



Earth, Marine
and Atmospheric
Science and
Technology

Aard-, Mariene
en Atmosferiese
Wetenskap en
Tegnologie

CSIR

WNNR

SEDIMENTATION IN THE KROMME ESTUARY:

DATA REPORT

Presented by

The Kromme River Steering Committee

MARCH 1992

Issued by:
Division of Earth, Marine and Atmospheric Science
and Technology
CSIR
P O Box 320
STELLENBOSCH
7600

SEDIMENTATION IN THE KROMME ESTUARY: DATA REPORT

Contributors:

Mr G G Smith, EMATEK-CSIR
Mr P Huizinga, EMATEK-CSIR
Mr J S V Reddering, Geological Survey
Prof D Baird, UPE, Dept of Zoology
Mr R Pereyra, UPE, Dept of Zoology
Mr G Prestedge, Kapp Prestedge Retief
Dr G Mocke, EMATEK-CSIR
Mr J S Schoonees, EMATEK-CSIR

Presented by:

The Kromme River Steering Committee

Consisting of Representatives of the following sponsors:

The Department of Water Affairs and Forestry
The Algoa Regional Services Council
The Department of Nature Conservation
Santareme Bay (Pty) Ltd.
Leighton Hullet (Pty) Ltd.
The St Francis/Kromme Trust

Keywords:

Kromme
Estuary
Sedimentation Study

March 1992

KROMME RIVER STEERING COMMITTEE:

Mr J J Erasmus	Department of Water Affairs and Forestry
Mr L J Erasmus	Department of Water Affairs and Forestry
Mr C A Bruwer	Department of Water Affairs and Forestry
Mr L Pretorius	Department of Water Affairs and Forestry
Mr W L Basson	Algoa Regional Service Council
Mr O Putzier	St Francis Bay Local Council
Mr D E Malan	CPA Nature Conservation
Mr E S Rivett-Carnac	Santareme Bay Ltd
Mr N L Hulett	Leighton Hulett (Pty) Ltd
Mr M Jonker	The St Francis/Kromme Trust
Mrs L Pagden	The St Francis/Kromme Trust
Mr B McWilliams	St Francis Bay Ratepayers Association
Mr P Huizinga	Ematek, CSIR
Prof D Baird	University of Port Elizabeth
Mr J D D Kettlewell	St Francis Bay Local Council
Mr J M Bridgman	Santareme Bay Ltd (replaced by Mr Rivett-Carnac)
Mr N I Taylor	St Francis Bay Local Council (replaced by Mr Putzier)
Mr J S V Reddering	Geological Survey

For the Kromme River Steering Committee I have the honour of presenting the report
on the sedimentation in the Kromme River Estuary.



J J ERASMUS (CHAIRMAN)

CSIR REPORT EMA-D9108

ERRATA

p 5.3, Section 5.4.2

line 2	7,5 mg/M	into 7,5 mg/l
line 8	5,5 mg/M	into 5,5 mg/l

p 5.4, Section 5.4.3

line 9	1,0 mg/M	into 1,0 mg/l
line 11	1,4 mg/M	into 1,4 mg/l

p 5.5, Section 5.5

line 14	2½ C	into 2°C
line 16	2,5½ C	into 2,5°C
line 25	7,5 mg/M	into 7,5 mg/l
line 26	5,5 mg/M	into 5,5 mg/l

p 5.10, Section: Temperature

line 1	24,2½ C	into 24,2°C
line 1	14,0½ C	into 14,0°C
line 2	17,6½ C	into 17,6°C
line 3	18,6½ C	into 18,6°C
line 3	19,1½ C	into 19,1°C

p 5.11, Section: Ammonium-N

line 2	40gM ⁻¹	into 40 gl ⁻¹
--------	--------------------	--------------------------

CONTENTS

	<u>Page</u>
LIST OF TABLES	v
LIST OF FIGURES	viii
LIST OF PHOTOGRAPHS	xii
INTRODUCTION	xiii
1. BACKGROUND INFORMATION	1.1
1.1 The Kromme Estuary	1.1
1.2 The Roadbridge	1.1
1.3 The Marina	1.2
1.4 Rainfall and Runoff	1.2
1.5 Dams	1.2
1.6 Sediment Sources	1.3
1.6.1 Coastal sediment	1.3
1.6.2 The Sand River	1.4
1.6.3 Fluvial sediment	1.5
REFERENCES	1.5
2. COASTAL SEDIMENT DYNAMICS AND REMEDIAL STRUCTURES	
AT THE ESTUARY MOUTH	2.1
2.1 Introduction	2.1
2.2 Coastal Dynamics	2.1
2.2.1 Indications of beach erosion near the estuary mouth	2.1
2.2.2 Aspects influencing coastal erosion and sedimentation at St Francis Bay	2.2

<u>CONTENTS</u> (continued)	<u>Page</u>
2.2.2.1 General	2.2
2.2.2.2 Wave refraction and longshore sediment transport at St Francis Bay	2.3
2.2.2.3 Erosion and sedimentation caused by on-offshore transport	2.6
2.2.2.4 Availability of sediment	2.6
2.3 Monitoring and Remedial Measures	2.9
2.3.1 General	2.9
2.3.2 Training the mouth - breakwaters	2.10
2.3.3 Fluidization	2.11
REFERENCES	2.11
3. ANALYSIS OF AERIAL PHOTOGRAPHS, CROSS-SECTIONS AND WATER-LEVEL RECORDINGS	3.1
3.1 Sedimentation in the Estuary	3.1
3.1.1 Information from aerial photographs	3.1
3.1.2 Information from cross-sections	3.1
3.1.2.1 Data processing	3.2
3.1.2.2 Results and discussion	3.2
3.1.3 Information from water-level recordings	3.4
3.1.4 Conclusion	3.4
3.2 The Sand River	3.4

<u>CONTENTS</u> (continued)	<u>Page</u>
3.2.1 Observations from maps and aerial photographs	3.5
3.3 Tidal Channel Configuration	3.6
3.3.1 Introduction	3.6
3.3.2 Detailed observations	3.7
3.3.3 Conclusions	3.9
3.4 Beach and Dune Dynamics	3.9
3.4.1 The dunefield	3.9
3.4.1.1 Observations	3.9
3.4.2 The St. Francis Bay beach	3.9
3.4.2.1 Method	3.10
3.4.2.2 Results and discussion	3.10
3.5 The Flood-tidal Delta	3.10
REFERENCES	3.11
4. FLOOD SCOUR STUDY	4.1
4.1 Introduction	4.1
4.2 The Flood Hydrograph Study	4.1
4.2.1 General catchment information	4.1
4.2.2 Empirical distribution of dam storage capacities	4.1
4.2.2.1 Churchill Dam	4.1
4.2.2.2 C W Malan Dam	4.2
4.2.3 Flood calculations	4.2
4.2.3.1 Design floods	4.3
4.2.3.2 Flood peaks and volumes	4.3

<u>CONTENTS</u> (Continued)	<u>Page</u>
4.2.3.3 Flood hydrographs	4.5
4.2.4 Summary and Conclusions	4.6
4.3 Hydrodynamic Model Simulations	4.7
4.3.1 Estuary flows	4.7
4.3.2 The effect of the roadbridge on flood flows	4.8
4.4 Simulated Sediment Transport	4.8
4.4.1 Introduction	4.8
4.4.2 Simulations	4.9
4.5 Conclusion	4.11
REFERENCES	4.12
5. NUTRIENT STATUS AND WATER QUALITY ASSESSMENT OF THE MARINE GLADES CANAL SYSTEM, KROMME ESTUARY, ST. FRANCIS BAY	5.1
5.1 Introduction	5.1
5.2 Previous Studies	5.1
5.3 Material and Methods	5.2
5.4 Results	5.2
5.4.1 Physico-chemical parameters in the water column	5.3
5.4.2 Dissolved oxygen	5.3
5.4.3 Inorganic nutrients	5.3
5.4.4 Coliform bacteria	5.4
5.5 Discussion	5.5

<u>CONTENTS</u> (Continued)	<u>Page</u>
5.6 Notes on the General Ecology of the Marina Glades Canals, St. Francis Bay	5.8
5.7 Notes on the General Ecology of the Kromme Estuary and a Comparison of Some Abiotic and Biotic Features Between the Marina and the Estuary	5.9
5.7.1 Abiotic features, phytoplankton and bacteria	5.9
5.7.2 Macrophytes, zooplankton, benthic invertebrates and fish	5.12
5.8 Freshwater Requirements of the Kromme Estuary	5.14
5.9 Concluding Remarks	5.16
5.9.1 Water quality of the marina	5.16
5.9.2 Ecology of the marina	5.17
5.9.3 Ecology of the Kromme Estuary	5.17
REFERENCES	5.17
6. EVALUATION OF WATER CIRCULATION IN THE KROMME MARINA, WITH REGARD TO THE PLANNED NEW EXTENSIONS	6.1
6.1 General	6.1
6.2 Application of the Solution in the Kromme Marina	6.1
6.3 Model Simulation Results	6.2
6.4 Conclusions	6.5
7. PUBLIC OPINION	7.1

LIST OF TABLES

TABLE 1.1 The C W Malan Dam

- 2.1 Summary of wave conditions on the study coastline
- 2.2 Summary of potential longshore transport computations
- 2.3 Distribution of longshore transport with distance offshore at KK1
- 2.4 Aeolian wind transport rates at Cape St Francis
- 3.1 Offsets of beach widths along St Francis Bay
- 4.1 General catchment and dam information
- 4.2 Churchill Dam: Inflow
- 4.3 Churchill Dam: Monthly reservoir capacities
- 4.4 C W Malan Dam: Inflow
- 4.5 Churchill Dam: Flood calculation (Dam inflow)
- 4.6 C W Malan Dam: Flood calculation (Excluding Churchill Dam)
- 4.7 C W Malan Dam: Flood calculation (Ignoring Churchill Dam)
- 4.8 Geelhoutboom River: Flood calculation
- 4.9 Kromme River: Flood calculation (Ignoring dams)
- 4.10 Churchill Dam: Outflow hydrographs
- 4.11 C W Malan Dam: Inflow hydrographs
- 4.12 C W Dam: Outflow hydrograph matrix
- 4.13 Kromme River: Outflow hydrograph matrix
- 4.14 Kromme River: Outflow hydrographs (Both reservoirs 80% full)

LIST OF TABLES (continued)

- 4.15 Kromme River: Outflow hydrographs (Both dams ignored)
- 4.16 Kromme River: Outflow hydrographs (Both reservoirs 50% full)
- 4.17 Sediment transport rates in the Kromme Estuary
- 5.1 Marina Glades canal system. Inorganic nutrient concentration and other biotic parameters measured in the water column
- 5.2 Marina Glades canal system. Statistics of inorganic nutrient concentration and other abiotic parameters measured in each sampling session
- 5.3 Marina Glades canal system. Concentration of coliform bacteria in the canals water during the 1989/90 holiday season
- 5.4 Comparison of mean values of inorganic nutrient concentrations and abiotic parameters in the study site and other E Cape estuaries
- 6.1 Summary of test results
- 6.2 Model results of maximum velocities in the marina

LIST OF FIGURES

- FIGURE 1.1 Location of the Kromme River
 - 1.2 Map of the Kromme Estuary and surroundings
 - 1.3 The Kromme Estuary
- 2.1 Wave energy and direction on the St Francis coastline (contributed by Kapp Prestedge Retief)
- 2.2 Bathymetry of Santareme Bay and surroundings (contributed by Kapp Prestedge Retief)
- 2.3 St Francis Bay wind conditions

LIST OF FIGURES (continued)

- 2.4 Aeolian creep diagrams Cape St Francis
- 2.5 Kromme Estuary breakwater design
- 3.1 Surveyed cross-sections
- 3.2 Kromme Estuary cross-sectional areas - 1982 and 1988
- 3.3 Kromme Estuary hydraulic radii- 1982 and 1988
- 3.4 Sedimentation of the Lagoon between 1921 and 1942
- 3.5 Tidal channels at the Kromme mouth (from the 1942 aerial photograph)
- 3.6 Tidal channels at the Kromme mouth (from the 1975 aerial photograph)
- 3.7 Tidal channels at the Kromme mouth (from the 1978 aerial photograph)
- 3.8 Tidal channels at the Kromme mouth (from the 1981 aerial photograph)
- 3.9 Tidal channels at the Kromme mouth (from the 1985 aerial photograph)
- 3.10 Tidal channels at the Kromme mouth (from the 1987 aerial photograph)
- 3.11 The increase of the Santareme Dunefield vegetation
- 3.12 High water levels along St Francis Bay beach (1942-1987)
- 4.1 Kromme River catchment
- 4.2 Kromme River longitudinal section
- 4.3 Churchill Dam monthly reservoir capacities
- 4.4 Churchill Dam cumulative frequency distribution of monthly reservoir capacities

LIST OF FIGURES (continued)

- 4.5 C W Malan Dam monthly reservoir capacities
- 4.6 Cumulative frequency distribution
of monthly reservoir capacities
- 4.7 Kromme River system diagram
- 4.8 Kromme River outflow hydrographs (Both dams ignored)
- 4.9 Kromme River outflow hydrographs (Both reservoirs
80 % full)
- 4.10 Kromme River outflow hydrographs (Both reservoirs
50 % full)
- 5.1 Map of the Marina Glades Canal System showing the
situation of the sampling stations in this study
- 5.2 Salinity profile in the Marina Glades Canal System
during the sampling period (November 1989 to March
1990).
- 5.3 Temperature profile in the Marina Glades Canal
System during the sampling period (November 1989 to
March 1990).
- 5.4 Dissolved Oxygen concentration in the Marina Glades
Canal System during the sampling period (November
1989 to March 1990).
- 5.5 Concentration of Soluble Reactive Phosphorous in the
Marina Glades Canal System during the sampling
period (November 1989 to March 1990).
- 5.6 Concentration of Nitrates (NO_3^- -N) in the Marina
Glades Canal System during the sampling period
(November 1989 to March 1990).
- 5.7 Concentration of Nitrites (NO_2^- -N) in the Marina
Glades Canal System during the sampling period
(November 1989 to March 1990).

LIST OF FIGURES (continued)

- 5.8 Concentration of Ammonia ($\text{NH}_3^- - \text{NH}_4^+$) in the Marina Glades Canal System during the sampling period (November 1989 to March 1990).
- 5.9 Mean concentration (all sampling stations averaged) of inorganic nutrients in the water of the Marina Glades Canal System during seven sampling sessions from November 1989 to March 1990. See details in the text.
- 5.10 Number of faecal coliforms per 100 ml of water recorded in the Marina Glades Canal System (Stns. 2-7B) and the Kromme Estuary (Stn. 1) on four occasions from November 1989 to March 1990. See details in the text.
- 6.1 The Kromme Marina with extension
- 6.2 The canal cross-section used for the marina extension
- 6.3 Starting conditions for model simulations
- 6.4 Test 1: Present marina; seaward entrance blocked after 5.25 days
- 6.5 Test 2: Marina and extension, seaward entrance blocked; sluice gate in operation; after 5.25 days
- 6.6 Test 3: Marina and extension; seaward access blocked; sluice gate in operation; canals cut off at A and B; after 5.25 days
- 6.7 Test 4: Marina and extension; no sluice gate; seaward entrance blocked after 5.25 days
- 6.8 Test 5: Present marina; seaward access open after 5.25 days

LIST OF FIGURES (continued)

- 6.9 Test 6: Marina and extension; sluice gate in operation; seaward access open after 5.25 days
- 6.10 Test 7: Marina and extension; seaward access open and sluice gate not in operation after 5.25 days

LIST OF PHOTOGRAPHS

- PLATE 1 The 1942 aerial photograph
- 2 The 1961 aerial photograph
- 3 The 1969 aerial photograph
- 4 The 1975 aerial photograph
- 5 The 1981 aerial photograph
- 6 The 1987 aerial photograph

INTRODUCTION

This data report contains detailed analyses and information for the Kromme sedimentation study. Important aspects, conclusions and recommendations, obtained from this report, are contained in the main report, (CSIR Report, EMA-C 91146).

The Kromme River is situated on the Cape south-east coast (Figures 1.1 and 1.2 at the end of Chapter 1). The Kromme Estuary is defined as the coastal section of the river which experiences variation in water-level due to tides, i.e. the lowest 13,7 km of the river in this case. A network of marina canals, called Marina Glades, is connected to the southern side of the estuary, near the mouth (Figure 1.3 at the end of Chapter 1). In recent years, concern has been expressed at the sedimentation in the estuary. There are three areas of concern:

- (i) The lower estuary: Lower estuary refers to the region of sand bars extending from the seaward access canal of Marina Glades to a point 4,5 km upstream, above the Humansdorp/St Francis Bay roadbridge (Figure 1.3). Boat-owners have complained of shoals, and the public perceives that sedimentation has occurred in this region.
- (ii) The estuary mouth: Shoals cause navigation problems in the mouth at times, especially in the surf zone (Figure 1.3). The public perceives that this region is shoaling.
- (iii) The seaward access canal to the marina: This access canal to the marina is situated close to the estuary mouth (Figure 1.3). In recent years, sand has accumulated in the canal, causing it to block up. Although it is periodically re-opened by dredging, at considerable expense, it is soon constricted by sand again. The blockage of the canal limits access of boats to the marina and reduces the tidal water circulation in the marina, which raises concerns about water quality.

There are two major dams on the Kromme River, the Churchill Dam, completed in 1943, and the C W Malan Dam, completed in 1982. The dams reduce the action of floods and it is alleged that this

significantly reduces scouring of sediment from the estuary, thereby indirectly causing sedimentation. The study investigates this and other possible causes of sedimentation in the estuary. Possible solutions are also investigated.

In this study, available publications were examined, and relevant background information was extracted (Chapter 1). The coastal sediment dynamics were also investigated (Chapter 2), since they have a bearing on sedimentation problems in the mouth region. In addition, aerial photographs, cross-sections and water-level recordings were analysed (Chapter 3).

Concern has been expressed about the effect of the dams on sedimentation in the estuary. This was therefore investigated in a study, involving a hydrological investigation, hydrodynamic modelling and sediment transport calculations (Chapter 4).

Concern exists also about the present water quality, since the circulation in the marina canals is reduced by the closure of the marina access canal. Thus, the water quality in the marina, and in the estuary, is assessed (Chapter 5).

An extension to the marina has been planned. An evaluation of the water circulation in the proposed layout was investigated, using the CSIR hydrodynamic transport-dispersion computer model (Chapter 6).

Public opinion is included; a public meeting was held and a questionnaire survey was conducted (Chapter 7).

1. BACKGROUND INFORMATION

1.1 The Kromme Estuary

The Kromme Estuary is 13,7 km long (Hanekom, 1982), with an approximate surface area of 3 km² (CSIR, 1984).

The upper estuary follows a vertically folded contact between Table Mountain and Bokkeveld Groups. The slate and immature quartzite of the latter is readily eroded, but the quartzite of the former resists weathering. The geological basement underlying most of the estuary consists of Bokkeveld slate.

Intertidal areas are narrow in the upper estuary, whereas sandy and intertidal flats are well developed in the lower 4,5 km of the estuary. The estuary mouth is permanently open, with a sand spit extending north-eastwards from its right bank (Figure 1.3).

The Geelhoutboom River, which originates in an area south of Humansdorp, joins the estuary about 8 km upstream from the inlet (Figure 1.2). In addition, several ephemeral stream channels occur on both sides of the estuary (CSIR, 1985).

Although the sand bar configuration near the estuary mouth is often complex, a navigable channel is always present. The depth of this channel is restricted by Bokkeveld slate.

1.2 The Roadbridge

The Humansdorp/St Francis Bay roadbridge was completed in 1979. It crosses the Kromme Estuary approximately 3 km upstream of the mouth (Figure 1.3). The bridge does not obstruct normal tidal flow (Bickerton and Pierce, 1988).

1.3 The Marina

Development of Marina Glades, in a marshy area, began in 1959. Initially, an estimated 2×10^6 tons of sand were excavated, to construct a network of canals, including a yacht harbour for ocean-going yachts (Seagrief, 1976). The sand spit was raised and vegetated to protect the marina and mouth area during strong south-easterly gales (Davies, 1978).

1.4 Rainfall and Runoff

The mean annual precipitation in the Kromme catchment is 724 mm (CSIR, 1985). Annual precipitation varies with topography, from 600 mm in the lower reaches, to 1 100 mm in the upper catchment (Ninham, Shand and Partners, 1977). On average, rainfall maxima occur in May and August, although there is a considerable monthly and annual variation.

The mean annual runoff for the Kromme is given as $105 \times 10^6 \text{ m}^3$, (Noble and Hemens, 1978; Heydorn and Tinley, 1980), $105,5 \times 10^6 \text{ m}^3$ (Reddering and Esterhuysen, 1983) and $123 \times 10^6 \text{ m}^3$ (Pitman et al., 1981). These figures reflect the runoff for the entire catchment and do not take the effects of the Churchill Dam and the C W Malan Dam into account. More detailed information is included in Chapter 4.

The rivers in the eastern Cape, such as the Kromme are typically subjected to sudden and violent floods. These may occur at any time of year, but are more likely during spring or early summer.

1.5 Dams

The Churchill Dam, constructed in 1943, lies 50 km from the mouth. It has a capacity of $33,0 \times 10^6 \text{ m}^3$ (Ninham, Shand and Partners, 1977).

The C W Malan Dam, formerly named the Elandsjagt Dam, was completed in 1982 and has a capacity of $100 \times 10^6 \text{ m}^3$. It is an earth and rockfill structure with a clay core, situated 4 km upstream of the tidal head of the Kromme Estuary (Figure 1.2). It retains water from a catchment area of 840 km^2 (including the catchment area of 360 km^2 for the Churchill Dam). This constitutes 77 percent of the total Kromme River catchment, which is estimated to be $1\,085 \text{ km}^2$ (CSIR, 1985).

The mean annual runoff at the C W Malan Dam is $95,25 \times 10^6 \text{ m}^3$, as estimated from a synthetic record of flow, which was obtained from rainfall records (Ninham, Shand and Partners, 1977). This runoff figure includes the mean annual runoff of $56,14 \times 10^6 \text{ m}^3$ for the Churchill Dam (based on recording from gauges situated just below the dam). Relevant information of this kind is summarised in Table 1.1 at the end of this chapter.

1.6 Sediment Sources

1.6.1 Coastal sediment

Sand from the adjacent beaches may be transported into the estuary mouth by tidal currents. This sand is supplied by longshore transport around Cape St Francis, and from the coastal dunefield (Chapter 2).

The headland bypass coastal dunefield extends from Oyster Bay to Cape St Francis (Figure 1.2). Historical evidence, from local inhabitants, indicates that the dunes were still vegetated at the turn of the century. This vegetation was destroyed through bad management of the land (Cowling, 1980; CSIR, 1984), such as burning and subsequent overgrazing. Due to the prevailing westerly wind, sand from dunes is

transported into the sea in the region of Santareme Bay; previous reports indicate that this occurred from the beginning of this century (CSIR, 1984).

Stabilization of the Santareme dunes commenced in 1960, with extensive use of the alien *Acacia cyclops* (Rooikrans). This caused a reduction in the source of dune sand, as revealed by the aerial photography analysis (Section 3.4.1).

1.6.2 The Sand River

The Sand River is a small, episodically flowing tributary that enters the Kromme Estuary 2 km from the mouth (Figure 1.3). According to the literature, the river is capable of transporting sand into the Kromme Estuary (Cowling, 1980; CSIR, 1984; Fromme and Badenhorst, 1987). Two suggested mechanisms of transport of sand in the Sand River are as follows:

(i) Since the bed of practically the entire Sand River is porous, rainwater sinks into it. Only after significant precipitation, does the level of the groundwater rise above the bed, and the Sand River thereby starts to flow and transport sand (Stear, 1984).

(ii) Intense runoff during floods occurs on the surface, thereby transporting large quantities of sand (Sparks, 1990).

The exact mechanism of transport is not certain.

The Sand River has not deposited sand in the estuary since 1983. This may be due to the recent drought period (no significant floods have occurred since 1983 (Von Below, Senior Water Control Officer, C W Malan Dam, pers. comm.), and/or due to the drop in the water table (Taylor, Algoa Regional Services Council, pers. comm.)

1.6.3 Fluvial sediment

There are indications that the fluvial sediment yield from the Kromme catchment is small (CSIR, 1985). In addition, the C W Malan Dam effectively stops fluvial sediment input from the Kromme River into the estuary (Reddering and Esterhuysen, 1983). Some clastic mud and rock fragments enter the estuary from the Geelhoutboom River, but the limited change in cross-sections downstream of the river suggest that the input is insignificant (Section 3.1.2).

REFERENCES

- BICKERTON, I.B. and PIERCE, S.(1988). Estuaries of the Cape; Part II: synopses on available information on individual systems; Report no 33, Kromme(CMS45), Seekoei(CMS46) and Kabeljous (CMS47), Stellenbosch. CSIR Research Report 432.
- COWLING, R.M. (1980). The coastal dune ecosystems of the Humansdorp District - a plea for their conservation. The Eastern Cape Naturalist, No. 70.
- CSIR (1984). The Kromme Estuary. Stellenbosch. CSIR Report C/Sea 8354 (Revised).
- CSIR (1985). Hydrological/Hydraulics study of Cape estuaries, Kromme CMS 45. Stellenbosch. NRIO Data Report D8502.
- DAVIES, B.R. (1978). A Report to the Department of Water Affairs Concerning the Ecological Impact of the Kromme River Government Water Scheme: Elands Jagt Dam. Grahamstown. Rhodes University. Inst. for Freshwater Studies. Unpublished Report. (Also additional comments, 15 June, 1978).

FROMME, G.A.W. and BADENHORST, P. (1987). The Dynamics of the Estuaries of St. Francis Bay (Kromme, Seekoei and Kabeljous). Stellenbosch. CSIR Report T/SEA 8707, .

HANEKOM, N. (1982). An Ecological Study of the Zostera Beds in the Kromme Estuary. Pretoria. SANCOR Report.

HEYDORN, A.E.F. and TINLEY, K.L. (1980). Estuaries of the Cape Part I. Synopsis of the Cape coast. Natural features, dynamics and utilization. CSIR Research Report 380.

NINHAM SHAND and PARTNERS INC. (1977). Report on proposed New Dam on Kromme River: Vol. 1. Report no. 453/2973

NOBLE, R.G. and HEMENS, J. (1978). Inland water ecosystems in South Africa - a review of research needs. Pretoria. S. Afr. Natl. Sci. Programmes Report 34. 150 pp.

PITMAN, W.V., MIDDLETON, B.J. AND MIDGLEY, D.C. (1981). Surface water resources of South Africa. Vol. IV. Johannesburg. Hydrological Research Unit Report No. 13/81.

REDDERING, J.S.V. and ESTERHUYSEN, K. (1983). Sedimentation in the Kromme Estuary, Dept. of Geology, University of Port Elizabeth. Rosie Report no. 6,

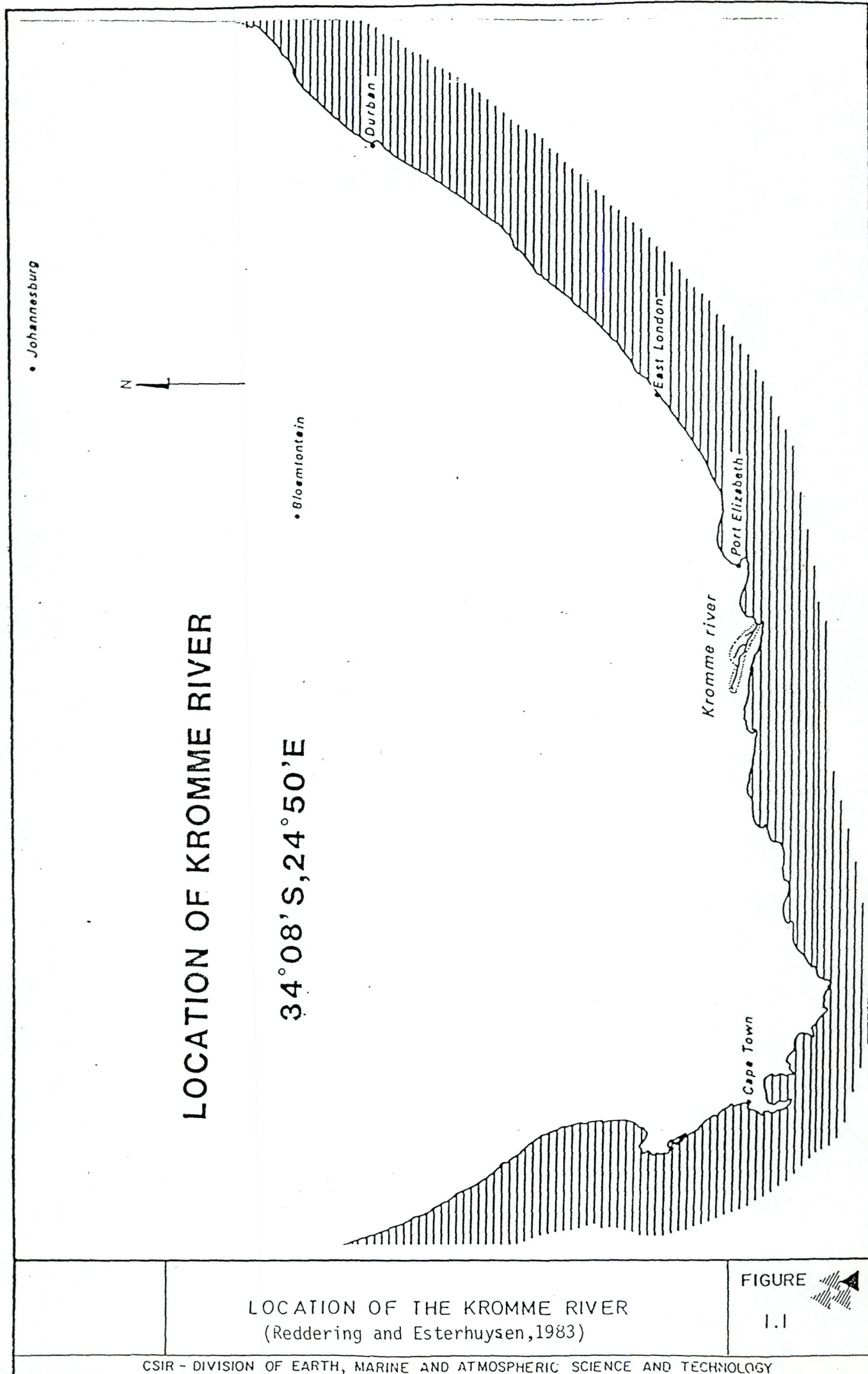
SEAGRIEF, S.C. (1976). The Colonisation of Estuarine Canals by Seaweeds at Sea Vista. Eastern Cape Naturalist, 59, pp 10-12.

STEAR, D.A. (1984). The dynamics of the Sand River., Dept. of Geology, University of Port Elizabeth, 31pp. Unpubl. B.Sc.Hons. Proj.

TABLE 1.1: THE C W MALAN DAM*

Construction completed	1982
Capacity (South Africa Dept of Water Affairs, 1977)	$100 \times 10^6 \text{ m}^3$
Catchment area (including Churchill Dam catchment (Ninham, Shand and Partners, 1977)	840 km^2
Mean annual runoff at the dam (Ninham, Shand and Partners, 1977)	$95,25 \times 10^6 \text{ m}^3$

* Further details are presented in Table 4.1

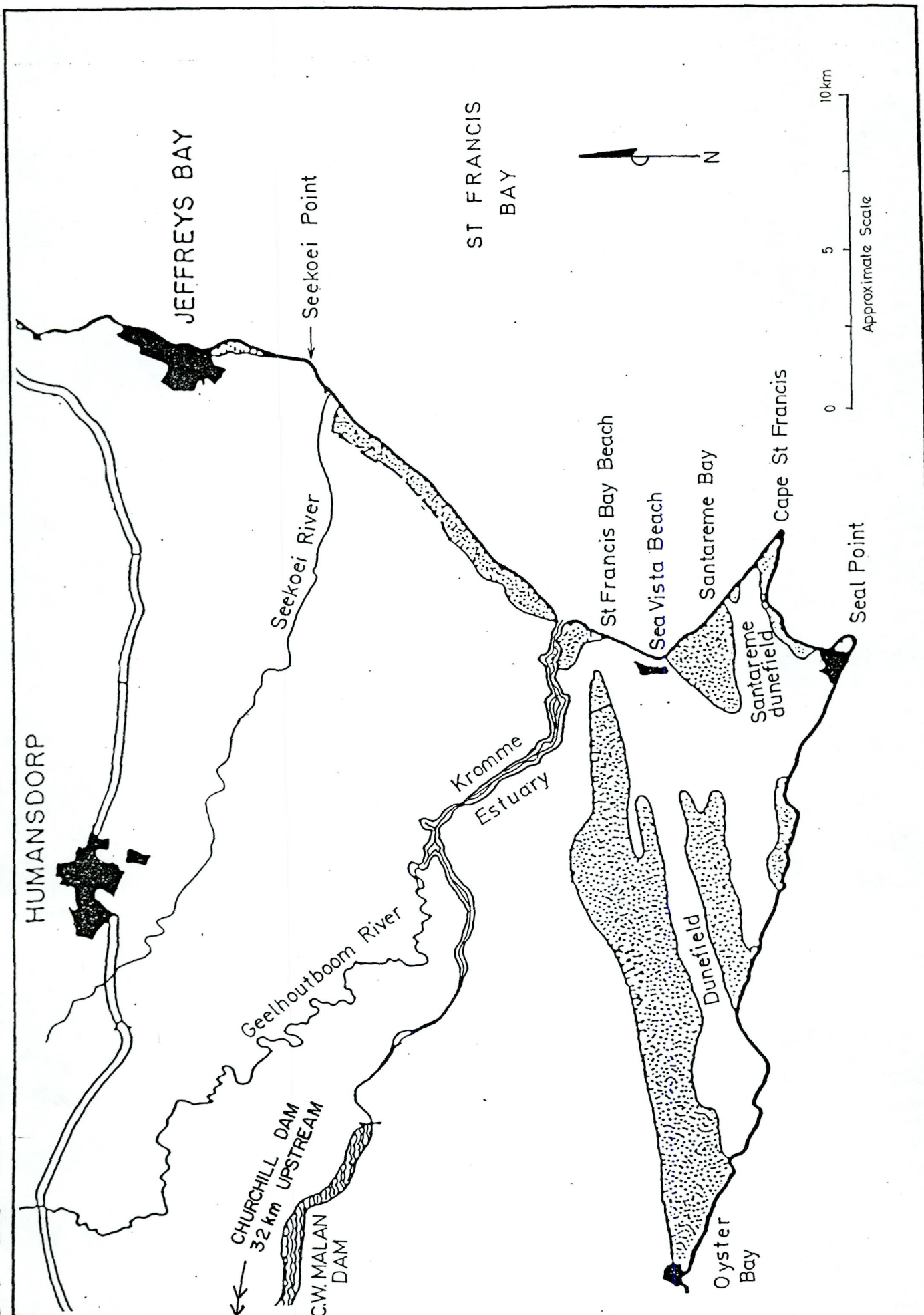


LOCATION OF THE KROMME RIVER
(Reddering and Esterhuysen, 1983)

FIGURE

1.1



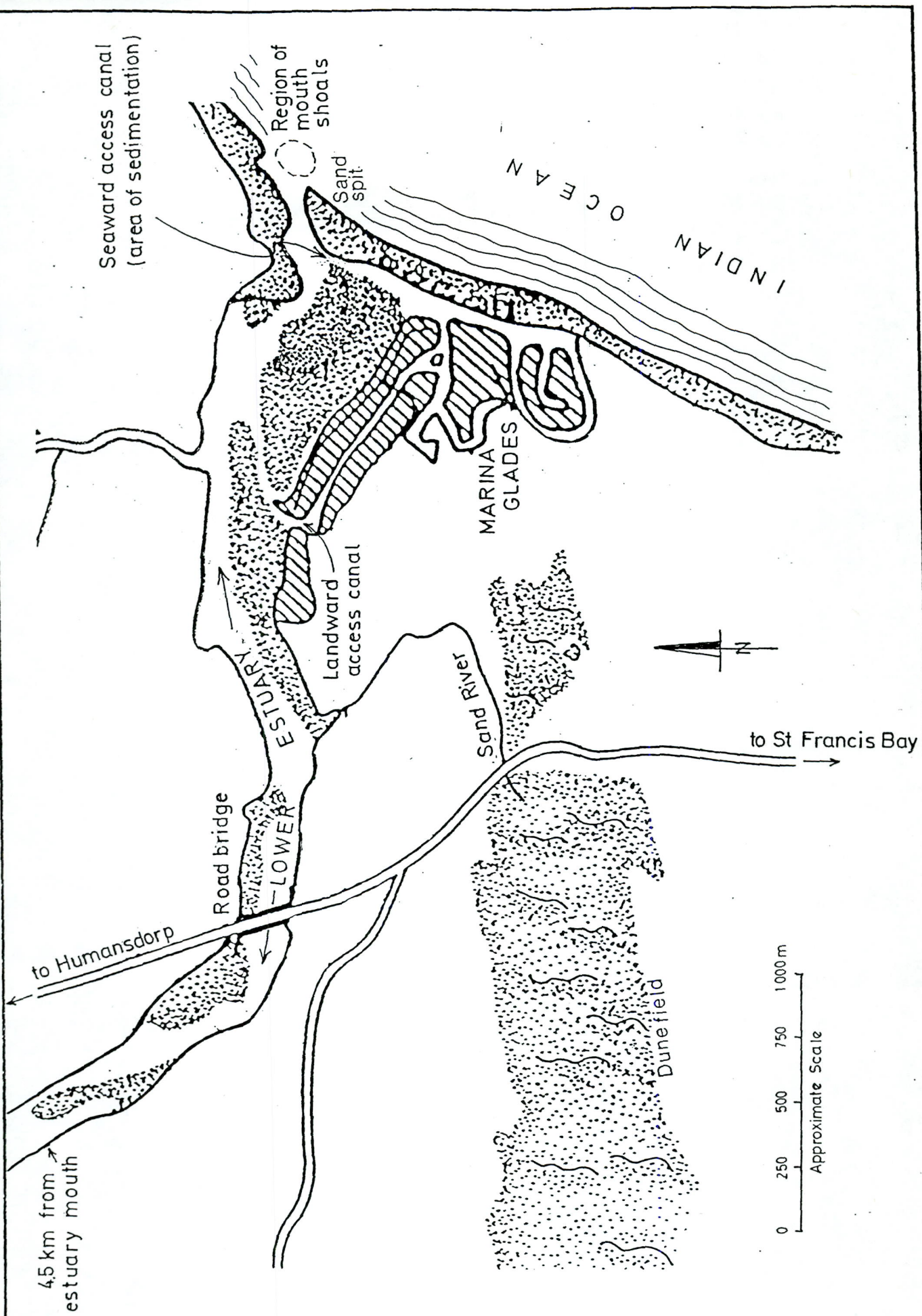


MAP OF THE KROMME ESTUARY AND
SURROUNDINGS

FIGURE

1.2





THE KROMME ESTUARY

FIGURE 1.3

2. COASTAL SEDIMENT DYNAMICS AND REMEDIAL STRUCTURES AT THE ESTUARY MOUTH

2.1 Introduction

Considerable contributions to this chapter have been made by Kapp, Prestedge Retief (KPR), Consulting Engineers, who acted as sub-consultants to the CSIR in this study. Their contribution was in particular based on experience obtained on other projects in the region.

Coastal sediment dynamics affect the sedimentation processes in the estuary mouth. Besides this, owing to the ongoing beach erosion, the estuary mouth dynamics processes move further inland. This indirectly affects the sedimentation in the seaward access canal to the marina.

Sedimentation and erosion of the beaches at St Francis Bay are not addressed in detail. However, a limited evaluation of the coastal dynamics in the area has been made as a background to the sedimentation study.

Additionally two conceptual solutions to improve the accessibility of the mouth are discussed briefly .

2.2 Coastal Dynamics

2.2.1 Indications of beach erosion near the estuary mouth

An analysis of aerial photographs of the area taken in 1942, 1961, 1975, 1980 and 1987, was done for another study (CSIR, 1990). The analysis indicates a fairly static situation up to 1975 with the maximum beach build-up circa 1969. For 1980, a fairly severe setback from the average values is recorded, particularly in the vicinity of Sea Vista beach. This extreme situation follows annual maximum wave events occurring immediately after the winter in both 1978 and 1979. The analysis of the 1987 photograph indicates that some recovery of the beaches near Sea Vista occurred subsequently. However, in the vicinity of the Kromme mouth co-incident with the entrance spit, a steady trend towards increasing beach erosion is detected.

Quantifying this erosion since 1969, an average setback of approximately 40 m over the 600 m stretch of beach adjacent to the mouth is evident.

Additionally, Lubke (1985) measured a 9m setback of the shoreline between beach surveys carried out in 1975 and 1982.

2.2.2 Aspects influencing coastal erosion and sedimentation at St Francis Bay

2.2.2.1 General

Erosion and sedimentation along a stretch of coastline are dependent on the balance between influx and outflow of sediments. The following aspects affecting coastal erosion and sedimentation can be distinguished:

- (i) Longshore sediment transport.
- (ii) On-offshore sediment transport.
- (iii) Availability of sediment.

Longshore sediment transport takes place in the breaker-zone, parallel to the coast, under the influence of waves and currents.

On-offshore transport is related to changes in wave conditions. Heavy wave action during storms causes an offshore transport of sediments, resulting in erosion of the beaches. During calmer periods sediment is transported back onshore, causing sedimentation on the beaches and tending to restore the earlier erosion.

Thus, sediment transport depends on wave action. The transport rate depends on wave energy and is related to wave height, period and direction. These parameters are obtained from a wave refraction study (Section 2.2.2.2).

Availability of sediment for transportation is a major aspect in coastal sediment dynamics. In periods of over supply,

sedimentation takes place and during shortages erosion occurs. It is therefore relevant to evaluate the history of sediment supply from possible sources (Section 2.2.2.4).

2.2.2.2 Wave refraction and longshore sediment transport at St Francis Bay

The study

Waves arriving obliquely at a coastline generate a current parallel to the beach. Sediments that have been stirred up and lifted into the water column primarily by the action of breaking waves are transported along the beach by these longshore currents. Longshore sediment transport varies in magnitude and direction (upcoast or downcoast) depending on the wave conditions.

Characteristics of deep-sea waves were available from recordings at the Mossel Bay oil rigs. These characteristics are representative of conditions along the southern Cape coast (Rossouw, 1989), and the data were used to define the deep-sea wave conditions offshore of St Francis. The wave data cover an effective period of about four years and consist of complete records of height, period and direction.

As waves move shorewards, they undergo changes in height and direction, due to refraction and diffraction effects. A mathematical wave refraction model was used to simulate these changes in wave conditions from the deep ocean to shallow water points of interest along the St Francis Bay coastline.

Results of the wave analysis, based on a method used by Prestedge (1987), are summarised by a number of nearshore energy 'roses' (Figure 2.1). These indicate the spread of wave direction and energy at the breaker line. As the rate of potential longshore sediment transport is directly proportional to the longshore component of wave energy, the wave energy roses represent the range and magnitude of potential alongshore transport. For each selected position the wave energy rose can

be compared with the effective orientation of the beach normal. The resultant or equivalent energies at selected nearshore positions are given in Table 2.1.

Each wave energy rose is used to assess the south-to-north and north-to-south components of potential longshore transport (order of magnitude and direction) as well as the offshore distribution of transport. The estimated gross and net potential alongshore transport rates, using the method employed in Prestedge (1987), are summarised in Table 2.2, and an indication of the distribution of potential longshore transport with distance offshore, for position KK1 at the Kromme River mouth (Figure 2.1), is given in Table 2.3.

Discussion of the results

The calculated quantities in this analysis are theoretical, and are used to gain insight into the order of magnitude of sediment transport rates. Therefore these values must not be taken at face value.

The numerical results indicate a fairly significant potential longshore movement of sediment, but since the resultant energy directions are close to normal to the coastline, the net potential transport is small (except for position AA1 in Figure 2.1).

The coastline west of Seal Point

The section of coastline west of Seal Point (Figure 2.1) is rocky. Other studies in this area reveal that sediment is present offshore of the rocky coastline and sediment can move from Slangbaai (Figure 2.1), eastwards towards Seal Point under suitable wave conditions. The transport rate in this area under normal conditions is insignificant, but under uninterrupted favourable wave conditions, "slugs" of sediment transport from west-to-east will occur.

The coastline from Seal Point to Cape St Francis

The above-mentioned slugs of sediment will be dispersed along the beach between Seal Point and Cape St Francis. Under suitable

conditions sand will be transported around Cape St Francis. In total the quantity of this sand is expected to be small.

The coastline between Cape St Francis and the Sea Vista beach

Between Cape St Francis and the Sea Vista beach (Figure 2.1) the waves are low in energy, but approach the coast at a large angle to the beach normal. Thus, the potential sediment transport rate here is high and once the sediment by-passes Cape St Francis, the sand moves rapidly along this section of coast. The transport rate here also affects the transport of dune sand blown into the sea, as discussed below (Section 2.2.2.4).

