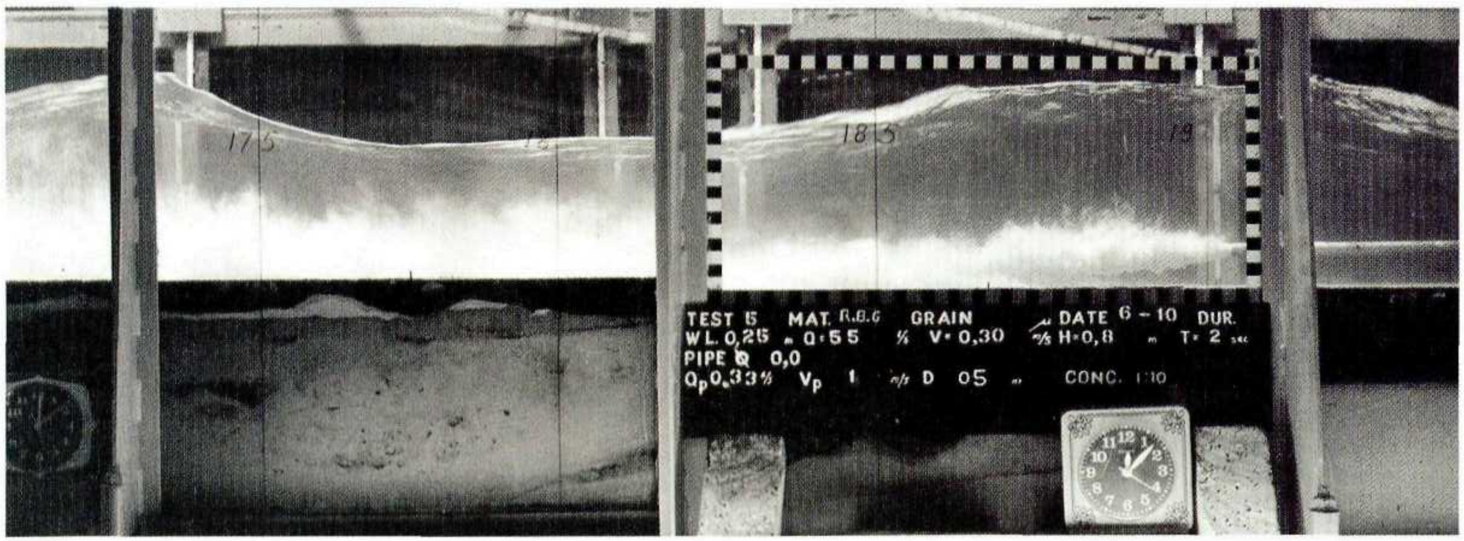
Research ship with sampler
(Photo: A D Connell, NIWR)



Direct extrusion of pipeline
(Photo: D A Lord, UPE)



Direct extrusion of pipeline
(Photo: D A Lord, UPE)



Testing of a gypsum effluent disposal in a tilting flume under combined current and wave action
(Photo: F van Dulm, NRIO)

Gypsum Smothering Studies

While every effort was made to test the smothering effects of gypsum on a shallow water marine community, both macrobenthos and meiofauna analysis of the results failed to reveal any clear trends of serious impact even when spread in a 10 mm thick layer over the experimental tanks. Thus it would appear that gypsum *pev se* is relatively innocuous at the levels tested.

Beam Trawling

This was initiated to provide biological samples for chemical analysis, but the catches have been analysed for species composition. Samples are reasonably quantitative, since they are usually made over a distance over the ground, of one nautical mile.

On several occasions the net and beam were damaged by large loads of rocks in the trawl. Examination of these rocks showed that they contained fossils, and were out of the cretaceous fossil beds which were penetrated during dredging operations in Richards Bay harbour. This is further evidence of the extent of dredge spoil dumping off Richards Bay. Nevertheless an interesting set of data was collected. By far the most commonly encountered species were Echinodermata, particularly the feather star *Tropiometva cavinata*, with the sand-dollar *Ctypeastev euvyehovtus* the second most common. At times penaeid prawns and various species of crabs were also found in fair numbers.

Neuston Netting

While the beam trawl is designed to slide along the bottom of the ocean, the neuston net is designed to plane along the surface, with the mouth of the net half in and half out of the water. Unfortunately as a result, the catch of this type of net is very dependent upon the weather. On quiet days when the sea surface is smooth, many juvenile fishes, fish eggs and pontellid copepods will be collected if they are abundant in the area, but when the sea is rough these animals will be several metres below the surface and the sample will be poor. Nevertheless, neuston netting can be carried out while beam trawling, and this net has thus been pulled through the water for one nautical mile while beam trawling. Since this net *s distance travelled is through the water, not over the ground, the ship's log is used to measure the nautical mile.