The beaches between Sea Vista and the Seekoei Estuary

The sandy beach areas between the Sea Vista area and the Seekoei Estuary are orientated such that the beach normal and the energy of the approaching waves are in close alignment. The spread of energy at the KK positions (Figure 2.1) indicates the extent to which movement of sediment is possible in both longshore directions. In this way sand is shifted back and forth along the coast. The energy at KK3 is greater than at KK1 owing to offshore bathymetry affecting the distribution of energy on this stretch of coast. The cause of this, (see bathymetry, Figure 2.2) is the relic river channel on the sea floor opposite the Kromme Estuary. This causes dispersal of wave rays and decreasing wave energy opposite KK1, while converging of wave rays opposite KK3 and KK4 increase wave energy. Energy concentrations at KK3 and KK4 are most pronounced for south-easterly wave directions.

Sand accretion at the cofferdam for the construction of the entrance to Marina Martinique just north of Seekoei Point is further evidence of the transport of sand from south-west to north-east in this area. This results from the loss of south-west-to-north-east transport, as reflected at KK2, "slipping" past the headland east of the Seekoei River during the back and forth sand movement which is reflected in isolation as a small net transport. According to order of magnitude calculations, there is the potential for a gross south-west to north-east transport of $375\ 000\ \text{m}^3/\text{yr}$ at KK2. There is a similarly high

386 000 m³/yr north to south transport at KK2. As a result of the unidirectional efficiency of sand by-passing at the Seekoei headland, the rate of sediment lost north-eastwards depends on the sequence of occurrence of transport conditions and not on the arithmetic net transport rate. It is conceivable that a loss rate of 100 000 m³/yr occurs at this point. Investigation of the estuary and adjacent shoreline at the Seekoei Estuary for another project reveals that after floods, beaches south and north of the estuary accrete and with time there is a north-eastward loss of sediment.

2.2.2.3 Erosion and sedimentation caused by on-offshore transport

During September 1978 a severe storm occurred and uncharacteristically approached from a very southerly direction (Shillington and Britton-Jones, 1979). Owing to the deep-sea direction associated with this storm, considerable beach erosion took place due to the offshore movement of sand. After such storm erosion, sand is normally transported back onshore during calmer wave conditions. In particular in bays, such as at St Francis, this process is relatively slow.

The observation that the beach has recovered very slowly since the September 1978 storm also indicates that the rate of sediment supply to this beach by longshore transport is low. Had longshore sand transport been high, sand on the beaches would have been replenished relatively quickly. This is consistent with the above suggestion that the supply of sand to St Francis Bay is small.

2.2.2.4 Availability of sediment

General

Erosion and sedimentation of beaches is to a large extent determined by the sand supply to those beaches. An evaluation of present and past sand supply will improve our understanding of these processes.

The following sources of sediment for the St Francis Bay coastline can be identified:

- (i) The coastal dunefields.
- (ii) Longshore sediment transport occurring from the south-west past Cape St Francis.
- (iii) The Kromme River.
- (iv) Sediments transported from deeper water onto the beach by onshore transport mechanisms.

Each of these sources is discussed.

The coastal dunefields.

Considerable changes have taken place during the past 50 years at the coastal dunefields near St Francis Bay. A detailed evaluation of the sand supply from these dunefields has therefore been made.

Sand is blown from the Santareme dunefield (Figure 2.1) into the sea. Since there is a high longshore drift potential along this coast, the sand is rapidly transported to Sea Vista beach. Here, fluctuations in longshore transport, as indicated above, distribute the sand along the St Francis Bay beach.

The dune sediment source was significant in previous years. However, stabilization of the dunes has reduced the supply. The quantities of sand involved can be determined from aeolian sediment transport calculations, and through interpretation of aerial photographs.

Wind data obtained from voluntary observing merchant ships (VOS) were utilized for a first estimate of the wind climate in the area (Figure 2.3). Using these data, a set of aeolian creep diagrams was constructed for the Santareme dunefield (Figure 2.4). These diagrams indicate how wind-blown sand encroaches from different directions towards the centre of an imaginary circle on the ground. The equivalent volumes of sand blown seasonally in specified directions by the prevailing winds are

provided in Table 2.4. The predictive aeolian transport calculations are based on formulae (Swart, 1986) derived for dry, cohesionless sand of unlimited quantity, blowing along a flat, unvegetated surface under constant wind conditions. Since these criteria are seldom met in practice, the calculated values indicate the potential maximum transport rates.

Table 2.4 and Figure 2.4 indicate that a significant potential exists for sediment to be moved predominantly towards the eastern sector (i.e. offshore) throughout the year. In fact, a potential annual sand transport of 67 m^3 per meter length of dunefield perpendicular to the wind (or component thereof) in the westerly direction, is calculated. Obtaining the required dimensions of the dunefield along the coast, from the 1942 aerial photograph, a sand supply of $150\,000 \text{ m}^3$ per year was estimated, before the stabilization of the dunefield.

Investigation of aerial photographs (Chapter 3) shows that the dunefield has subsequently been extensively stabilized. Measurements of the dimensions of the dunefield from recent aerial photographs reveal that the sand supply has been reduced to about $12\,000 \text{ m}^3$ per year.

Additionally the 1961 aerial photograph indicates that the more northern bypass dunefield connected to Oyster Bay at that time extended to the stretch of coastline south-west of the estuary mouth. Any contribution from this source has also been cut-off with the development of the marina.

These results indicate a drastic reduction of sand supply by aeolian transport from these dunefields. Indirectly, this was a major reason for the beach erosion between Sea Vista and the estuary mouth.

Longshore sediment transport occurring from the south-west past Cape St Francis.

The longshore sediment transport has been described extensively in Section 2.2.2.2. As mentioned, it is probable that little

sediment is transported from the south-west past Cape St Francis. It is therefore unlikely that drastic changes in this transport occurred in recent history.

The Kromme River

A possible source of sediment at times would have been from sediment flushed out of the mouth of the Kromme during flood events. However, as indicated by the wave roses most sediment would be carried northwards of the mouth. In addition this is a cyclic event, with much of the flushed sediment gradually moving back into the mouth subsequent to the flooding.

Sediments transported from deeper water onto the beach by onshore transport mechanisms

This aspect, previously described in section 2.2.2.3, is also a cyclic event, which alternates with offshore transport mechanisms. Thus in the long term, no major changes of the beaches result from this mechanism.

The main reason for beach erosion

It is therefore concluded that reduced sand supply from coastal dunefields is the major reason for beach erosion adjacent to the Kromme Estuary mouth.

The possibility of further beach erosion in the future

The first two kilometres of the beach at Sea Vista has receded drastically under the influence of recent storms and does not appear to be recovering from this erosion.

For the final kilometre of beach adjacent to the river mouth, there is also strong evidence of long term beach erosion occurring. The aerial photographic analysis indicated that an average net erosion of 25 m has occurred between 1975 and 1987. At this rate and over a period of 50 years an erosion of 100 m from present conditions could be expected.

Further erosion at the mouth would also mean that the mouth dynamic processes would move further inland. This, in turn would further aggravate the sedimentation problems in the seaward access canal to the marina.

2.3 Monitoring and Remedial Measures

2.3.1 General

This evaluation of coastal sediment dynamics and assessment of beach erosion was not performed to solve the beach erosion problems, but to provide background information to the sedimentation problems in the estuary and to assess the possibility of remedial measures.

Nevertheless, important conclusions can be drawn from the evaluation:

- It is essential that erosion of the beach south west of the mouth is monitored and it is recommended that measures be considered to stabilize this section of beach against further erosion, particularly considering the vulnerability of developments in and near the marina.
- The results from the evaluation of the longshore transport can also be used to assess the possibility of remedial measures for the access problems in the estuary mouth.

Confirmation of ongoing sedimentation in the estuary mouth could not be obtained (see main report, Section 4.1). Therefore measures to improve the accessibility are not justified as a "restoration" of a previous better situation and are therefore not really part of the present study. Nevertheless, demand for improved accessibility for recreational or commercial boating might warrant possible measures such as breakwaters and fluidization. A brief evaluation of these possible solutions for improving the accessibility is therefore described.

2.3.2 Training the mouth - breakwaters

Training the mouth would comprise the construction of a pair of breakwaters as shown on Figure 2.5. The object is to maintain a

dredged channel with the breakwaters acting as groynes to prevent longshore sediment transport from infilling the channel. The breakwaters would have to be aligned to ensure minimum obstruction to strong river flows. Initial dredging would be required. The proposal shown is purely conceptual and if acceptable would require detailed engineering investigation.

The offshore extent of the breakwaters is based on wave and sediment calculations that indicate that a significant wave height of 3 m is only exceeded four percent of the time. The entrance would accordingly be free of breakers (considering maximum waves in a wave train) for a 96 percent utilization. All longshore movements occur shorewards of the 6 m depth contour with 87 percent of gross transports at depths shallower than 4 m.

The estimated costs based on available seabed depth information is R15 million including allowance for contingencies commensurate with this preliminary conceptual proposal.

The training works would substantially reduce sediment entrainment into the estuary and improve navigability and access to the sea.

Conditions at this location are well suited for this type of solution owing to the lack of strong longshore sediment transport. The beaches between Sea Vista and the estuary mouth would also be improved. However, further studies are required to determine the extent of this improvement. Beaches east of the estuary would not be deleteriously affected.

2.3.3 Fluidization

Fluidization consists of a hydraulic and pneumatic piping system laid on the seabed in the estuary and used to fluidize the bottom sediments on the ebbing tide. The system is a partial solution to reduce sand bank formation and improve navigability. Engineering aspects would have to be carefully considered taking into account the method of installation, operation and hydraulic design. Provided problematic foundation conditions are not

encountered, the costs are estimated at R7 million. This system would not be as beneficial for the improvement of beach conditions as the training works would be.

REFERENCES

CSIR (1990). Sedimentation problems at Marina Martinique, Aston Bay. Stellenbosch, CSIR Contract Report EMA-C 90218.

MARTIN, A.K. and FLEMMING, B.W. (1984). The Holocene Shelf Sediment Wedge off the South and East Coast of South Africa, Stellenbosch. CSIR Research Report.

PITMAN, W.V., POTGIETER, D.J., MIDDLETON, B.J. and MIDGLEY, D.G. (1981). Surface Water Resources of South Africa, Hydrological Research Unit, University of the Witwatersrand, Johannesburg. Report No. 13/81.

PRESTEDGE, G.K. (1987). Nuclear Power Station Site Investigations in the Tsitsikama/Cape St Francis Area, Watermeyer Halcrow and Partners Report submitted to ESKOM.

ROOSEBOOM, A. (1978). Sedimentafvoer in Suider-Afrikaanse Riviere, Water SA, Vol. 1, No. 1.

ROSSOUW, J. (1989). Design waves for the South African coastline, Ph.D thesis, University of Stellenbosch.

SHILLINGTON, F. and BRITTEN-JONES, A. (1979). Features of surf waves off the Southern Cape Coast during a severe storm between 30 August 1978 and 3 September 1978, S.A. Journal of Science, Vol. 75.

SWART, D.H. (1986). Prediction of wind-driven transport rates, Proceedings 20 International Conference in Coastal Engineering (ICCE), Taipei, Taiwan, Vol. 2, pp 1 595-1 611.

TABLE 2.1: SUMMARY OF WAVE CONDITIONS ON THE STUDY COASTLINE

POSITION	WAVE CONDITIONS		EQUIVALENT ENERGY	
	(Hs) 20% (m)	(Hs) 1yr (m)	Magnitude (GJ/yr/m crest)	Wave Direction (degrees true)
Deep Sea	3,5	8,1	1 390	
TP1	3,7	8,0	1 147	205
DH1	3,6	7,3	1 047	202
DH4	3.6	7,8	1 070	209
KK1	2.2	4.4	308	129
KK2	3,0	6,8	706	135
KK3	2,6		446	112
KK4	2,6		511	128

TABLE 2.2: SUMMARY OF POTENTIAL LONGSHORE TRANSPORT COMPUTATIONS

POSITION	GROSS TRANSPORT		NET TRANSPORT	
	Magnitude m ³ /yr		Magnitude	Direction
	S - N	N - S	m ³ /yr	
KK1	100 000	45 000	55 000	S - N
KK2	375 000	386 000	11 000	N - S
KK3	91 000	151 000	60 000	N - S
KK4	135 000	191 000	56 000	N - S

TABLE 2.3: DISTRIBUTION OF LONGSHORE TRANSPORT WITH DISTANCE
OFFSHORE AT KK1

DEPTH INTERNAL	TRANSPORT MAGNITUDE (M ³ /YR)		
	S - N	N - S	NET
0 - 2 M	22 000	9 000	13 000
2 - 4 M	62 000	35 000	27 000
4 - 6 M	15 000	1 000	14 000
6 - 8 M	1 000		1 000
TOTAL	100 000	45 000	55 000

TABLE 2.4: AEOLIAN WIND TRANSPORT RATES AT CAPE ST FRANCIS

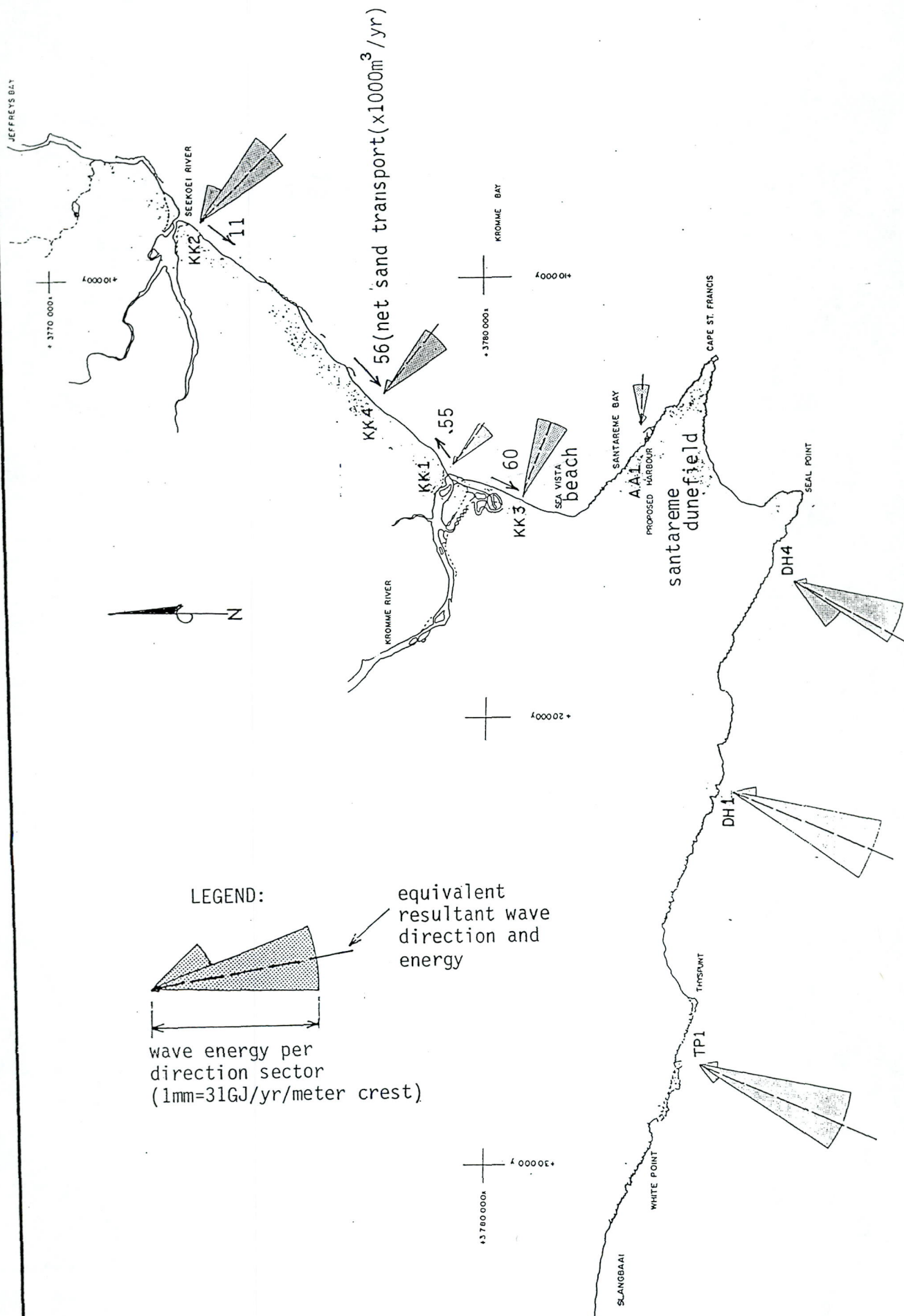
AEOLIAN WIND TRANSPORT RATE - ST FRANCIS SUMMER	
DIRECTION OF WIND-BLOWN MATERIAL	CUB.M / METRE / YEAR
SOUTH BOUND	4
SOUTH-WEST BOUND	19
NORTH-WEST BOUND	14
NORTH BOUND	15
NORTH-EAST BOUND	39
EAST BOUND	42
SOUTH-EAST BOUND	22

AEOLIAN WIND TRANSPORT RATE - ST FRANCIS AUTUMN	
DIRECTION OF WIND-BLOWN MATERIAL	CUB.M / METRE / YEAR
SOUTH BOUND	5
SOUTH-WEST BOUND	14
WEST BOUND	16
NORTH-WEST BOUND	11
NORTH BOUND	11
NORTH-EAST BOUND	46
EAST BOUND	56
SOUTH-EAST BOUND	35

AEOLIAN WIND TRANSPORT RATE - ST FRANCIS WINTER	
DIRECTION OF WIND-BLOWN MATERIAL	CUB.M / METRE / YEAR
SOUTHBOUND	7
SOUTH-WEST BOUND	9
WEST BOUND	10
NORTH-WEST BOUND	10
NORTH BOUND	22
NORTH-EAST BOUND	78
EAST BOUND	94
SOUTH-EAST BOUND	59

AEOLIAN WIND TRANSPORT RATE - ST FRANCIS SPRING	
DIRECTION OF WIND-BLOWN MATERIAL	CUB.M / METRE / YEAR
SOUTH BOUND	7
SOUTH-WEST BOUND	20
WEST BOUND	23
NORTH-WEST BOUND	16
NORTH BOUND	18
NORTH-EAST BOUND	65
EAST BOUND	75
SOUTH-EAST BOUND	44

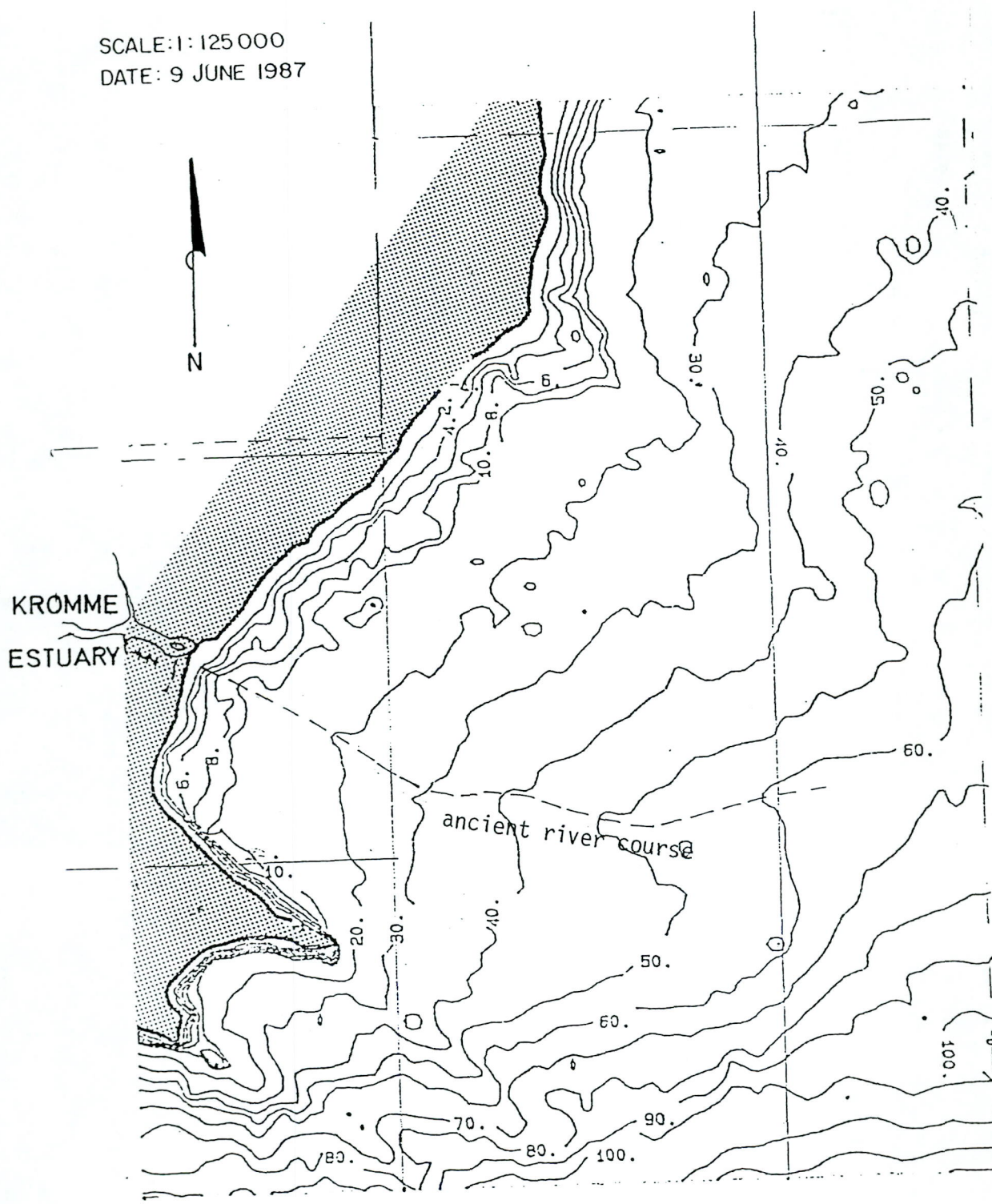
AEOLIAN WIND TRANSPORT RATE - ST FRANCIS ANNUAL	
DIRECTION OF WIND-BLOWN MATERIAL	CUB.M / METRE / YEAR
SOUTH BOUND	5
SOUTH-WEST BOUND	14
WEST BOUND	17
NORTH-WEST BOUND	12
NORTH BOUND	16



WAVE ENERGY AND DIRECTION ON THE ST FRANCIS COASTLINE
(Contributed by KAPP PRESTEDGE RETIEF)

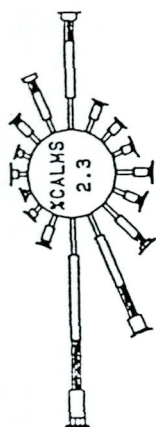
FIGURE
2.1

SCALE: 1:125 000
DATE: 9 JUNE 1987

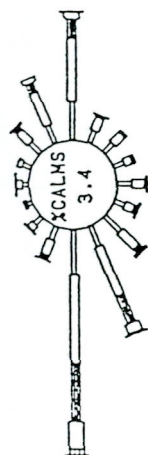


BATHYMETRY OF SANTAREME BAY AND SURROUNDINGS
(Contributed by KAPP PRESTEDGE RETIEF)

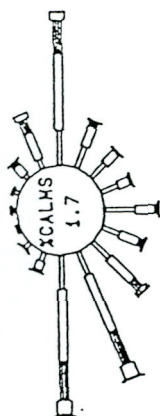
FIGURE
2.2



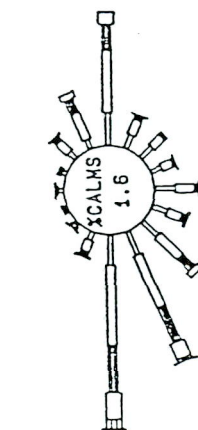
ALL YEAR



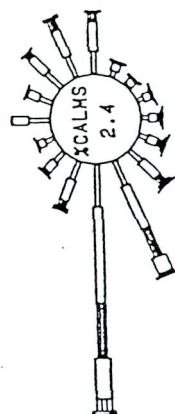
AUTUMN



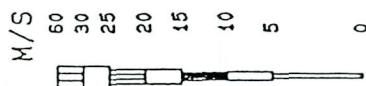
SUMMER



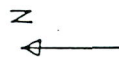
SPRING



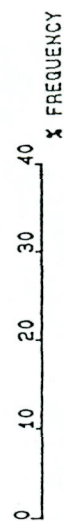
WINTER



WIND ROSE



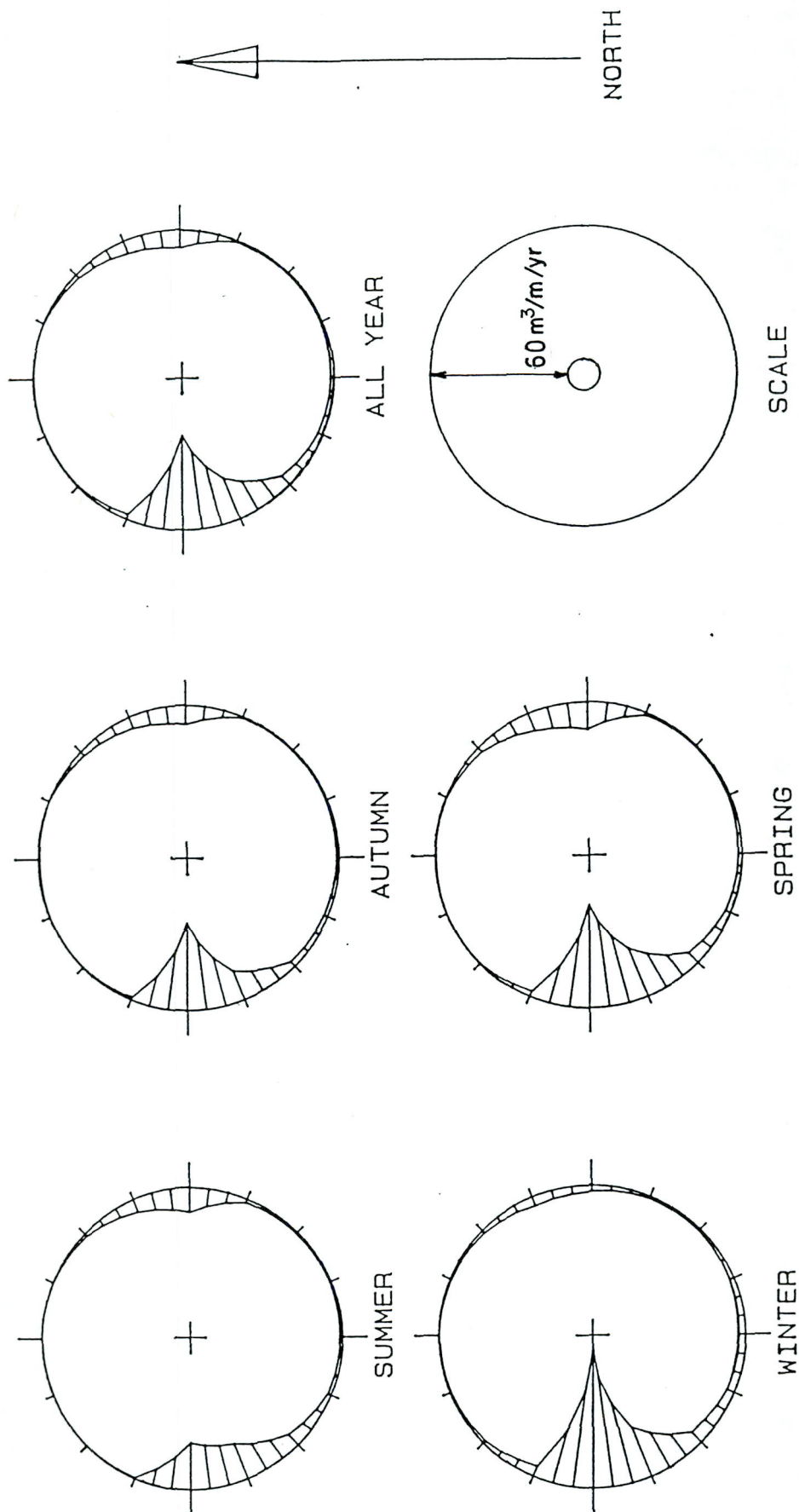
AREA
34° 0'S - 36° 0'S LATITUDE
25° 0'E - 26° 0'E LONGITUDE



ST FRANCIS BAY WIND CONDITIONS

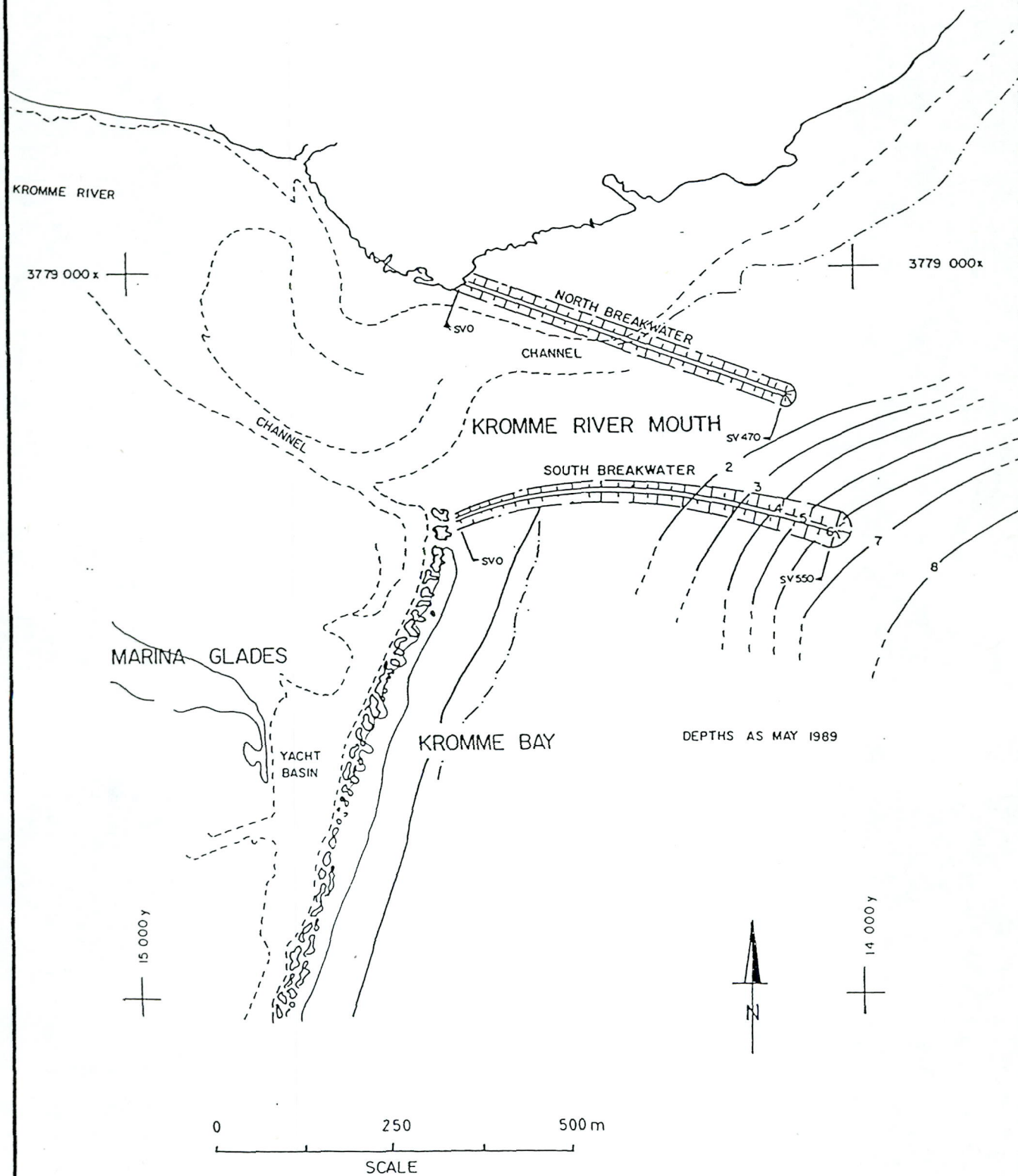
FIGURE
2.3





AEOLIAN TRANSPORT RATES ARE GIVEN IN FRACTIONS OF 10000CUBIC METRES/YEAR/KILOMETRE WITH DUE COGNIZANCE FOR FREQUENCY OF OCCURRENCE OF WIND EVENTS





KROMME ESTUARY BREAKWATER DESIGN
(Contributed by KAPP PRESTEDGE RETIEF)

FIGURE
2.5

3. ANALYSIS OF AERIAL PHOTOGRAPHS, CROSS-SECTIONS AND WATER-LEVEL RECORDINGS

Useful information about sediment movements can be obtained from aerial photographs, early maps, cross sections and water-level recordings. The following aspects are investigated:

- (i) Sedimentation in the estuary.
- (ii) The Sand River.
- (iii) Tidal channel configurations.
- (iv) Beach and dune dynamics.
- (v) The flood-tidal delta.

3.1 Sedimentation in the Estuary

The aerial photographs from 1942 to 1987 show sand bars extending from the estuary mouth to a point about 4,5 km upstream, where they end abruptly. Only this lower sandy region has shown any significant sediment movements since 1942, as corroborated by a previous study (Reddering and Esterhuysen, 1983). Since this is where shoaling problems are experienced, the investigation, to determine if sediment has accumulated, concentrates on this lower estuary region. Aerial photography, cross-sections and water-level recordings are investigated.

3.1.1 Information from aerial photographs

Preliminary examination of the aerial photographs showed no obvious sedimentation. More detailed studies were conducted by determining areas of sand, water, vegetation, etc, on the flood plain, however, nothing could be deduced from this study, mainly because sediment volume changes in the vertical dimension cannot be detected.

3.1.2 Information from cross-sections

Cross-sections of the estuary bed were measured at intervals of

approximately 1 km along the whole length of the estuary, in 1982 and 1988 (Figure 3.1). The data were processed and compared, concentrating on the lower estuary.

3.1.2.1 Data processing:

The 1988 sections were measured from bank to bank, but the 1982 sections were terminated at the high water mark and excluded the saltmarshes. To facilitate comparison of the results, the 1988 coordinates were adjusted so that the saltmarshes in the estuary are thus excluded from the interpretation that follows.

After processing the data, an error within ± 20 mm is estimated. This error would cause a maximum error of 3% in the cross-sectional area.

The cross-section at the mouth (i.e. Section 1 in Figure 3.1) could not be measured in 1982 since the benchmarks had been destroyed. This cross-section would have had little value for comparison anyway, because of the significant short-term cross-section changes frequently occurring at the estuary mouth.

The cross-sectional areas and hydraulic radii were computed for two cases:

- (i) The maximum cross-section elevation at MSL (mean sea level).
- (ii) The maximum cross-section elevation at MSL + 0,8 m. This corresponds roughly to the high water-level.

3.1.2.2 Results and discussion

(i) Cross-section areas:

Little significant change is apparent between the cross-section areas of 1982 and 1988 (see Figure 3.2). Cross-sections 2 and 3 have undergone the most marked change of all the cross-sections and they have increased in area between 1982 and 1988. On the other hand, Section 4 (at the road bridge) has shoaled since 1982; it is possible that sediment deposited in the estuary by the Sand River at Section 3 during the 1983 flood moved upstream

and thereby contributed to the shoaling at Section 4. One kilometre further upstream, it is apparent that Section 5 has remained practically unchanged.

Further upstream, no significant changes are apparent (sections 6 to 15). This region is not of concern since it is much deeper.

On average, the cross-section areas in the lower estuary (cross sections 2 to 5) have increased between 1982 and 1988, suggesting a slight decrease in the sediment volume. However, the spacing between cross-sections is too large to determine whether sedimentation has or has not definitely occurred in the six year period.

The magnitude of the changes in cross-sections between 1982 to 1988 is, with few exceptions, the same for the MSL and +0,8 m MSL water-levels. This indicates that most of the change since 1982 has occurred below MSL (this was also indicated in other studies (Reddering, 1988)), suggesting that changes in sediment volume of the estuary usually take place in the subtidal zone, where they are far less visible than in the intertidal zone.

(ii) The hydraulic radii:

The hydraulic radii (i.e. area divided by wetted perimeter) give an indication of the average depth of a cross-section. They confirm that the lower 4 to 5 km of the estuary are considerably shallower than the upper estuary (Figure 3.3), showing that this is the main area of long-term sediment accumulation.

Section 2 had a prominently larger hydraulic radius in 1982 than in 1988, at MSL. This is because the hydraulic radius does not reflect the average depth for the 1982 cross section. Since a significant part of the bed was exposed at low tide (approx. MSL), it did not form part of the wetted perimeter of the channel, therefore causing a large hydraulic radius (area divided by wetted perimeter). At high tide (approx. + 0,8 m MSL) this was not apparent. Considering this, the hydraulic radii in the lower estuary show no significant changes in depth between 1982 and 1988 (Figure 3.3)

3.1.3 Information from water-level recordings

An increase in sedimentation in the lower estuary or the estuary mouth would reduce the channel dimensions and restrict ebb-tidal drainage out of the estuary, so that the lowest tide level would be elevated. If a systematic increase in this low water-level is detected, it can be deduced that sedimentation has occurred, provided that the record of water-levels is long enough to average out any other systematic influences on the water level (e.g. spring-neap tidal variations and atmospheric pressure).

Available water-level recordings were analysed. Data are available for 12 days in August 1988 and for 74 days in 1990. Low tide levels in the estuary were listed, for both records. In the 1988 record, only one low tide value below mean sea level (MSL) was encountered, out of 23 values. For the 1990 record however, an average of about one level in four was below MSL. This suggests that no accumulation of sediment has occurred in the lower estuary and the estuary mouth (and even implies a slight decrease in the sediment volume). However, the 1988 record is very short and the higher water-levels evident may represent other influences e.g. low atmospheric pressure. Longer records are needed to draw definite conclusions.

3.1.4 Conclusion

The above data suggest that no significant accumulation of sediment has occurred in the lower estuary. However, the data are limited and therefore a small accumulation may not have been detected.

3.2 The Sand River

The aerial photographs show that the Sand River deposits sand in the estuary. Its confluence with the Kromme Estuary is presently 750 m downstream of the roadbridge (Plate 6). In 1942, the confluence was 500 m further east of the present position (Plate 1). In the 1961, 1969 and 1975 photographs, two branches of the Sand River are apparent. This is because the Sand River was diverted during the construction of the marina;

the branch visible on the eastern side is the old Sand River course and the branch on the western side is (approximately) the present sand river course.

3.2.1 Observations from maps and aerial photographs

(i) Deposition in a lagoon:

Maps from 1790 to 1921 indicate the existence of a large embayment/lagoon on the south side of the lower estuary (Fromme and Badenhorst, 1987) e.g. Figure 3.4. The aerial photograph from 1942 shows that this lagoon has sanded up (Figure 3.4). This is supported by geological investigations, which show that dune sand overlies lagoon deposits in this region.

The sand may have been deposited in the lagoon by the Sand River, as suggested by the extensive sand bar at the Sand River mouth, in 1942 (indicated by the arrow in Plate 1). A major flood in 1932 may have caused the deposition.

(ii) The orientation of sand bars:

Aerial photographs show that sand bars in the estuary migrate both upstream and downstream, away from the junction of the Sand River with the Kromme Estuary. This is evident from the orientation of the slip faces of these sand bars, which is most obvious in the 1942, 1975, 1981 and 1987 photographs (Plates 1, 4, 5 and 6 - at the end of this chapter). The downstream migration appears to be dominant. Although the sand is moving away from the region of the Sand River mouth, no significant deepening of the estuary bed is evident (indicated by the shallowness of section 3 in Figure 3.1 and the lack of significant change in the section between 1982 and 1988). This indicates that the sand bars are supplied with sand from the Sand River.

(iii) Deposition by the Sand River:

Large sand bars are evident at the junction of the Sand River with the estuary in 1942, 1961 and 1969 (indicated by the arrows in Plates 1, 2 and 3). Subsequently, in the 1975, 1981 and 1987

photographs, less deposition is evident at the confluence (Plates 4, 5, and 6) suggesting that the supply of sediment from the Sand River has decreased.

During a major flood in 1983, the Sand River deposited sand into the estuary. Since most of this flood was collected in the near-empty C W Malan dam, the flow in the estuary was reduced. This encouraged deposition of a delta at the mouth of the Sand River. Aerial photographs taken on the day after the 1983 flood were used to estimate the dimensions of this delta. Its surface extent was about 25 m x 100 m. From a cross section surveyed in 1982 (Section 3 in Figure 3.1), the water depth was, at the most, 1,3 m below MSL. Assuming that: (1) the delta has a rhomboidal cross-section and (2) the delta surface lay close to MSL, the volume of the delta is thus estimated at 3 250 m³.

If a similar depth of the deltas is assumed, estimates of the volume of the sand at the confluence of the Sand River in 1942, 1961 or 1969 are at least 10 times larger than the 1983 value (this is particularly significant when it is considered that during these times, the river flow was not attenuated by the C W Malan Dam and large quantities of sand coming from the Sand River could have been carried out of the estuary). Thus, it appears that deposition by the Sand River decreased after 1969. This is probably because of stabilization of the eastern region of the dunefield (Plate 3) between 1969 and 1981 (Plate 5), primarily by alien vegetation.

3.3 Tidal Channel Configuration

3.3.1 Introduction

Tidal channels tend to shift considerably in time; time series aerial photographs show moderately high lateral displacements of the estuary channels, between 1942 and 1981 (CSIR, 1985). Such lateral movements of the estuary channels cause sedimentation in some parts of the estuary and erosion in others.

Flood- and ebb-tidal channels often follow separate, distinct routes in the lower estuary, due to inertial effects. In the region of the Kromme mouth, these tidal channels can be distinguished in aerial photographs.

3.3.2 Detailed observations

Photographs dated 1942, 1961, 1969, 1975, 1978, 1981, 1985, 1987, 1988 and 1990 were used. The dynamics of the lower estuary were studied and the findings are discussed below.

The 1942 photograph reveals a prominent sand body close to the estuary mouth (labelled 'FD' in Figure 3.5), on the southern side of the estuary. This is the *flood-tidal delta*, common in tidal estuaries of the south eastern Cape. It is formed from deposition by the flood-tidal currents. The erosional ebb-dominant channel lay to the north of this delta, causing erosion to occur in this region. This channel configuration of 1942 is very similar to that in the 1961 and 1969 photographs.

The 1975 photograph indicates a distinct change in channel configuration (Figure 3.6). The flood-tidal delta lay between two ebb channels, with the dominant, more erosional channel on the southern side of the estuary. Thus, since 1969, the centre of deposition shifted from the southern to the northern bank. The marina was under construction at the time and the seaward access canal was connected to the ebb channel. Since this ebb channel was eroding at the time, little shoaling occurred at the canal entrance, allowing adequate tidal circulation in the marina and adequate navigational access to the marina.

The 1978 photograph reveals that the situation had changed little except that the small ebb channel to the north had sanded up, so that the remaining one to the south was the only ebb channel (Figure 3.7). This channel had migrated southward by eroding into the sand bar. As this channel was still erosional, the access canal to the marina did not undergo undue shoaling. The flood dominant channel in the estuary mouth was directed towards the south-west at this stage, which possibly influenced the changes that were to follow.

The 1981 photograph (Figure 3.8) indicates an intermediate stage between the 1978 and 1985 channel configurations. The southern ebb channel had shoaled significantly and a second, more dominant ebb channel cut directly through the flood-tidal delta. In addition, it appears that the centre of deposition had moved from the northern side to the southern side of the estuary.

By 1985, the ebb channel to the south had become ineffective and the other ebb channel had established itself at the northern estuary bank (Figure 3.9). The centre of deposition had totally reverted back to its 1942 position on the southern bank, whereas erosion occurred at the northern bank. During the process, the flood-tidal delta became attached to the southern bank. Thus, the access canal to the marina was blocked by this deposition. The marina was still connected to the estuary via the old ebb channel but the marina canal was very shallow at the estuary end and tidal flow into the marina had to follow a tortuous route around the flood-tidal delta. Since both marina access canals were then close to each other, the hydraulic head necessary for tidal flushing through the marina must have been small.

There are indications that the change in channel configuration resulted from natural causes. The fact that a similar channel configuration existed before 1942, suggests a reversion to a previous natural state. In addition, the configuration of the flood-dominant channel, before the change, was conducive to the formation of the flood-tidal delta on the southern bank. Furthermore, it is likely that the ebb channel was too tortuous to be efficient, resulting in the formation of the second, more direct ebb channel.

Subsequent aerial photographs of 1987 (Figure 3.10) and 1988 show that the configuration of the lower estuary changed very little since 1985. It is also clear that local sedimentation has occurred at the estuary end of the seaward marina canal. This canal has been periodically dredged, to enter directly into the estuary, as evident in a recent aerial photograph (1990). A berm wall innovated by a local resident is also evident. This has clearly succeeded in concentrating tidal flow in the canal,

to assist in keeping the channel open but the sand mass at the end of the sand spit moves upstream, thereby threatening to close the channel (This actually occurred recently).

3.3.3 Conclusions

It is clear that extensive redistribution of sand has occurred in the lower estuary, especially since 1975. Aerial photographs show that the closure of the seaward access canal is due to a change in the configuration of tidal channels, which caused the flood-tidal delta to move from the northern to the southern bank. There are some indications that this occurred naturally.

3.4 Beach and Dune Dynamics

The dynamics of the beaches adjacent to the Kromme mouth and of the nearby headland bypass dunefield, may have a significant effect on sedimentation in the lower estuary.

3.4.1 The dunefield

Sand from the Santareme dunefield is blown into the sea by the prevailing westerly wind. This sand is then transported to the Cape St. Francis beach, by wave-induced longshore transport (Chapter 2). This dune sand supply is investigated.