The most remarkable result of this type of netting has been the high number of anchovy eggs found in the area in the winter months, and the number of juvenile goatfish (Mullidae) found in the samples.

Toxic Metals

The normal range of toxic metals, including Hg, Cu, Cd, Cr, Pb, Zn, As and Se have been measured in water and sediment samples, and in fish from the Richards Bay area and the Tugela Banks. All that can be said at present is that the levels fell between expected limits for data from the Natal coast, and it remains to be seen whether these will change as a result of effluent discharge.

Chemical Quality

Samples of water and sediment from offshore and the beaches, were analysed for such parameters as OA, DOC, suspended solids, sulphate, dissolved oxygen, salinity and sulphides as appropriate. A number of anomalous results obtained especially at the northern beach stations, have been directly attributable to the dredging operations with the resultant fine silts present on the beaches at the time of sampling.

Chlorinated Hydrocarbons

Although sediments were collected and analysed, no chlorinated hydrocarbons were detected off Richards Bay.

Fluoride in Seawater and Fish Skeletal Tissue

Water samples showed a fluoride level ranging from 1,2 to 1,7 mg 1 apart from two outlying values of 2,2 mg I"*- These data compare well with values consistently recorded for Natal coast seawater, and with data from elsewhere in the world.

Fluoride levels in fish tissue from the Northumbrian coast were of similar magnitude to levels detected in fish from the beam trawls off Richards Bay and the Tugela Banks. In all, some 55 fish have been analysed, providing a reasonable baseline of data for comparison with samples to be collected after discharge has become well established.

Effluent Toxicity

Three different levels of testing of effluents were conducted. Initially the toxicity of mixtures of paper mill effluent, Triomf effluent and sewage was tested for studies relating to the proposal to place a single open-ended pipeline off Richards Bay. These showed that by far the most toxic effluent was from Trioraf, which required a dilution in excess of 1:500. The paper mill effluent was only toxic at about 1:50 dilutions to eggs and larvae of the amphipod *Grandidi-erella.*

Secondly, a similar mixture of the effluents was tested in multi-generation studies on the reproductive capacity of *Gvan&vd-leveVla** These showed the effluent mix to be similarly toxic, with reduced reproductive capacity in 60 day studies, at around 800 dilutions.

Finally, some effluent from a "sister" mill was imported, and tested in short-term tests with the eggs of the marine fish *Dascyllus.* Two tests were conducted, with slightly different results, but it was concluded that the effluent tested was toxic *at* only 1:100 or less dilutions. Since the "A" line is designed to achieve a dilution of 250 at the boil, and some 50% of the water in that line is seawater, this suggests that there is little likelihood of problems arising from the discharge of the paper mill effluent, provided it achieves the quality of the imported effluent which was tested.

The data from the Triomf toxicity test suggested the need for a dilution of 1 000 times- This should be achieved, since the slurry of 2 800 m^3 day^{-1} is diluted to 86 400 m^3 day^{-1} with mill effluent and seawater providing an initial dilution in the pipe of some 30 times. The diffuser characteristics are then predicted to achieve 170 dilutions under the worst conditions of no current, thus providing a total initial dilution in excess of 5 000 times.

Histopathology of Fish Livers

A library of sections of the livers of two flat fishes (soles) commonly encountered in the beam trawls, has been collected, and will be used to assess the health of these same species of fish after discharge begins.

Harbour and Sanctuary Survey

Apart from the routine bacteriological sampling in the harbour, a survey of metals and chemistry of the harbour and sanctuary relating to the detection of possible penetration of effluent into these areas, was requested, and has been completed. In addition, results from a previous survey in 1976 add to the store of pre-discharge data. Generally levels showed no increase over the 1976 survey and mercury was found to have dropped from some above background levels detected in 1976. Fluoride levels in water were measured for the first time, and levels in the area of the Bhizolo canal and coal terminal area showed the influence of Alusaf in this area. Mussels collected from navigation buoys in the harbour showed no unusual levels of trace metals.

Colonisation of Offshore Moorings

The colonisation by plants and animals of offshore rafts is shown to follow discernible trends over a four month period. This time period is also well within the life expectancy of rafts and moorings used in the study. The emphasis of this project is on the comparison between biota settling on test and control rafts - such that seasonal variability is excluded and the need for historic data is obviated.

In addition to this, invaluable data is being collected on the settlement seasonality and biology of important marine organisms such as mussels, prawns and juvenile fish.

Strategic positioning of rafts should serve to identify the area of impact and offer verification of predicted performance of the pipeline as regards dilution characteristics.

THE RICHARDS BAY PIPELINE

Environmental Considerations and Criteria

In order to limit the environmental impact of the effluent as far as possible, much attention was given to the formulation of environmentally acceptable criteria for concentrations of the various effluent constituents in the marine environment. These discharge criteria were to a large extent based on the fairly conservative values used by the USA Environmental Protection Agency (EPA), and were supplemented with locally-available and tested criteria, where applicable.

The environmental discharge criteria also determined and guided the design of the pipeline, and the later permit conditions and legal standards for individual effluents into the pipeline were also based on these criteria, combined with the dilution rates which were calculated for the pipeline.

From an environmental point of view, it was considered that the phosphogypsum slurry and the fluoride contained within it presented the greatest immediate threat. Before pipeline design commenced it was necessary to establish methods of limiting the amount of phosphogypsum and of fluoride which reach the sea.

Phosphogypsum disposal : Phosphogypsum (CaSO^. 2H2O) is moderately soluble in seawater, about 0,15 % by weight. For dissolution of phosphogypsum in seawater a maximum time in suspension in the water column is desirable. Should any undissolved material settle on the seafloor, reliance is then placed on ambient mixing to facilitate further dissolution. The study of the behaviour of phosphogypsum upon discharge, particularly its characteristics of solubility, its mechanism of transport under a variety of different current and wave conditions, as well as estimating the area that could be blanketed by gypsum was suitably completed in scaled physical models. These studies showed that the proportion of solid gypsum which reaches the sea bed is directly related to the time spent by each particle in the water column.

In fact, a 90% solubility of phosphogypsum can be obtained provided that initial concentrations of phosphogypsum in the slurry do not exceed a critical value which was measured to be 3,5 g/1. In these studies it was also shown that steady velocities exceeding 0,3 m/sec will sweep the bed clean of any gypsum. However, this is far greater than the median velocities experienced in the area, and so it would be anticipated that undissolved gypsum in the area could ultimately form a semi-compacted layer of 5-10 cm thickness above the bed. Initial estimates indicated that the blanketted area would grow with time to some equilibrium size not exceeding 4 km^ in size, and with the greatest deposition at the centre.

The effects of fluoride on locally occurring organisms:

We are all seeing more frequently, that large scale effects of marine pollution are no longer being demonstrated in a manner which was predicted, and in some cases observed during past decades. Indeed, in some fields, for example oil pollution, there is a growing body of considered opinion that the fears that oil pollution would sterilize the world's seas have been shown to be quite unfounded.

Is pollution on the run? Certainly not. But what has changed is its intensity. The serious polluters have in most places been weeded out. However, discharges are still occurring and a change is taking place from observing the more readily measurable gross effects, to looking for and learning how to measure, subtle long term effects. A constant dilemma in this regard is "how hard should we keep looking for subtle effects before we are satisfied that we are providing sufficient caution to our disposal practices?"

Effects can be monitored by observing reactions occurring in individual cells, or changes in behaviour of whole animals or plants or by observing the changes in composition of a group of plants and animals. Clearly, any change in a system is only significant if it influences the total population of a species, and its ability to survive.

Making such measurements in the field are notoriously fraught with difficulties. Consequently observing the reproductive success of selected organisms in the laboratory is still one of the most sensitive methods of assessing sub-lethal effects realistically. This technique is being strongly developed in South Africa, and was used to assess sub-lethal toxicity of the fluoride in the buoyant component of the effluent. Incidentally, little is known about the toxicity of fluoride to estuarine and marine fauna. For example, the international literature suggests a level of 1,5 mg of fluoride per litre constitutes a hazard to the marine environment, yet South African coastal waters contain between 1,3 to 1,7 mg of fluoride per litre anyway!

The widely occurring burrowing amphipods ***Grandid-ievella tutosa*** Barnard, and ***G* lignovum*** Barnard were then chosen to study the effects of fluoride on the marine environment. In these two species, the females are indistinguishable, although the mature males can be separated by sight. For both species, the full life cycle from egg to adult is only about 30 days, with females carrying eggs in brood pouches. The pouches are green when the eggs are fresh, and turn brown as egg development proceeds• Development of young continues in the female pouch such that the young, when they emerge from the pouch, have habits similar to the adult. Consequently, it is convenient to observe these animals through a full life cycle and to measure their reproductive success. Furthermore, the potential is there to follow these animals through a number of life cycles.