3.4.1.1 Observations

Aerial photographs show that the Santareme dunefield to the south of the Kromme Estuary was extensively stabilized. Photographs dating between 1942 and 1981 show that two thirds of the contact zone between the dunefield and the coast was blocked by the southern section of the Sea Vista development (Fromme and Badenhorst, 1987). By 1987 even more stabilization had occurred. Figure 3.11 schematically illustrates the increase in stabilization from 1969 to 1987. This reduction in supply probably affects the St Francis Bay beach.

3.4.2 The St. Francis Bay beach

Since the estuary may be affected by the condition of beaches adjacent to the estuary mouth, an aerial photograph study of the beach along St. Francis Bay, is appropriate.

3.4.2.1 Method

The aerial photographs of 1942, 1961, 1975, 1980 and 1987 were analysed. In order to demarcate the beach shoreline, the photographs were reproduced at a common scale of 1:10 000. A template with a grid for measuring offset distances was constructed, from an undistorted orthophoto. The result of the analysis is a series of traces of the high-water mark (Figure 3.12), and a corresponding table of offset distances measured from the template grid (Table 3.1).

3.4.2.2 Results and discussion

The analysis tends to indicate a fairly static situation until 1975, with a maximum beach accretion around 1969. A fairly severe setback from the average values is evident from the 1980 photograph, particularly in the vicinity of Sea Vista beach. This situation follows extreme storms in both 1978 and 1979. The analysis of the 1987 photograph indicates a slow recovery of the beaches near Sea Vista, suggesting that the longshore sand supply from Cape St Francis point is small (supporting the findings of the coastal sediment dynamics study - Chapter 2).

In the region of the sand spit at the Kromme mouth, a steady trend towards increasing beach erosion is detected. Quantifying this erosion since 1969, the beach has receded an average distance of approximately 40 m, over the 600 m stretch of beach adjacent to the mouth. This may be due to the stabilization of the Santareme dunefield, which also occurred in earnest from 1969.

3.5 The Flood-tidal Delta

As mentioned above, the flood-tidal delta is the sand body upon which sand is deposited by flood-tidal flow. The rate of growth of this delta gives some indication of the rate of sand

transport into the estuary. Since the flood-tidal delta tends to grow laterally, an increase in the plan area of the flood-tidal delta represents an increase in volume.

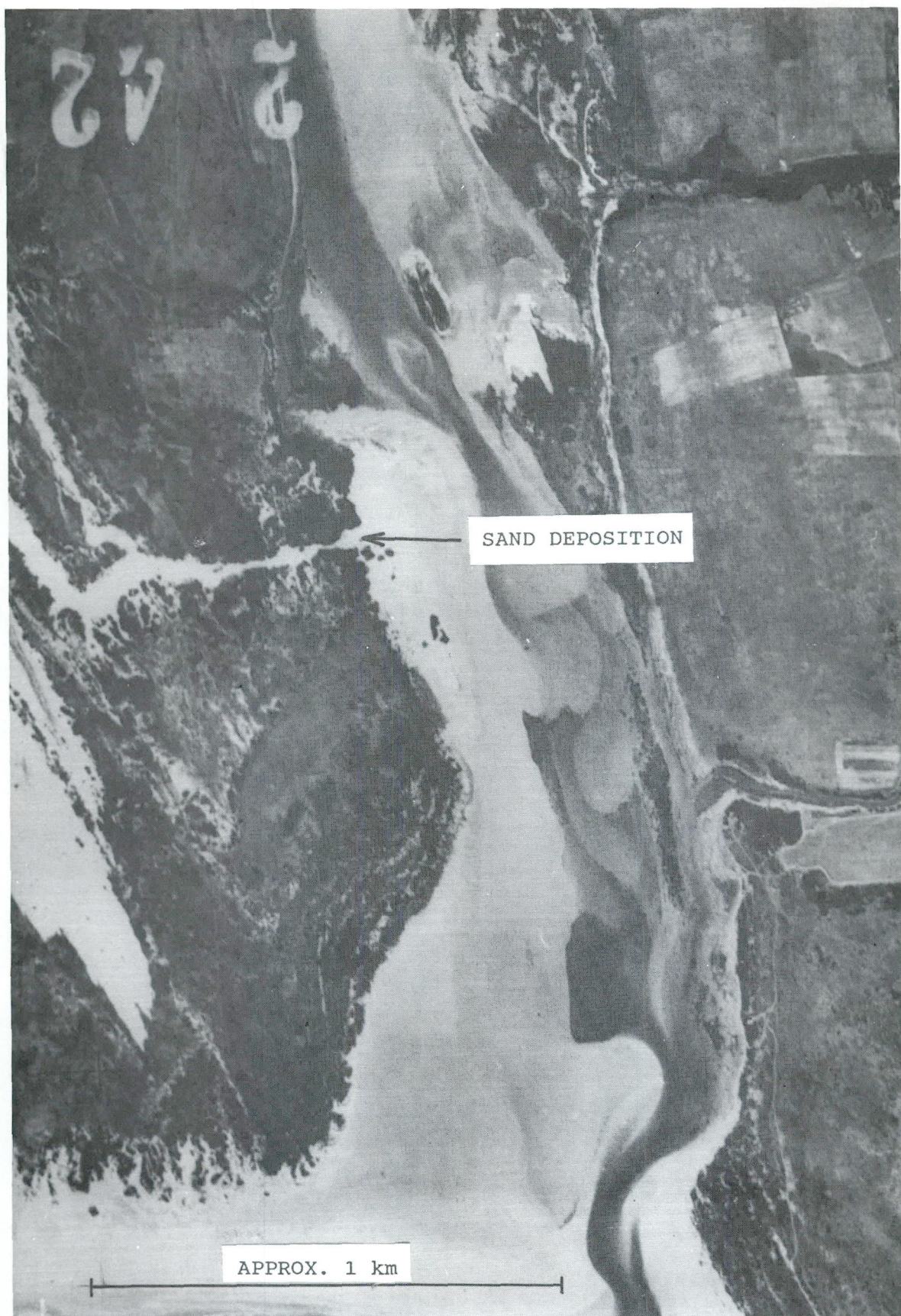
The areas of the flood-tidal deltas in 1987 and 1990 were obtained from photographs. The delta area in 1987 was 12.2 ha and the delta area in 1990 was 13,0 ha. This would indicate an increase of 0,8 ha in three years, however, uncertainties about tidal water-levels and inaccuracies in aerial photography analysis warrant caution. The aerial photographs show in general a stable flood-tide delta, which underwent small changes over the years, indicating that little net transport into or out of the estuary occurred due to the tides.

REFERENCES

- CSIR (1984). The Kromme Estuary. Stellenbosch. CSIR Report C/Sea 8354 (Revised).
- CSIR (1985). Hydrological/Hydraulics study of Cape estuaries, Kromme CMS 45. Stellenbosch. NRIO Data Report D8502.
- FERREIRA, E.P. (1983). The sedimentology of the St Francis Bay area - lower Kromme estuary and beach. Dept. of Geology, University of Port Elizabeth, Unpubl. B.Sc.hons. Proj., 49pp.
- FROMME, G.A.W. and BADENHORST, P. (1987). The dynamics of the estuaries of St. Francis Bay (Kromme, Seekoei and Kabeljous). Stellenbosch. CSIR Report T/SEA 8707.
- REDDERING, J.S.V. and ESTERHUYSEN, K. (1983) Sedimentation in the Kromme Estuary, Dept. of Geology, University of Port Elizabeth. ROSIE Report no. 6,
- REDDERING, J.S.V. (1988). Prediction of the Effects of Reduced River Discharge on the Estuaries of the South-Eastern Cape Province, South Africa. South African Journal of Science, vol.84.

TABLE 3.1: OFFSETS OF BEACH WIDTHS ALONG ST. FRANCIS BAY
 Alongshore intervals of 100m from aerial photographs (1942-1987)
 *Offsets from beach survey for April 1990
 Stn. 0 : Sea Vista beach
 Stn. 3000 : Krome Inlet Spit

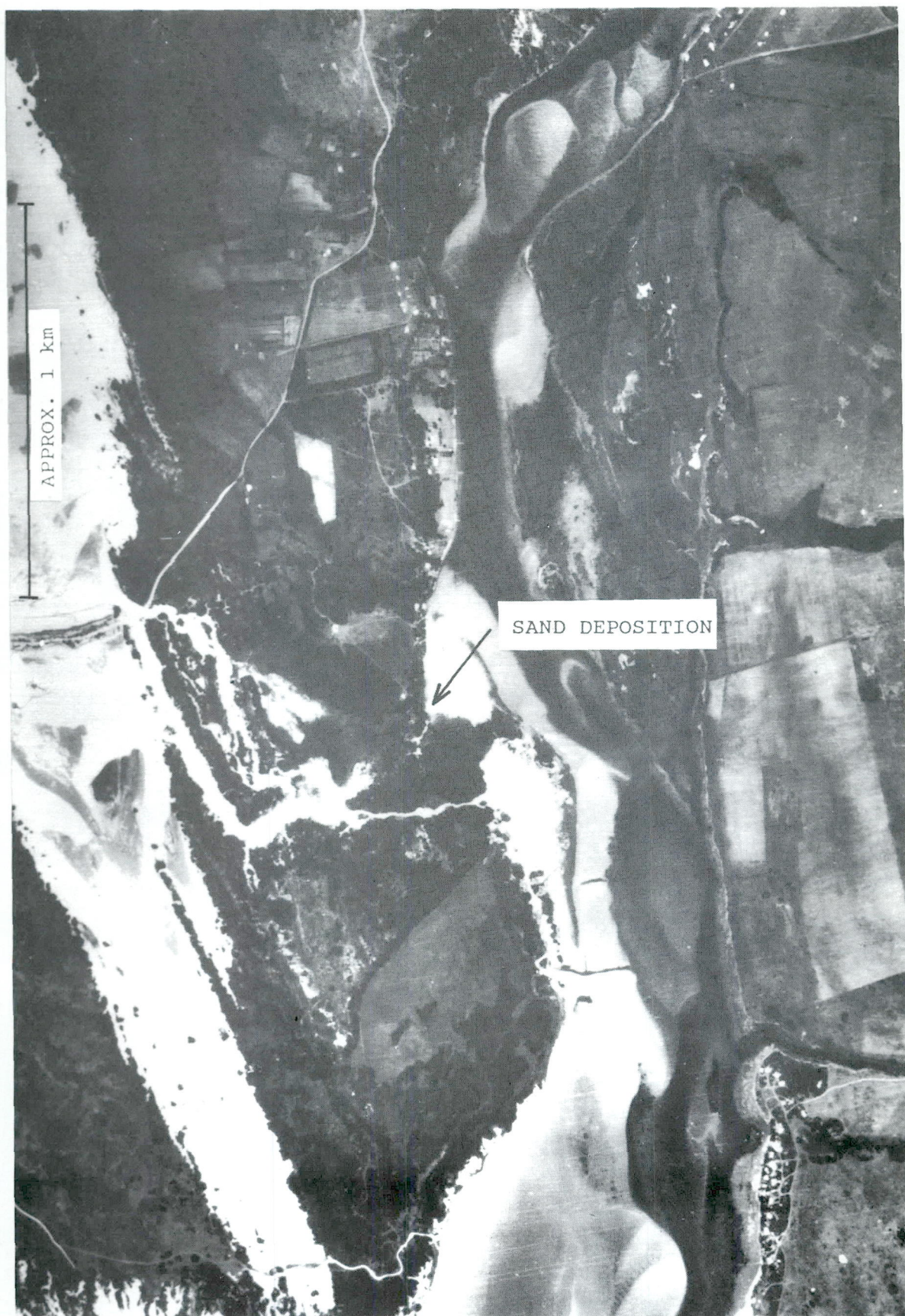
STN (m)	DATE				OFFSETS				* 10 APR 1990	AVG	OFFSET FOR THE YEAR MINUS THE AVERAGE OFFSET							
	FEB 1942	24 1961	NOV 1961	8 1969	MAY 1969	JULY 1975	JULY 1980	3 1980	FEB 1987		1942	1961	1969	1975	1980	1987	1990	* 1990
0	450	440	440	440	440	430	430	430	440	438	12	2	2	-8	-8	2	-13	0
100	310	360	360	325	325	350	290	285	285	318	-8	42	7	32	-28	-33	7	-13
200	240	260	260	265	265	265	215	235	235	248	-8	12	17	17	-33	-13	6	-13
300	195	220	220	220	220	225	185	200	200	209	-14	11	11	16	-24	-9	6	-2
400	155	195	195	195	195	190	160	170	170	177	-22	18	18	13	-17	-7	11	-2
500	130	160	160	170	170	160	120	140	140	149	-19	11	21	11	-29	-9	11	11
600	130	160	160	150	150	150	120	140	140	144	-4	11	6	6	-24	-4	11	11
700	135	165	165	165	165	160	135	145	145	151	-16	14	14	9	-16	-6	-1	-1
800	130	170	170	155	155	145	125	125	125	141	-11	29	14	4	-16	-16	-1	-1
900	135	160	160	135	135	145	100	100	130	132	3	28	3	13	-32	-12	-2	-2
1000	145	150	150	150	150	145	100	130	130	137	8	13	13	8	-37	-7	3	3
1100	145	155	155	155	155	165	130	130	145	146	-1	9	9	19	-16	-16	-1	-1
1200	155	170	170	165	165	165	125	145	145	154	1	16	11	11	-29	-9	1	1
1300	155	190	190	185	185	170	125	160	160	164	-9	26	21	6	-39	-4	-4	-4
1400	170	200	200	205	205	175	150	175	185	180	-10	20	25	-5	-30	-5	5	5
1500	175	210	210	215	215	200	170	185	185	194	-19	16	21	6	-24	-9	6	6
1600	190	215	215	220	220	200	180	185	201	201	-11	14	19	-1	-21	-16	14	14
1700	185	215	215	220	220	195	190	190	201	201	-16	14	19	-6	-11	-11	9	9
1800	200	220	220	220	220	205	205	205	215	210	-10	10	10	-5	-5	-5	5	5
1900	205	215	215	230	230	220	210	205	220	215	-10	0	15	5	-5	-10	5	5
2000	205	215	215	225	225	220	215	205	205	215	-10	0	10	5	0	-10	5	5
2100	200	205	205	220	220	210	190	190	200	205	-5	10	15	5	-15	-15	15	15
2200	175	200	200	210	210	190	175	180	180	190	-15	10	20	0	-15	-10	10	10
2300	170	180	180	200	200	190	185	180	180	184	-14	-4	16	6	1	-4	-4	-4
2400	170	170	170	205	205	185	175	165	170	177	-7	-7	28	8	-2	-12	-7	-7
2500	175	175	175	200	200	180	165	155	155	173	2	2	27	7	-3	-18	-18	-18
2600	175	170	170	195	195	175	165	155	160	171	4	-1	24	4	-6	-16	-11	-11
2700	185	190	190	200	200	175	170	160	155	176	9	14	24	-1	-6	-16	-21	-21
2800	180	185	185	200	200	185	170	155	155	176	4	9	24	9	-6	-21	-21	-21
2900	170	190	190	200	200	165	205	155	155	177	-7	13	23	-12	28	-22	-22	-22
3000	110	145	145	200	200	150	145	125	125	146	-36	-1	54	4	-1	-21	-22	-22
AVG.	183	202	202	208	208	196	175	175	179	190	-8	11	17	6	-15	-12	0	0



THE 1942 AERIAL PHOTOGRAPH

PLATE 1

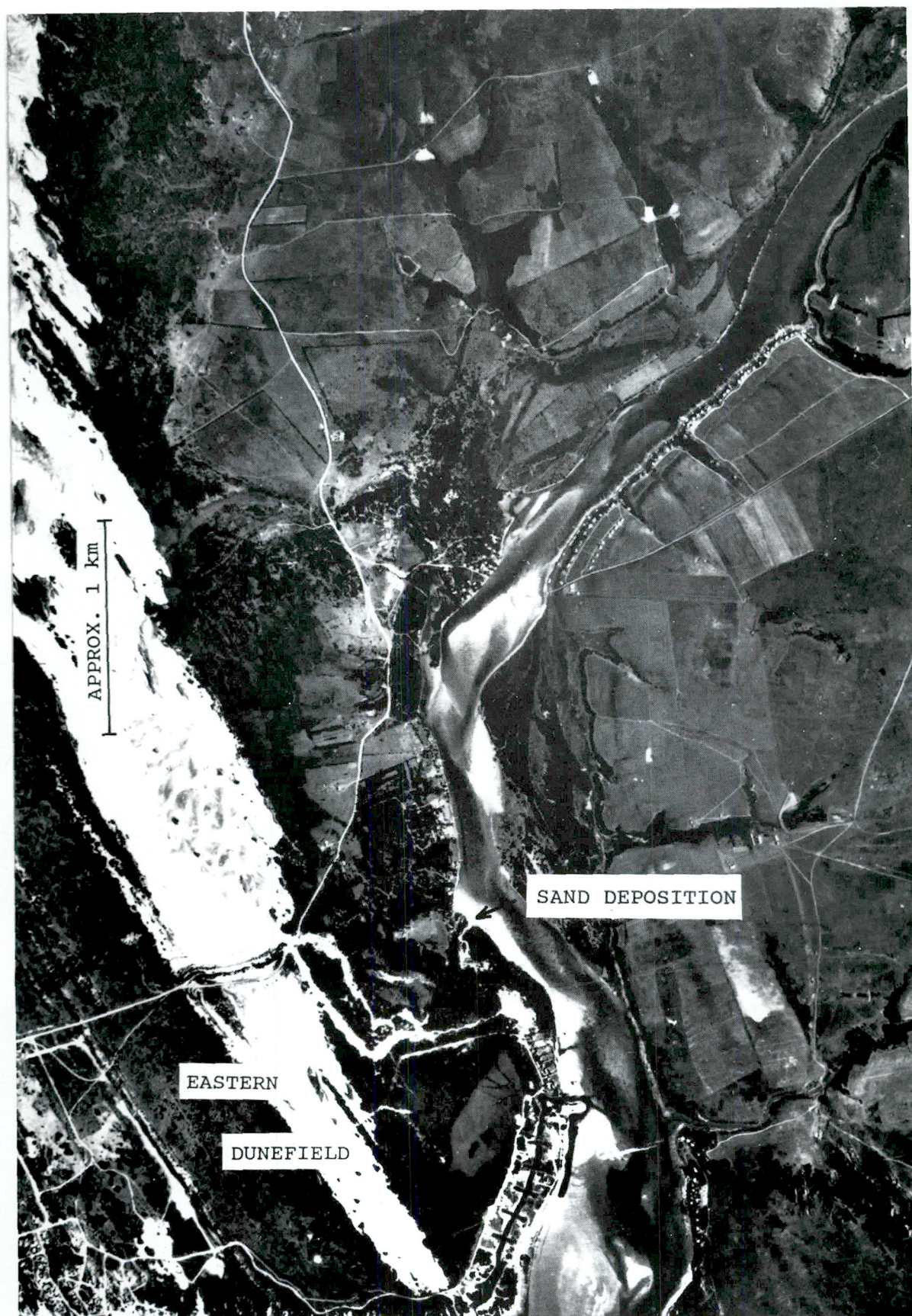




THE 1961 AERIAL PHOTOGRAPH

PLATE 2

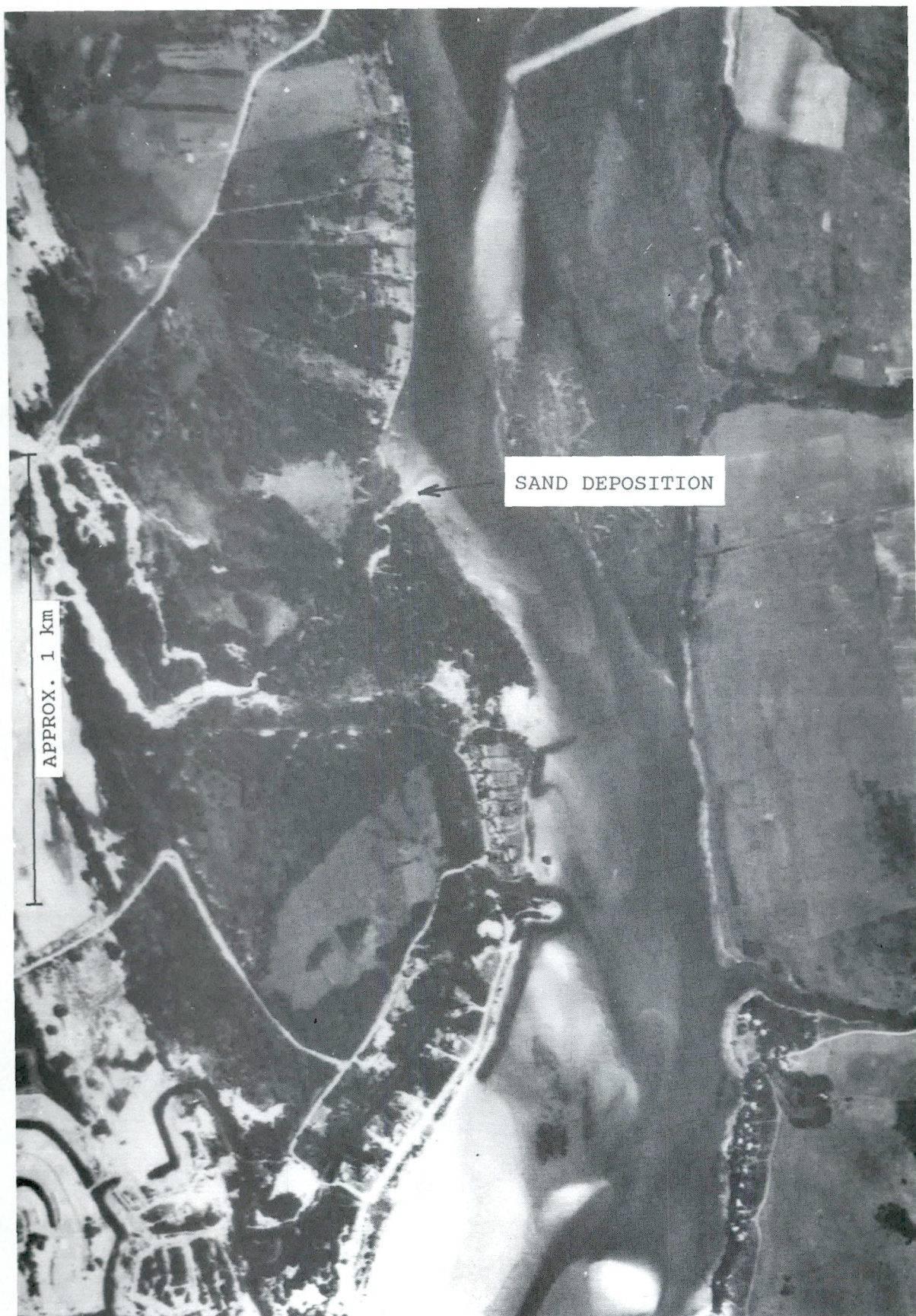




THE 1969 AERIAL PHOTOGRAPH

PLATE
3





THE 1975 AERIAL PHOTOGRAPH

PLATE
4





THE 1981 AERIAL PHOTOGRAPH

PLATE
5

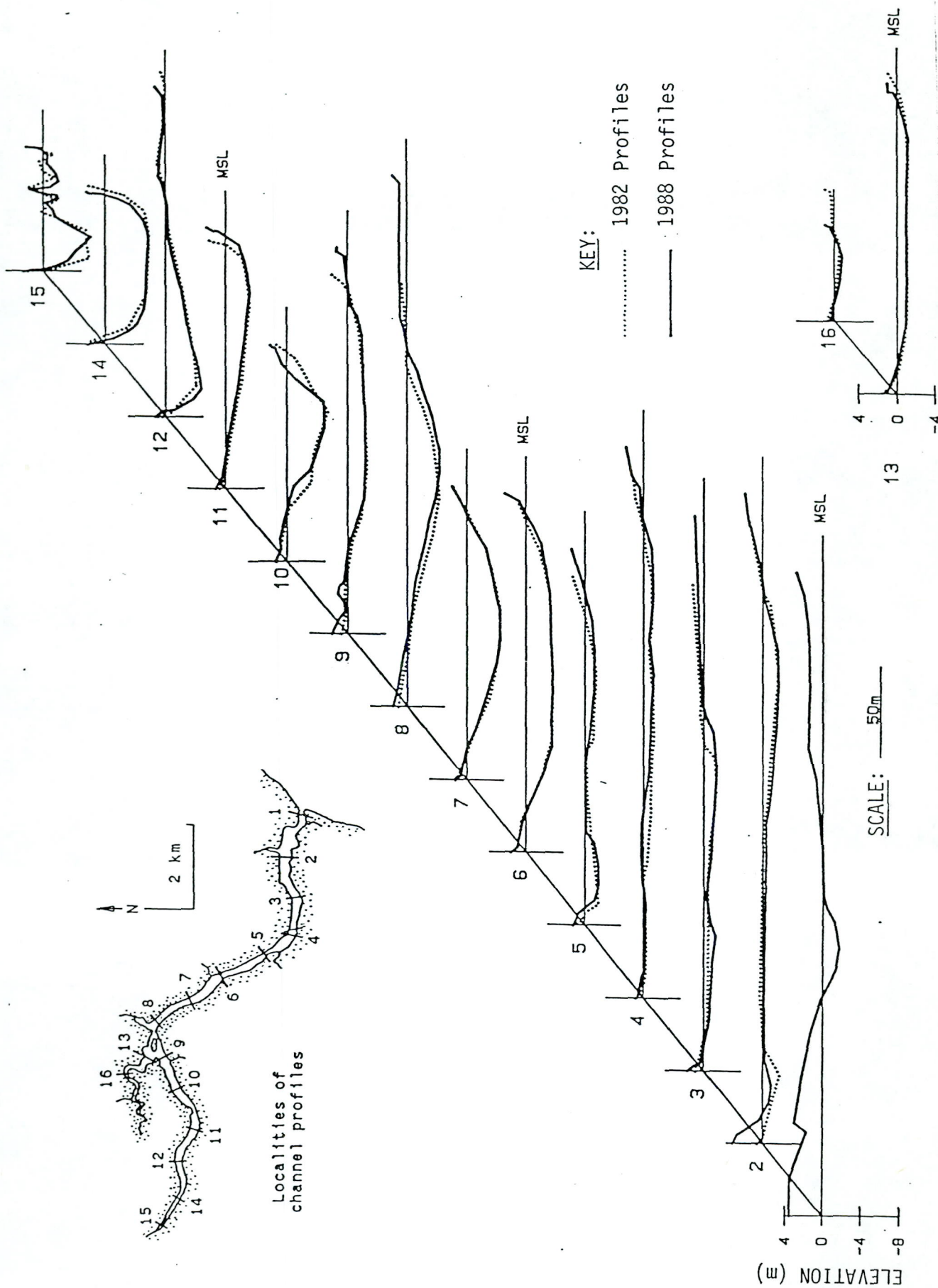




THE 1987 AERIAL PHOTOGRAPH

PLATE 6

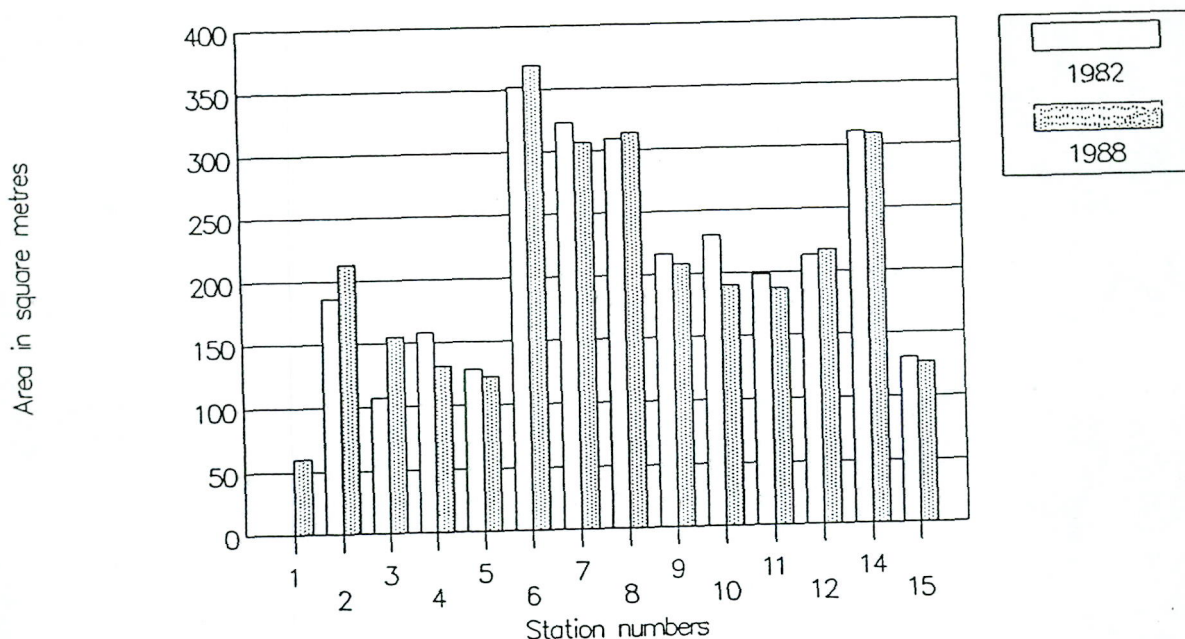




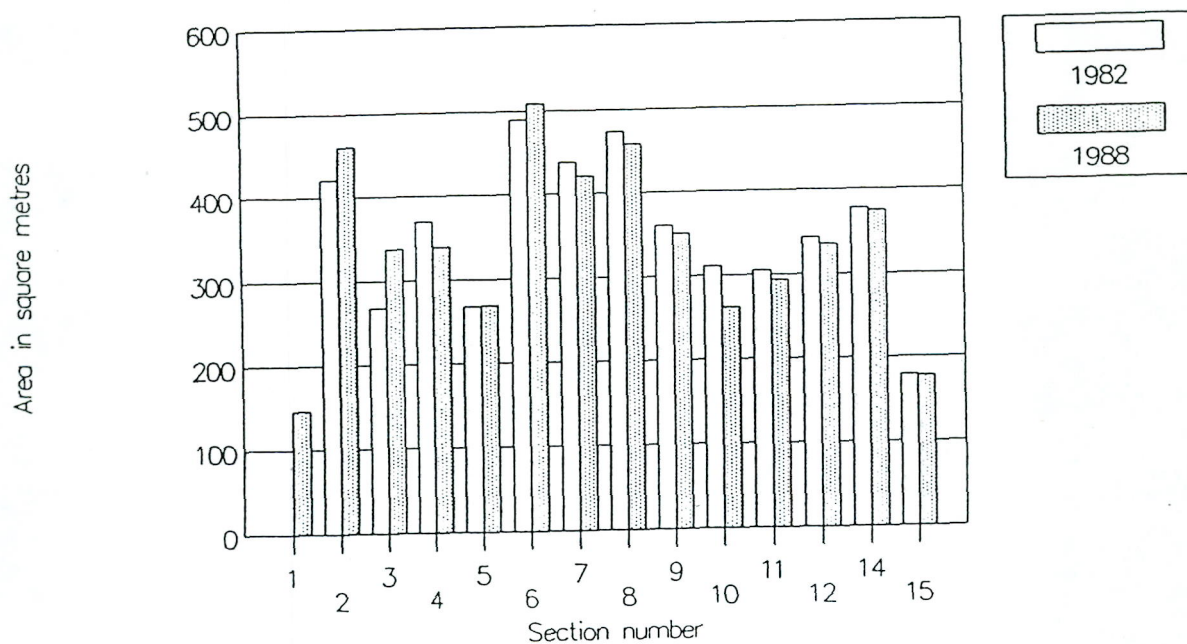
SURVEYED CROSS SECTIONS

FIGURE
3.1

Cross-sectional areas at msl: Krom estuary 1982 vs 1988



Cross-sectional area at msl + 0,8m: Krom estuary 1982 vs 1988

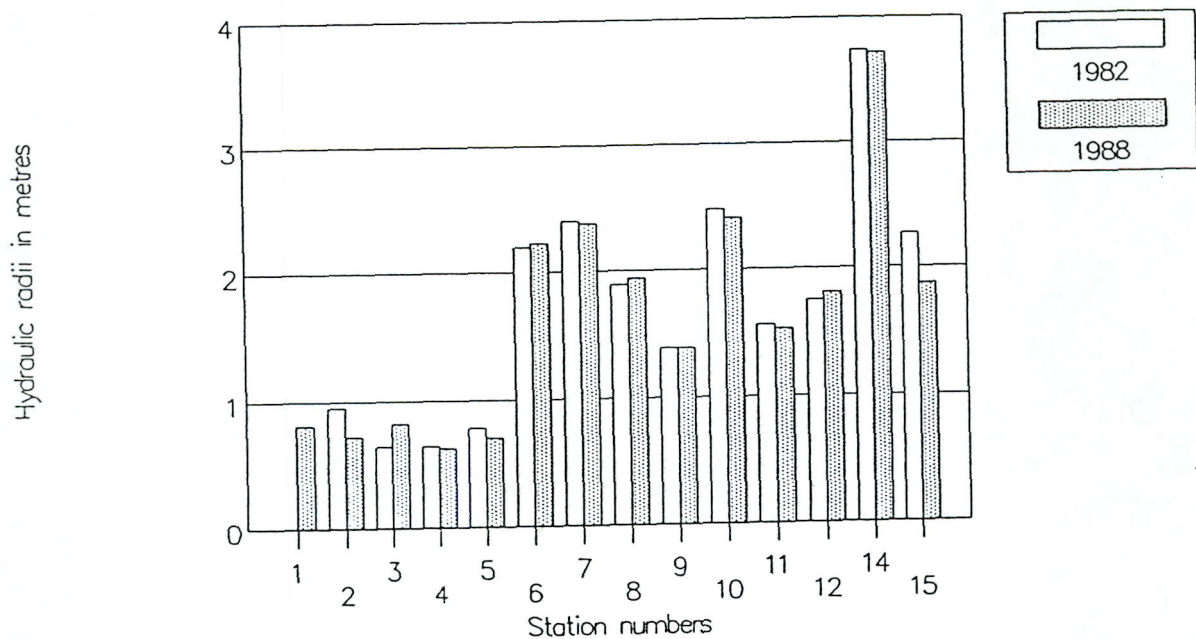


KROMME ESTUARY - CROSS-SECTIONAL
AREAS 1982 - 1988

FIGURE 
3.2

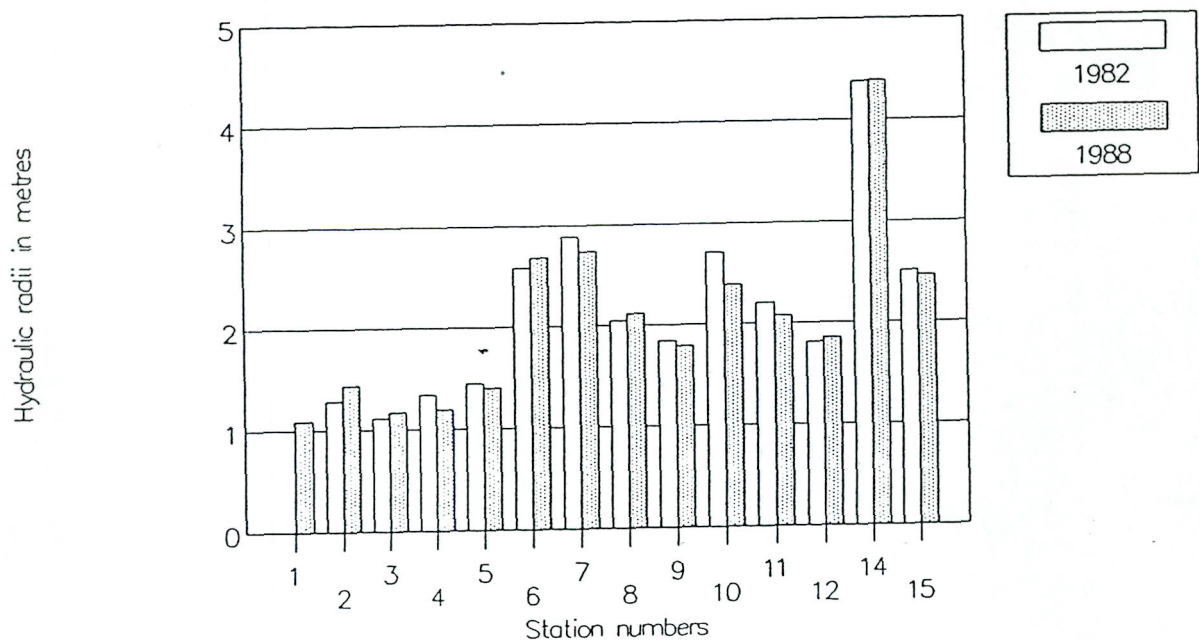
Hydraulic radii at msl

Krom estuary 1982 vs 1988

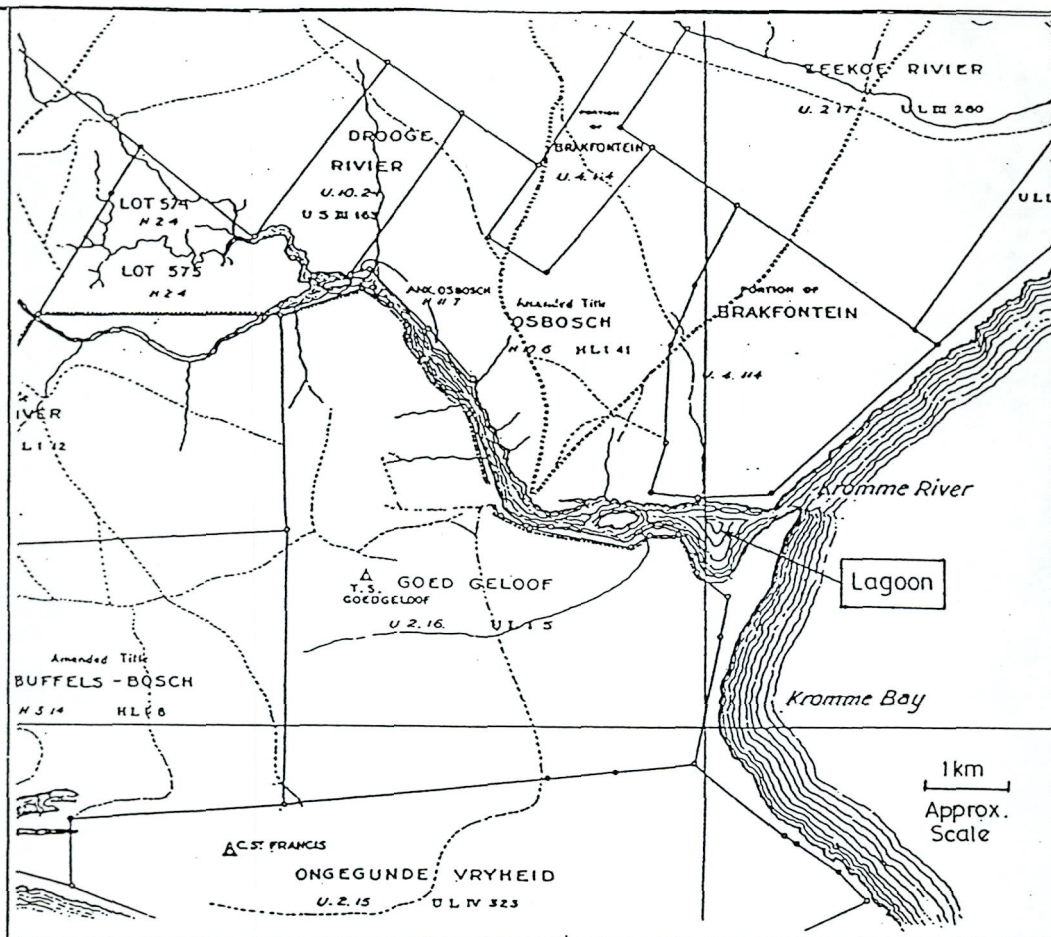


Hydraulic radii at msl + 0.8m

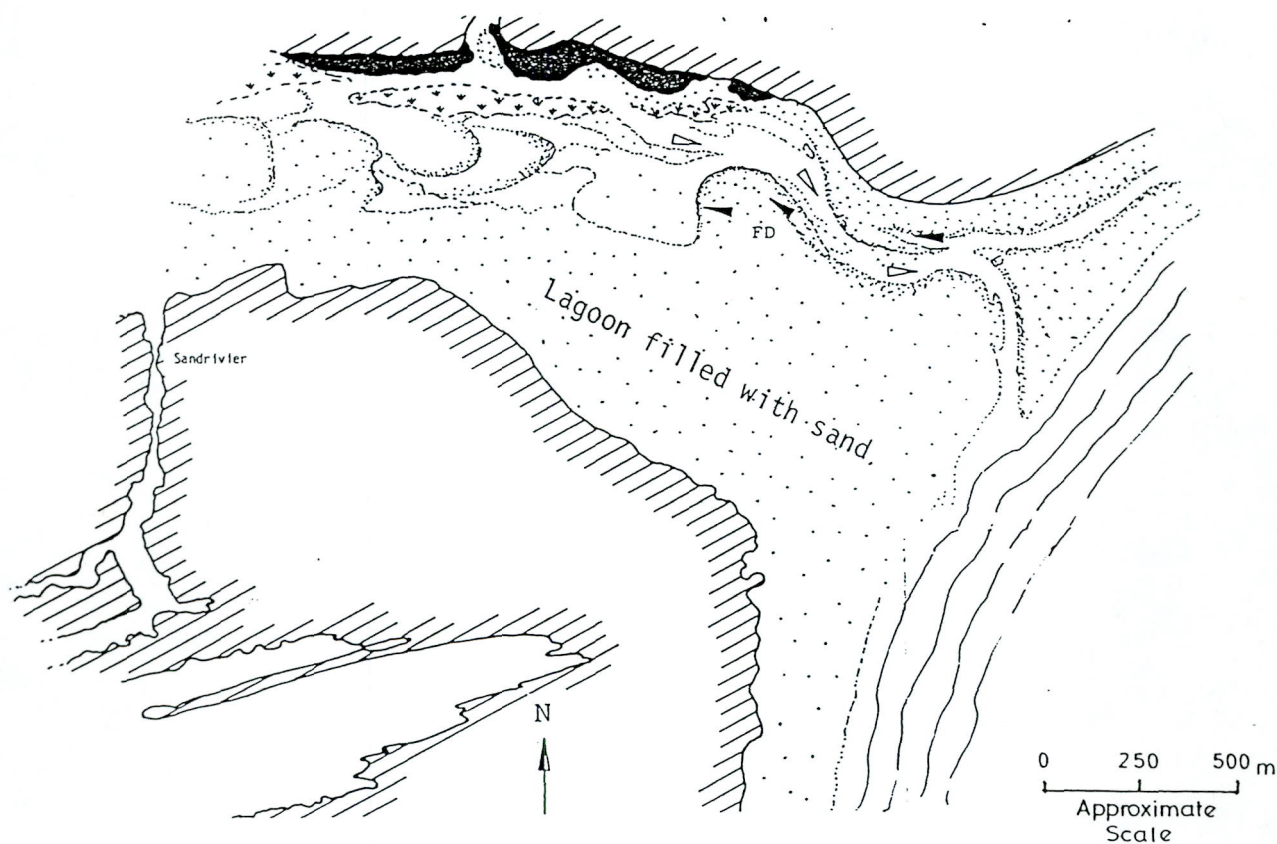
Krom estuary 1982 vs 1988



KROMME ESTUARY - HYDRAULIC RADII
1982 and 1988



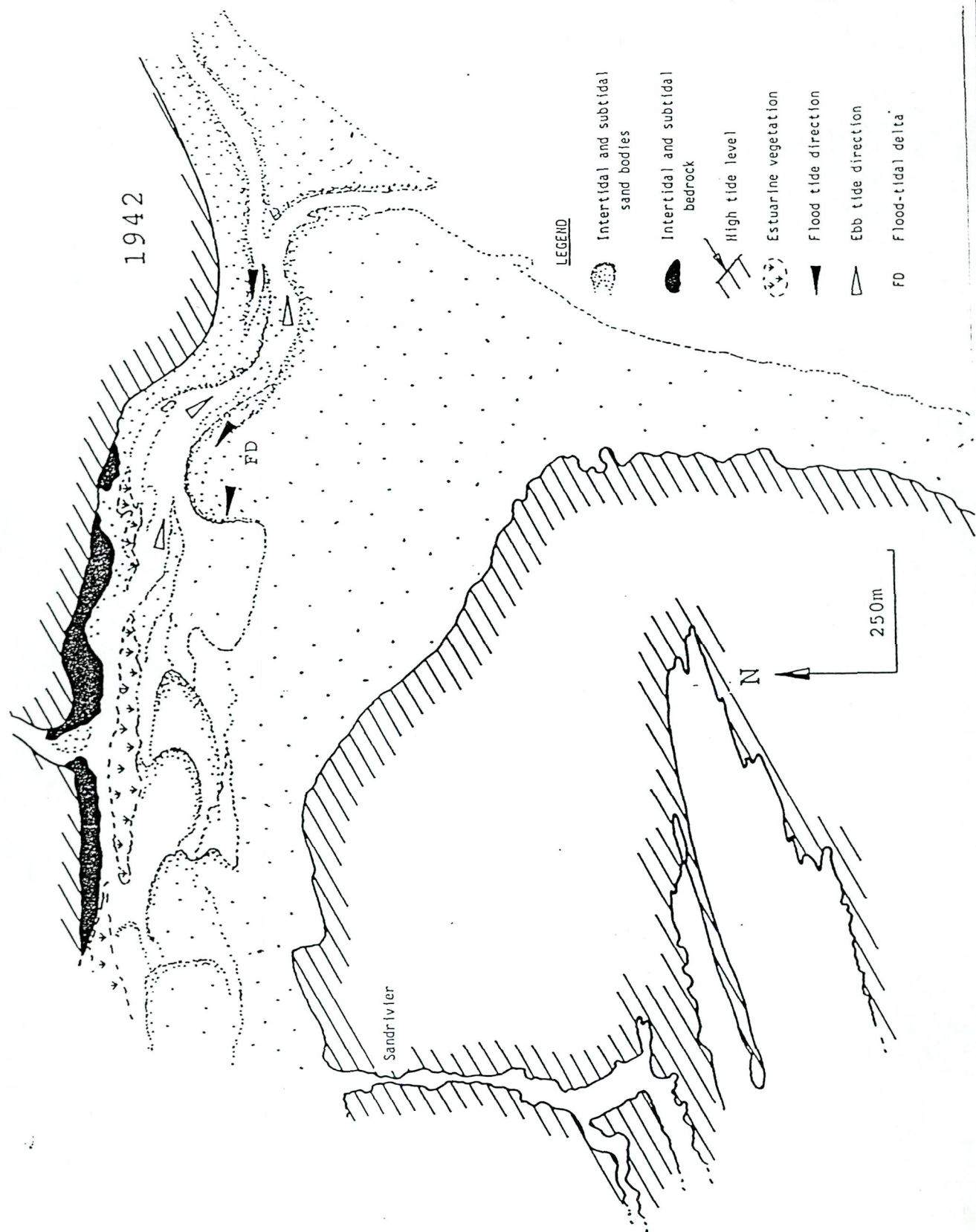
DIVISIONAL MAP OF HUMANSDORP; 1921
(Cape Archives M4/1574)



REPRODUCTION OF 1942 AERIAL PHOTOGRAPH
(Reddering and Esterhuysen, 1983)

SEDIMENTATION OF THE LAGOON
BETWEEN 1921 AND 1942

FIGURE 
3.4



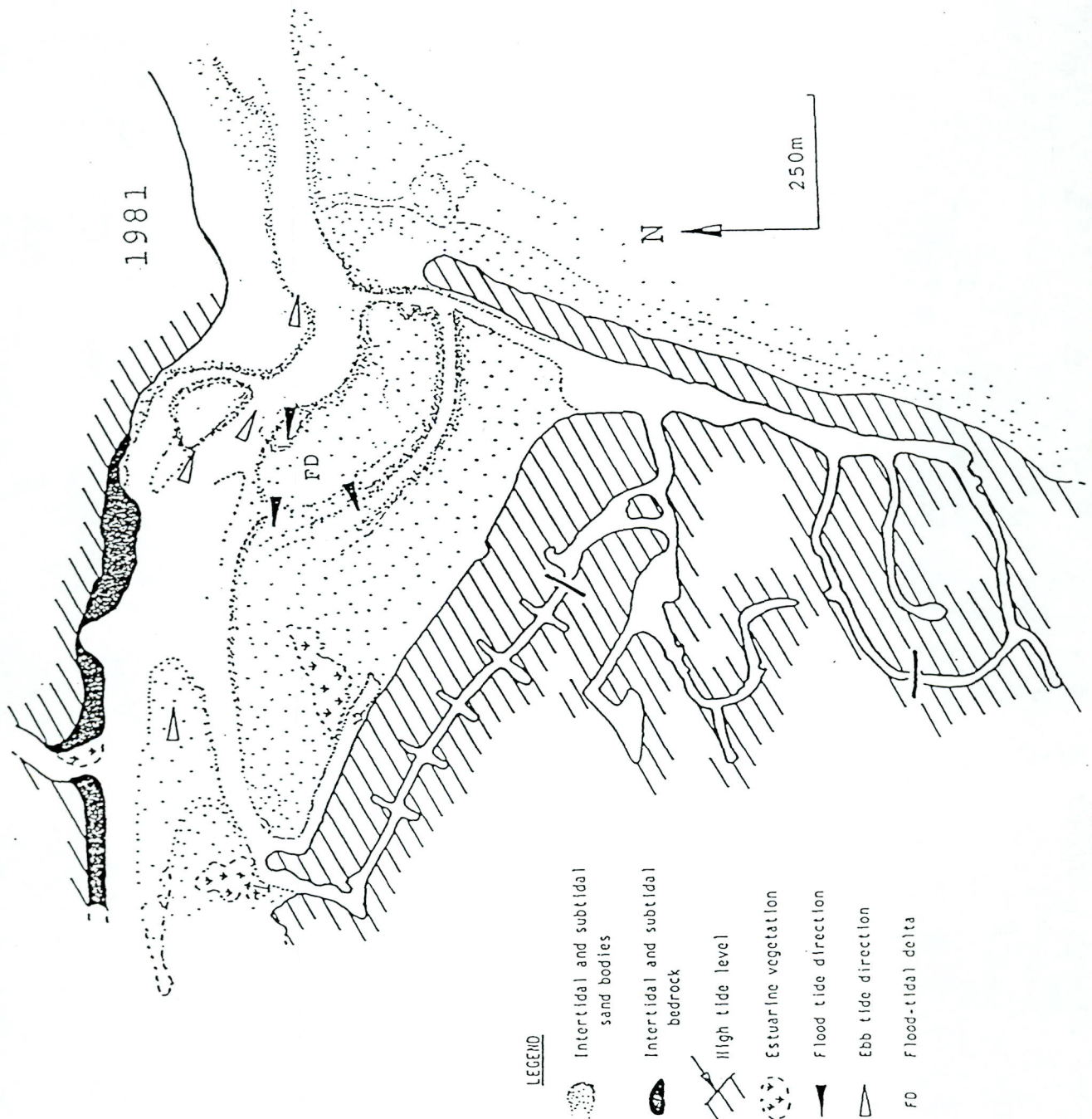
TIDAL CHANNELS AT THE KROMME MOUTH
(from the 1942 aerial photograph)
(Reddering and Esterhuysen, 1983)

FIGURE

3.5



FIGURE
3.7

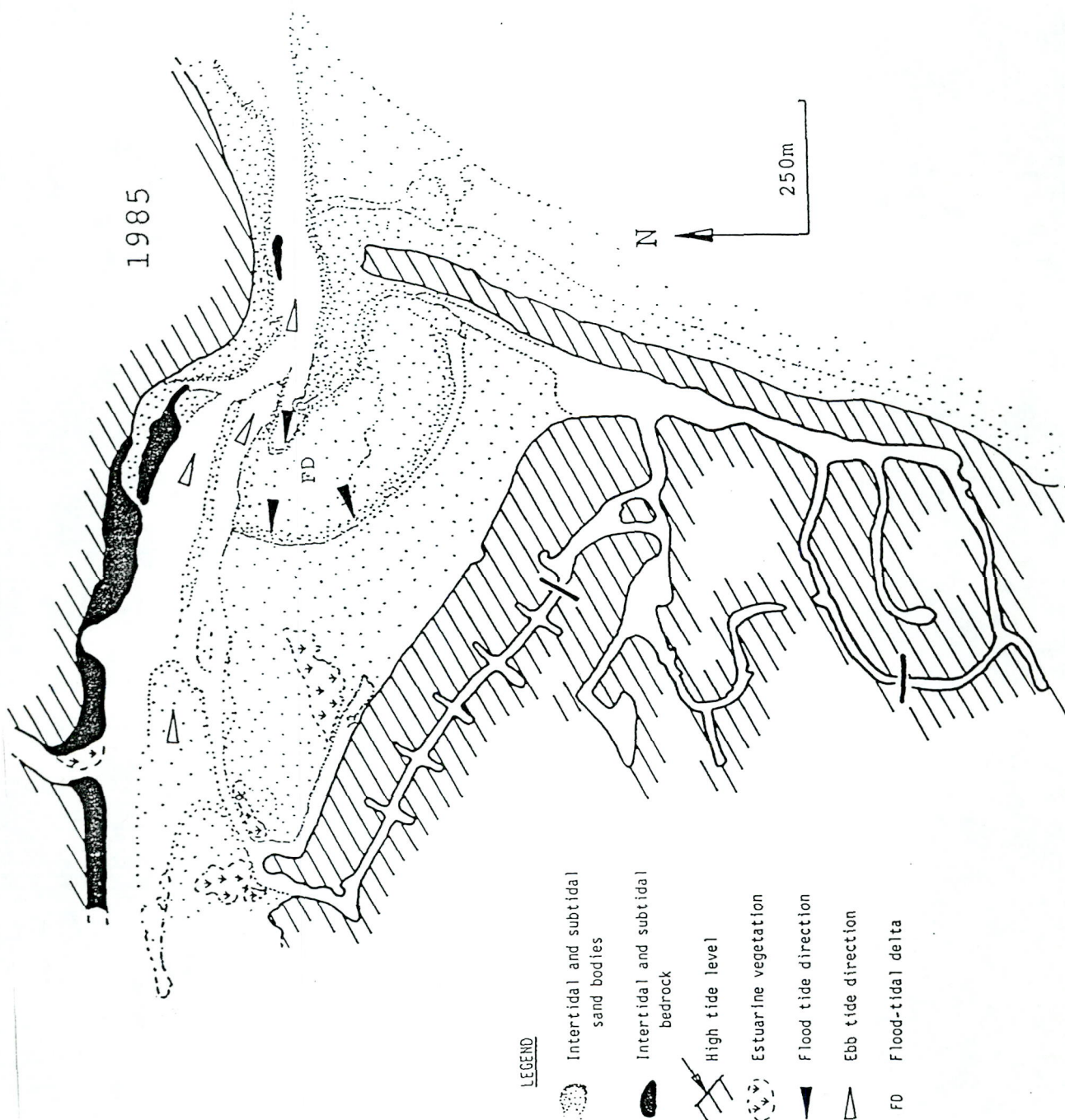


TIDAL CHANNELS AT THE KROMME MOUTH

(from the 1981 aerial photograph)
(Reddering and Esterhuysen, 1983)

FIGURE

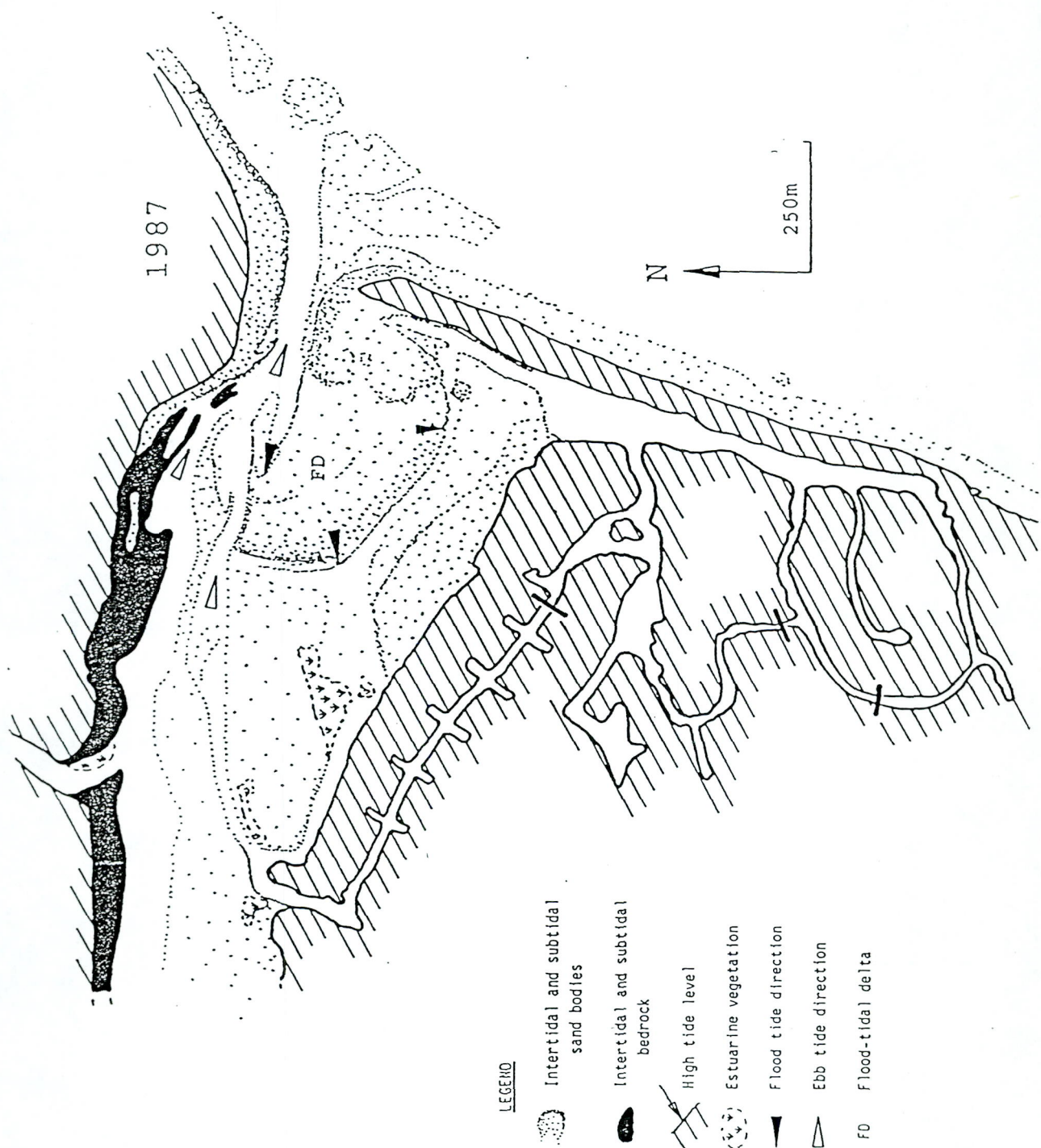
3.8



TIDAL CHANNELS AT THE KROMME MOUTH
(from the 1985 aerial photograph)

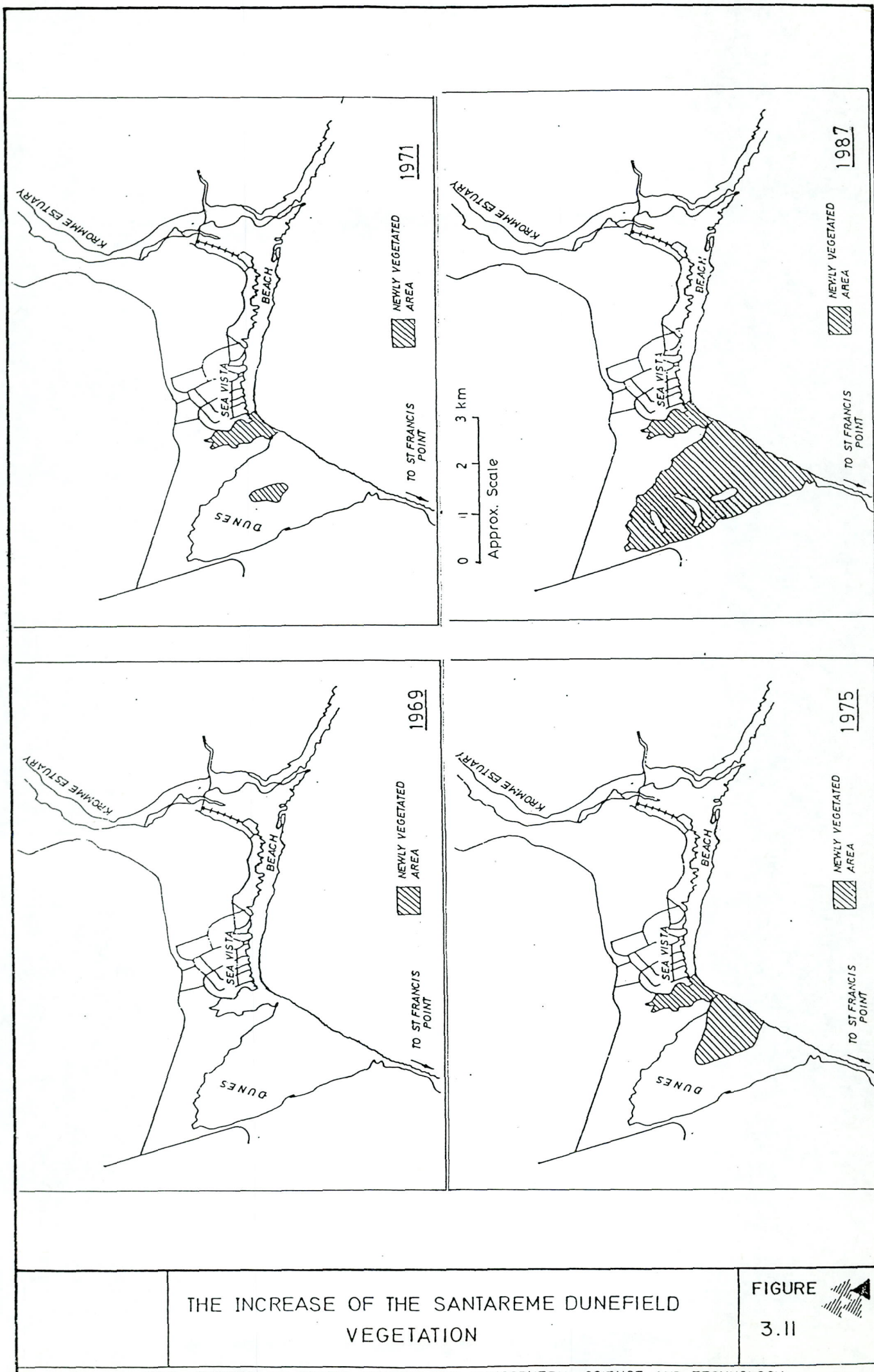
FIGURE

3.9



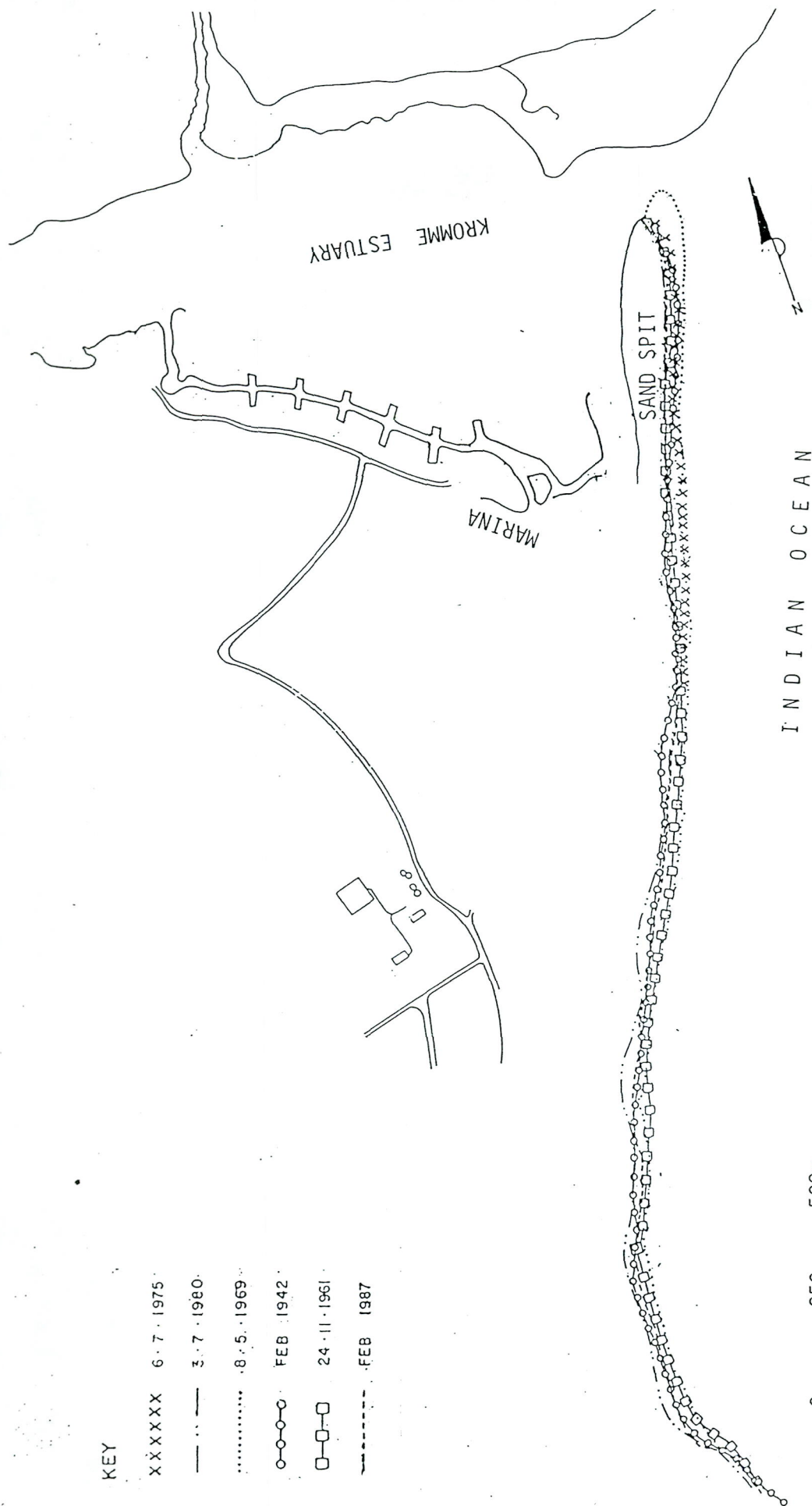
TIDAL CHANNELS AT THE KROMME MOUTH
(from the 1987 aerial photograph)

FIGURE
3.10



THE INCREASE OF THE SANTAREME DUNEFIELD
VEGETATION

FIGURE 3.11



HIGH WATER MARKS ALONG ST FRANCIS BAY BEACH
(1942- 1987)

FIGURE
3.12



4 FLOOD SCOUR STUDY

4.1 Introduction

The primary aim of this study is to determine the effect of upstream damming on the potential of floods to scour sediment from the estuary. To achieve this, a hydrological study was conducted by the University of Stellenbosch to calculate the flood hydrographs, including and excluding the dams. The resulting simulated discharge rates were then used in a hydrodynamic estuary model, to determine the flood flows in the lower estuary, the area of concern. Finally, using this information in a sediment dynamics computation, the quantities of scoured sediment for the various simulated floods were computed.

4.2 The Flood Hydrograph Study

4.2.1 General catchment information

The Kromme River rises east of Joubertina and flows in a southeasterly direction into the Indian Ocean near Cape St Francis (Figure 4.1). The mean annual precipitation (MAP) over the catchment ranges between 600 mm in the lower reaches and 1100 mm in the upper reaches. General catchment information is summarised in Table 4.1.

4.2.2 Empirical distribution of dam storage capacities

The dams in the catchment have an attenuating effect on floods. In order to perform a flood retention calculation, the storage capacity of the dam at the beginning phase of the routing procedure must be known, or a plausible value must be assumed. Reservoir records have been analyzed to find the probabilities of certain storage capacities being equalled or exceeded.

4.2.2.1 Churchill Dam

Inflow data for the Churchill Dam for the period 1938 - 1988 are presented in Table 4.2 and for the period 1948 - 1988 for the C W Malan Dam in Table 4.4. A monthly record of the reservoir capacities for the Churchill Dam for the period 1948 - 1988 is

presented in Table 4.3 and graphically displayed in Figure 4.3. The cumulative frequency distribution of these data, presented in Figure 4.4, shows that the reservoir was 100 percent full or spilling for 20 percent of the time, 50 percent of the time the reservoir was 80 percent full or more and 80 percent of the time the reservoir was 50 percent full or more.

4.2.2.2 C W Malan Dam

Only 5,5 years of reservoir record are available for the C W Malan Dam since the completion of the dam in 1983. These data, together with the corresponding data for the Churchill Dam are presented in Figure 4.5 and a cumulative frequency distribution of the same data is given in Figure 4.6. During this time the volume of water in the dam dropped from 100 percent to below 30 percent, due to a drought period. At the Churchill Dam a similar performance was experienced.

It should be noted that the reservoir capacity records are also influenced by the water usage strategy of the Department of Water Affairs and/or the Port Elizabeth City authorities.

Figure 4.5 shows that after the C W Malan Dam was filled in August 1983, little water was used till September 1985. Thereafter a steady decline in water volume in the C W Malan Dam till the end of the data record (March 1989) is visible. It was decided that at this stage for C W Malan Dam the same distribution of reservoir capacities could be used as that calculated for Churchill Dam (Fig. 4.4).

4.2.3 Flood calculations

Floods (peaks and volumes) for rainfall durations up to 24 hours and return periods up to 50 years have been computed at points 1, 3 and 5 (Figure 4.7) in the catchment, as well as for the Diep River and for the Geelhoutboom River.

Families of flood hydrographs have been calculated with a non-uniform rainfall distribution by means of the Peak Factor Method (Sinske, 1988), with rainfall intensities according to Sinske

(1982), and area reduction factors according to Alexander (1980). Runoff factors were calculated by Curve Number Method (Burec, 1973).

Calculations at points 3 and 5 do not take into account any attenuating influence of dams and are for comparison and auxiliary purpose only. The results are shown in the tables and the figures.

4.2.3.1 Design floods

Design flood calculations were performed for a number of locations and conditions in the catchment.

Table 4.5: Inflow (design floods) into the Churchill Dam

Design floods for various rainfall durations and return periods of 2, 5, 10, 20 and 50 years for the inflow into the Churchill Dam (point 1 in Figure 4.7) are shown in Table 4.5.

Table 4.6 and 4.7: Inflow (design floods) into the C W Malan Dam, excluding and including the Churchill Dam Catchment respectively

Similar design floods for the same return periods for the inflow into the C W Malan Dam (point 3 in Figure 4.7) are presented in Tables 4.6 and 4.7.

In Table 4.6 the Churchill Dam catchment has not been included. In Table 4.7 this catchment is included, but the existence of the Churchill Dam is ignored.

Table 4.8: Inflow (design floods) from the Geelhoutboom River

Design floods for the Geelhoutboom River (see Figure 4.7) are presented in Table 4.8.

Table 4.9: Inflow (design floods) into the estuary, ignoring the dams

Design floods for the whole catchment, ignoring the existence of the dams are presented in Table 4.9.

4.2.3.2 Flood peaks and volumes

Calculations of flood peaks and volumes were performed for a number of locations and conditions in the catchment.

In order to reduce computation work, it was decided that for further flood calculations at points 2, 3, 4 and 5 (see Figure 4.7), where reservoir- and streamflow routing had to be done, only one rainfall duration, representative of the whole should be adopted. According to Nemec (1972), a rainfall duration of 12 hours was chosen.

The results of the computations of the flood peaks and volumes for various positions in the catchment, for the conditions described above, are summarized in a number of tables.

Table 4.10: Outflow (peak flows and volumes) from the Churchill Dam

Peak flows and volumes for return periods of 2, 5, 10, 20 and 50 years for the outflow from the Churchill Dam (point 2 in Figure 4.7) are shown in Table 4.10 for the dam being 100 %, 80 % and 50 % full.

Table 4.11: Inflow (peak flows and volumes) into the C W Malan Dam.

Similar peak flows and volumes for the inflow into the C W Malan Dam (point 3 in Figure 4.7) are presented in Table 4.11 for the Churchill Dam being 100 %, 80 % and 50 % full.

Table 4.12: Outflow (peak flows and volumes) from the C W Malan Dam

Peak flows and volumes for the outflow from the C W Malan Dam (point 4 in Figure 4.7) are presented in Table 4.12. The nine combinations of the Churchill Dam and the C W Malan Dam being 100%, 80% and 50% full are covered.

Table 4.13: Inflow (peak flows and volumes) into the estuary

Peak flows and volumes for the inflow into the estuary (point 5 in Figure 4.7) are presented in Table 4.13. The nine combinations of the Churchill Dam and the C W Malan Dam being 100%, 80% and 50% full are covered.

4.2.3.3 Flood hydrographs

Hydrographs for inflow into the estuary, determined for the various situations and flood return periods, are also presented in tables and figures.

Table 4.14 and Figure 4.8: Flood hydrographs for the Kromme Estuary without the dams.

Flood hydrographs for return periods of 2, 5, 10, 20 and 50 years for the flow into the estuary (point 5 in Figure 4.7) for the Kromme Estuary without the dams are shown in Table 4.14 and Figure 4.8.

These hydrographs can be used to estimate the scouring potential of riverfloods before the construction of the dams.

Table 4.15 and Figure 4.9: Flood hydrographs for the Kromme Estuary, assuming that both dams are 80 % full.

Similar flood hydrographs for the flow into the estuary (point 5 in Figure 4.7) for the Kromme Estuary with the dams being 80 % full are presented in Table 4.15 and Figure 4.9.

Based on the data on reservoir capacities for both dams (see Figures 4.4, 4.5 and 4.6) it was decided to assume that this situation of an 80 % full capacity of the dams is the most likely one to exist at the start of a flood.

The results show that the 1 : 5 and 1 : 10 year floods are completely absorbed by the dams, only the direct inflow from the Geelhoutboom River occurs in the estuary. The peak flows for the bigger floods are drastically being reduced by the dams. The 1 :

50 year flood from 2 097 m³/s to 1 078 m³/s (46,6 %), the 1 : 20 year flood from 1 536 m³/s to 664 m³/s (56,8 %) and the 1 : 10 year flood from 1 128 m³/s to 294 m³/s (73,9 %)

Table 4.16 and Figure 4.10: Flood hydrographs for the Kromme Estuary, assuming that both dams are 50 % full.

Flood hydrographs for the flow into the estuary (point 5 in Figure 4.7) for the Kromme Estuary with the dams being 50 % full are presented in Table 4.16 and Figure 4.10

The results show that all the floods, except the 1 : 50 year flood, are completely absorbed by the dams. Only the direct inflow from the Geelhoutboom River occurs in the estuary. The peak flow for the 1 : 50 year flood is reduced from 2 097 m³/s (no dams) to 314 m³/s (15,0 %)

4.2.4 Summary and Conclusions

Flood flow into the tidal zone, represents spill from the C W Malan Dam combined with discharge from the Geelhoutboom River. In order to appraise the attenuation effect of the two dams on the flood discharge into the tidal zone, the results of Sections 4.2.4.4 and 4.2.4.5 can be compared with Table 4.9, where floods originating from the total Kromme River catchment have been calculated, ignoring the two dams. An extract of Table 4.9 (for t = 12 h) is given below:

T = 2 a	V = 18,3 hm ³	Q = 387 m ³ /s
T = 5 a	V = 34,1 hm ³	Q = 720 m ³ /s
T = 10 a	V = 53,4 hm ³	Q = 1 128 m ³ /s
T = 20 a	V = 72,7 hm ³	Q = 1 536 m ³ /s
T = 50 a	V = 99,2 hm ³	Q = 2 097 m ³ /s

The detailed flood hydrographs are to be found in Figure 4.9 and in Table 4.15.

For the most likely event that both dams are 80 % full, it can be seen that in the case of the 2 and 5-year floods no significant spill from the C W Malan Dam can be expected, and that the Geelhoutboom River is the main contributor to floods. In the case of the 10-year flood the influence of the Geelhoutboom River diminishes because of the time lag. Less than half of the original flood volume can be expected, with a flood peak a quarter of the original size. In the case of the 20 and 50-year floods 60% to 70% of the original flood volumes can be expected with flood peaks 40% to 50% of the original size.

An additional study was conducted to investigate the effect of the dams on flood flows, if the dams are 50% full. The resulting flood hydrographs are to be found in Figure 4.10 and Table 4.16. Here it is evident that most Kromme River floods are totally halted by the dams, and the only flood flow that occurs is a small contribution from the Geelhoutboom River. The exception is the 50-year flood, for which a relatively small contribution overflows from the dams.

4.3 Hydrodynamic Model Simulations

4.3.1 Estuary flows

The following data, determined above, was entered into the hydrodynamic computer model, to determine the flows in the Kromme Estuary:

- (i) Flood hydrographs with no dams in the catchment (Table 4.15)
- (ii) Flood hydrographs with both dams 80% full (Table 4.14). As determined in the hydrological study, this is the most likely situation.
- (iii) Flood hydrographs with both dams 50% (Table 4.16). In this case, due to the extreme attenuation of smaller floods, only the 50-year flood was worth consideration.

The model simulations revealed that very little attenuation of flood flows occurs between the head and the mouth of the

estuary. The flows resulting from these simulations were used to compute the sediment quantity scoured for the various floods, discussed below (Section 4.4).

4.3.2 The effect of the roadbridge on flood flows

Conditions at the bridge during floods were also investigated, using the hydrodynamic computer model. A 50-year flood was simulated, with the assumption that both dams were 80% full (determined to be the most likely capacity of the dams). The water-levels at peak flow ($1\,078\text{ m}^3/\text{s}$), at positions above and below the bridge (250 m apart), were computed to be +2,73 m and +2,81 m MSL respectively. This small water-level difference of 8 cm over 250 m represents a very gradual water gradient, which indicates that the bridge has no significant effect on water flow. In fact, even steeper water surface gradients are evident upstream of the bridge, under natural conditions.

The 50-year flood, assuming that no dams are present, was also simulated. Even for this condition, the water-level difference between positions above and below the bridge were found to be insignificant, with regard to the flow conditions (i.e. an 11 cm difference).

The northern approach road to the bridge is situated on an embankment across a supratidal flat. For ecological reasons, excessive damming in this region is undesirable (Reddering and Esterhuysen, 1983). From the results of hydrodynamic modelling though, it is estimated that the effect of the embankment is not significant.

4.4 Simulated Sediment Transport

4.4.1 Introduction

The flows computed with the hydrodynamic computer model, as discussed above, are used to determine sediment transport, for various floods. For each of these floods, the effect of the two upstream dams is assessed by simulating the floods that either include, or ignore the dams.

For the numerical calculation of sediment transport, reference is made to formulae proposed by Engelund and Hansen (1967), Ackers and White (1973), and Yang (1976). In extensive evaluations of selected sediment transport formulae, Nakato (1990), White et al. (1976) and Yang (1976) found the above three to be among the most valuable.

Ackers and White used physical considerations and dimensional analysis to derive an equation representing total sediment discharge in terms of dimensionless numbers characteristic of the flow and sediment properties. Also by means of dimensional analysis, Engelund and Hansen relate input power per unit area of channel boundary to sediment discharge. For a more detailed presentation of these formulae, reference should be made to White et al. (1976) and T.O.W. (1976).

Yang takes a somewhat different approach, with his hypothesis that for a steady uniform flow, total sediment concentrations should be related to the rate of potential energy dissipation per unit weight of water. This rate, known as the unit stream power can be expressed by the velocity and slope product:

VS where $\log C = M + N \log (VS)$, C being the total sediment concentration and M, N the parameters related to sediment and flow characteristics.

4.4.2 Simulations

Input

For the calculation of sediment transport a total of five cross-sections along the Kromme Estuary were chosen co-incident with stations at which flow parameters were calculated in the 1-D hydrodynamic model, at the same locations as the cross sections 1 to 5 in Figure 3.1. The relative positions of these stations stretch from near the estuary mouth to approximately 1 km upstream of the bridge. The sediment characteristics required in the transport formulations were extracted from Reddering and Esterhuysen (1983).

A total of five different flood hydrographs were used as input, corresponding to floods having return periods of occurrence of respectively 2, 5, 10, 20 and 50 years. For each of these flood events, hydrographic simulations were carried out for the presence and absence of dams, the dams usually considered to be 80% full at the time of the floods.

Results and discussion

For each flood scenario, sediment transport was calculated at hourly intervals using each of the three formulae. By summing over the total simulation period of 50 hours and multiplying by the respective sectional widths the unit rates are transformed into a total transport across the section.

The resultant simulated values are presented in Table 4.17. In comparing the results it should be noted that the predictions from the Ackers-White and Engelund-Hansen formulations are in relatively close agreement. The values predicted by the Yang formula are, however, consistently higher. It may also be observed that all three methods predict the highest transport rates across the section at the estuary mouth. The second highest values were recorded at the upstream limit, with significantly smaller transport rates at the central stations. Continuity considerations would thus indicate a net deposition of sediment in the middle section, with the greatest scour near the estuary mouth. Before accepting such a finding, it should be recalled that the hydrodynamic and sediment models are not interactive. Hence morphological changes due to sediment movement, are not reflected in the calculation of flow parameters in the hydrodynamic model.

As the main objective of this exercise is to assess the **relative effect** of the dams over the entire lower estuary included in the study area, the values obtained by each method are averaged over all the sections. The mean of these 3 resultant values is then deemed to be the best estimate of the net sediment discharge rate for the estuary.

When comparing scenarios with and without the dams it should be noted that the dams indeed do have a discernible effect, particularly for the low return period floods. For a 50-year return period flood, the presence of the dams reduces the average volume of sediment transported by 65% from 149 000 m³ to 54 000 m³ (Table 4.17). However, for a 10-year flood, the sediment transport drops from 45 000 m³ to 5 000 m³, an approximate 90% reduction in scour potential. It is interesting to note that since construction of the dams, nothing less than a 1 in 50-year flood is required to exceed the discharge rate formerly obtained with a 1 in 10-year flood.

The 1983 Flood

Records show that a volume of at least $110 \times 10^6 \text{ m}^3$ was contained by the dams before overflowing. In particular, the C W Malan dam filled to over $100 \times 10^6 \text{ m}^3$ in 60 hours, before overflowing (Von Below, Senior Water Control Officer, pers. comm.). Thus, the 1983 flood was a major flood, having approximately the volume of a 50-year flood, according to Table 4.8, although the peak flow was not as high. According to Table 4.17, the sediment quantity scoured would have been significant if the flood had been uninhibited by the dams.

Estimation of the sedimentation rate

Considering the volumes of sediment scoured by floods (Table 4.17) an approximate rate of sediment accumulation due to the reduction in flood action by the dams can be estimated. The volume scoured by the 50-year flood (with no dams) is about 149 000 m³. This would cause an average decrease of about 100 mm in the bed elevation of the lower estuary (which has an area of about 150 ha). Thus, assuming that all other influences on sedimentation (e.g. tides and waves) remain constant, it can be argued that the elimination of the 50-year flood by the dams would effectively cause an average increase in the bed elevation of 100 mm in 50 years, or 2 mm per year. Although more frequent floods and other influences will also occur, this gives a crude idea of the order of magnitude of the rate of sedimentation which can be expected due to the dams.

4.5 Conclusion

The above study clearly shows that the dams cause a significant reduction in the potential scouring of sediment by floods in general and, in particular, the 1983 flood. It is thus concluded that a slow rate of sedimentation is likely to occur.

REFERENCES

- ACKERS, P, and WHITE, W R (1973). Sediment Transport: New approach and Analysis, J. Hydr. Div., ASCE, 99(11)pp, 2041-2060.
- ALEXANDER, W J R (1980). Depth-Area-Duration-Frequency Properties of Storm Precipitation in S.A. Technical Report 103, Dept Water Aff, Pretoria.
- BUREC (1973). Design of Small Dams. Washington. US Dept of Interior.
- ENGELUND, F, and HANSEN, E (1967). A monograph on sediment transport in alluvial streams. Copenhagen, Denmark. Teknisch Forlag.
- NAKATO, T (1990). Tests of selected sediment transport formulas. J. Hydro. Div., ASCE, 111(3) pp .
- NEMEC, J (1972). Engineering Hydrology. London. McGraw-Hill.
- SINSKE, B H (1982). Bepaling Van Uiterste Neerslag vir Intermediêre Reënvalduurtes in Suidelike Afrika. Water SA, Vol. 8, No. 3, pp 149-154.
- SINSKE, B H (1988). Modelling Design Floods by Peak Factor Method. San Francisco. Proc. 16th ICOLD Congress, Vol. 5, pp 556-561.
- T.O.W. (1976). Coastal Sediment Transport, Computation of longshore transport. R986, part 1. Delft Hydraulics Laboratory, Delft.
- WHITE, W R, MILLI, H, and CRABBE, A D (1976). Sediment Transport theories: a review. Proc. Inst. Civ. Engrs., 59, pp 265-292.

YANG, C T (1976). Additional discussion of sediment transport theories: a review. Proc. Inst. Civ. Engrs., Part 2, 61, pp 803-810.

LEGEND OF SYMBOLS USED IN CHAPTER 4

A	= catchment area (km^2)
H	= average height difference (m)
hm	= hectometre
L	= longest watercourse (km)
Q	= flow (m^3/s)
Q2	= 1 in 2 year hydrograph (m^3/s)
Q5	= 1 in 5 year hydrograph (m^3/s)
Q10	= 1 in 10 year hydrograph (m^3/s)
Q20	= 1 in 20 year hydrograph (m^3/s)
Q50	= 1 in 50 year hydrograph (m^3/s)
t	= time (h)
t _C	= time of concentration (h)
T	= time
V	= volume (hm^3)

TABLE 4.1: GENERAL CATCHMENT AND DAM INFORMATION

(topographical data from 1 : 50 000 topographical
maps have been used)

Total catchment

Area	1 000 km ²
Longest watercourse	107,6 km
Average height difference	339 m
Time of concentration* (total catchment)	22 h

Diep River tributary

Catchment area	322 km ²
Longest watercourse	45 km
Average height difference	275 m
Time of concentration	9 h

Geelhoutboom River tributary

Catchment area	60 km ²
Longest watercourse	30,6 km
Average height difference	149 m
Time of concentration	7 h

Churchill Dam

Catchment area	361 km ²
Longest watercourse	62,3 km
Average height difference	340 m
Time of concentration	12 h
Mean annual precipitation (MAP)	760 mm

Mean annual runoff (MAR)	54,3 hm ³
	(= 54,3 x 10 ⁶ m ³)
Gross storage capacity	35,6 hm ³
Net storage capacity (= 0,61 MAR)	33,3 hm ³
Area of full supply level	252,9 ha
Spillway, total crest length (6 arches)	148,5 m
1 sluice gate (B x H0)	12,19 m x 7,62 m

C W Malan Dam

Catchment area	(Churchill Dam incl.)	840 km ²
Catchment area	(,, , excl.)	479 km ²
Longest watercourse	(,, , incl.)	90 km
Longest watercourse	(,, , excl.)	61,9 km
Average height difference	(,, , incl.)	377 m
Average height difference	(,, , excl.)	291 m
Time of concentration	(,, , incl.)	18 h
Time of concentration	(,, , excl.)	12 h
Mean annual precipitation (MAP)		630 mm
Mean annual runoff for Deep River		38,3 hm ³
Mean annual spill over Churchill Dam		31,1 hm ³
Combined MAR (see also Table 4.4)		69,4 hm ³
Gross storage capacity		107,1 hm ³
Net storage capacity (= 1,54 MAR)		106,9 hm ³
Area of full supply level		628,8 ha
Spillway, crest length (side channel)		100 m

* Time of concentration is the time taken for water to travel from the most remote location in the catchment to the point of interest along the river, i.e. the head of the estuary, in this case.