The experimental procedure developed during this testing is quite simple, and described here for interest. In each experimental chamber (which consisted of a 12 L perspex tank) 20 egg bearing females plus 10 mature males were placed. Toxicant (i.e. fluoride) was supplied via a standard proportional diluter, with concentrations routinely measured in the experimental tanks. Experiments were run for 90 days, at the end of which animals were collected from each tank and counted. Results were prepared and presented in terms of both population response and reproductive success. Recommendations concerning the maximum allowable toxic concentration (MATC) were set according to the definition of Mount and Stephan namely "the hypothetical toxic threshold concentration between the highest concentration tested having no observed effects, and the next higher toxicant having significant toxic effects". For population response assuming controls as 'normal', the MATC occurs at fluoride levels of between 4,6 and 5,6 mg of fluoride per litre. For fecundity this occurs at approximately the same levels. Consequently, the conclusion reached was that the upper limit of fluoride concentration in the immediate vicinity of the discharge should be 5 mg of fluoride per litre. In terms of the actual marine discharge of concern, this has been translated by the Department of Environment Affairs to mean 5 mg of fluoride "at the boil" and in this particular instance, the discharger is being allowed to use the initial dilution gained upon discharge of a buoyant effluent, to dilute the effluent to meet this criterion.

It should be noted that in this project a number of different organisms were used for the testing of the sub-lethal effects of fluoride. Of these, this amphipod was significantly more sensitive than any other; an important factor.

Engineering Design

The design criteria for the pipeline were

- minimise the amount of undissolved gypsum reaching the sea floor

  maintain total fluoride levels in the sea to less than 5 mg/1.

In its initial form, the principle of the design of the Richards Bay pipeline consisted of combining all the effluents and discharging these through a single pipeline. This design concept included a very important compromise limiting the optimum performance of the pipeline. The compromise results from the fact that to discharge the buoyant part of the effluent containing the fluoride in the most effective way, it is advantageous to discharge as deep as possible to make use of the increased depth of water for dilution. However, it is most effective to discharge the slightly soluble and dense component of the effluent which contains the gypsum at high velocity at a relatively shallower water depth where wave agitation can assist in minimising the amount of gypsum deposited.

Where a single effluent contains separate components possessing these characteristics discharge is normally undertaken at an intermediate depth where some wave action is still present on the sea bed, but which is sufficiently deep to provide adequate dilution.

After a thorough review, it was decided to separate the wastes at or close to their source into a dense mixture and a buoyant mixture. Each of these could then be discharged through a separate outfall and diffuser system designed to give optimum performance.

As designed and constructed the first of these lines, the buoyant line, contains the effluent from the Mondi mill combined with that portion of the Triomf effluent which contains 92 tonnes of fluoride per day. The strictest design criteria imposed a level of 5 mg/1 (5ppm) fluoride 'at the boil' on the water surface. This in fact allows an addition of only 3,5 mg/1 of fluoride per unit volume of sea water as the sea water contains 1,5 mg/1 fluoride anyway.

To achieve the desired levels of initial dilution, the buoyant line was designed with a diffuser section with 106 ports, placed in water of 29 *m* depth 5 km offshore, and will accept a capacity of 160 000 m^3/day of fluid. Theoretical worst case dilution "at the boil" of the diffuser section is 250 times.

The second line containing the dense effluent can receive up to 86 000 m-Vday an(j was designed to provide the facility for jetting the slurry of phosphogypsum into the water column to provide maximum opportunity for the material to dissolve- Theoretical worst case dilution for this line is 170 times. The design recommended propelling the slurry containing undissolved gypsum out of 16 inclined ports at very high velocity (in fact at 15 m/sec). The end of this pipeline is located 4 km offshore at a depth of 25 m and the trajectory of the discharged material reaches a height of 15 m above the sea floor before the material starts to settle down through the water again. It has been calculated that this will provide each particle with an excess of 25 minutes in the water column where slow dissolution can occur, and it can be expected that 95 % of the gypsum will be dissolved in this manner.

THE RICHARDS BAY PIPELINE : DESCRIPTION OF THE SCHEME

In its final form the Richards Bay effluent disposal scheme consists of two pipes, as described above. The single most interesting feature of these effluent pipes is that they are not constructed from lined steel or concrete - normal materials for such projects - but from "plastic", this being high density polyethylene (HDPE). The sealines consist of pipes of 1 000 mm and 900 mm internal diameter HDPE pipes, which were manufactured on site by direct extrusion in lengths varying from 400 m to 600 m.

In passage through the surf zone the pipes were weighted and buried beneath the sea bed while beyond the surf zone the pipe is laid on the sea floor using concrete collars as weights to provide stability. The preparation of the sea bed in the surf area was a major activity and was undertaken with the construction of a 400 m long jetty which was dismantled after the laying was completed in June 1984.

MONITORING OF THE RICHARDS BAY PIPELINE

An important aspect of any marine disposal scheme is the monitoring which occurs while the pipeline is operating. As a result of the relative magnitude of this pipeline facility considerable attention was given to the post-operational monitoring programme, as follows:

<u>Regulatory monitoring</u>

The pipeline was constructed and is owned by the Mhlatuze Water Board but the Department of Water Affairs will, as is normal with any other discharge, lay down acceptance standards for each effluent discharged into the pipeline and will also exercise control over these discharges through permits issued in terms of Section 21 of the Water Act, 1956 (as amended). The acceptance standards for each effluent are determined in line with the criteria which have to be obtained at the "boil".

It will also be the Department's responsibility to monitor the quality of the effluents discharged on the premises of each discharger, through regular chemical assays of the effluents.

On-line toxicity testing

Effluent will also be directly tested by the use of numbers of fish contained in aquaria. A sample of the effluent will be passed through these aquaria in a continuous manner and effects of changes in effluent composition on the behaviour of fish in the tanks, and on their rates of gill movement will be electronically monitored. This facility, which will be managed by the National Institute for Water Research of the CSIR, will thus also provide an early-warning system to detect changes in the quality of the effluent.

Monitoring of the marine environment

An intensive monitoring programme will be undertaken to assess the environmental impact of the effluent on the receiving waters as related to the results of the pre-discharge monitoring surveys, and also to compare this with the predicted effects. Concentrations of selected chemicals in the water column as well as in the sediment and in animals found in the area, such as fish and mussels, will be regularly measured to detect any changes which may occur. In addition, the diversity and abundance of resident animals and plants will be compared to pre -operational levels. The sea floor in the vicinity of the dense effluent discharge will also be closely studied to quantify any smothering of the sea bed with gypsum.

The monitoring programme will consist of three cruises per year, and stations have been clumped nearer to the end of the pipeline. Also, the number of stations occupied has been increased to 17, all within a 2 km radius of the diffuser systems. Fifteen stations will be randomly selected from a grid of 124 stations, while two are fixed stations, positioned 150 m to the north of the centre of each diffuser. It is felt that this will aid in the rapid detection of deleterious effects if these develop as a result of effluent discharge.

This monitoring programme will be a joint undertaking between the National Institute for Water Research of the CSIR, the Oceanographic Research Institute and the National "Research Institute for Oceanology of the CSIR. Both the pre-operational ecological surveys as well as the post-operational monitoring is undertaken within the framework and guidance of the Marine Pollution Research Programme of SANCOR. Funding is provided by the Department of Environment Affairs.

CONCLUSION

In spite of the relatively short time allowed, every attenpt has been made to develop this pipeline facility, which is large by any standard, in the best possible way. Throughout the project the best available scientific information has been utilized and the design, planning, construction and operation of this facility have been dictated by environmental requirements or criteria.

In this way it is confidently expected that the assimilative capacity of the marine environment in that area will be utilized positively. This will be verified and checked by a comprehensive monitoring programme.

22 INSTITDTIONS INVOLVED IN

MARINE POLLUTION RESEARCH IN SOUTH AFRICA

COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH (CSIR) National

Research Institute for Oceanology (NRIO) National Institute

for Water Research (NIWR) National Research Institute for

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LOCAL AUTHORITIES OF ALL COASTAL CITIES

APPENDIX I

RICHARDS BAY EFFLUENT PIPELINE RESEARCH COORDINATING COMMITTEE

T P C van Robbroeck (Chairman)	Mhlatuze Water Board/Department of Water Affairs
A P Bowmaker G C	Oceanographic Research Institute
D Claassens	Department of Environment Affairs, Directorate of Water Affairs
N D Geldenhuys J	Department of Environment Affairs, Environmental Conservation Branch
Hemens D A Lord A	CSIR, National Research Institute for Water Affairs
Moldan K S	Department of Oceanography, University of Port Elizabeth
Russell	Department of Environment Affairs, Sea Fisheries Research Institute
	CSIR, National Research Institute for Oceanology

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