TABLE 4.2: CHURCHILL DAM INFLOW

Years	Inflow (hm3)
38 / 39	42.7
39 / 40	40.0
40 / 41	11.4
41 / 42	30.8
42 / 43	42.3
43 / 44	141.0
44 / 45	54.7
45 / 46	24.5
46 / 47	53.9
47 / 48	13.1
48 / 49	17.7
49 / 50	19.6
50 / 51	103.0
51 / 52	66.5
52 / 53	33.7
53 / 54	150.0
54 / 55	59.4
55 / 56	92.8
56 / 57	171.0
57 / 58	45.1
58 / 59	49.2
59 / 60	60.4
60 / 61	31.8
61 / 62	24.9
62 / 63	47.8
63 / 64	57.8
64 / 65	30.9
65 / 66	53.9
66 / 67	47.8
67 / 68	142.1
68 / 69	25.0
69 / 70	6.9
70 / 71	168.9
71 / 72	48.1
72 / 73	9.5
73 / 74	93.0
74 / 75	33.9
75 / 76	26.3
76 / 77	79.4
77 / 78	12.9
78 / 79	128.3
79 / 80	11.3
80 / 81	147.5
81 / 82	49.4
82 / 83	47.8
83 / 84	23.4
84 / 85	11.6
85 / 86	1.7
86 / 87	23.3
87 / 88	6.5

MAR 54.29

TABLE 4.3 Churchill Dam: Monthly reservoir capacities

CHURCHILL DAM: RESERVOIR CAPACITY (hm³)

	OCT	NOV	DEC	JAN	FEB	MRT	APR	MAY	JUN	JUL	AUG	SEP
49	33.4	33.3	33.3	33.1	32.5	31.9	30.9	29.7	29.4	28.7	28.3	28.0
50	27.3	26.7	33.2	33.0	32.0	31.0	29.9	29.0	28.4	27.0	32.4	33.4
51	33.3	33.3	33.4	33.4	33.5	33.2	33.2	32.1	33.5	33.5	33.7	33.4
52	33.6	33.3	33.1	32.7	31.7	33.3	32.9	32.9	32.7	32.9	33.0	33.3
53	33.3	33.3	33.3	33.1	32.7	31.7	30.5	29.0	28.0	27.5	28.7	33.7
54	33.5	33.6	33.4	33.4	32.4	31.0	30.4	29.1	33.4	33.4	33.7	33.5
55	33.4	33.4	33.4	33.3	31.8	33.5	28.0	26.2	25.9	26.2	26.7	28.4
56	28.9	30.7	34.1	32.9	31.6	30.8	30.0	29.3	33.6	33.3	33.3	33.6
57	33.5	33.3	33.4	33.4	33.1	32.7	33.3	33.2	33.3	33.4	32.7	33.4
58	33.3	32.5	32.2	31.3	29.8	28.1	26.3	24.9	23.7	24.7	24.6	26.0
59	25.9	27.8	29.3	28.8	28.9	28.8	29.3	29.2	28.5	29.2	29.0	29.0
60	27.4	26.2	27.1	25.7	26.4	25.2	23.8	22.9	15.5	15.4	15.3	15.5
61	16.1	16.3	16.9	14.9	13.2	12.0	13.7	15.5	17.0	17.0	16.7	16.9
62	16.5	16.9	15.2	13.2	11.2	9.9	9.6	8.7	7.7	6.2	5.2	15.8
63	17.0	19.8	19.8	17.6	15.2	13.1	15.1	24.6	29.3	30.3	31.4	32.9
64	32.3	30.7	28.9	28.8	27.4	26.1	23.8	22.8	21.1	25.1	25.8	33.3
65	33.4	33.3	32.9	30.9	28.1	24.9	23.5	23.5	23.4	28.0	28.9	27.8
66	25.8	33.3	33.3	33.1	30.9	30.9	29.7	27.8	26.2	24.3	22.6	23.2
67	21.7	22.5	20.8	17.5	13.3	10.5	8.1	18.1	25.1	29.7	33.1	33.2
68	33.4	32.7	32.7	27.4	23.4	19.8	17.2	16.7	16.8	33.5	33.3	33.4
69	33.4	33.3	32.7	29.5	25.8	22.6	19.7	17.0	14.6	14.3	13.4	11.6
70	12.8	13.1	12.9	11.3	9.8	9.4	8.5	7.9	8.3	6.7	6.0	5.9
71	6.5	9.1	8.5	16.0	16.3	15.8	15.0	33.2	33.3	33.3	33.3	33.3
72	33.3	33.3	33.2	32.1	29.5	32.7	30.6	28.2	31.5	33.0	33.2	33.3
73	32.2	29.8	27.2	23.6	20.3	18.3	16.3	17.5	18.2	17.7	17.6	16.1
74	15.2	14.3	16.0	16.7	15.6	15.7	17.1	17.9	20.9	20.3	18.7	33.4
75	33.6	33.1	30.8	27.8	25.2	25.0	25.5	23.3	20.5	19.7	21.0	21.2
76	33.4	31.3	28.7	28.6	26.6	24.3	23.0	21.5	21.4	20.4	21.3	26.0
77	26.5	33.4	33.2	31.7	31.8	31.1	29.6	27.9	33.4	33.4	33.3	33.2
78	32.9	32.5	32.5	31.0	28.6	25.6	23.1	21.5	20.1	21.0	20.3	19.4
79	19.7	21.9	26.6	27.3	26.2	23.6	20.6	18.8	17.3	18.4	33.4	33.8
80	33.3	33.1	31.5	28.2	25.1	22.0	19.2	16.9	15.2	15.3	14.7	14.0
81	15.0	17.4	16.8	20.1	23.2	23.6	33.6	33.3	33.8	33.4	33.3	33.6
82	33.3	33.4	33.1	32.5	29.9	27.1	25.5	33.0	33.1	33.1	33.3	33.1
83	33.0	30.9	28.5	25.5	22.7	21.0	19.3	18.1	17.7	19.2	33.8	33.3
84	33.3	33.1	32.7	30.9	29.0	26.6	25.5	23.6	21.6	19.9	19.1	18.7
85	17.6	16.0	13.8	12.6	13.2	12.3	10.0	9.8	8.4	8.0	10.1	9.8
86	9.7	10.8	15.4	17.6	17.2	16.7	16.2	16.0	15.8	15.4	14.7	15.0
87	16.3	22.0	23.9	22.0	20.2	19.4	18.5	20.2	19.8	21.3	20.4	19.6
88	22.8	24.4	22.7	20.9	18.4	16.8	16.2	16.3	16.3	17.1	16.5	16.0

TABLE 4.4: C.W. MALAN DAM
Inflow (hm3)

YEAR	CHURCHILL SPILL	DIEP R. INFLOW	TOTAL INFLOW
48/49	14.09	3.80	17.89
49/50	2.24	25.29	27.53
50/51	92.97	49.59	142.56
51/52	55.79	59.39	115.18
52/53	20.24	15.67	35.91
53/54	136.32	80.32	216.64
54/55	29.83	36.20	66.03
55/56	64.97	35.43	100.40
56/57	147.49	43.40	190.89
57/58	10.67	19.11	29.78
58/59	0.00	24.50	24.50
59/60	0.00	22.63	22.63
60/61	0.00	25.36	25.36
61/62	0.00	40.00	40.00
62/63	0.00	48.01	48.01
63/64	27.58	56.13	83.71
64/65	6.03	16.57	22.60
65/66	22.07	28.87	50.94
66/67	0.85	45.02	45.87
67/68	103.68	156.27	259.95
68/69	7.50	14.10	21.60
69/70	0.00	7.94	7.94
70/71	125.65	185.48	311.13
71/72	19.79	19.75	39.54
72/73	0.00	5.95	5.95
73/74	51.63	71.84	123.47
74/75	3.16	12.06	15.22
75/76	0.45	10.37	10.82
76/77	48.37	44.00	92.37
77/78	0.00	6.86	6.86
78/79	87.31	72.47	159.78
79/80	0.92	6.91	7.83
80/81	109.25	89.90	199.15
81/82	19.13	19.63	38.76
82/83	21.85	95.06	116.91
83/84	12.76	17.03	29.79
84/85	0.00	5.84	5.84
85/86	0.00	6.45	6.45
86/87	0.00	5.64	5.64
87/88	0.00	3.67	3.67
MEAN	31.06	38.31	69.38

TABLE 4.5 Churchill Dam:

Flood calculation
(Dam inflow)

DESIGN FLOODS

Name of site: CHURCHILL DAM

$A = 361 \text{ km}^2$ $CN = 85$ $hP (1h, 25a) = 65 \text{ mm}$
 $L = 62.3 \text{ km}$ $tC = 11.9 \text{ h}$ $hP (24h, 25a) = 160 \text{ mm}$
 $H = 340 \text{ m}$ $\rightarrow 12 \text{ h}$ Non-Uniform Rainfall Distribution

Rainfall	Return Period									
Duration	$T = \text{MMF}$ a									
t (h)	3	6	8	9	10	11	12	15	18	24
hP (mm)	39	47	51	52	54	55	56	58	61	64
Area Factor	0.84	0.88	0.89	0.90	0.90	0.91	0.91	0.92	0.92	0.93
Runoff Coef	0.26	0.34	0.37	0.38	0.39	0.39	0.40	0.42	0.43	0.46
hR (mm)	9	14	17	18	19	20	20	23	24	27
Peak Factor	0.48	0.84	1.02	1.09	1.16	1.22	1.28	1.43	1.55	1.73
V (hm ³)	3.1	5.1	6.0	6.4	6.7	7.1	7.4	8.1	8.8	9.8
Q (m ³ /s)	138	197	212	215	217	218	218	215	210	196

Rainfall	Return Period									
Duration	$T = 5$ a									
t (h)	3	6	8	9	10	11	12	15	18	24
hP (mm)	56	68	73	75	76	78	79	83	86	91
Area Factor	0.84	0.88	0.89	0.90	0.90	0.91	0.91	0.92	0.92	0.93
Runoff Coef	0.38	0.46	0.48	0.49	0.50	0.51	0.52	0.53	0.55	0.57
hR (mm)	18	27	31	33	35	36	37	41	44	48
Peak Factor	0.48	0.84	1.02	1.09	1.16	1.22	1.28	1.43	1.55	1.73
V (hm ³)	6.4	9.8	11.3	11.9	12.5	13.0	13.5	14.7	15.8	17.4
Q (m ³ /s)	287	380	398	402	403	402	401	390	377	348

Rainfall	Return Period									
Duration	$T = 10$ a									
t (h)	3	6	8	9	10	11	12	15	18	24
hP (mm)	74	90	97	99	102	104	106	111	115	122
Area Factor	0.84	0.88	0.89	0.90	0.90	0.91	0.91	0.92	0.92	0.93
Runoff Coef	0.47	0.55	0.57	0.58	0.59	0.60	0.60	0.62	0.63	0.65
hR (mm)	30	43	49	52	54	56	58	63	67	73
Peak Factor	0.48	0.84	1.02	1.09	1.16	1.22	1.28	1.43	1.55	1.73
V (hm ³)	10.7	15.7	17.8	18.7	19.6	20.3	21.0	22.7	24.2	26.5
Q (m ³ /s)	479	608	629	632	631	628	623	603	579	530

Rainfall	Return Period									
Duration	$T = 20$ a									
t (h)	3	6	8	9	10	11	12	15	18	24
hP (mm)	92	112	120	123	126	129	131	137	142	150
Area Factor	0.84	0.88	0.89	0.90	0.90	0.91	0.91	0.92	0.92	0.93
Runoff Coef	0.54	0.61	0.63	0.64	0.65	0.66	0.66	0.68	0.69	0.70
hR (mm)	42	60	68	71	74	76	79	85	90	98
Peak Factor	0.48	0.84	1.02	1.09	1.16	1.22	1.28	1.43	1.55	1.73
V (hm ³)	15.1	21.6	24.4	25.6	26.6	27.5	28.4	30.7	32.5	35.5
Q (m ³ /s)	676	838	861	862	858	852	844	813	778	709

Rainfall	Return Period									
Duration	$T = 50$ a									
t (h)	3	6	8	9	10	11	12	15	18	24
hP (mm)	115	140	150	154	158	161	164	172	179	189
Area Factor	0.84	0.88	0.89	0.90	0.90	0.91	0.91	0.92	0.92	0.93
Runoff Coef	0.61	0.67	0.69	0.70	0.71	0.71	0.72	0.73	0.74	0.75
hR (mm)	59	83	93	97	101	104	107	115	122	132
Peak Factor	0.48	0.84	1.02	1.09	1.16	1.22	1.28	1.43	1.55	1.73
V (hm ³)	21.4	29.8	33.4	34.9	36.3	37.5	38.6	41.5	43.9	47.7
Q (m ³ /s)	955	1157	1180	1178	1171	1161	1148	1101	1051	954

TABLE 4.6

C.W. Malan Dam: Flood calculation
(Excluding Churchill Dam)

DESIGN FLOODS

Name of site: CHARLIE MALAN DAM

(Excluding Churchill Dam)

A = 479 km²

CN = 85

hP (1h, 25a) = 65 mm

L = 61.9 km

tC = 12.5 h

hP (24h, 25a) = 160 mm

H = 291 m

--> 12 h

Non-Uniform Rainfall Distribution

Rainfall		Return Period									T =MMF	a
Duration												
t (h)		3	6	8	9	10	11	12	15	18	24	
hP (mm)		39	47	51	52	54	55	56	58	61	64	
ea Factor		0.83	0.86	0.88	0.88	0.89	0.89	0.90	0.90	0.91	0.92	
o of Coef		0.25	0.33	0.36	0.37	0.38	0.39	0.40	0.42	0.43	0.45	
hR (mm)		8	14	16	17	18	19	20	22	24	27	
ak Factor		0.48	0.84	1.02	1.09	1.16	1.22	1.28	1.43	1.55	1.73	
V (hm³)		3.9	6.5	7.7	8.2	8.7	9.1	9.5	10.5	11.4	12.7	
Q (m³/s)		175	253	272	277	280	282	282	279	272	255	

Rainfall		Return Period									T =	5 a
Duration												
t (h)		3	6	8	9	10	11	12	15	18	24	
h _P (mm)		56	68	73	75	76	78	79	83	86	91	
Area Factor		0.83	0.86	0.88	0.88	0.89	0.89	0.90	0.90	0.91	0.92	
Coeff Coef		0.37	0.45	0.48	0.49	0.50	0.51	0.51	0.53	0.54	0.56	
h _R (mm)		17	26	30	32	34	35	36	40	43	47	
Peak Factor		0.48	0.84	1.02	1.09	1.16	1.22	1.28	1.43	1.55	1.73	
V (hm ³)		8.2	12.6	14.6	15.4	16.2	16.8	17.5	19.1	20.5	22.7	
Q (m ³ /s)		365	489	514	519	521	521	519	507	490	453	

Rainfall		Return Period									T =	10 a
Duration												
t (h)		3	6	8	9	10	11	12	15	18	24	
hP (mm)		74	90	97	99	102	104	106	111	115	122	
Area Factor		0.83	0.86	0.88	0.88	0.89	0.89	0.90	0.90	0.91	0.92	
Coeff Coef		0.47	0.54	0.57	0.58	0.59	0.59	0.60	0.62	0.63	0.65	
hR (mm)		29	42	48	51	53	55	57	62	66	72	
Peak Factor		0.48	0.84	1.02	1.09	1.16	1.22	1.28	1.43	1.55	1.73	
V (hm³)		13.7	20.2	23.1	24.3	25.4	26.3	27.2	29.6	31.5	34.6	
Q (m³/s)		613	785	814	819	818	815	809	784	753	691	

Rainfall		Return Period									T =	20 a
Duration												
t (h)		3	6	8	9	10	11	12	15	18	24	
hP (mm)		92	112	120	123	126	129	131	137	142	150	
Area Factor		0.83	0.86	0.88	0.88	0.89	0.89	0.90	0.90	0.91	0.92	
Coeff Coef		0.53	0.60	0.63	0.64	0.64	0.65	0.66	0.67	0.68	0.70	
hR (mm)		41	58	66	69	72	75	77	83	88	97	
Peak Factor		0.48	0.84	1.02	1.09	1.16	1.22	1.28	1.43	1.55	1.73	
V (hm³)		19.4	27.9	31.6	33.1	34.5	35.8	36.9	39.9	42.4	46.3	
Q (m³/s)		868	1083	1115	1118	1114	1107	1097	1058	1014	926	

Rainfall		Return Period									T = 50 a
Duration											
t (h)		3	6	8	9	10	11	12	15	18	24
hP (mm)		115	140	150	154	158	161	164	172	179	189
re Factor		0.83	0.86	0.88	0.88	0.89	0.89	0.90	0.90	0.91	0.92
unff Coef		0.60	0.67	0.69	0.69	0.70	0.71	0.71	0.73	0.74	0.75
hR (mm)		57	81	91	95	98	102	105	113	120	130
Peak Factor		0.48	0.84	1.02	1.09	1.16	1.22	1.28	1.43	1.55	1.73
(hm³)		27.5	38.6	43.4	45.4	47.2	48.8	50.3	54.1	57.3	62.3
(m³/s)		1227	1498	1531	1530	1522	1510	1494	1435	1371	1246

TABLE 4.7

C.W. Malan Dam: Flood calculation
(Ignoring Churchill Dam)

DESIGN FLOODS

Name of site: CHARLIE MALAN DAM

(Ignoring Churchill Dam)

A = 840 km²

CN = 85

hP (1h, 25a) = 65 mm

= 90 km

tC = 17.5 h

hP (24h, 25a) = 160 mm

= 377 m

→ 18 h

Non-Uniform Rainfall Distribution

Rainfall		Return Period					T =MMF a				
Duration	t (h)	3	6	8	9	10	11	12	15	18	24
hP (mm)		39	47	51	52	54	55	56	58	61	64
Area Factor		0.79	0.83	0.85	0.85	0.86	0.86	0.87	0.88	0.88	0.90
Runoff Coef		0.24	0.32	0.35	0.36	0.37	0.38	0.39	0.41	0.42	0.44
hR (mm)		7	13	15	16	17	18	19	21	23	25
Peak Factor		0.35	0.63	0.79	0.85	0.92	0.98	1.03	1.18	1.30	1.49
V (hm³)		6.2	10.6	12.6	13.5	14.3	15.0	15.7	17.5	18.9	21.3
Q (m³/s)		199	309	345	356	364	371	375	381	380	368

Rainfall		Return Period					T = 5 a				
Duration	t (h)	3	6	8	9	10	11	12	15	18	24
hP (mm)		56	68	73	75	76	78	79	83	86	91
Area Factor		0.79	0.83	0.85	0.85	0.86	0.86	0.87	0.88	0.88	0.90
Runoff Coef		0.36	0.44	0.47	0.48	0.49	0.50	0.50	0.52	0.54	0.56
hR (mm)		16	25	29	30	32	33	35	38	41	45
Peak Factor		0.35	0.63	0.79	0.85	0.92	0.98	1.03	1.18	1.30	1.49
V (hm³)		13.2	20.7	24.1	25.5	26.8	28.0	29.1	32.0	34.3	38.1
Q (m³/s)		422	605	657	673	684	691	695	697	688	658

Rainfall		Return Period					T = 10 a				
Duration	t (h)	3	6	8	9	10	11	12	15	18	24
hP (mm)		74	90	97	99	102	104	106	111	115	122
Area Factor		0.79	0.83	0.85	0.85	0.86	0.86	0.87	0.88	0.88	0.90
Runoff Coef		0.45	0.53	0.56	0.57	0.58	0.58	0.59	0.61	0.62	0.64
hR (mm)		27	40	46	48	50	52	54	59	63	70
Peak Factor		0.35	0.63	0.79	0.85	0.92	0.98	1.03	1.18	1.30	1.49
V (hm³)		22.3	33.4	38.3	40.4	42.3	44.0	45.6	49.6	53.0	58.4
Q (m³/s)		714	978	1047	1066	1078	1086	1089	1083	1063	1007

Rainfall		Return Period					T = 20 a				
Duration	t (h)	3	6	8	9	10	11	12	15	18	24
hP (mm)		92	112	120	123	126	129	131	137	142	150
Area Factor		0.79	0.83	0.85	0.85	0.86	0.86	0.87	0.88	0.88	0.90
Runoff Coef		0.52	0.59	0.62	0.63	0.64	0.64	0.65	0.66	0.68	0.69
hR (mm)		38	55	63	66	69	71	74	80	85	93
Peak Factor		0.35	0.63	0.79	0.85	0.92	0.98	1.03	1.18	1.30	1.49
V (hm³)		31.7	46.3	52.7	55.4	57.8	59.9	62.0	67.2	71.5	78.3
Q (m³/s)		1017	1354	1438	1460	1473	1479	1481	1465	1433	1351

Rainfall		Return Period					T = 50 a				
Duration	t (h)	3	6	8	9	10	11	12	15	18	24
hP (mm)		115	140	150	154	158	161	164	172	179	189
Area Factor		0.79	0.83	0.85	0.85	0.86	0.86	0.87	0.88	0.88	0.90
Runoff Coef		0.59	0.66	0.68	0.69	0.69	0.70	0.71	0.72	0.73	0.74
hR (mm)		54	76	86	90	94	98	101	109	115	126
Peak Factor		0.35	0.63	0.79	0.85	0.92	0.98	1.03	1.18	1.30	1.49
V (hm³)		45.1	64.2	72.5	76.0	79.1	81.9	84.5	91.3	96.8	105.6
Q (m³/s)		1446	1879	1980	2004	2017	2022	2020	1991	1941	1821

TABLE 4.8 Geelhoutboom River: Flood calculation

DESIGN FLOODS

Name of site: GEELHOUTBOOM RIVER

A = 60 km²
L = 30.6 km
H = 149 m

CN = 85
tC = 7.2 h
→ 7 h

hP (1h, 25a) = 65 mm
hP (24h, 25a) = 160 mm
Non-Uniform Rainfall Distribution

Rainfall		Return Period									
Duration		T = MMF a									
t (h)		2	3	4	5	6	7	8	9	12	24
hP (mm)		34	39	43	45	47	49	51	52	56	64
Area Factor		0.94	0.95	0.96	0.96	0.97	0.97	0.97	0.97	0.98	0.98
Runoff Coef		0.25	0.30	0.33	0.35	0.37	0.38	0.39	0.40	0.43	0.47
hR (mm)		8	11	13	15	17	18	19	21	23	30
Peak Factor		0.51	0.72	0.89	1.03	1.15	1.25	1.34	1.42	1.60	1.98
V (hm ³)		0.5	0.7	0.8	0.9	1.0	1.1	1.2	1.2	1.4	1.8
Q (m ³ /s)		35	45	50	53	54	54	54	54	52	41

Rainfall		Return Period									
Duration		T = 5 a									
t (h)		2	3	4	5	6	7	8	9	12	24
hP (mm)		49	56	61	65	68	70	73	75	79	91
Area Factor		0.94	0.95	0.96	0.96	0.97	0.97	0.97	0.97	0.98	0.98
Runoff Coef		0.37	0.42	0.45	0.47	0.49	0.50	0.51	0.52	0.54	0.58
hR (mm)		17	22	26	29	32	34	36	38	42	52
Peak Factor		0.51	0.72	0.89	1.03	1.15	1.25	1.34	1.42	1.60	1.98
V (hm ³)		1.0	1.3	1.6	1.8	1.9	2.0	2.2	2.3	2.5	3.1
Q (m ³ /s)		72	89	96	100	101	101	100	99	93	72

Rainfall		Return Period									
Duration		T = 10 a									
t (h)		2	3	4	5	6	7	8	9	12	24
hP (mm)		65	74	81	86	90	94	97	99	106	122
Area Factor		0.94	0.95	0.96	0.96	0.97	0.97	0.97	0.97	0.98	0.98
Runoff Coef		0.47	0.51	0.54	0.56	0.58	0.59	0.60	0.61	0.62	0.66
hR (mm)		29	36	42	46	50	53	56	59	65	79
Peak Factor		0.51	0.72	0.89	1.03	1.15	1.25	1.34	1.42	1.60	1.98
V (hm ³)		1.7	2.2	2.5	2.8	3.0	3.2	3.4	3.5	3.9	4.8
Q (m ³ /s)		121	145	155	159	160	159	157	154	144	109

Rainfall		Return Period									
Duration		T = 20 a									
t (h)		2	3	4	5	6	7	8	9	12	24
hP (mm)		81	92	100	106	112	116	120	123	131	150
Area Factor		0.94	0.95	0.96	0.96	0.97	0.97	0.97	0.97	0.98	0.98
Runoff Coef		0.53	0.58	0.60	0.62	0.64	0.65	0.66	0.66	0.68	0.71
hR (mm)		40	51	58	64	69	73	76	79	87	106
Peak Factor		0.51	0.72	0.89	1.03	1.15	1.25	1.34	1.42	1.60	1.98
V (hm ³)		2.4	3.0	3.5	3.8	4.1	4.4	4.6	4.8	5.2	6.3
Q (m ³ /s)		172	201	214	218	219	216	213	208	194	146

Rainfall		Return Period									
Duration		T = 50 a									
t (h)		2	3	4	5	6	7	8	9	12	24
hP (mm)		101	115	126	134	140	145	150	154	164	189
Area Factor		0.94	0.95	0.96	0.96	0.97	0.97	0.97	0.97	0.98	0.98
Runoff Coef		0.60	0.64	0.66	0.68	0.69	0.70	0.71	0.72	0.73	0.76
hR (mm)		57	70	80	88	94	99	104	108	118	142
Peak Factor		0.51	0.72	0.89	1.03	1.15	1.25	1.34	1.42	1.60	1.98
V (hm ³)		3.4	4.2	4.8	5.3	5.6	5.9	6.2	6.5	7.1	8.5
Q (m ³ /s)		243	281	296	301	299	295	290	283	262	195

TABLE 4.9 Kromme River:

Flood calculation
(Ignoring dams)

DESIGN FLOODS

Name of site: KROMME RIVER MOUTH
(Ignoring Dams)A = 1000 km²

CN = 85

hP (1h, 25a) = 65 mm

L = 107.6 km

tC = 22.4 h

hP (24h, 25a) = 160 mm

h = 339 m

→ 22 h

Non-Uniform Rainfall Distribution

Rainfall		Return Period		T = MMF		a					
Duration	t (h)	6	9	12	15	16	17	18	19	20	24
hP (mm)	47	52	56	58	59	60	61	61	62	64	
Factor	0.82	0.84	0.86	0.87	0.87	0.87	0.87	0.88	0.88	0.88	0.89
off Coef	0.31	0.36	0.38	0.40	0.41	0.41	0.42	0.42	0.42	0.43	0.44
hR (mm)	12	16	18	20	21	22	22	23	23	25	
Factor	0.54	0.75	0.91	1.05	1.09	1.13	1.17	1.21	1.24	1.36	
(hm ²)	12.3	15.7	18.3	20.4	21.0	21.6	22.2	22.7	23.2	25.0	
(m ² /s)	309	362	387	398	400	401	401	401	400	395	

Rainfall		Return Period		T = 5 a							
Duration	t (h)	6	9	12	15	16	17	18	19	20	24
hP (mm)	68	75	79	83	84	85	86	87	88	91	
Factor	0.82	0.84	0.86	0.87	0.87	0.87	0.87	0.88	0.88	0.88	0.89
off Coef	0.43	0.47	0.50	0.52	0.52	0.53	0.53	0.54	0.54	0.55	
hR (mm)	24	30	34	37	38	39	40	41	42	45	
Factor	0.54	0.75	0.91	1.05	1.09	1.13	1.17	1.21	1.24	1.36	
(hm ²)	24.1	29.8	34.1	37.4	38.4	39.4	40.3	41.1	41.9	44.8	
Q (m ² /s)	605	686	720	730	730	730	728	726	723	707	

Rainfall		Return Period		T = 10 a							
Duration	t (h)	6	9	12	15	16	17	18	19	20	24
hP (mm)	90	99	106	111	112	114	115	116	118	122	
Factor	0.82	0.84	0.86	0.87	0.87	0.87	0.87	0.88	0.88	0.88	0.89
off Coef	0.53	0.56	0.59	0.60	0.61	0.61	0.62	0.62	0.62	0.64	
hR (mm)	39	47	53	58	60	61	62	63	65	69	
Factor	0.54	0.75	0.91	1.05	1.09	1.13	1.17	1.21	1.24	1.36	
V (hm ²)	39.0	47.3	53.4	58.2	59.6	61.0	62.2	63.4	64.6	68.6	
Q (m ² /s)	980	1089	1128	1135	1133	1130	1125	1120	1113	1083	

Rainfall		Return Period		T = 20 a							
Duration	t (h)	6	9	12	15	16	17	18	19	20	24
hP (mm)	112	123	131	137	139	141	142	144	145	150	
Factor	0.82	0.84	0.86	0.87	0.87	0.87	0.87	0.88	0.88	0.88	0.89
off Coef	0.59	0.62	0.65	0.66	0.67	0.67	0.67	0.68	0.68	0.68	0.69
hR (mm)	54	65	73	79	81	82	84	86	87	92	
Factor	0.54	0.75	0.91	1.05	1.09	1.13	1.17	1.21	1.24	1.36	
V (hm ²)	54.1	64.8	72.7	78.9	80.7	82.4	84.0	85.5	87.0	92.1	
Q (m ² /s)	1360	1492	1536	1538	1533	1527	1519	1510	1500	1454	

Rainfall		Return Period		T = 50 a							
Duration	t (h)	6	9	12	15	16	17	18	19	20	24
hP (mm)	140	154	164	172	175	177	179	181	182	189	
Factor	0.82	0.84	0.86	0.87	0.87	0.87	0.87	0.88	0.88	0.88	0.89
off Coef	0.65	0.68	0.70	0.72	0.72	0.72	0.73	0.73	0.73	0.74	
hR (mm)	75	89	99	107	110	112	114	116	118	124	
Factor	0.54	0.75	0.91	1.05	1.09	1.13	1.17	1.21	1.24	1.36	
V (hm ²)	75.1	89.1	99.2	107.2	109.6	111.7	113.8	115.8	117.6	124.3	
Q (m ² /s)	1888	2051	2097	2091	2082	2071	2058	2044	2029	1961	

TABLE 4.10

CHURCHILL DAM: OUTFLOW HYDROGRAPHS

	Churchill Dam	100%	80%	50%	full
T = 2 a	V (hm3)	7.4	0.7	0	0
	Q (m3/s)	193	26	0	0
T = 5 a	V (hm3)	13.5	6.8	0	0
	Q (m3/s)	366	262	0	0
T = 10 a	V (hm3)	21.0	14.3	4.4	4.4
	Q (m3/s)	581	510	217	217
T = 20 a	V (hm3)	28.4	21.7	11.8	11.8
	Q (m3/s)	797	752	501	501
T = 50 a	V (hm3)	38.6	31.9	22.0	22.0
	Q (m3/s)	1095	1060	891	891

C W MALAN DAM: INFLOW HYDROGRAPHS

TABLE 4.1.1:

	Churchill Dam	100%	80%	50%	full
T = 2 a	V (hm3)	16.9	10.2	9.5	
	Q (m3/s)	332	282	282	
T = 5 a	V (hm3)	31.0	24.3	17.5	
	Q (m3/s)	626	519	519	
T = 10 a	V (hm3)	48.2	41.5	31.6	
	Q (m3/s)	991	809	809	
T = 20 a	V (hm3)	65.3	58.6	48.7	
	Q (m3/s)	1357	1162	1097	
T = 50 a	V (hm3)	88.9	82.2	72.3	
	Q (m3/s)	1865	1672	1494	

TABLE 4.1.2:

OUTFLOW HYDROGRAPH MATRIX

C W MALAN DAM:

T = 2 a

		Churchill Dam			
		100%	80%	50%	full
C W Malan Dam	100% full	V (hm3) Q (m3/s)	16.9 10.2	9.5 158	
	80% full	V (hm3) Q (m3/s)	0 0	0 0	
	50% full	V (hm3) Q (m3/s)	0 0	0 0	

T = 5 a

		Churchill Dam			
		100%	80%	50%	full
C W Malan Dam	100% full	V (hm3) Q (m3/s)	31.0 24.3	17.5 328	
	80% full	V (hm3) Q (m3/s)	9.6 2.9	0 0	
	50% full	V (hm3) Q (m3/s)	0 0	0 0	

T = 10 a

		Churchill Dam			
		100%	80%	50%	full
C W Malan Dam	100% full	V (hm3) Q (m3/s)	48.2 41.5	31.6 549	
	80% full	V (hm3) Q (m3/s)	26.8 20.1	10.2 153	
	50% full	V (hm3) Q (m3/s)	0 0	0 0	

TABLE 4.1.2: (Continued)

T = 20 a		Churchill Dam				
		100%	80%	50%	full	
C W Malan Dam	100% full	V (hm3)	65.3	58.6	48.7	
		Q (m3/s)	1109	961	778	
	80% full	V (hm3)	43.9	37.2	27.3	
		Q (m3/s)	851	737	444	
50% full		V (hm3)	11.8	5.1	0	
		Q (m3/s)	206	78	0	
T = 50 a		Churchill Dam				
		100%	80%	50%	full	
C W Malan Dam	100% full	V (hm3)	88.9	82.2	72.3	
		Q (m3/s)	1565	1414	1174	
80% full		V (hm3)	67.5	60.8	50.9	
		Q (m3/s)	1325	1196	961	
50% full		V (hm3)	35.4	28.7	18.8	
		Q (m3/s)	686	524	348	

KROMME RIVER: OUTFLOW HYDROGRAPH MATRIX

TABLE 4.13:

T = 2 a

C W Malan Dam		Churchill Dam		
		100%	80%	50%
100% full	V (hm3)	18.3	11.6	10.9
	Q (m3/s)	214	145	145
80% full	V (hm3)	1.4	1.4	1.4
	Q (m3/s)	52	52	52
50% full	V (hm3)	1.4	1.4	1.4
	Q (m3/s)	52	52	52

T = 5 a

C W Malan Dam		Churchill Dam		
		100%	80%	50%
100% full	V (hm3)	33.5	26.8	20.0
	Q (m3/s)	439	322	299
80% full	V (hm3)	12.1	5.4	2.5
	Q (m3/s)	121	93	93
50% full	V (hm3)	2.5	2.5	2.5
	Q (m3/s)	93	93	93

T = 10 a

C W Malan Dam		Churchill Dam		
		100%	80%	50%
100% full	V (hm3)	52.1	45.4	35.5
	Q (m3/s)	726	600	499
80% full	V (hm3)	30.7	24.0	14.1
	Q (m3/s)	417	294	144
50% full	V (hm3)	3.9	3.9	3.9
	Q (m3/s)	144	144	144

TABLE 4.13: (Continued)

T = 20 a	C W Malan Dam		Churchill Dam			
			100%	80%	50%	full
	100% full	V (hm3)	70.5	63.8	53.9	
		Q (m3/s)	1024	893	722	
	80% full	V (hm3)	49.1	42.4	32.5	
		Q (m3/s)	762	664	404	
	50% full	V (hm3)	17.0	10.3	5.2	
		Q (m3/s)	194	194	194	
T = 50 a	C W Malan Dam		Churchill Dam			
			100%	80%	50%	full
	100% full	V (hm3)	96.0	89.3	79.4	
		Q (m3/s)	1442	1308	1101	
	80% full	V (hm3)	74.6	67.9	58.0	
		Q (m3/s)	1187	1078	873	
	50% full	V (hm3)	42.5	35.8	25.9	
		Q (m3/s)	604	465	314	

TABLE 4.14 Kromme River:
Outflow hydrographs
(Both reservoirs 80% full)

KROMME RIVER
Outflow hydrographs

Charlie Malan Dam 80% full					
Churchill Dam 80% full					
t	Q2	Q5	Q10	Q20	Q50
(h)	(m ³ /s)	(m ³ /s)	(m ³ /s)	(m ³ /s)	(m ³ /s)
0	0	0	0	0	0
1	1	1	1	2	3
2	2	3	4	6	8
3	4	7	12	16	21
4	9	17	26	35	47
5	17	31	48	64	86
6	29	52	81	109	147
7	39	70	108	146	197
8	48	86	134	180	244
9	52	93	144	194	262
10	49	87	135	182	246
11	43	77	120	161	217
12	34	61	95	128	184
13	26	47	72	104	130
14	21	37	58	140	155
15	10	19	29	196	290
16	5	9	18	294	456
17	2	4	39	402	613
18	1	2	84	504	744
19	0	0	137	582	1029
20	0	0	189	636	1074
21	0	0	233	662	1078
22	0	0	265	664	1051
23	0	0	285	649	1000
24	0	0	294	619	934
25	0	3	294	581	859
26	0	6	287	538	782
27	0	11	276	494	706
28	0	15	261	449	634
29	0	20	245	407	566
30	0	24	227	366	503
31	0	27	210	328	446
32	0	29	192	294	395
33	0	31	175	262	349
34	0	31	159	234	308
35	0	32	145	208	272
36	0	31	131	186	240
37	0	31	118	165	212
38	0	30	107	147	188
39	0	29	97	131	166
40	0	28	87	117	147
41	0	27	79	105	131
42	0	25	71	94	116
43	0	24	65	84	103
44	0	23	59	76	92
45	0	21	53	68	83
46	0	20	48	61	74
47	0	19	44	55	66
48	0	18	40	50	60

TABLE 4.15: OUTFLOW HYDROGRAPHS (BOTH DAMS IGNORED)

KROMME RIVER: Total catchment

t (h)	q	T (a)	Qin (m3/s)				
			2	5	10	20	50
0	0.00	0	0	0	0	0	0
1	0.01	4	4	7	11	15	21
2	0.02	8	8	14	23	31	42
3	0.03	12	12	22	34	46	63
4	0.06	23	23	43	68	92	126
5	0.08	31	31	58	90	123	168
6	0.13	50	50	94	147	200	273
7	0.20	77	77	144	226	307	419
8	0.28	108	108	202	316	430	587
9	0.39	151	151	281	440	599	818
10	0.52	201	201	374	587	799	1090
11	0.66	255	255	475	744	1014	1384
12	0.78	302	302	562	880	1198	1636
13	0.89	344	344	641	1004	1367	1866
14	0.97	375	375	698	1094	1490	2034
15	1.00	387	387	720	1128	1536	2097
16	0.97	375	375	698	1094	1490	2034
17	0.93	360	360	670	1049	1428	1950
18	0.88	341	341	634	993	1352	1845
19	0.80	310	310	576	902	1229	1678
20	0.72	279	279	518	812	1106	1510
21	0.63	244	244	454	711	968	1321
22	0.54	209	209	389	609	829	1132
23	0.44	170	170	317	496	676	923
24	0.36	139	139	259	406	553	755
25	0.28	108	108	202	316	430	587
26	0.21	81	81	151	237	323	440
27	0.15	58	58	108	169	230	315
28	0.10	39	39	72	113	154	210
29	0.07	27	27	50	79	108	147
30	0.04	15	15	29	45	61	84
31	0.03	12	12	22	34	46	63
32	0.02	8	8	14	23	31	42
33	0.01	4	4	7	11	15	21
34	0.00	0	0	0	0	0	0

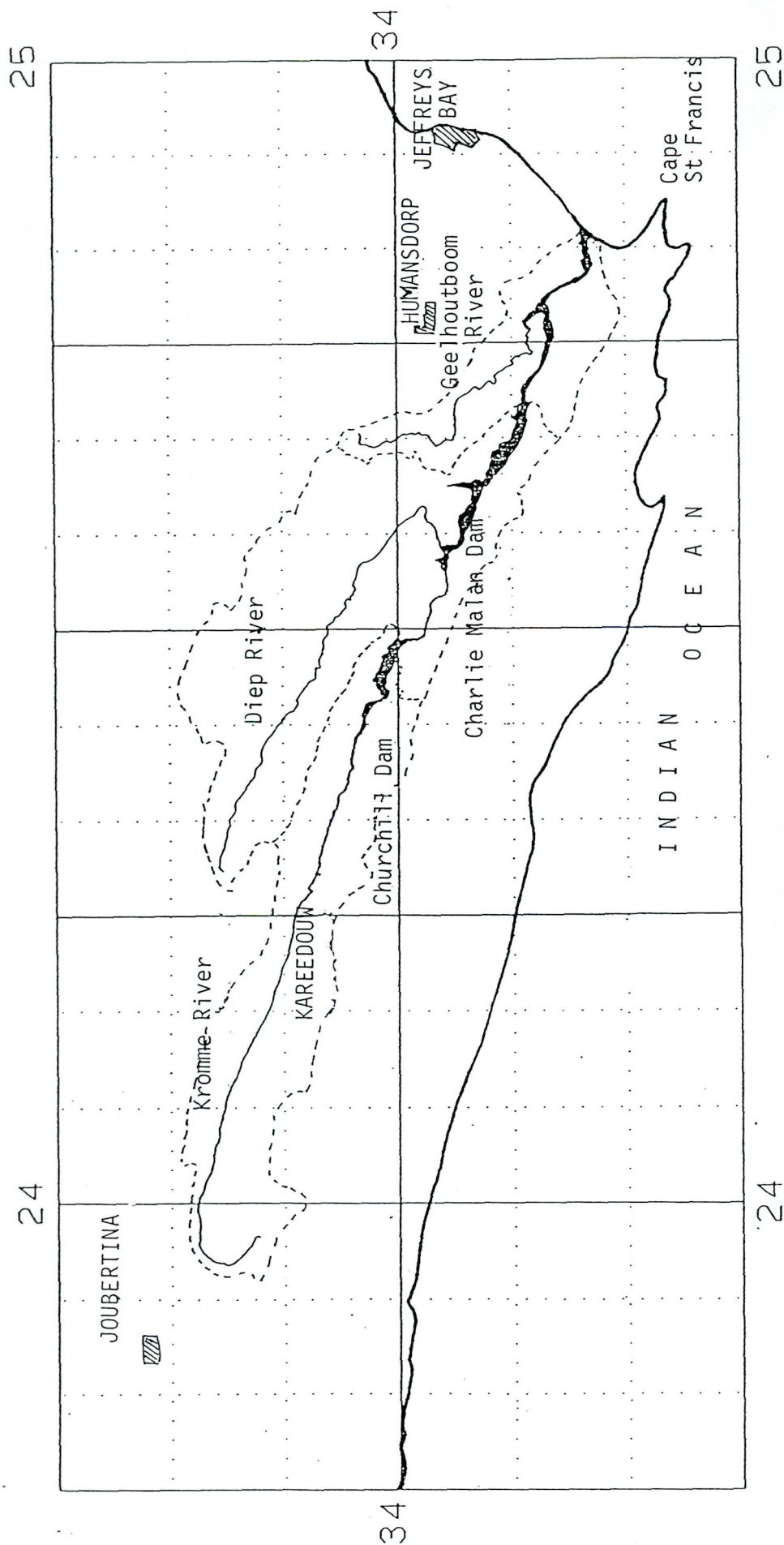
TABLE 4.16 Kromme River:
Outflow hydrographs
(Both reservoirs 50% full)

KROMME RIVER
Outflow hydrographs

C W Malan Dam 50% full Churchill Dam 50% full					
t	Q2	Q5	Q10	Q20	Q50
(h)	(m ³ /s)	(m ³ /s)	(m ³ /s)	(m ³ /s)	(m ³ /s)
0	0	0	0	0	0
1	1	1	1	2	3
2	2	3	4	6	8
3	4	7	12	16	21
4	9	17	26	35	47
5	17	31	48	64	86
6	29	52	81	109	147
7	39	70	108	146	197
8	48	86	134	180	244
9	52	93	144	194	262
10	49	87	135	182	246
11	43	77	120	161	217
12	34	61	95	128	173
13	26	47	72	97	131
14	21	37	58	78	105
15	10	19	29	39	52
16	5	9	14	19	26
17	2	4	6	8	10
18	1	2	3	4	5
19	0	0	0	0	6
20	0	0	0	0	45
21	0	0	0	0	103
22	0	0	0	0	165
23	0	0	0	0	221
24	0	0	0	0	264
25	0	0	0	0	293
26	0	0	0	0	309
27	0	0	0	0	314
28	0	0	0	0	311
29	0	0	0	0	301
30	0	0	0	0	286
31	0	0	0	0	269
32	0	0	0	0	250
33	0	0	0	0	230
34	0	0	0	0	211
35	0	0	0	0	192
36	0	0	0	0	174
37	0	0	0	0	158
38	0	0	0	0	142
39	0	0	0	0	128
40	0	0	0	0	115
41	0	0	0	0	104
42	0	0	0	0	94
43	0	0	0	0	84
44	0	0	0	0	76
45	0	0	0	0	69
46	0	0	0	0	62
47	0	0	0	0	56
48	0	0	0	0	51

TABLE 4.17 SEDIMENT TRANSPORT RATES AT 5 STATIONS IN KROMME RIVER
 Transport rates calculated using Ackers-White, Engelund-Hansen and Yang formulae
 Stn. 1 : Kromme mouth
 Stn. 5 : Kromme bridge

Return Period (yrs)	SIMULATION Days (% Full)	ACKERS-WHITE					TOTAL SEDIMENT TRANSPORT (x 10 ³ m ³)					ENGELUND-HANSEN					YANG					AVG	
		Stn 1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 1	Stn 2	Stn 3	Stn 4	Stn 5		
50	No Dam	245.5	38.89	5.24	31.05	72.5	78.63	302.2	38.59	5.53	30.31	75.14	90.35	122.7	15.71	96.07	930.9	122.7	15.71	96.07	226.2	278.32	149.10
50	80	103.5	8.03	1.51	7.14	16.23	27.29	122.2	8.16	2.08	7.31	16	31.15	25.95	5.37	23	411.9	25.95	5.37	23	51.32	103.51	53.98
50	50	15.3	0.28	0.31	0.57	0.61	3.41	17.6	0.48	0.57	0.84	0.81	4.06	1.15	1.36	2.25	64.6	1.15	1.36	2.25	2.17	14.31	7.26
20	No Dam	139.1	17.34	2.59	14.55	33.72	41.46	165.8	17.03	3.02	14.22	33.67	46.75	54.99	8.26	45.54	538.5	54.99	8.26	45.54	105.7	150.61	79.61
20	80	41.24	2.17	0.67	2.12	4.62	10.16	47.37	2.48	1.11	2.46	4.73	11.63	7.36	2.73	7.31	167.9	7.36	2.73	7.31	14.94	40.04	20.61
10	No Dam	83.92	7.63	1.3	6.74	15.42	23.00	98.17	7.65	1.73	6.79	15.15	25.90	24.54	4.49	21.58	331.6	24.54	4.49	21.58	48.65	86.17	45.02
10	80	12.06	0.21	0.22	0.25	0.45	2.64	13.95	0.37	0.43	0.45	0.61	3.16	0.86	0.98	1.06	51.14	0.86	0.98	1.06	1.62	11.13	5.64
5	No Dam	40.73	2.21	0.53	2.11	4.66	10.05	47.16	2.42	0.87	2.34	4.66	11.49	7.36	2.12	7.09	16.56	7.36	2.12	7.09	14.94	9.61	10.38
5	80	0.79	0.004	0.009	0.004	0.001	0.16	0.98	0.029	0.044	0.034	0.016	0.22	0.034	0.065	0.041	3.53	0.034	0.065	0.041	0.014	0.74	0.37
2	No Dam	15.21	0.35	0.24	0.41	0.8	3.40	17.70	0.52	0.44	0.59	0.93	4.05	1.33	1.06	1.58	64.26	1.33	1.06	1.58	2.73	14.19	7.22
2	80	0.38	0.001	0.002	0.001	0	0.08	0.5	0.015	0.02	0.016	0.005	0.11	0.014	0.022	0.014	1.73	0.014	0.022	0.014	0.002	0.36	0.18

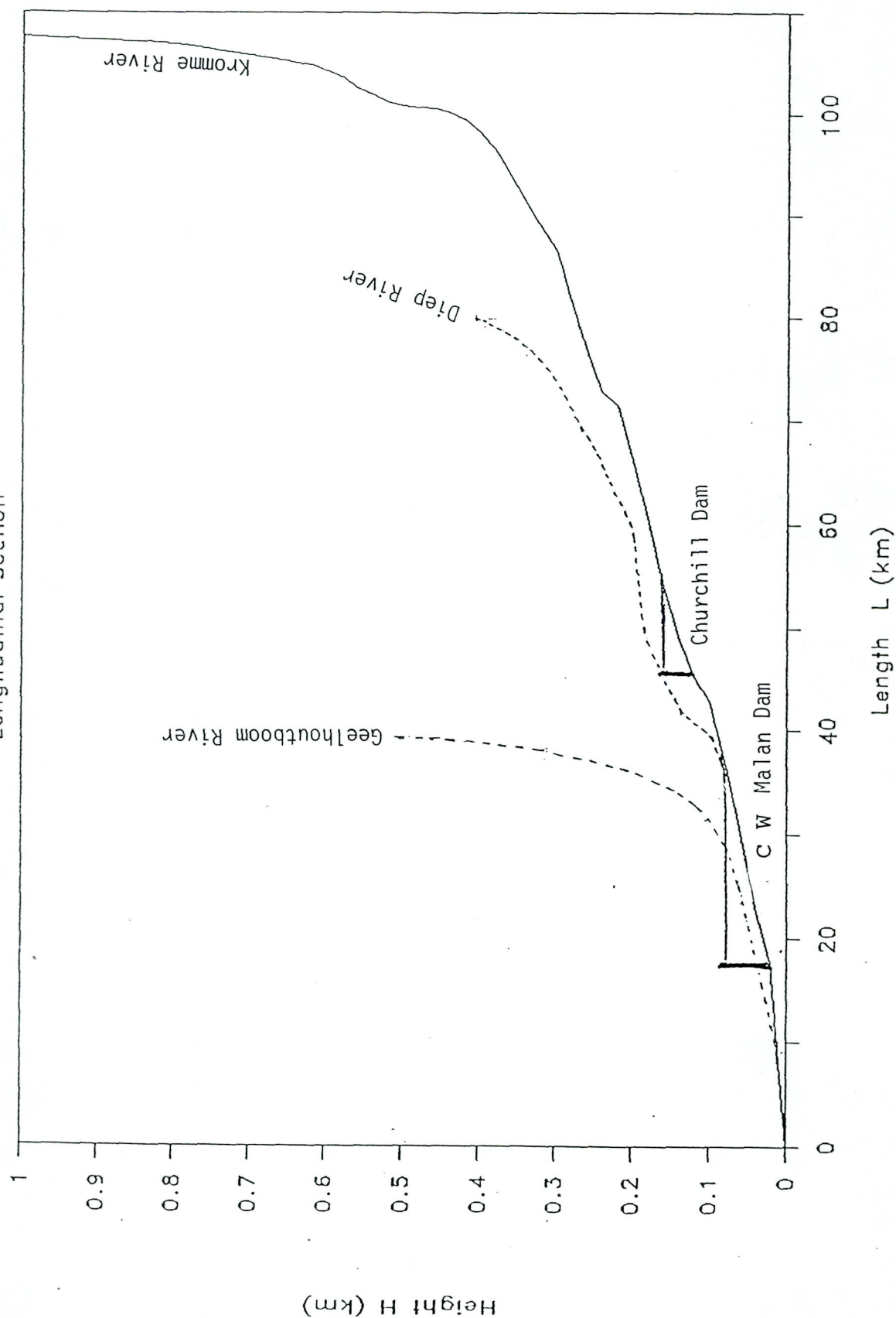


KROMME RIVER CATCHMENT

FIGURE 4.1

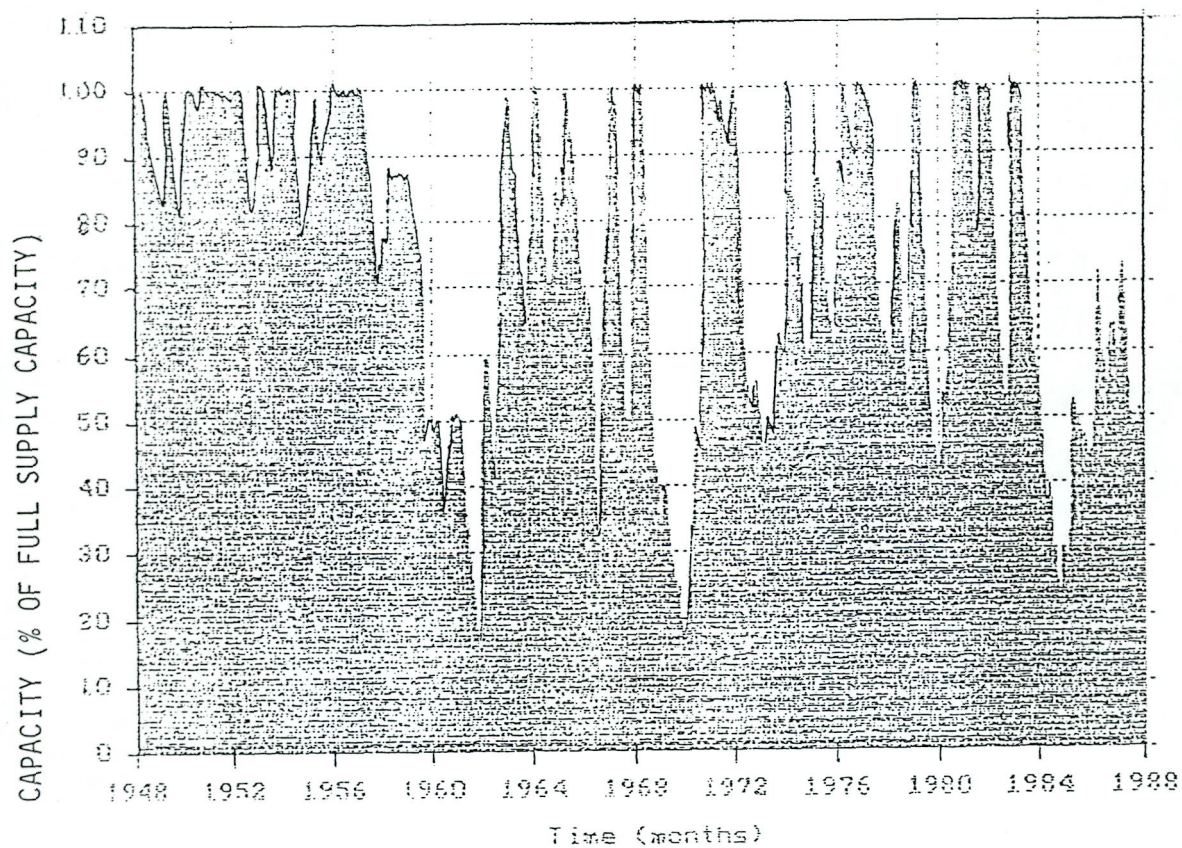
KROMME RIVER (Total Catchment)

Longitudinal Section



LONGITUDINAL SECTION OF THE KROMME RIVER

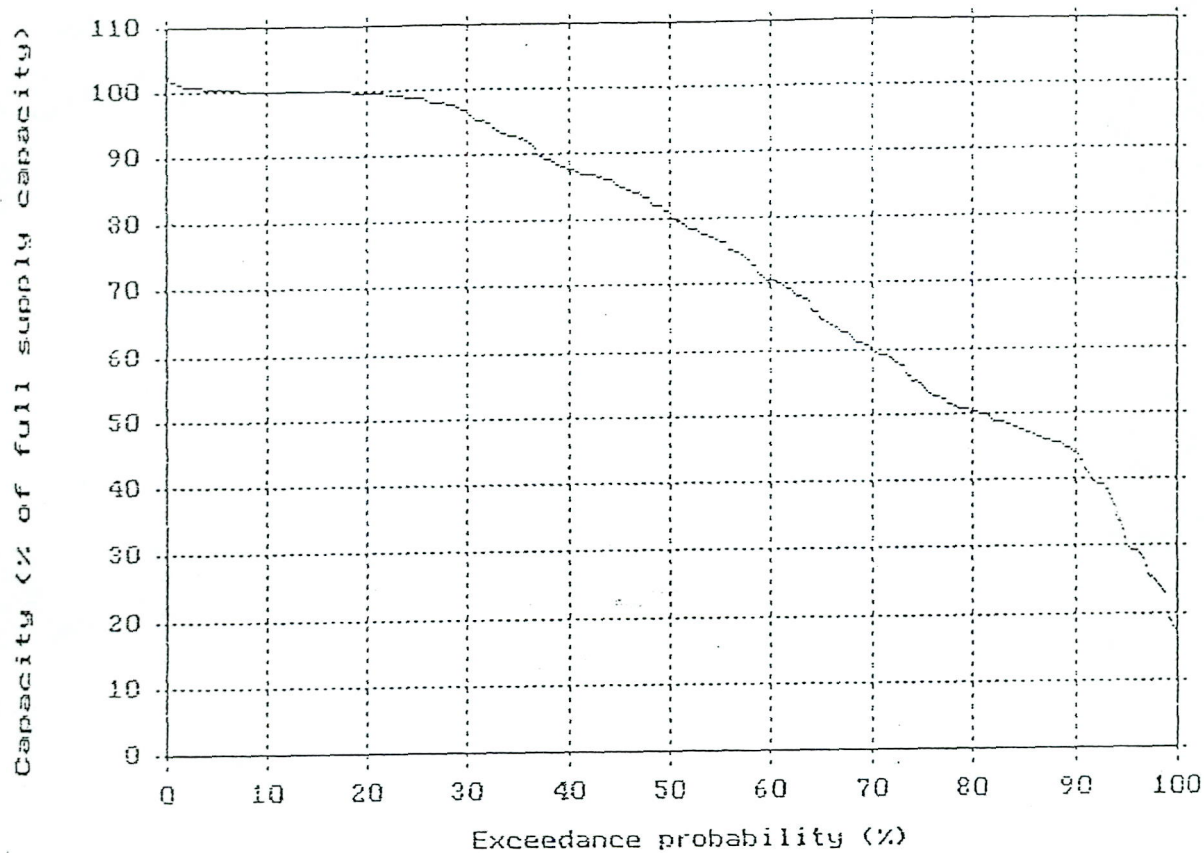
FIGURE 4.2



CHURCHILL DAM : MONTHLY RESERVOIR CAPACITIES

FIGURE 
4.3

CHURCHILL DAM



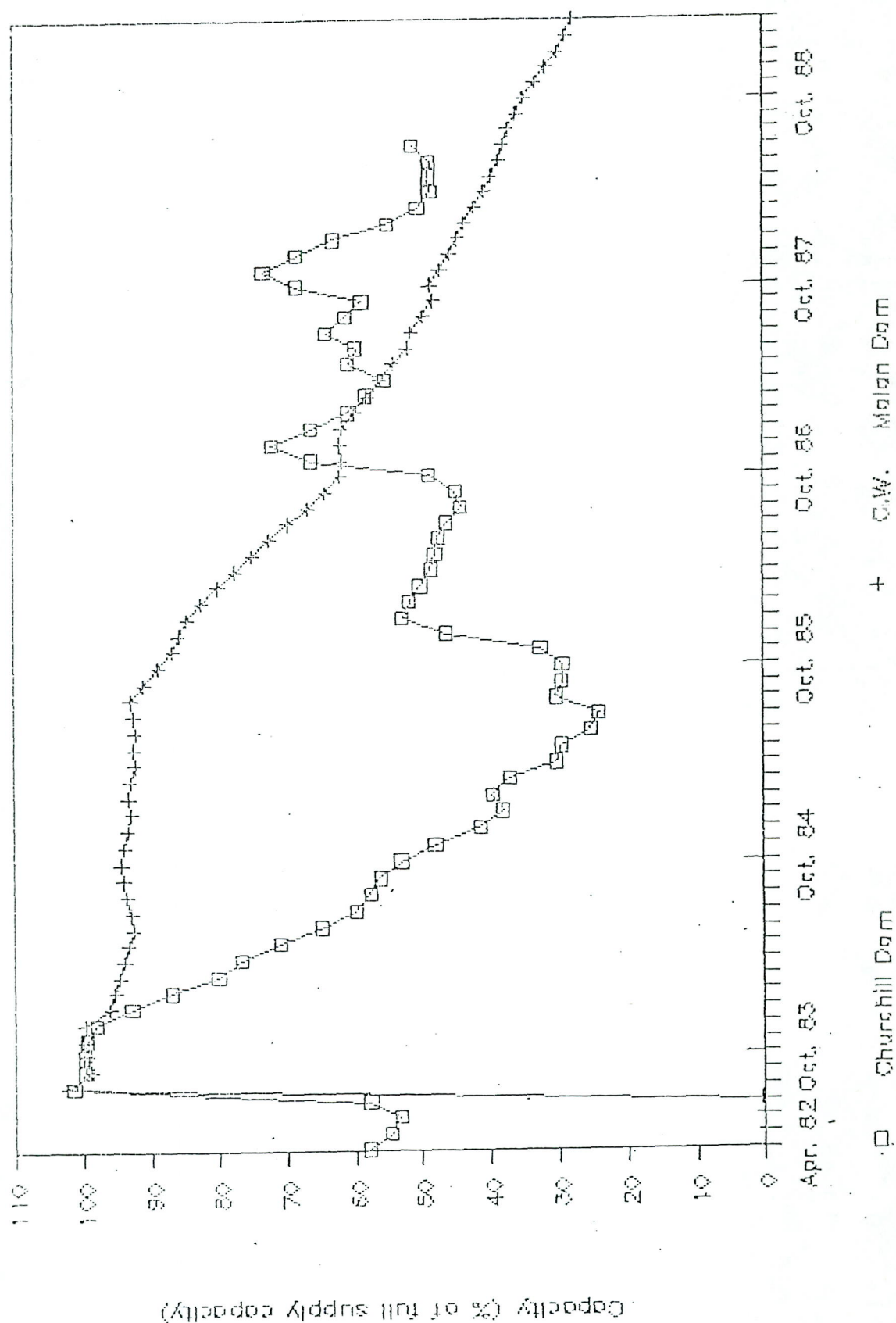
CHURCHILL DAM: CUMULATIVE FREQUENCY DISTRIBUTION OF MONTHLY RESERVOIR CAPACITIES

FIGURE

4.4



RESERVOIR CAPACITY



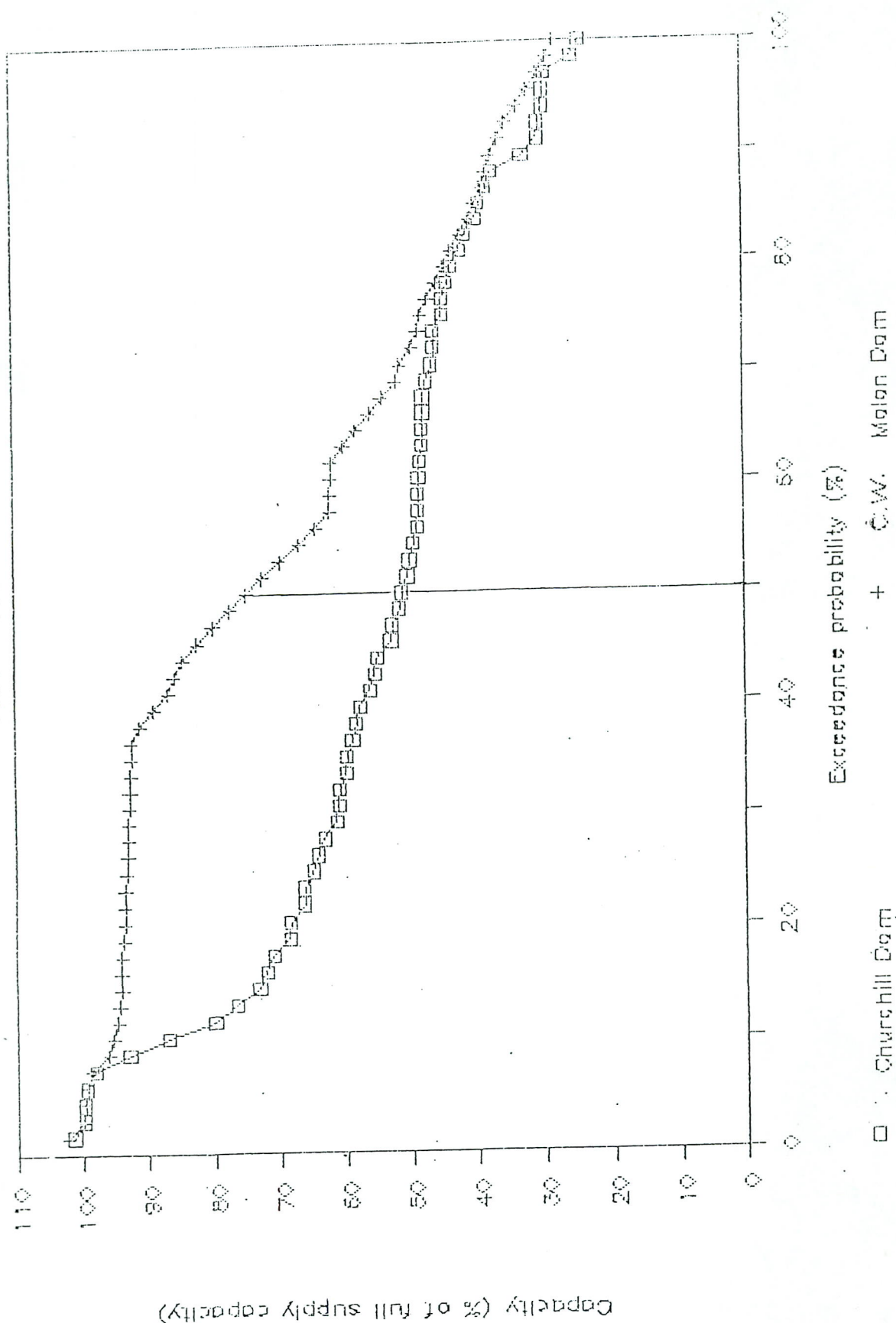
C.W MALAN: DAM: MONTHLY RESERVOIR CAPACITIES

FIGURE

4.5

RESERVOIR CAPACITY

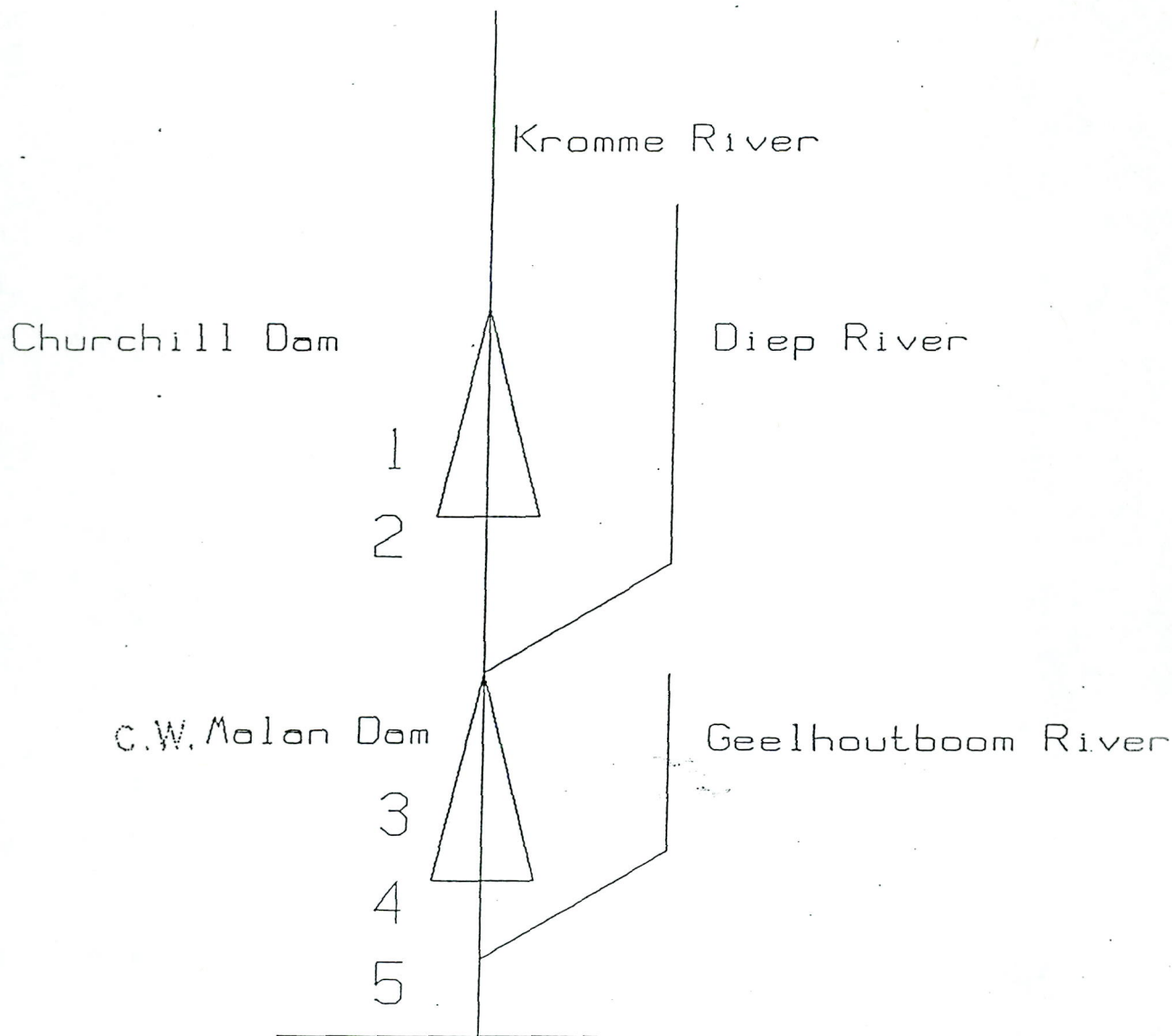
1983 - 1988



CUMULATIVE FREQUENCY DISTRIBUTION OF MONTHLY RESERVOIR CAPACITIES

FIGURE 4.6



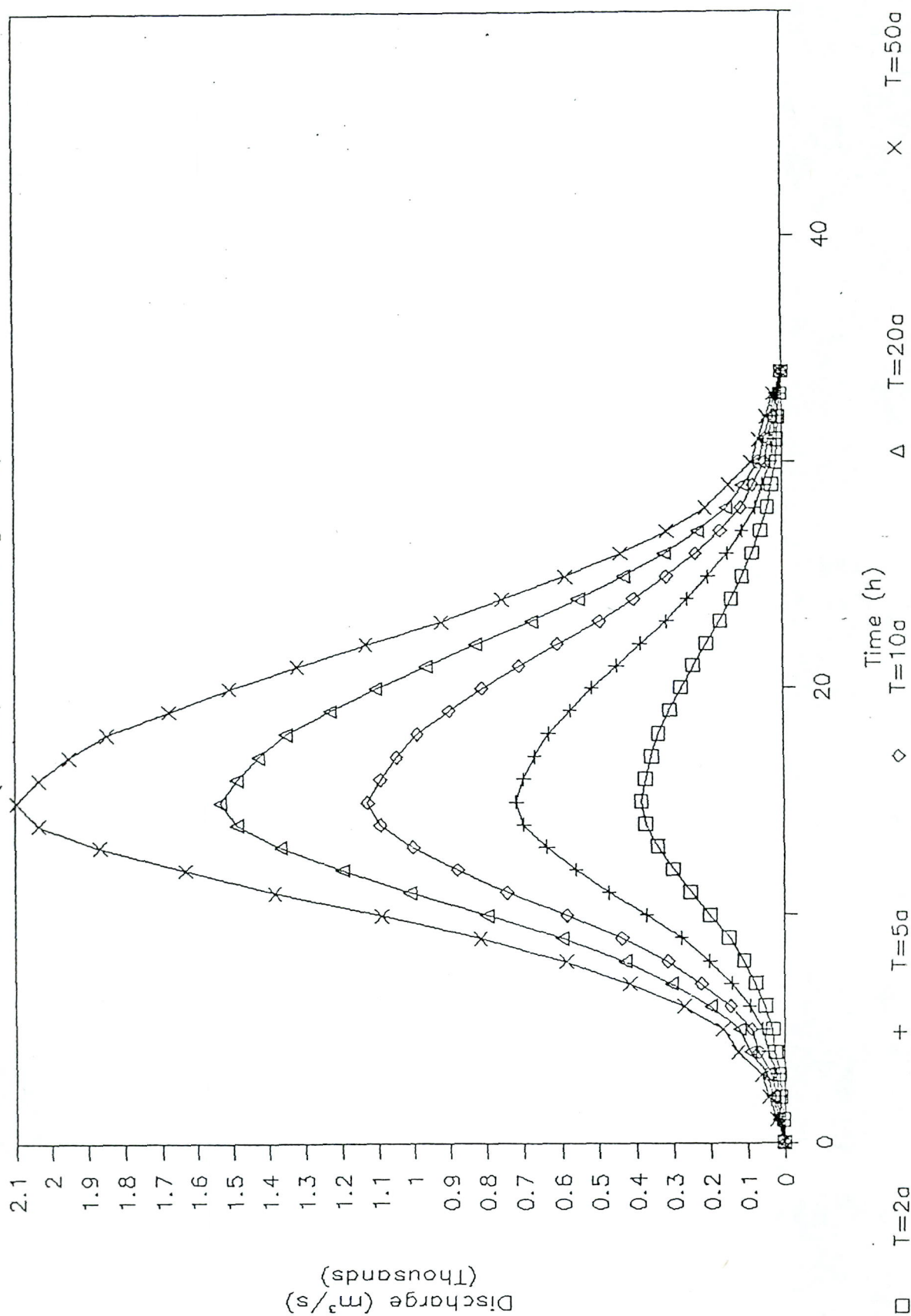


KROMME RIVER : SYSTEM DIAGRAM

FIGURE 
4.7

KROMME RIVER: Outflow Hydrographs

($t=12h$, both dams ignored)



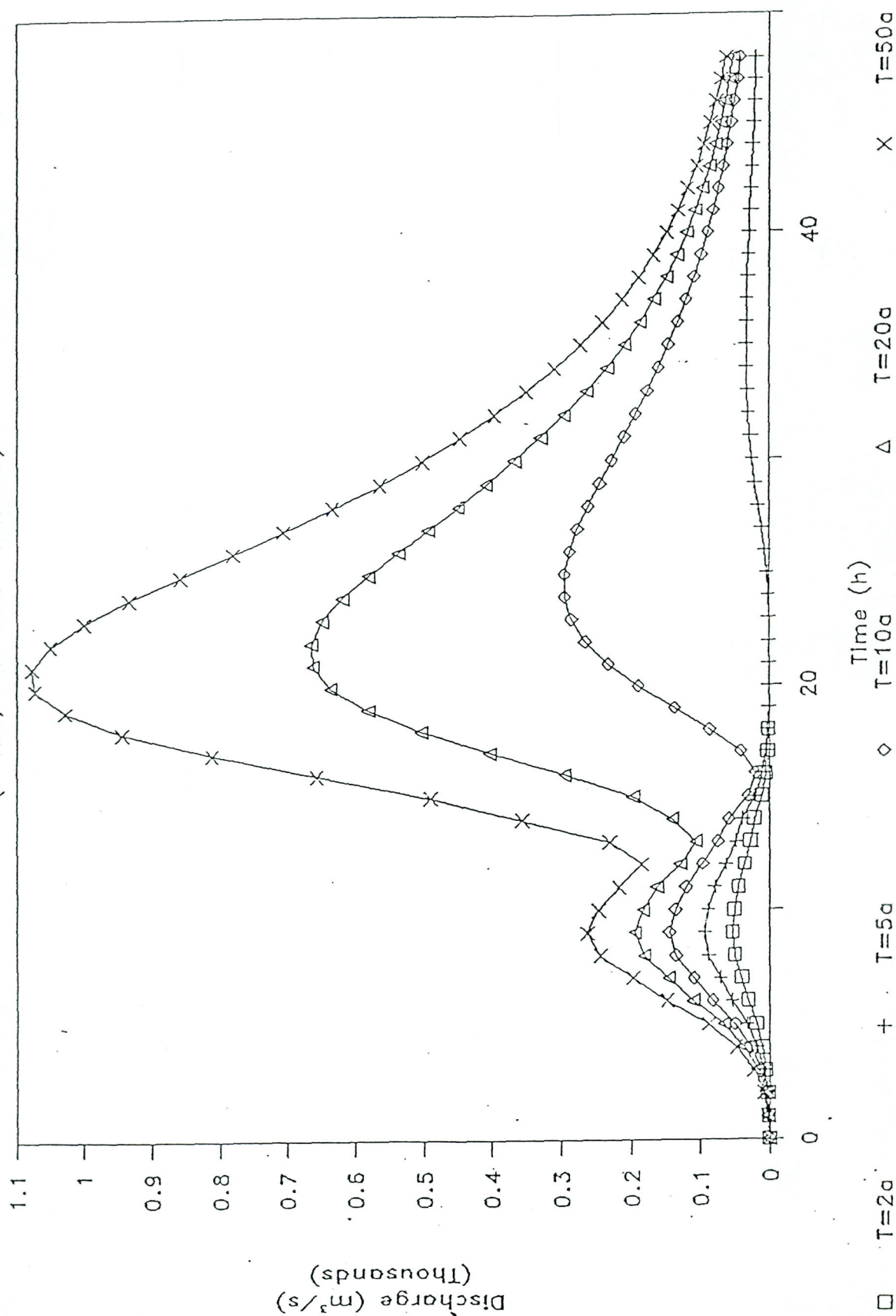
KROMME RIVER : OUTFLOW HYDROGRAPHS
(BOTH DAMS IGNORED)

FIGURE

4.8

KROMME RIVER: Outflow Hydrographs

($t=12h$, both dams 80% full)

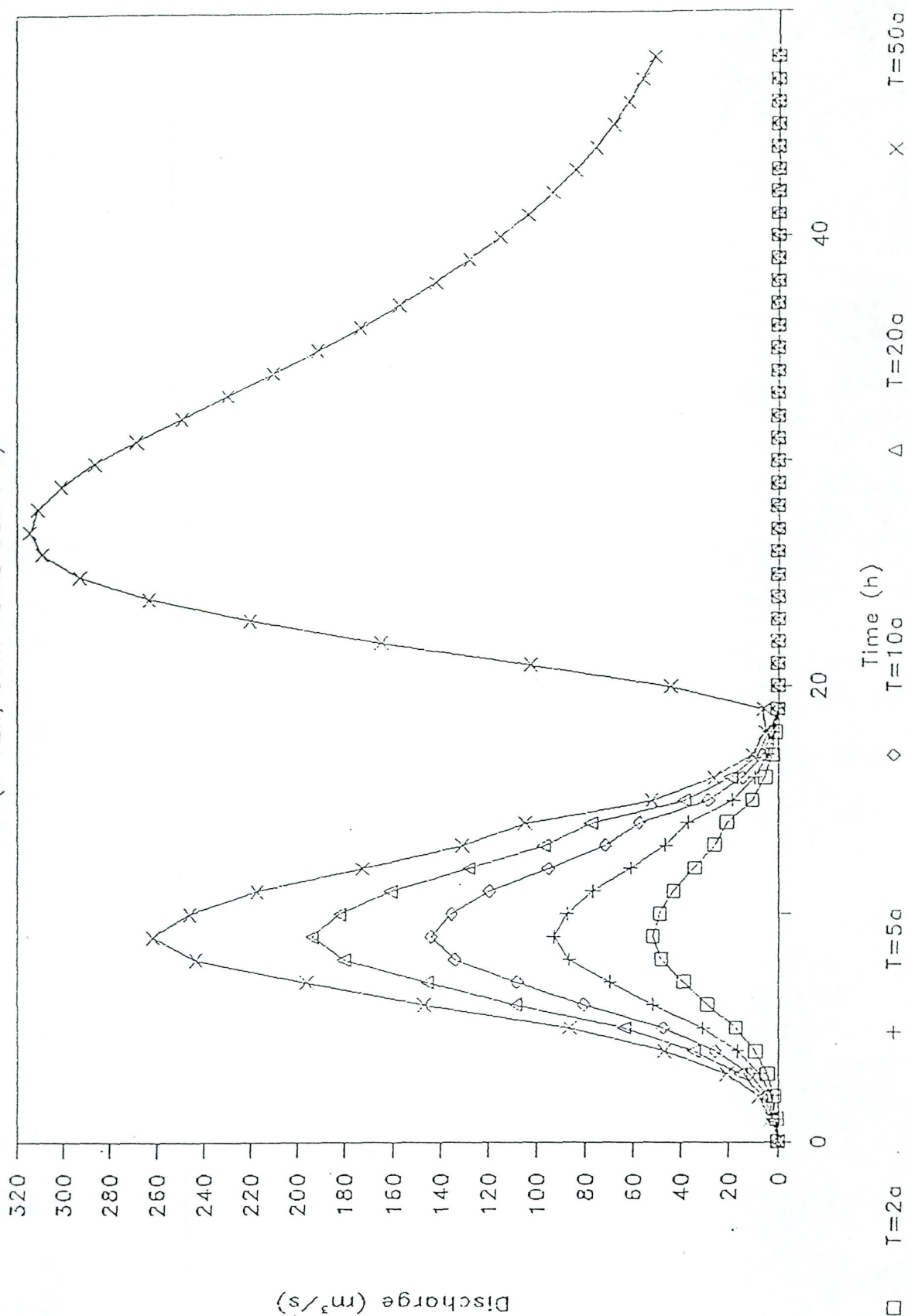


KROMME RIVER : OUTFLOW HYDROGRAPHS
(BOTH RESERVOIRS 80% FULL)

FIGURE

4.9

KROMME RIVER: Outflow Hydrographs (t=12h, both dams 50% full)



KROMME RIVER : OUTFLOW HYDROGRAPHS
(BOTH RESERVOIRS 50% FULL)

5. NUTRIENT STATUS AND WATER QUALITY ASSESSMENT OF THE MARINA GLADES CANAL SYSTEM, KROMME ESTUARY, ST. FRANCIS BAY

5.1 Introduction

A marina canal system (Marina Glades) has been developed on the west bank of the Kromme Estuary near its outlet (see Figure 5.1). Excavations began in 1959 and at present about 12 km of canals have been constructed, comprising an area of approximately 131,979 m². The prime objective of this development was the erection of water-front housing. The marina was linked to the main estuary by two access canals; one close to the mouth of the estuary and the second about two kilometres upstream. During the past few years the seaward access canal closed due to extensive redistribution of sediments in the mouth region of the Kromme Estuary. The closure of this access canal has lead to a decrease in the rate of water circulation in the marina, which could lead to a deterioration in the water quality.

In order to determine how serious this problem is, a study to assess the water quality in the marina was conducted during the summer of 1989/90 by the University of Port Elizabeth. In this study special reference is made to the dissolved inorganic nutrient load and the presence of indicators of domestic pollution in the canal waters. The nutrient status of the waters in the canal system is also compared with that of the Kromme Estuary and other eastern Cape estuaries for which comparable data exist, and comments on the general ecology of the marina canals and the estuary are made.

5.2 Previous Studies

A study of water quality and biota of the marina canals was done by Baird et al. (1981). Studies on various aspects of the ecology of the Kromme Estuary were done by Emmerson and Erasmus (1987) and Emmerson (1989) (nutrient status and abiotic parameters in estuarine waters), Bickerton & Pierce (1988) and Hanekom & Baird (1988) (botanical aspects), and Hecht (1973), Baird et al. (1981), Hanekom (1982), Hanekom & Baird (1984), and

Marais (1983, 1984) (zoological aspects). Much of the information recently gathered on the system is summarised in Bickerton & Pierce (1988).

5.3 Material and Methods

Seven sites were selected for sampling; five in the canal system, and one in the Kromme Estuary for comparative purposes. Samples were collected on four occasions (20/11/89, 11/12/89, 19/02/90, and 09/03/90) and a total of seven series of samples were obtained to represent various stages of the tide, maximum and minimum solar irradiation, and before and after the December/January holiday season. Water samples were collected from approximately 20 cm below the surface at Stations 1 to 5. At Stations 6 and 7 (blind canal stations, see Figure 5.1) where the lowest tidal water exchange takes place, replicate samples were collected directly below the surface (termed 6T and 7T), and from just above the bottom (called 6B and 7B).

Water samples were analysed for total ammonia as $\text{NH}_3\text{-N}_4^+$, nitrite as $\text{NO}_2^-\text{-N}$, and nitrate as $\text{NO}_3^-\text{-N}$. Phosphorus was measured as soluble reactive phosphorus (PO_4^{3-}). Water analysis was made in the field with a Hach DR\1A Portable Colorimeter. Water samples to assess the levels of faecal pollution were collected at all stations, and analysed for total and faecal coliforms at the Port Elizabeth Municipality Water Quality Monitoring Laboratory. Temperature, salinity, levels of dissolved oxygen, and pH were also measured at each station.

5.4 Results

Results of water analyses are summarised in Tables 5.1 and 5.2. Table 5.3 shows the concentration of coliforms determined on four occasions before and after the peak of the holiday season. Figures 5.2 to 5.8 show the distribution of salinity, temperature, dissolved oxygen, soluble reactive phosphorus, nitrates, nitrites, and ammonia respectively during each sampling session. Figure 5.9 shows the mean concentration of each nutrient (all data combined) measured per sampling session. Figure 5.10 shows the concentration of faecal coliforms at all stations over the period November 1989 to March 1990.

5.4.1 Physico-chemical parameters in the water column

Salinity and temperature in the marina canals were relatively uniform during the sampling period. Salinity remained close to that of the sea, varying between 32,5 ppt. to 36,0 ppt. Stations 4 and 7T were slightly hypersaline on 19/02/90, and marked stratification occurred in the afternoon of 20/11/89 between the surface and the bottom of Stations 6 and 7 (Figure 5.2). Temperature followed a pattern of progressive warming up of the canal waters away from the outlets to the estuary (Figure 5.3), the largest difference being found between Station 1 (estuary main channel) and Station 6T on 19/02/90 (6,5 °C). Slight stratification occurred on the morning of 20/11/89 and the afternoon of 11/12/89 between top and bottom of stations 6 and 7. pH was also relatively uniform and close to that of sea water, with a slight tendency of the waters to become more alkaline at stations 5, 6 and 7 (Tables 5.1 and 5.2). No consistent seasonal or tidal pattern of variation was found.

5.4.2 Dissolved oxygen

The concentration of oxygen in the water of the canals was uniform on most occasions, varying between 6,0 and 7,5 mg/M (Figure 5.4). During the morning of 11/12/89 high values were recorded at stations 1, 2, and 3, and the water was oversaturated with the gas. On this occasion, a strong south easterly wind was blowing, and the estuary and canal waters were choppy. During the afternoon of the 11/12/89 levels below 5.5 mg/M were recorded at stations 6 and 7. These levels, although lower than average, still represent fairly well oxygenated water.

5.4.3 Inorganic nutrients

Levels of Soluble Reactive Phosphorus were uniformly low (Figure 5.5) although sharp differences in concentration were recorded between stations during the morning of 20/11/89, and on 19/02/90 and 09/03/90. These relatively high concentration values seem to be episodic events in the marina canals, since no pattern of variation is evident between the stations sampled.

The same also applies to day and night samples, high and low tide samples, and samples before and after the December holidays.

Nitrogen concentrations, as nitrates, show a different picture. Mean values (see Table 5.1 and 5.2) recorded in the marina were one to two orders of magnitude higher than comparable values recorded in the Kromme Estuary proper by Watling (1982) and by Emmerson (1987), and an order of magnitude higher than in other Eastern Cape estuaries (Table 5.4). Lower nitrate concentrations in the marina (below 1,0 mg/M) were recorded during November (Figure 5.6). Values increased during December and remained above 1.4 mg/M in February and March. No clear pattern of variation is evident between the sampling stations in the marina canals, but Station 1 in the estuary's main channel showed consistently lower nitrate concentrations during all sampling sessions (Figure 5.6).

Nitrogen values, as nitrites and ammonia, were uniformly low in the marina canals at all stations and during sampling sessions (Figures 5.7 and 5.8 respectively). This is usually the case in well oxygenated waters, in which the reduced forms of inorganic nitrogen are rapidly oxidised to NO_3^- . Highest values of nitrite were recorded at all the sampling stations on the morning of 11/12/89, which corresponds with the highest average values of nitrates (Table 5.2).

5.4.4 Coliform bacteria

Total and faecal coliform counts in the marina canals are summarised in Table 5.3 and Figure 5.10. Coliform concentrations in the water were consistently low in all cases, with the exception of Station 2 on 12/12/89. These values are within the range of coliform counts recorded in the Kromme and Sundays estuaries by Emmerson (1987, 1989), and much lower than those in the Swartkops River and estuary which drains the densely populated areas of Uitenhage and Port Elizabeth (Table 5.4). Faecal coliform counts in the marina are also well

within the limits established for direct recreational use of sea water and the gathering of filter-feeding organisms for food (Lusher, 1984).

5.5 Discussion

As reported before by other workers (Baird et al., 1981, and Bickerton and Pierce, 1988), the Marina Glades canals in the Kromme Estuary are primarily a marine-dominated system. In the present study, salinity values in the canals were similar to those in the lower reaches of the estuary. The saline stratification observed in Stations 6 and 7 on 20/11/89 (Figure 5.2) was possibly the effect of surface freshwater run off. Water temperature in the canals is greatly influenced by heat gain and loss from and to the atmosphere (De Meillon, 1989). On 20/11/89, sampling was performed in the morning and again in the afternoon; on 11/12/89, sampling took place at noon, and again at night. On both dates the water temperature pattern in the canal was similar (Figure 5.4). On 20/11/89 however, afternoon water temperatures were $2\frac{1}{2}^{\circ}\text{C}$ higher on average than the morning temperatures. On 11/12/89, nighttime water temperatures were on average $2,5\frac{1}{2}^{\circ}\text{C}$ lower than noon temperatures. Differences in temperature at Station 1 represent tidal and seasonal differences. pH values were also close to those of sea water (Table 5.1 and 5.2) and only slightly higher than those recorded in the Kromme Estuary (Table 5.4). Dredging operations in the canals may have a short term effect on the water pH because they cause re-suspension of sediments and other organic material.

Levels of dissolved oxygen in the canal waters remained relatively high (6,0 - 7,5 mg/M) on most occasions (Figure 5.4). Low levels (5,0 - 5,5mg/M) were measured during the night on 11/12/89 at Stations 6 and 7. Decaying plant material and some man-made pollution (e.g. plastic bags, bottles, cans, etc.) were present on the bottom of the dead-end canals during the study period (observations made with SCUBA). Also present were dense patches of seaweed (*Caulerpa filiformis*, *Codium* sp.), hydrozoans, burrows of the sandprawn *Callianassa kraussi* and the estuarine red bait *Pyura stolonifera*. Patches of eelgrass,

Zostera capensis, were also present in the narrow intertidal areas. As a result of these low oxygen levels, some degree of anaerobic breakdown of plant material may be taking place on the bottom. Also, since low values were only measured at night; oxygen utilisation by seaweeds and macrofauna may significantly decrease the oxygen level in the water column. Signs of widespread anaerobic conditions, such as the release of SO_2 , and the absence of macro-invertebrates from the sediment were, however, absent.

Except in the case of nitrates all other inorganic nutrients measured in the Marina Glades canals showed mean concentrations within the range previously reported in the Kromme Estuary and other Eastern Cape estuaries (Table 5.4). High levels of nitrates and phosphates could be expected in the estuaries of rivers which drain agricultural farmland where chemical fertilizers are applied to the crops. The Kromme river, however, drains mainly undisturbed forested land and flows over well leached sandstone (Reddering & Esterhuysen, 1983). Emmerson and Erasmus (1987) classified the Kromme Estuary as low in nitrates and phosphates and conservative in silicates. High levels of nitrates in the marina canals show the sources of nitrogen to be both local and anthropogenic. Firstly, nitrate concentrations at station 1 were consistently lower than those in the marina canals, which means a limited riverine or marine nutrient input. Secondly, nitrate values which were relatively low in the canals in November, rapidly increased in December and remained high in February and March, during and after the 1989/90 holiday season. The increase in the human population at Marina Glades during these months is therefore likely to be largely responsible (Figure 5.10).

Two possible sources of nitrogen to the water in the canals are firstly, chemical fertilizers used in the gardens of water front houses, and secondly, organic nitrogen from septic tanks leached into the canals or transported by the underground freatic layer. Chemical fertilizers, which are commonly used in excess in gardens, would enter the canals through direct surface run off. Nitrogen originated in domestic sewage is usually in the form of

organic nitrogen or its reduced form. Organic nitrogen is mineralized by bacteria to nitrate. In oxic environments, reduced forms (NH_3) are also rapidly oxidized to NO_3^- .

Inorganic nutrients are not pollutants *per se*, and are not toxic in the concentrations measured in the marina canals. However, high nutrient levels, (particularly nitrates), coupled with inefficient water exchange in the canals and thermal or saline stratification of the water column, may give rise to undesirable conditions. They may accumulate in the sediments and be released episodically, facilitating the formation of phytoplankton blooms. These blooms would produce an unsightly discolouration of the water and deplete its oxygen content, giving rise to anoxic conditions and mass mortality of fish and benthic animals. Similarly, excessive growth of seaweeds on the bottom of the canals would become a nuisance for traffic of power boats.

Concentration of faecal coliforms in the water is a good indicator of domestic sewage pollution. Numbers of faecal coliforms were low in all samples but one (Table 5.3) and lower than the average in the Kromme Estuary (Table 5.4). This indicates that the septic tank system installed in the area is capable of disposing with the domestic sewage at the peak of the holiday season, and that raw sewage is not being leached into the canals. Also, foul odours and the accumulation of floating detritus which are characteristic of this type of pollution were not encountered during the study period. Although high nitrate levels do indicate land seepage (fertilizers and/or sewage), these results show that the septic tank system used in the area sufficiently removes bacteria and detritus from the sewage effluent before it enters the canals.

This study deals only with inorganic nutrients, and faecal coliforms. Measurements of the concentrations of organic nitrogen forms, heavy metals and hydrocarbons (due to boating activities) in the canal waters is recommended in order to confirm these results.

5.6 Notes on the General Ecology of the Marina Glades Canals, St. Francis Bay

The ecology of the marina canals has been studied in some detail by Baird et al. (1981). More recent studies on the biotic communities of the marina system by Heymans (1990), Groeneveld (1990) and Cloete (1990) showed no significant changes in the species composition and abundance when compared to the earlier work of Baird et al. (1981).

Biological communities in the marina canals are abundant but less diverse than in the Kromme Estuary. The most abundant fish observed in the canals was small-sized mullet. Shoals of small juvenile fish (probably also mullet species) are often seen in the shallows of the main canal and around the island (Figure 5.1). Octopi were also observed in the main canal, using SCUBA. Intertidal and subtidal benthic invertebrate fauna is similar in composition to that of the lower Kromme Estuary (for details refer to Bickerton & Pierce (1988) and Baird et al. (1981), and include dense patches of sand prawn *Callinassa kraussi*, blood worm *Arenicola loveni*, and scattered individuals of pencil bait *Solen capensis*. Sessile organisms such as red bait, *Pyura stolonifera*, and as yet unidentified hydrozoans, are also abundant in the canals. The hard substrates of the embankment of the canals have been colonised by barnacles, *Balanus elizabethae*, and polychaetes, *Sabellastarte* sp. The sea urchin, *Parechinus angulosus*, is also fairly abundant in the main canal.

Subtidal vegetation has increased dramatically in the last few years, and the bottom of some canals are covered in dense beds of *Caulerpa filiformis* and *Codium* sp. The explosive growth of these seaweeds may be the result of nutrient-enriched ground water entering the canals. A complex and diverse community of fauna is usually associated with these macro-algae, which possibly provide an excellent nursery ground for juvenile fish (Hanekom & Baird, 1984). Phytoplankton blooms have not been observed during the study period.

In the absence of obvious sources of external pollutants, the stability and viability of biological communities in artificial canal systems which are tidally dominated will ultimately depend on two factors: firstly, an efficient turnover and flux of water through the canals, and secondly, the presence at all times of well oxygenated water (refer to IAWPCR & AWWA, 1988). In the case of the Marina Glades canals this is a subject of concern. Although net sedimentation in the mouth region of the Kromme Estuary appears to be insignificant, the redistribution of sand in this area has caused the closure of the seaward access canal during recent years. This has lead to a less effective tidal flushing of the marina waters and an increase in the residence time of water in the canals. It has been determined by means of a hydrodynamic simulation model (Chapter 6) that the concentration of a pollutant, present in the marina at stations 2, 4 and 7 (see Fig. 5.1) will be diluted by 100%, 68% and 25% respectively after about 11 tidal cycles (or 5,25 days). When both inlets of the marina are open to the estuary, the dilution rate at stations 4 and 7 then increases 97% and 50% respectively. These results clearly indicate the vulnerability of the marina to pollution and to the importance of maintaining good water quality in this coastal marina system.

5.7 Notes on the General Ecology of the Kromme Estuary and a Comparison of Some Abiotic and Biotic Features Between the Marina and the Estuary

In addition to the work done in the marina, a comprehensive study on ecological aspects of the Kromme Estuary was conducted during the period 1988-1990. A substantial amount of information was collected on the plant and animal communities during the present study, and some of these results are presented here and compared with data sets of the same communities collected during the early eighties.

5.7.1 Abiotic features, phytoplankton and bacteria

Measurements of the parameters discussed below were sampled at 7-12 stations in the estuary between August 1989 and December 1990. One station was situated in the Yacht Basin of the Marina,

one in the Geelhoutsboom tributary, and the others along the length of the estuary proper. Samples were taken at 0,5 m depth intervals, from the surface to the bottom.

Salinity

Salinity decreased up the estuary, from a mean of 34,69ppt at the mouth to 31,66ppt (n = 48) in the upper reaches over a 16 month period (August 1989 - December 1990). Salinity values were slightly higher in summer than in winter. The salinity dropped below 30ppt on only one occasion after some heavy rains during November 1990. If this episodic event is excluded, then the mean salinity in the upper reaches over the abovementioned period is 32,82ppt. The vertical salinity profiles during times of fresh water releases from the C W Malan Dam show a thin layer of fresh water (ca 5-10 cm deep) on top of high salinity water, and extending downstream from the head of the estuary for about 0,75-1,0 km before mixing is complete.

Temperature

Mean temperature fluctuated from 24,2⁰C in summer to 14,0⁰C in winter. Temperature also increased up the estuary, from 17,6⁰C to 18,6⁰C. The Geelhout station showed a mean of 19,1⁰C. TX
r
KX

Light extinction

Turbidity also increased up the estuary, reaching a maximum in the Geelhout tributary. The turbidity was in general, however, very much lower than that found, for example, in the Sundays River estuary, indicating relatively clear waters in the Kromme Estuary.

Chlorophyll-a

Values increased up the estuary and were twice as high in the upper reaches than at the mouth. Winter concentrations were also lower than those in summer. Phytoplankton production was estimated to be in the order of 15 mgC.m⁻³hr⁻¹ (or about 88 g Cm⁻²year¹) in the Kromme Estuary, which is about the same as measured in the Swartkops Estuary, but much lower than in the Sundays Estuary.

Suspended material

Mean values were highest in the Geelhout tributary, but otherwise showed no pattern.

Ammonium-N

Mean ammonium levels increased up estuary and were generally less than 40gM⁻¹ during October 1990 in the Geelhout tributary. ?

Nitrate-N and phosphate

Both nutrients showed no temporal or spatial pattern, except for a small peak coinciding with the ammonium peak in the Geelhout tributary during October 1990. clock
Prob

The mean concentration values of inorganic nutrients (Ammonium-N, Nitrate-N and phosphate) in the estuary and the marina fall within the same range, but concentrations are much higher in the marina than in the rest of the estuarine waters. This is most probably due to non-point source inputs to the canal system during summer.

Diatoms

Cell numbers increased up the estuary and displayed a small bloom at the head during November 1990, which coincided with the inflow of a relatively large amount of fresh water. Cell numbers decreased during winter.

Dinoflagellates

Dinoflagellates showed no seasonal pattern, but were mainly restricted to the upper estuary.

Picoflagellates

Picoflagellates were twice as numerous in the upper estuary than near the mouth and tended to increase during the summer months.

Euglenoids

Euglenoids showed a patchy distribution and were most abundant in the upper estuary.

Bacteria

Numbers of rod-shaped bacteria were initially high and then decreased during the year. Coccoid bacteria showed an increase during winter. Attached bacteria were most abundant in the middle reaches and decreased towards the mouth and head of the estuary.

Comparisons of variables in the marina and the mouth area of the Kromme Estuary were also made over a full year, as opposed to comparisons over the summer season only (see above). No significant differences were noted between the two localities for most of the variables measured. Exceptions are the phytoplankton taxa and attached bacteria which occurred in higher concentrations in the marina than in the mouth area of the estuary.

It can be concluded:

- (i) that there do not appear to be significant differences between most of the water column variables in the marina and estuary proper;
- (ii) that dissolved inorganic nutrient concentrations are much higher in the marina than in the estuary;
- (iii) that the concentrations of dissolved inorganic nutrients are lower in waters of the Kromme Estuary than in other estuaries (see Table 5.4), and
- (iv) that the rate of phytoplankton production falls within the range measured for the Swartkops Estuary, but is much lower than that of the Sundays Estuary.

5.7.2 Macrophytes, zooplankton, benthic invertebrates and fish

Preliminary analyses of the data collected on these communities over the past three years showed the following trends:

- (i) macrophytes, such as eelgrass, *Zostera capensis*, flourish and are as abundant as before. There is also a noticeable increase in the biomass and upstream distribution of more

typically marine macrophytes such as *Codium* spp. and *Caulerpa* spp. These macrophytes provide large amounts of organic material through decomposition and thus provide the food basis for detritus feeders and particulate suspension feeders (see 5.7.2(c) below);

- (ii) the zooplankton community is relatively poor in diversity, and low in biomass and productivity when compared to other eastern Cape estuaries. This could be due to the homogeneous salinity regime and/or to the relatively low rates of phytoplankton production in the Kromme Estuary;
- (iii) the density and productivity of the benthic invertebrate communities are approximately in the same order as measured 10 years ago. There is no apparent decrease in the diversity of these communities, nor in their relative biomass (per unit area). These observations suggest that reduced fresh water supply to the estuary had little impact on these communities. It is also clear that typically marine species, such as sea-urchins and barnacles, have penetrated the estuary and occur as high as the upper reaches of the estuary as a result of the high salinities that prevail in the Kromme Estuary;
- (iv) that although there is no significant difference between the diversity of the fish community between earlier and present surveys, there is clearly a decrease in the catch per unit effort (CPUE) (an index of relative abundance) of both seine and gill net catches over the past few years. Summer values of diversity and CPUE are higher than those of winter. *Mugilidae* predominated in the recent catches in terms of both mass and numbers which indicate a change in the dominant species in the estuary from larger species (e.g. *L. amia*, *A. hololepidotus*) during the early eighties to *Mugilidae*.

Preliminary results thus indicate a change in the salinity regime from a typical estuarine gradient to a more homogeneous "marine" regime with no clear or persistent gradient from the

inlet to the upper reaches of the estuary since 1982/3, most probably due to reduced fresh water inflow. Results also show a decrease in abundance and biomass of zooplankton and a decrease in CPUE of seine- and gill net catches as well as a change in the composition of the fish community. Phytoplankton and water column bacterial production is low when compared to other estuaries, but there appear to be no changes in the diversity or abundance of the benthic invertebrate community. Macrophytes appear to flourish in the estuary which provide substantial organic material to detritus feeders.

5.8 Freshwater Requirements of the Kromme Estuary

The concept of freshwater requirements in estuaries is indeed a difficult one to address quantitatively and comprehensively. This particular issue is at present a subject of study and it is unlikely that a simple answer will be forthcoming in the immediate future. The reasons being that salinity affects different communities and populations differently in terms of diversity, productivity and physiological responses. Estuaries also differ from each other in their physical attributes and biological make-up, so that what may apply to one may not apply to another.

Evidence suggests that in estuaries where a salinity gradient exists, in other words, where there is a consistent inflow of freshwater with salinities in the upper reaches lower than in the mouth region, biomass and productivity of phytoplankton and zooplankton appear to be higher than in estuaries with an even salinity distribution (Wooldridge, Lord and Bate, 1990). For example, high salinities throughout the Kromme Estuary, lead to a decrease in phytoplankton biomass and production which resulted in a switch from a phytoplankton dominated system to one dominated by submerged macrophytes (Bickerton & Pierce 1988). Phytoplankton in the Kromme Estuary is about $88 \text{ gCm}^{-2}\text{y}^{-1}$ in contrast to a production value of about $300 \text{ gCm}^{-2}\text{y}^{-1}$ for the Sundays Estuary where a distinct salinity gradient exists from 35ppt in the mouth to about 10ppt at the head. Wooldridge et al.(1990) also remarked that high zooplankton production is closely linked with an adequate supply of freshwater and the

presence of a salinity gradient. Marais (1988) concluded that in estuaries where no salinity gradient prevails, such as the Kromme and at times in the Swartkops estuary, the fish communities are characterised by a lower diversity and lower numbers of individuals per species in comparison to other estuarine systems. It has also been noted by anglers that fish catches increased dramatically after a substantial influx of fresh water into the Kromme Estuary during November 1990.

It would thus appear that the presence of a salinity gradient could be beneficial for estuaries in general. It is also known that the salinity regime in the Kromme Estuary has been fairly homogeneous during the past eight years, mainly due to low fresh water inflows. This has resulted in the penetration of typically marine species such as barnacles, sea urchins, etc., into the estuary, low phytoplankton and zooplankton biomass and production, low fish diversity, and abundant macrophytic growth.

The question remains of how much freshwater inflow is required to maintain a salinity gradient in the Kromme Estuary, and this can be answered through the application of the hydrodynamic model to the Kromme Estuary, developed by Huizinga (1985).

By means of this model, continuous inflows were simulated to maintain equilibrium salinity profiles of various orders during high and low tides. For example, to maintain a salinity gradient of 35ppt at the mouth to 30ppt in the upper reaches, a continuous inflow of $0,1 \text{ m}^3/\text{sec}$ (i.e. $60\,480 \text{ m}^3$ per week) is required, which is about three times the weekly amount presently released by the dam to balance evaporation losses. To maintain a salinity of 15ppt in the upper reaches a release of $0,5 \text{ m}^3/\text{sec}$ (or $302\,400 \text{ m}^3$ weekly) is required, i.e. about 15 times the present rate of weekly releases.

It is impossible to predict the consequences of a salinity gradient on ecological processes in an estuary which has received little freshwater for some time. These responses will vary from estuary to estuary, and may influence various

processes differently. One can only speculate in general terms on the effects of higher salinity on some of these in the Kromme Estuary:

- (i) Water column productivity may increase;
- (ii) Turbidity levels may increase;
- (iii) Fish diversity and biomass may show an increase in the short and long term;
- (iv) Lower salinities may affect some typically marine species adversely, especially in the upper reaches of the estuary, and
- (v) Benthic macrophytes may decrease in diversity and biomass due to lower salinities, especially in the upper reaches.

It must be stressed that the comments on the freshwater requirements for the Kromme Estuary are of a preliminary nature, especially as far as the ecological responses are concerned. A comparative assessment of diversity, productivity and salinity is being conducted at present and these results should be available by the end of 1991.

5.9 Concluding Remarks

5.9.1 Water quality of the marina

Results from recent studies clearly show that the concentrations of dissolved nutrients, in particular nitrate, nitrogen and reactive phosphate, are higher than in the Kromme proper and in any of the other estuaries examined to date. However, these concentrations are well within the accepted international standards for the recreational use of sea and fresh water and pose no health or other problems at the moment. The maintenance of good water quality in the marina is directly related to efficient water circulation through the canals, and should this be impaired, it can be predicted that the water quality in the marina will deteriorate.

5.9.2 Ecology of the marina

The general ecology of the marina is in a healthy state and with a few exceptions appears to be approximately the same as during the previous survey during 1979-1981. The state of affairs is mainly due to the good quality of the water in the greater part of the marina which is in turn related to efficient water circulation.

5.9.3 Ecology of the Kromme Estuary

Despite a reduction in the diversity and abundance of zooplankton and some fish species, a decrease in the CPUE of fish catches, and low watercolumn productivity, the estuary functions normally. The absence of a typical salinity gradient, which is found in other productive systems, is of some concern and is mainly responsible for the above comment. The estuary has responded and adapted ecologically to small, freshwater inflows. If these continue to be low, the estuary will effectively become a finger of the sea and its definition as an estuary becomes debatable.

The dams in the catchment area have undoubtedly affected the estuary by changing the ecology. Until now, ecologists have considered such changes permissible. It is therefore concluded that the present condition of the estuary is within acceptable standards. However, current research addresses such changes to estuarine ecology, and their acceptability. Thus further monitoring of the estuary is essential, and if ecological standards change, a reassessment should be undertaken.

REFERENCES

- BAIRD, D., MARAIS, J.F.K., and WOODRIDGE, T. (1981). The Influence of the marina canals system on the ecology of the Kromme Estuary, St. Francis Bay. S. Afr. J. Zool. 16 pp 21-34
- BICKERTON, I.B. and PIERCE, S.M. (1988). Estuaries of the Part II Synopses of available information on individual systems. Rep.No. 33, Kromme(CMS45), Seekoei(CMS46) and Kabeljous (CMS47),

Heydorn, A E F and Morant, P D (eds). Stellenbosch. CSIR Research Report 432 1-109.

CLOETE, A (1990) A comparative study of the seasonal abundance, distribution and catch-per-unit-of-effort of fishes in the Kromme estuary by gill and seine nets, with notes on the fishes in the marina canal system. Department of Zoology, University of Port Elizabeth. B.Sc.(Hons) project report.

DE MEILLON, L. (1989). The dynamics of the St. Francis Bay Marina. University of Port Elizabeth. Department of Oceanography. pp 68. B.Sc.(Hons) project.

EMMERSON, W.D. and ERASMUS, T. (1987). The nutrient status of the Kromme River estuary, South Africa. Hydrobiologia 148 pp. 87-96.

EMMERSON, W.D. (1989). The nutrient status of the Sundays River estuary, South Africa. Water Research 23 pp. 1059-1067.

GROENEVELD, J.C. (1990) Ecology of the meiofauna community in the marina canals at the Kromme estuary, St. Francis Bay. Department of Zoology, University of Port Elizabeth. B.Sc.(Hons) project report. .

HANEKOM, N. (1982). An Ecological Study of the *Zostera* Beds in the Kromme Estuary. University of Port Elizabeth. Zoology Department Report Series 18, p 163.

HANEKOM, N. and BAIRD, D. (1984). Fish community structure in *Zostera* and non-*Zostera* regions of the Kromme Estuary, St. Francis Bay. S. Afr. J. Zool. 19 pp.295-301.

HANEKOM, N. and BAIRD, D. (1988). Distribution and variations in seasonal biomass of eelgrass *Zostera capensis* in the Kromme Estuary, St. Francis Bay, South Africa, S. Afr. J. Mar. Sci. 7, pp. 51-60.

HECHT, T. (1973). The ecology of the Kromme Estuary with special reference to *Sesarma catenata*. University of Port Elizabeth. M.Sc. Thesis. 150 pp.

HEYMANS, J. (1990). A quantitative survey of the benthic macrofauna in the marina canals of the Kromme estuary, St. Francis Bay. Department of Zoology, University of Port Elizabeth. B.Sc.(Hons) project report.

HUIZINGA, P. (1985) A dynamic one-dimensional water quality model. Stellenbosch. CSIR Research Report 562, 23pp.

IAWPRC 7 AWWA (1988) Water Quality and Management for Recreation and Tourism. International Association on Water Pollution Research and Control, and Australian Water and Wastewater Association. Proceedings of an International Conference, 10-15 July 1988, Brisbane, Australia. p 247.

LUSHER, J.A. (1984). Water quality criteria for the South African coastal zone. Pretoria. South African National Scientific Programmes, Report No. 94.

MARAIS, J.F.K. (1983). Seasonal abundance, distribution and catch per unit effort of fishes in the Kromme Estuary, South Africa. S. Afr. J. Zool. 18. pp.96-102.

MARAIS, J.F.K. (1984). Feeding ecology of major carnivorous fish from four Eastern Cape estuaries. S. Afr. J. Zool. 19. pp.210-223.

REDDERING, J.S.V. and ESTERHUYSEN, K. (1983). Research on sedimentation in estuaries. Sedimentation in the Kromme estuary. University of Port Elizabeth, Department of Geology. ROSIE Report no. 8, p 42.

WATLING, J.R. (1982). East Cape marine pollution monitoring programme report for the period May - December 1981. University of Port Elizabeth, Department of Zoology, Rep. series No. 17, 49 pp.

WOOLDRIDGE, T.H., LORD, D. and BATE, G.C. (1990) Sundays River Processes. Final Report to FRD, 23pp (unpublished).

TABLE 5.1: MARINA GLADES CANAL SYSTEM. Inorganic nutrient concentration and other biotic parameters measured in the water column

STATIONS	PO4(3-)	NO3-N	NO2-N	NH3-NH4	diss.O2	pH	SAL.ppt	TEMP.*C	
	mg/l								
1	0.318	0.22	0.006	0.002	7.2	8.0	34.0	17.9	DATE: 20/11/89
2	0.438	0.81	0.005	0.005	7.2	8.0	30.5	18.4	AVG. TIME: 10:15
3	0.738	0.61	0.004	0.003	7.0	8.0	33.7	18.0	TIME H.T.: 09:36
4	1.800	1.40	0.009	0.002	7.4	8.0	32.3	18.9	TIME L.T.: 16:10
5	0.219	0.81	0.007	0.003	7.2	8.5	31.5	20.1	TIDES: high
6T	2.400	0.81	0.007	0.003	6.8	8.4	27.5	22.0	neap
6B	0.699	0.50	0.008	0.002	7.1	8.6	31.9	19.5	
7T	0.630	0.90	0.004	0.003	6.9	8.6	32.4	22.2	
7B	0.399	0.90	0.000	0.003	7.2	8.8	32.3	20.5	
1	1.749	0.30	0.016	0.005	7.0	8.8	33.2	20.8	DATE: 20/11/89
2	0.480	0.90	0.010	0.008	7.0	8.7	31.1	21.6	AVG. TIME: 15:45
3	0.198	0.50	0.007	0.003	6.8	8.8	32.8	19.6	TIME H.T.: 09:36
4	0.438	1.00	0.007	0.002	6.8	8.3	32.8	20.4	TIME L.T.: 16:10
5	0.210	0.70	0.008	0.003	7.0	8.7	31.4	22.7	TIDES: ebb/low
6T	0.180	0.50	0.005	0.003	6.5	8.7	23.3	23.8	neap
6B	0.399	0.50	0.004	0.002	6.5	8.3	31.8	21.4	
7T	0.558	0.90	0.003	0.003	6.7	8.8	23.9	22.4	
7B	0.120	0.50	0.001	0.003	6.9	8.8	32.6	22.0	
1	1.068	0.61	0.025	0.007	9.8	8.7	34.3	20.8	DATE: 11/12/89
2	0.150	1.50	0.025	0.007	9.5	8.7	33.5	24.6	AVG. TIME: 12:05
3	0.078	1.80	0.025	0.005	9.2	8.6	34.1	23.5	TIME H.T.: 08:15
4	0.549	1.80	0.026	0.005	7.9	8.7	34.0	23.7	TIME L.T.: 14:30
5	0.150	1.60	0.024	0.004	8.8	8.8	34.1	24.5	TIDES: ebb/low
6T	0.060	1.60	0.025	0.010	7.8	8.8	33.6	25.2	spring
6B	0.030	2.10	0.014	0.012	7.6	8.8	33.9	24.9	
7T	0.060	1.50	0.025	0.006	7.2	8.8	34.1	25.8	
7B	0.150	1.90	0.020	0.010	7.5	8.8	34.0	25.0	
1	0.099	0.56	0.005	0.002	6.7	8.6	34.3	19.8	DATE: 11/12/89
2	0.159	1.00	0.005	0.005	6.7	8.7	32.6	20.5	AVG. TIME: 22:00
3	0.180	1.10	0.004	0.002	6.0	8.7	32.8	20.2	TIME H.T.: 20:54
4	0.168	1.20	0.005	0.002	6.0	8.6	34.1	21.6	TIME L.T.: -- --
5	0.150	1.10	0.004	0.003	6.5	8.7	33.7	20.8	TIDES: high/ebb
6T	0.120	1.10	0.003	0.003	5.8	8.8	32.9	23.1	spring
6B	0.228	1.30	0.003	0.003	5.4	8.8	33.8	21.5	
7T	0.099	1.30	0.005	0.006	5.5	8.7	32.6	23.9	
7B	0.090	1.30	0.002	0.005	5.3	8.7	34.2	22.0	

TABLE 5.1 Continued.

	P04(3-)	N03-N	N02-N	NH3-NH4	diss.O2	pH	SAL.ppt	TEMP.°C	
STATIONS	mg/l								
1	0.069	0.50	0.025	0.003	6.6	8.5	34.5	20.3	DATE: 12/12/89
2	0.159	1.20	0.023	0.007	6.6	8.7	33.5	26.0	AVG. TIME: 11:00
3	0.168	1.90	0.022	0.004	6.9	8.6	34.1	22.9	TIME H.T.: 15:18
4	0.129	1.70	0.024	0.003	5.7	8.6	34.3	26.6	TIME L.T.: 09:03
5	0.108	1.50	0.024	0.005	6.5	8.6	34.1	23.7	TIDES: flood
6T	0.210	1.80	0.027	0.006	5.8	8.6	33.6	25.0	spring
6B	0.009	1.70	0.025	0.007	5.6	8.7	34.1	24.5	
7T	0.090	1.40	0.025	0.005	5.9	8.7	34.0	24.6	
7B	0.129	1.80	0.024	0.007	6.0	8.8	34.1	24.2	
1	0.999	0.82	0.004	0.003	7.3	8.8	35.0	19.5	DATE: 19/02/90
2	1.200	1.00	0.000	0.005	6.3	8.3	35.5	23.0	AVG. TIME: 14:00
3	0.369	1.40	0.002	0.004	6.9	8.1	34.5	23.0	TIME H.T.: 10:18
4	0.219	1.50	0.003	0.004	6.2	8.1	37.0	24.0	TIME L.T.: 18:11
5	1.809	1.50	0.002	0.005	6.3	7.8	35.0	24.0	TIDES: ebb
6T	0.168	1.50	0.000	0.004	6.7	7.8	32.5	26.0	neap
6B	0.228	1.50	0.050	0.006	6.2	7.9	35.0	25.0	
7T	2.400	1.20	0.000	0.005	6.1	7.9	37.0	25.5	
7B	0.360	1.30	0.003	0.005	6.7	8.3	36.0	25.0	
1	0.234	0.58	0.005	0.006	7.3	8.7	35.5	19.0	DATE: 09/03/90
2	0.390	1.76	0.002	0.003	6.3	9.1	35.0	21.0	AVG. TIME: 11:30
3	0.060	1.80	0.003	0.004	6.9	9.0	35.0	21.0	TIME H.T.: 15:04
4	3.900	1.50	0.002	0.029	6.2	8.9	35.0	22.0	TIME L.T.: 08:59
5	0.219	1.60	0.003	0.005	6.3	9.0	35.0	21.5	TIDES: flood
6T	0.168	2.00	0.003	0.005	5.7	8.9	34.5	22.5	spring
6B	0.408	1.50	0.005	0.006	6.2	9.0	35.0	22.5	
7T	0.249	1.70	0.005	0.007	6.1	9.0	36.0	22.0	
7B	0.489	1.60	0.001	0.009	6.7	9.0	36.0	22.5	
MEAN	0.455	1.22	0.010	0.005	6.5	8.3	32.4	21.7	
MAX.	3.900	2.10	0.050	0.029	9.8	9.1	37.0	26.6	
MIN.	0.009	0.220	0.000	0.002	5.3	7.8	23.3	17.9	
SD (N-1)	0.695	0.450	0.011	0.004	0.9	0.3	2.4	2.2	

TABLE 5.2: MARINA GLADES CANAL SYSTEM. Statistics of inorganic nutrient concentration and other abiotic parameters measured in each sampling session.

	mg/l							
	PO4(3-)	NO3-N	NO2-N	NH3-NH4	Diss.O2	pH	SAL.ppt	TEMP. °C
10/11/89 mean	0.849	0.77	0.006	0.003	7.1	8.3	31.7	19.2
range	2.400-0.219	1.40-0.22	0.009-0.004	0.005-0.002	7.2-6.8	8.8-8.0	34.0-27.5	22.2-17.9
SD(N-1)	0.745	0.32	0.003	0.001	0.2	0.3	1.9	1.6
20/11/89 mean	0.481	0.68	0.007	0.004	6.8	8.7	30.3	21.6
range	1.749-0.120	1.00-0.30	0.016-0.001	0.008-0.002	7.0-6.5	8.8-8.3	33.2-23.3	23.8-19.6
SD(N-1)	0.500	0.24	0.004	0.002	0.2	0.2	3.9	1.273
11/12/89 mean	0.225	1.71	0.023	0.007	8.4	8.7	33.9	24.2
range	1.068-0.003	2.10-1.50	0.026-0.014	0.012-0.004	9.8-7.2	8.8-8.6	33.5-34.3	20.8-25.8
SD(N-1)	0.343	0.20	0.004	0.003	1.0	0.1	0.3	41.468
11/12/89 mean	0.114	1.20	0.004	0.003	5.9	8.7	33.4	21.4
range	0.228-0.090	1.40-1.00	0.005-0.002	0.006-0.002	6.7-5.3	8.8-8.6	34.3-32.6	23.9-19.8
SD(N-1)	0.046	0.13	0.001	0.002	0.5	0.1	0.7	1.4
12/12/89 mean	0.119	1.58	0.024	0.005	6.1	8.6	34.0	24.2
range	0.210-0.009	1.90-1.20	0.027-0.022	0.007-0.003	6.9-5.6	8.8-8.5	34.5-33.5	23.6-20.3
SD(N-1)	0.059	0.26	0.001	0.002	0.5	0.1	0.3	1.8
19/02/90 mean	0.861	1.37	0.007	0.005	6.5	8.1	35.2	23.8
range	2.400-0.0168	1.50-1.00	0.050-0.000	0.006-0.003	9.1-7.3	8.8-7.8	37.0-32.5	26.0-19.5
SD(N-1)	0.805	0.17	0.016	0.001	0.4	0.3	1.4	1.9
09/03/90 mean	0.680	1.69	0.003	0.008	6.4	8.9	35.2	21.5
range	3.900-0.060	2.00-1.50	0.005-0.001	0.029-0.006	7.3-5.7	9.1-8.7	36.0-34.5	22.5-19.0
SD(N-1)	1.215	0.16	0.001	0.008	0.5	0.1	0.5	1.1

TABLE 5.3: MARINA GLADES CANAL SYSTEM. Concentration of coliform bacteria in the canals water during the 1989/90 holiday season.

	STATIONS								
	1	2	3	4	5	6T	6B	7T	7B
22/11/89									
total:	8	12	<10	3	1	4	7	<10	<10
faecal:	3	12	5	2	0	4	5	4	7
12/12/89									
total:	10	140	2	5	6	5	7	12	3
faecal:	1	53	2	2	3	2	7	9	3
20/02/90									
total:	0	14	0	0	0	6	0	1	0
faecal:	0	3	0	0	0	5	0	1	0
09/03/90									
total:	3	8	0	0	2	4	0	3	4
faecal:	0	5	0	0	0	1	0	0	4

TABLE 5.4: Comparison of mean values of inorganic nutrient concentrations and abiotic parameters in the study site and other E. Cape estuaries.

	KROMME	SWARTKOPS	SUNDAYS	ST. FRANCIS	MARINA
	mean	mean	mean	mean	SD(N-1)
Temperature °C	17.8	19.6	19.3	22.4	2.2
Salinity (ppt)	25.8	22.9	20.5	33.4	2.4
pH	8.0	8.1	8.2	8.6	0.3
Oxygen (mg/l)	7.4	7.2	7.7	6.8	0.9
NH3-NH4 (mg/l)	0.003	0.204	0.041	0.005	0.004
NO3-N (mg/l)	0.064	0.516	0.630	1.225	0.447
NO2-N (mg/l)	0.005	0.013	0.018	0.011	0.011
PO4(3-) (mg/l)	0.121	1.320	0.233	0.484	0.695
Coliforms:					
total (/100 ml)	-----	-----	-----	8	22.90
faecal (/100 ml)	26	640	18	4	8.89
50 % samples	-----	-----	-----	≤2	-----
98 % samples	-----	-----	-----	≤12	-----

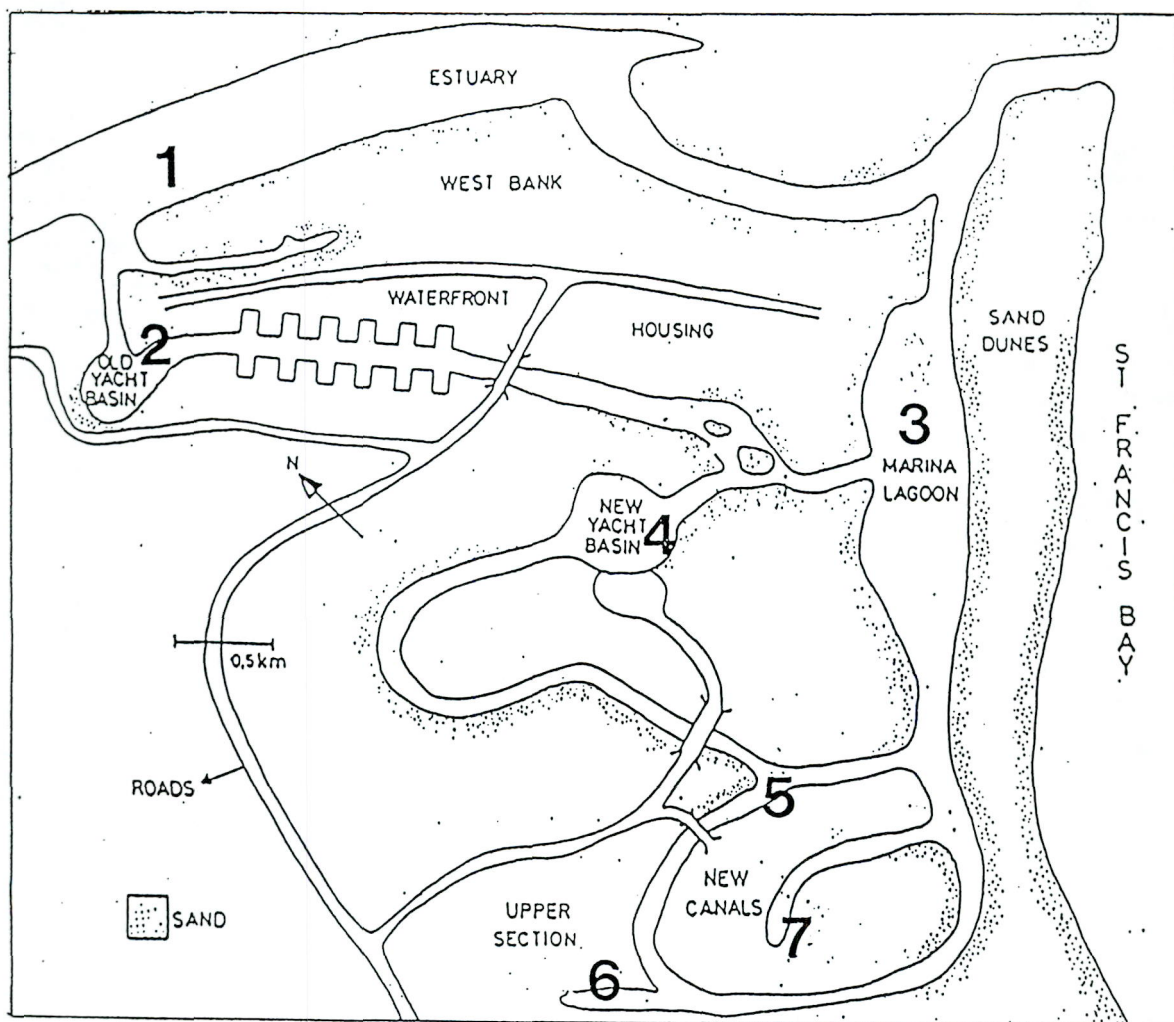


Figure 5.1 - Map of the Marina Glades Canal System showing the situation of the sampling stations in this study.



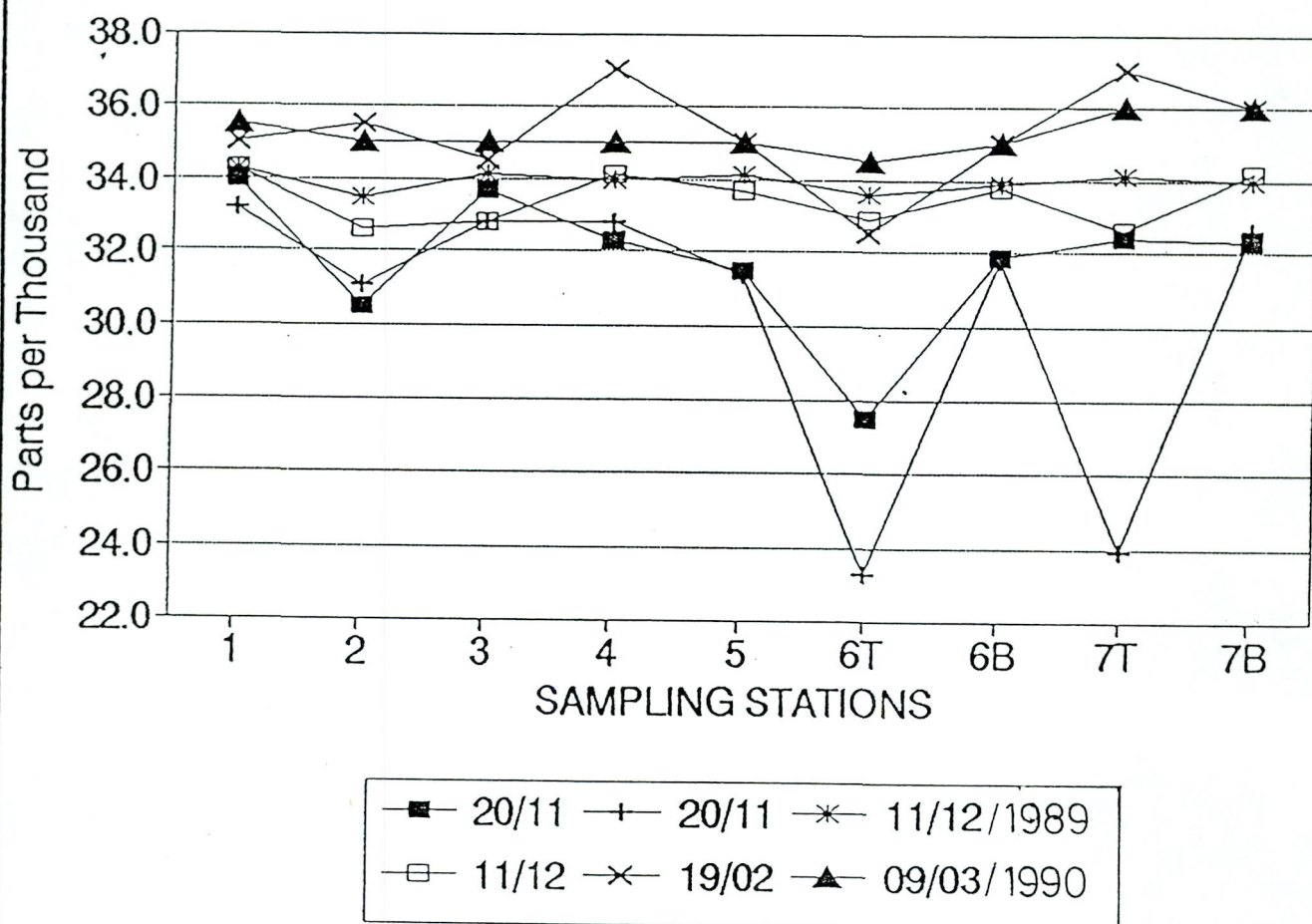


Figure 5.2 - Salinity profile in the Marina Glades Canal System during the sampling period (November 1989 to March 1990). Stations 2 to 7B were situated in the marina canals (see Figure 1). Station 1 was situated in the Kromme Estuary main channel. T and B refer to Top and Bottom of the water column.

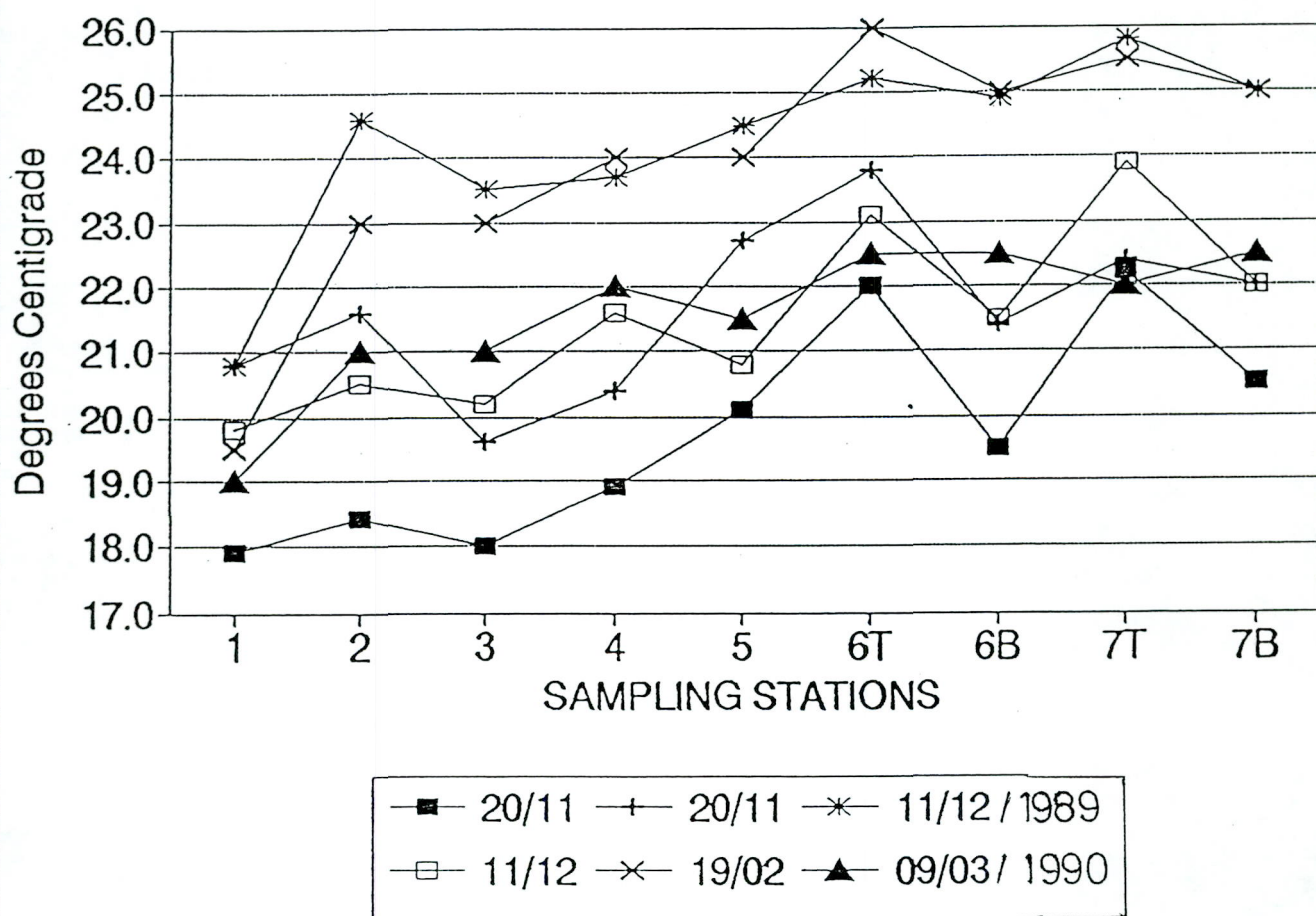


Figure 5.3 - Temperature profile in the Marina Glades Canal System during the sampling period (November 1989 to March 1990). Stations 2 to 7B were situated in the marina canals (see Figure 1). Station 1 was situated in the Kromme estuary main channel. T and B refer to Top and Bottom of the water column.

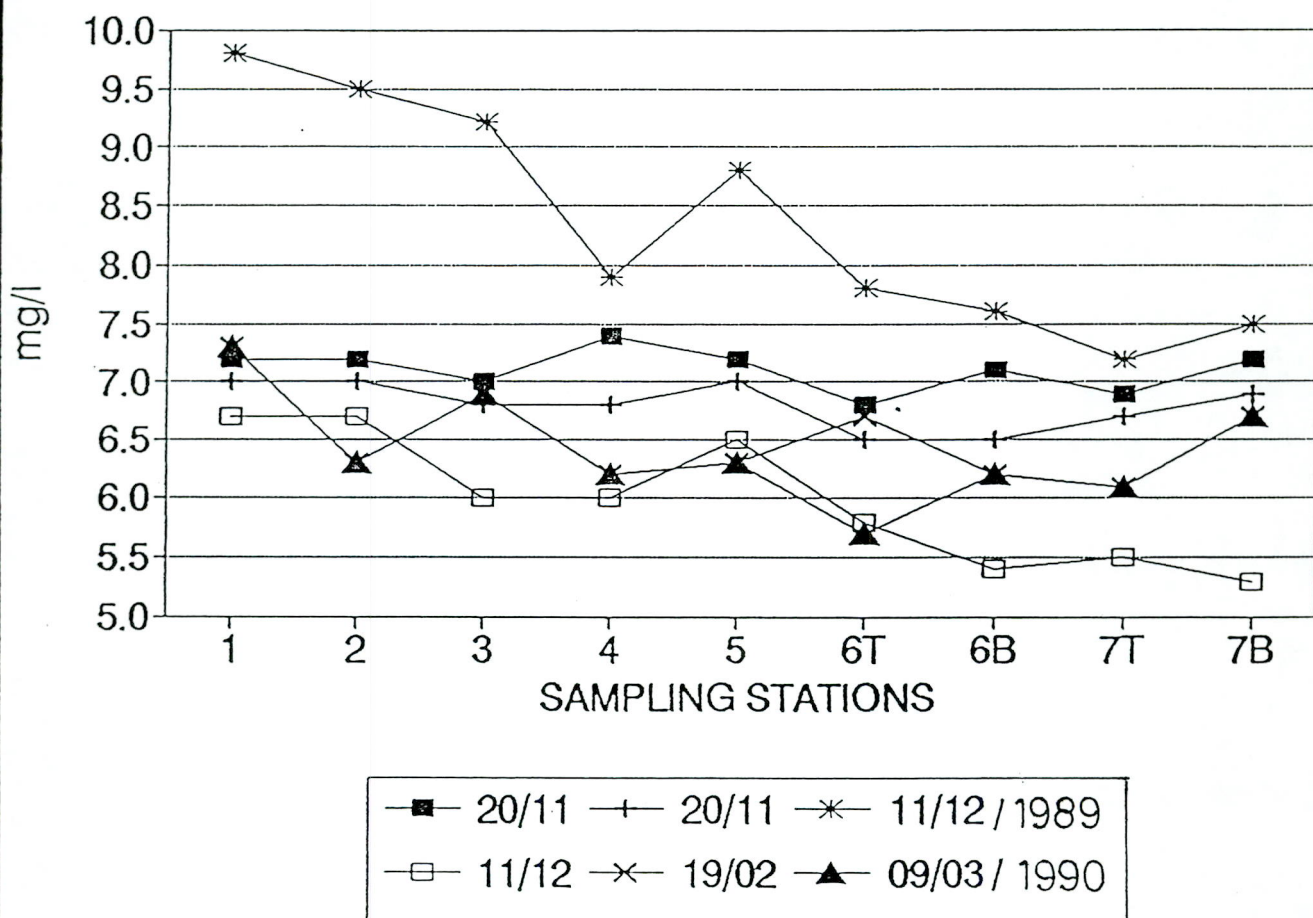


Figure 5.4 - Dissolved Oxygen concentration in the Marina Glades Canal System during the sampling period (November 1989 to March 1990). Stations 2 to 7B were situated in the marina canals (see Figure 1). Station 1 was situated in the Kromme Estuary main channel. T and B refer to Top and Bottom of the water column.



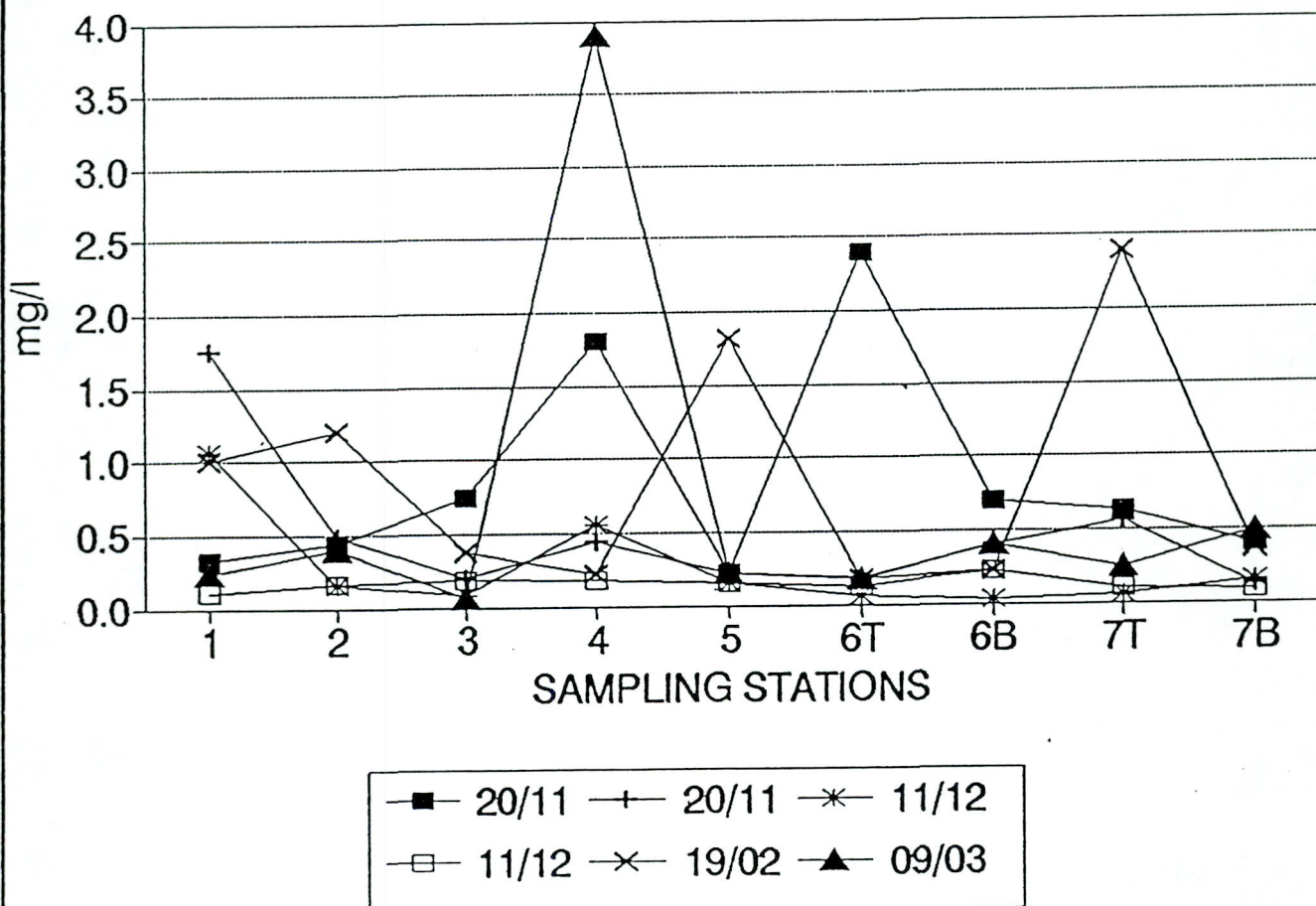


Figure 5.5 - Concentration of Soluble Reactive Phosphorous in the Marina Glades Canal System during the sampling period (November 1989 to March 1990). Stations 2 to 7B were situated in the marina canals (see Figure 1). Station 1 was situated in the Kromme estuary main channel. T and B refer to Top and Bottom of the water column.

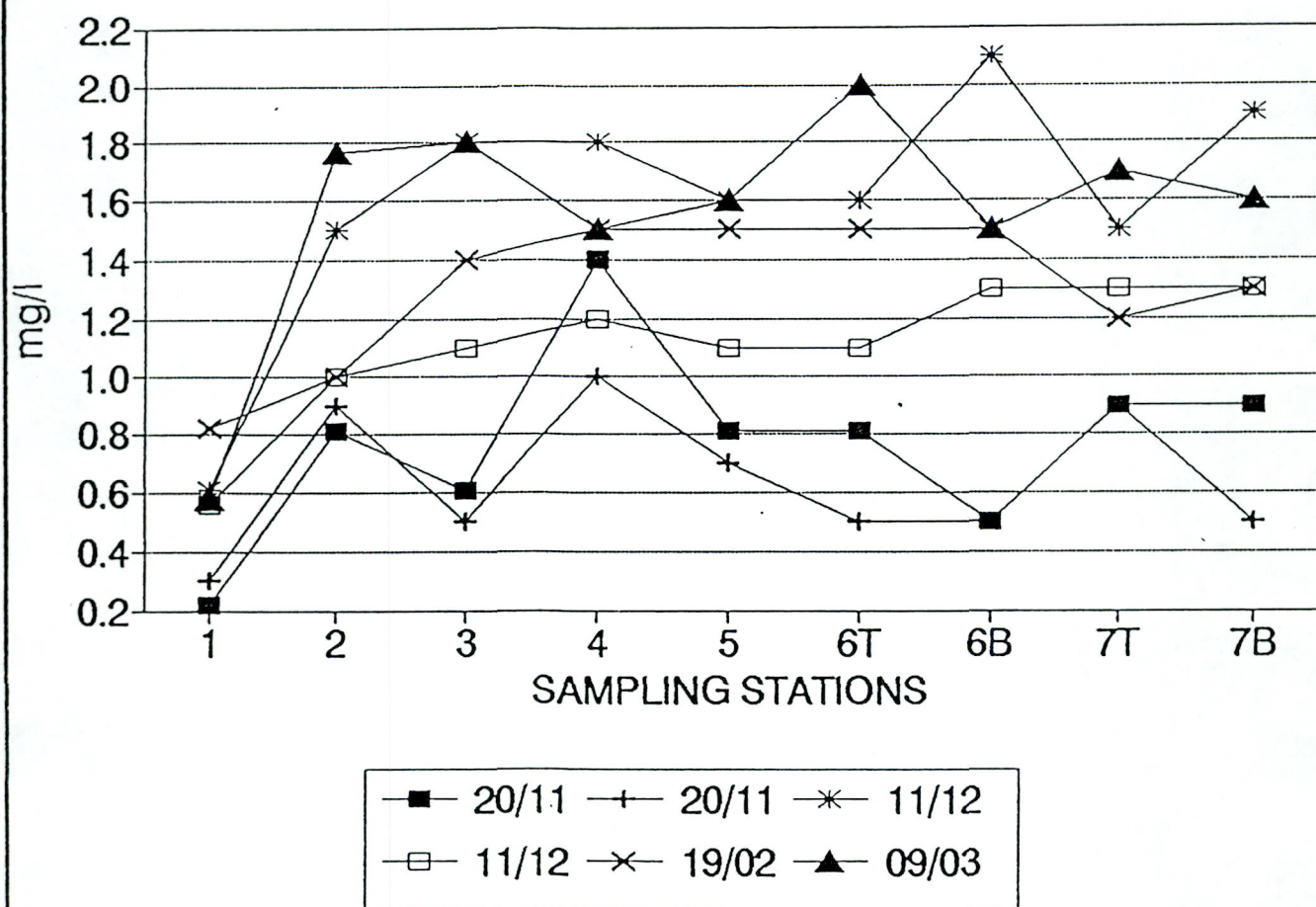


Figure 5.6 - Concentration of Nitrates ($\text{NO}_3\text{--N}$) in the Marina Glades Canal System during the sampling period (November 1989 to March 1990). Stations 2 to 7B were situated in the marina canals (see Figure 1). Station 1 was situated in the Kromme estuary main channel. T and B refer to Top and Bottom of the water column.



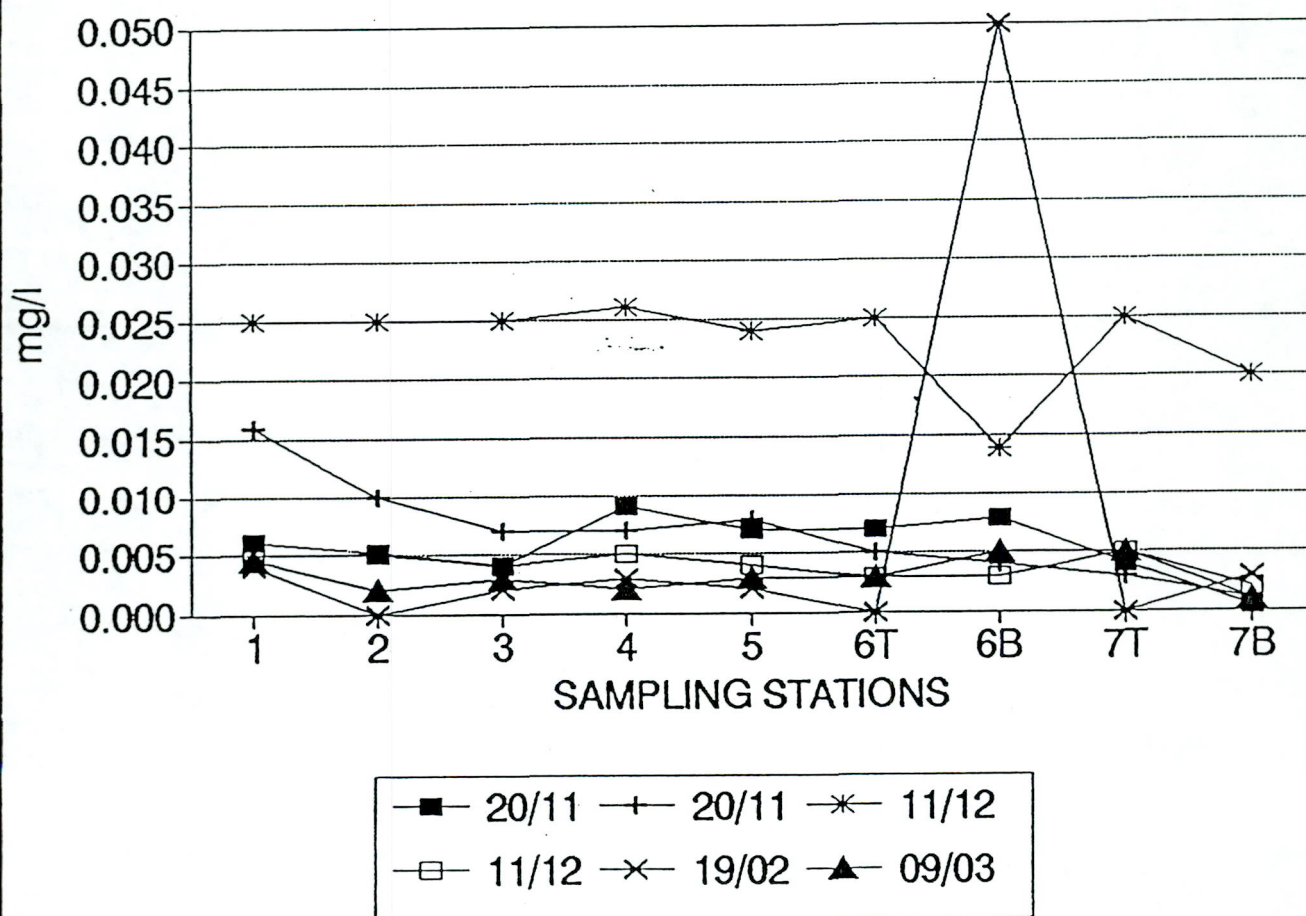


Figure 5.7 - Concentration of Nitrites (NO_2^- -N) in the Marina Glades Canal System during the sampling period (November 1989 to March 1990). Stations 2 to 7B were situated in the marina canals (see Figure 1). Station 1 was situated in the Kromme estuary main channel. T and B refer to Top and Bottom of the water column.

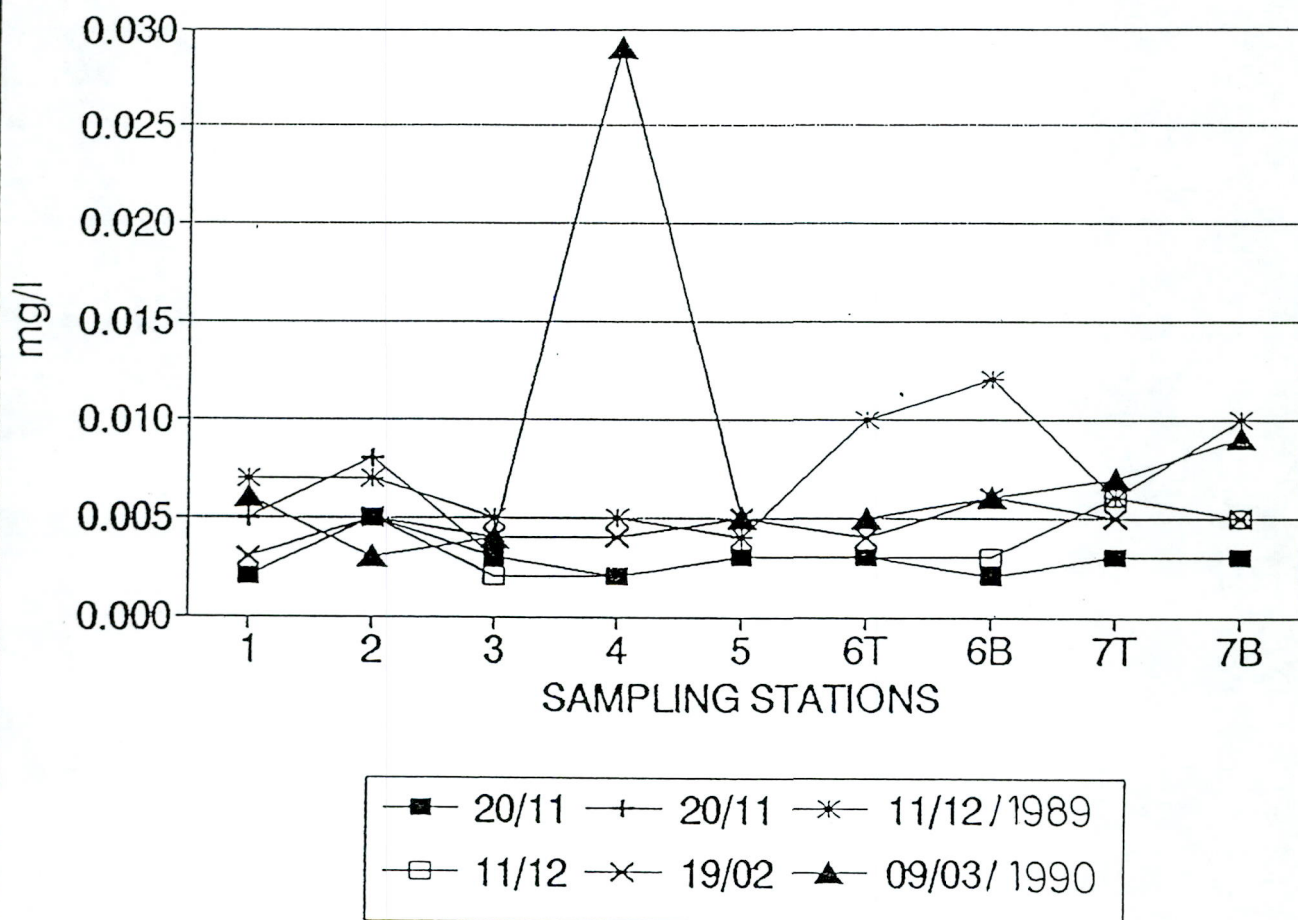


Figure 5.8 - Concentration of Ammonia (NH_3 - NH_4^+) in the Marina Glades Canal System during the sampling period (November 1989 to March 1990). Stations 2 to 7B were situated in the marina canals (see Figure 1). Station 1 was situated in the Kromme Estuary main channel. T and B refer to Top and Bottom of the water column.

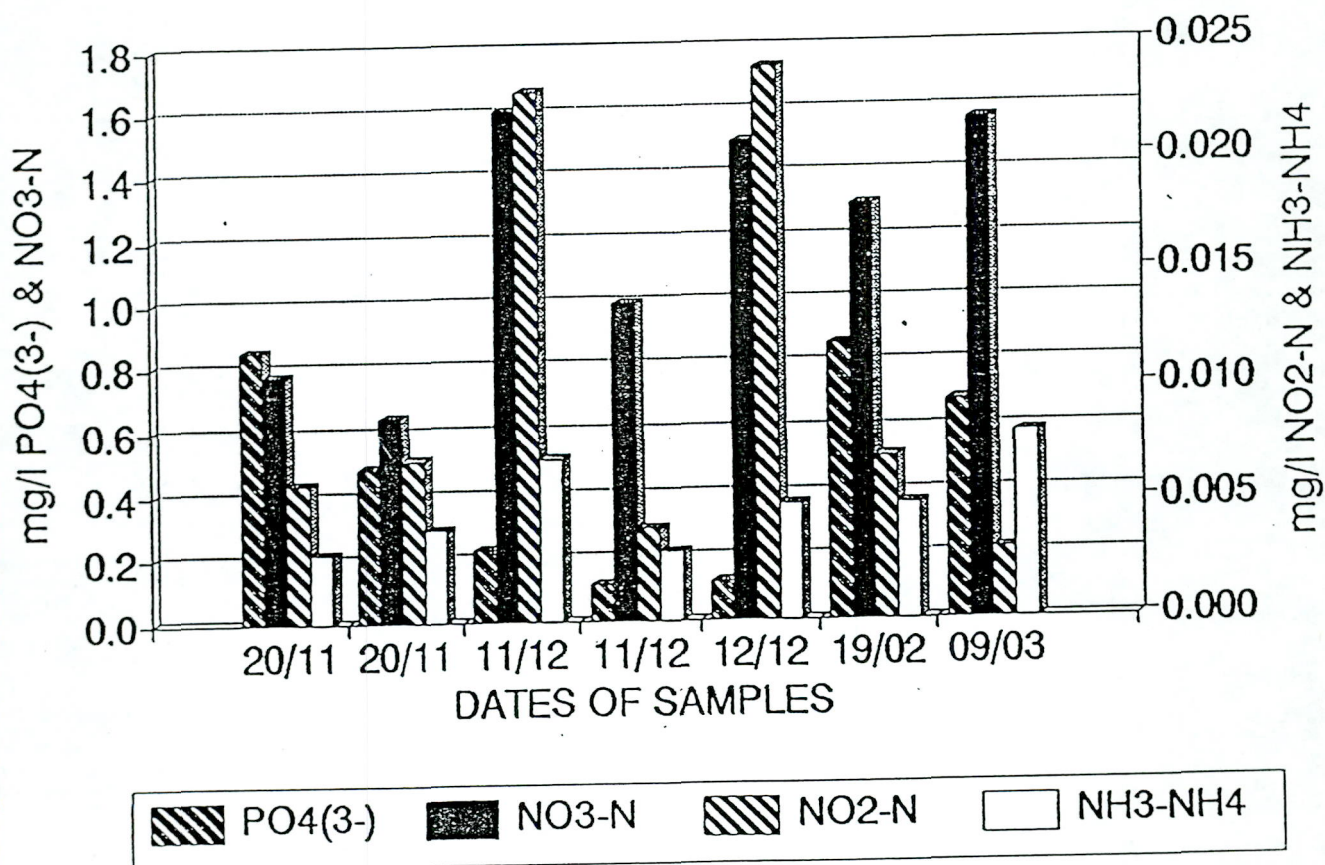


Figure 5.9 - Mean concentration (all sampling stations averaged) of inorganic nutrients in the water of the Marina Glades canals on seven sampling sessions from November 1989 to March 1990. See details in the text.

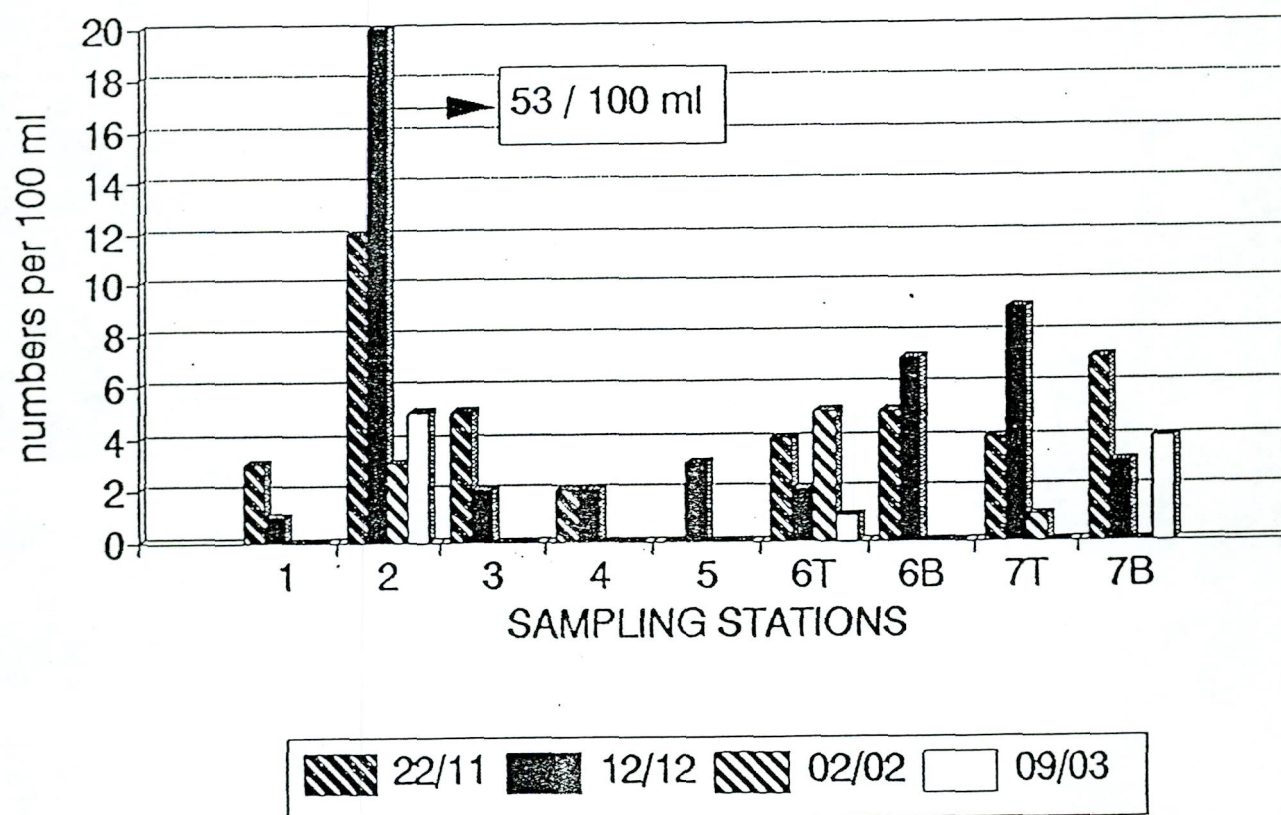


Figure 5.10 - Number of faecal coliforms per 100 ml of water recorded in the Marina Glades Canal System (Stns. 2-7B) and the Kromme estuary (Stn. 1) on four occasions from November 1989 to March 1990. See details in the text.

6. EVALUATION OF WATER CIRCULATION IN THE KROMME MARINA, WITH REGARD TO THE PLANNED NEW EXTENSIONS.

6.1. General

New extensions to the Kromme Marina are being planned. As discussed in Chapter 5, there is a danger of a deterioration in water quality if water circulation in the estuary is reduced, particularly when the seaward access canal is blocked, owing to sedimentation. Unless a solution can be found, this potential problem could be even worse in the planned new extensions to the marina.

A possible solution to the potential water quality problem is to create a nett one-way water circulation in the marina, by the operation of a sluice gate to control tidal flows.

In this study, the effectiveness of the sluice gate system has been evaluated with the CSIR's one-dimensional computer model of the estuary.

6.2. Application of the Solution in the Kromme Marina

A layout of the marina, with the planned extensions, is presented in Figure 6.1. The sluice gate is situated close to the landward access canal, in the loop created by the extensions. The proposed operation of the sluice is as follows:

- (i) On the incoming flood tide, it would be opened, to allow inflow through the sluice and through the other canals.
- (ii) On the outgoing ebb tide, it would be closed, thereby forcing the water to flow anti-clockwise, out of the marina.
- (iii) On the next flood tide, it would be re-opened, and the cycle would be repeated. In this way the water in the marina can be replaced by water from the estuary, over a number of tidal cycles.

(iv) This forced tidal circulation can only be created if a loop exists in the marina canal system, and can therefore only be applied to the Kromme marina if the new extensions are implemented.

(v) In addition, the circulation could be further improved in the region of the existing marina, by closing off certain canals (at positions A and B in Figure 6.1), to avoid stagnant loops.

6.3. Model Simulation Results

The effectiveness of the tidal gate flushing system on removing polluted water from the marina was investigated for various conditions, with the CSIR's hydrodynamic and transport-dispersion computer model of the Kromme Estuary. An initial arbitrary concentration (of 50 units) was introduced into the entire marina (Figure 6.3), with the remainder of the estuary having a zero concentration. The effect of the forced tidal flushing on the concentrations in the marina was simulated, and the results after 5,25 days are compared.

The following conditions were simulated:

Test 1: The present marina with the seaward access canal closed, which is the situation causing concern at the moment (Figure 6.4).

Test 2: The marina with the extensions, the seaward access canal closed, and with a sluice gate in operation (Figure 6.5).

Test 3: The marina with the extensions, the seaward access canal closed; with a sluice gate in operation, and canals closed off at A and B (see Figure 6.1). The results are presented in Figure 6.6.

Test 4: The marina with the extensions, and with the seaward access canal closed, but without the sluice gate in operation (Figure 6.7).

Test 5: The present marina layout, with the seaward access canal open (Figure 6.8).

Test 6: The marina with the extensions, with the seaward access canal open, and with the sluice gate in operation (Figure 6.9).

Test 7: The marina with the extensions, and with the seaward access canal open, but without the sluice gate in operation (Figure 6.10).

In the above simulations, the canal cross-section illustrated in Figure 6.2 was used, for the marina extensions.

Discussion of the results.

A summary of the computed concentrations at various positions in the marina is presented in Table 6.1, at the end of this chapter. The location of these Positions 1 to 7, referred to in the table, are illustrated in Figures 6.4 to 6.10.

Access canal closed condition.

A drop in concentration of almost 90 % percent, i.e. from 21,09 to 2,70, is observed at position 1 in the present marina, if the extensions with the tidal sluice gate system are implemented. A further drop to 1,66 can be achieved by applying additional sluice gates (at A and B in Figure 6.1).

The concentrations at Positions 1 and 2 are 38,49 and 40,05 respectively, if the tidal sluice gate system is not implemented with the new extensions, indicating far worse circulation for this situation.

These findings prove that for a closed access canal condition, the new extensions, combined with the sluice gate system, considerably improve the circulation both in the new extensions and in the present marina, and will therefore strongly reduce the possibility of deteriorating water-quality in the marina.

Solutions to the sedimentation problem in the seaward access canal are presently being investigated. If a satisfactory solution is not found, then at least the circulation and related potential water-quality problem in the marina could effectively be resolved, by the implementation of the sluice gate system in the new extensions.

Considerably higher concentrations were computed for the dead-end canals in the marina for all the tests (Positions 4- 7). At Position 7, the blocked seaward access canal, a complete blockage was assumed. However, in reality, flow at high water spring tides will occur at this position, removing water of bad quality. It is recommended that the water quality in the dead-end canals be monitored. If it deteriorates, additional measures, for example pumping of water, could be used to solve problems.

Access canal open condition.

A slight increase in concentrations, from 0,67 to 1,48, is observed between tests 5 (present marina) and 6 (new extensions with sluice gate) in the open ended canal at Position 1. However, the highest concentration in the new extensions (Position 2) is considerably lower (0,04), again indicating the effectiveness of the tidal flushing system. Further improvements can be achieved by installing the additional gates at positions A and B (Figure 6.1).

Flow velocities.

The effects of the operation of the sluice gate system on the flow velocities has also been investigated. Table 6.2 presents the maximum velocities of flow in the marina, which all occurred at Position E (see Figure 6.1), for the various test conditions.

The highest velocities, 0,87 for the closed access canal and 0,71 for the open access canal, are observed for the present marina layout.

6.4 Conclusions

The model simulations prove that the sluice gate system can resolve the circulation and related potential water-quality problem in the new extensions to the marina.

In addition, for a closed seaward access canal condition, the new extensions, combined with the sluice gate system, will considerably improve the circulation in the present marina and will therefore strongly reduce the possibility of deteriorating water-quality.

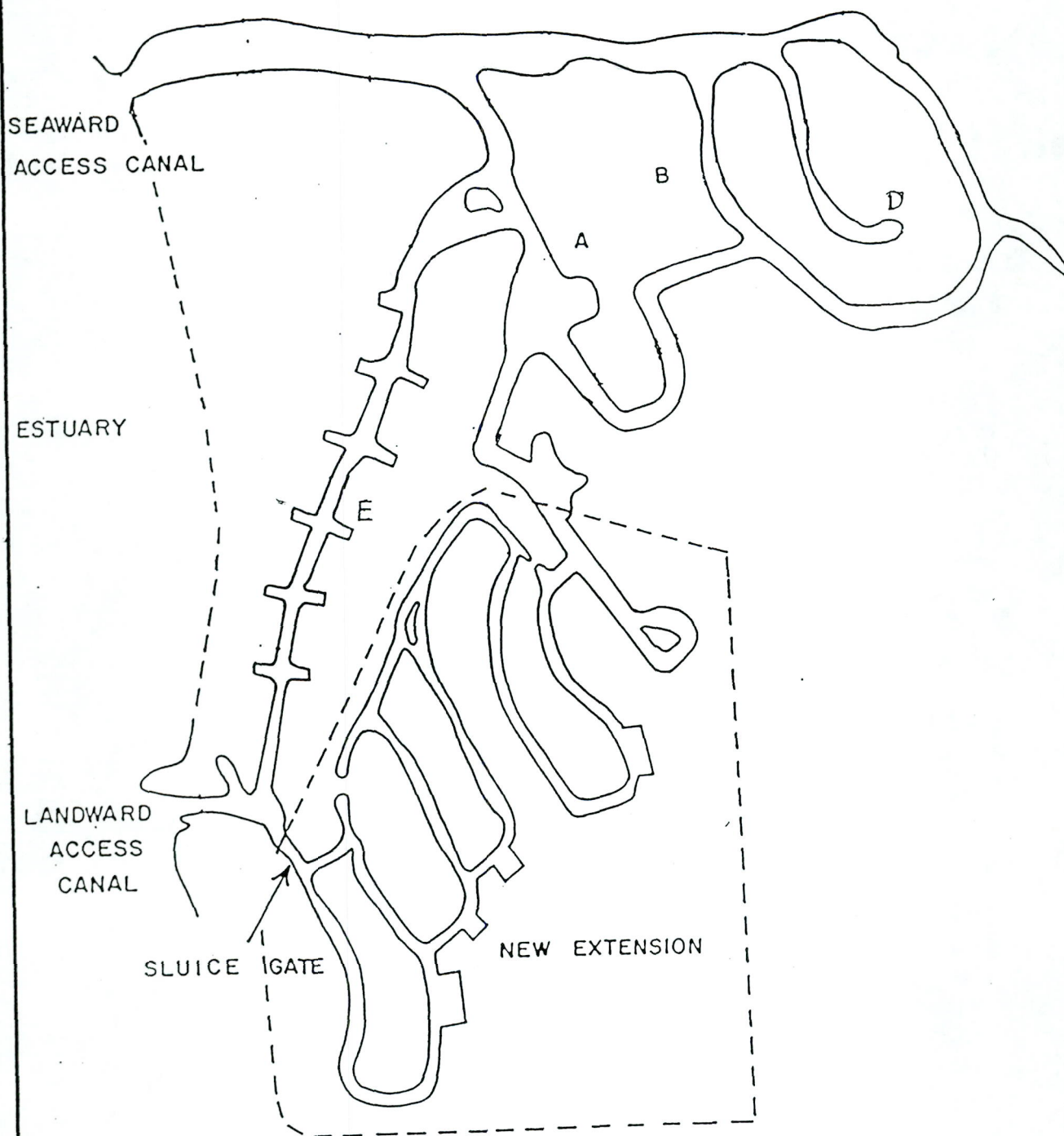
Furthermore, the new extensions, with and without the sluice gate in operation, will result in a reduction of maximum flow velocities in the marina.

TABLE 6.1: SUMMARY OF TEST RESULTS

CONCENTRATIONS							
TEST No:	1	2	3	4	5	6	7
FIGURE No:	4	5	6	7	8	9	10
POSITION 1	21.09	2.70	1.66	38.49	0.67	1.48	3.00
POSITION 2	-	2.46	1.67	40.05	-	0.04	7.71
POSITION 3	-	0.04	0.84	0.00	0.78	0.00	0.00
POSITION 4	10.60	0.65	0.84	41.47	1.05	0.31	0.72
POSITION 5	-	11.10	10.20	47.10	-	4.45	6.84
POSITION 6	37.70	20.30	8.35	39.39	24.53	5.45	6.80
POSITION 7	44.58	45.58	43.45	50.00	0.00	0.00	0.00

TABLE 6.2: Model results of maximum velocities in the marina

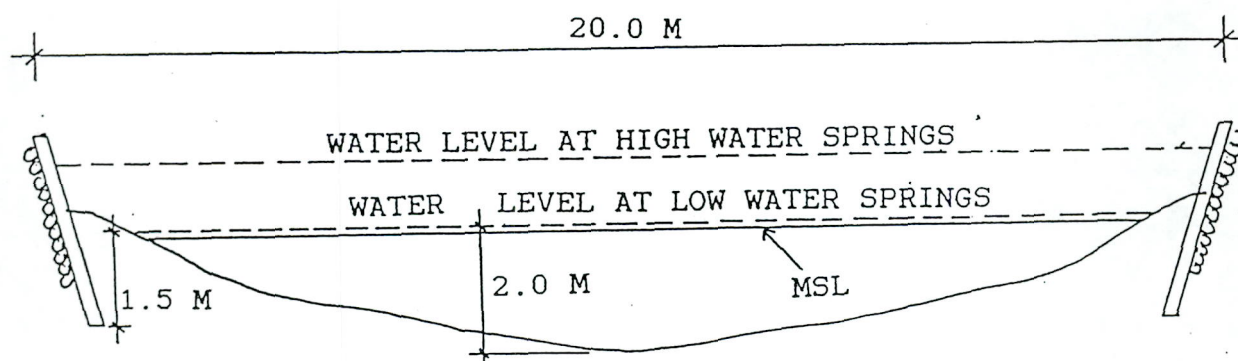
Test 1:	Present marina layout, but with the seaward access canal closed	0,87 m/s
Test 2:	Marina with extensions, seaward access canal closed; with the sluice gate in operation	0,60 m/s
Test 3:	Marina with extensions; seaward access canal closed; sluice gate in operation; and canals closed off at A and B	0,56 m/s
Test 4:	Marina with extensions, and with the seaward access canal closed, but without the sluice gate in operation	0,56 m/s
Test 5:	The present marina layout and the seaward access canal open	0,71 m/s
Test 6:	Marina with extensions and sluice gate in operation and the seaward access canal open	0,54 m/s
Test 7:	Marina with proposed extensions without the sluice gate in operation	0,52 m/s



THE KROMME MARINA WITH EXTENSION

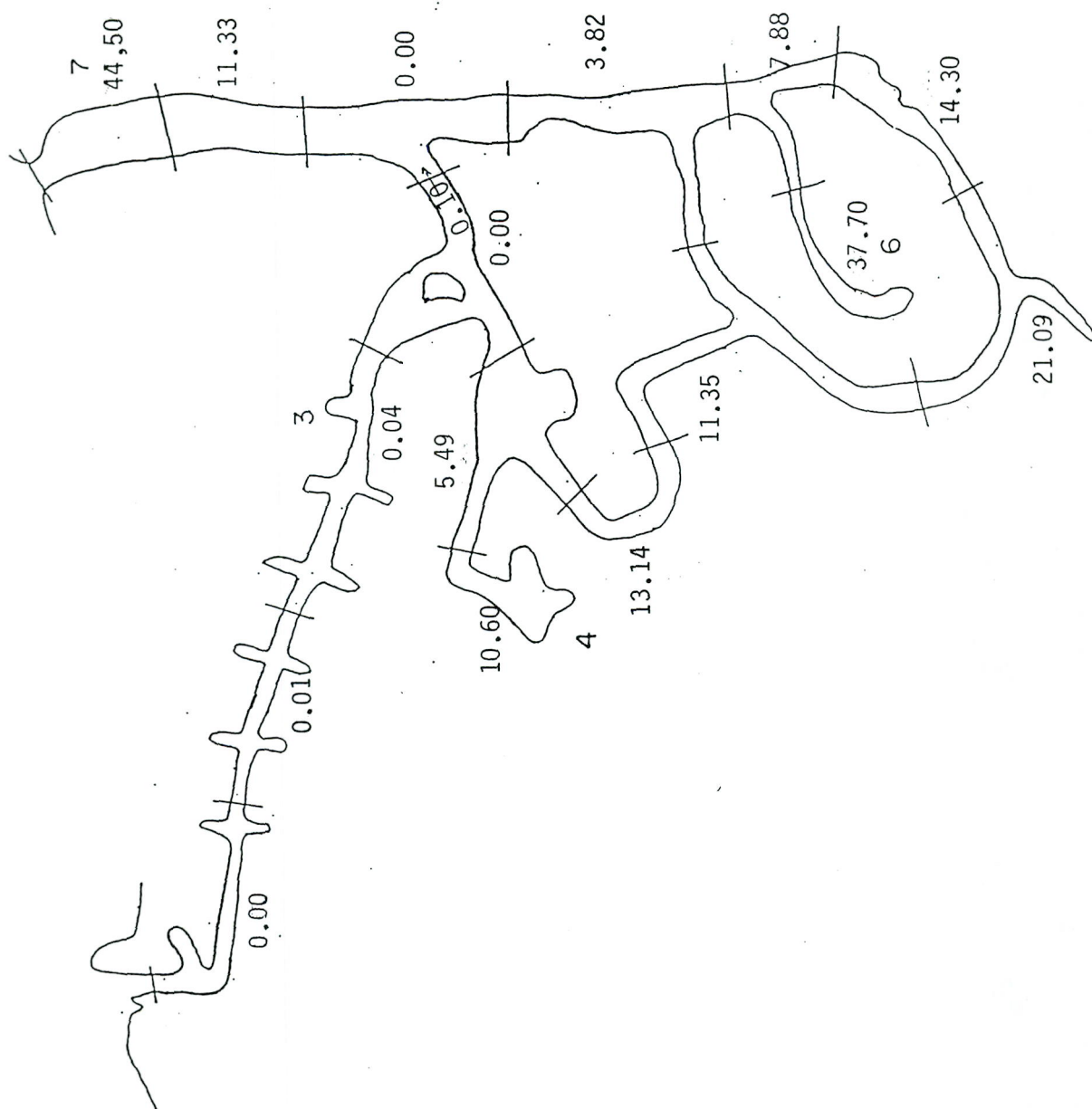
FIGURE
6.1





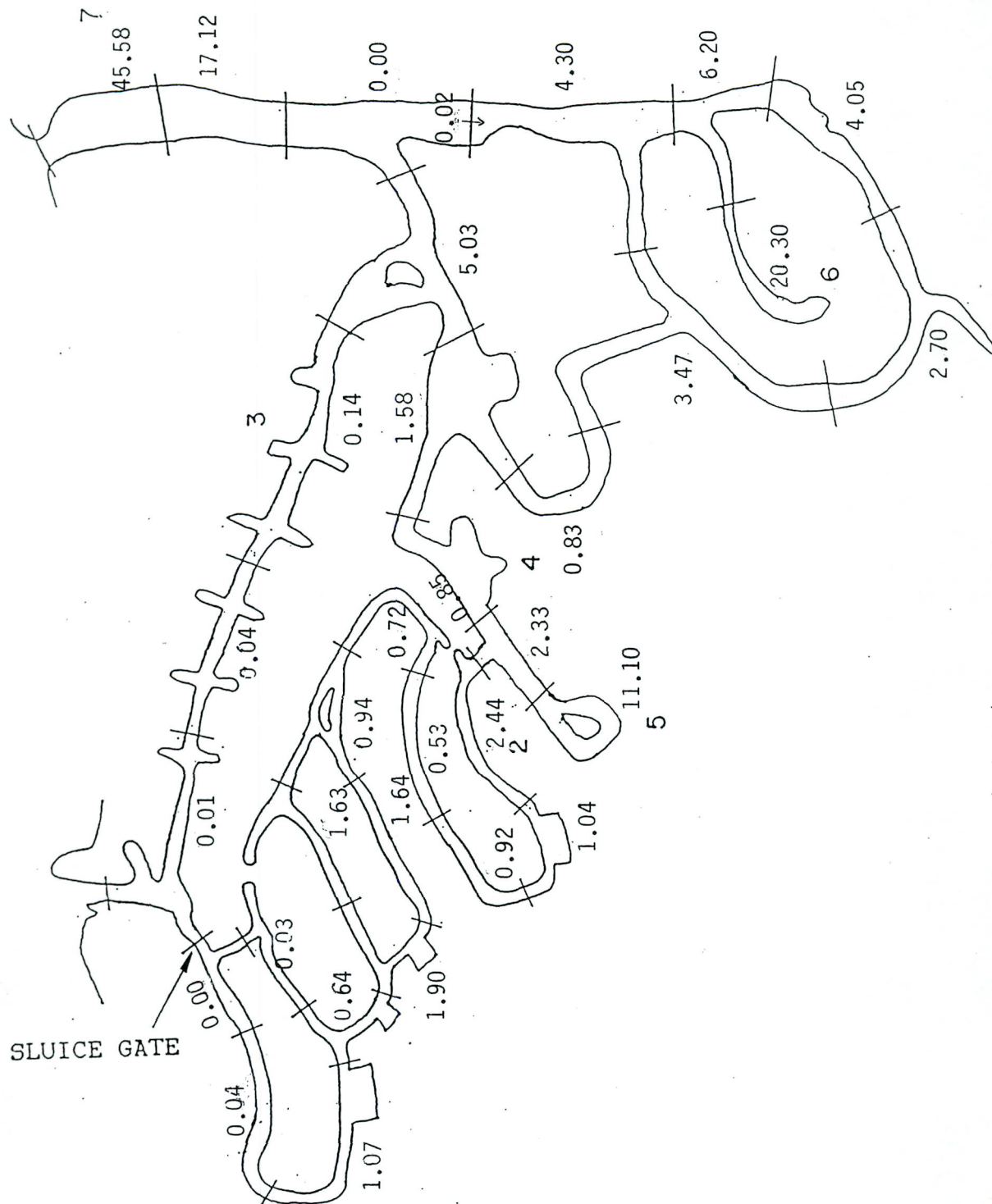
THE CANAL CROSS-SECTION USED
FOR THE MARINA EXTENSION

FIGURE 
6.2



TEST 1: PRESENT MARINA
SEAWARD ENTRANCE BLOCKED
AFTER 5,25 DAYS

FIGURE 
6.4

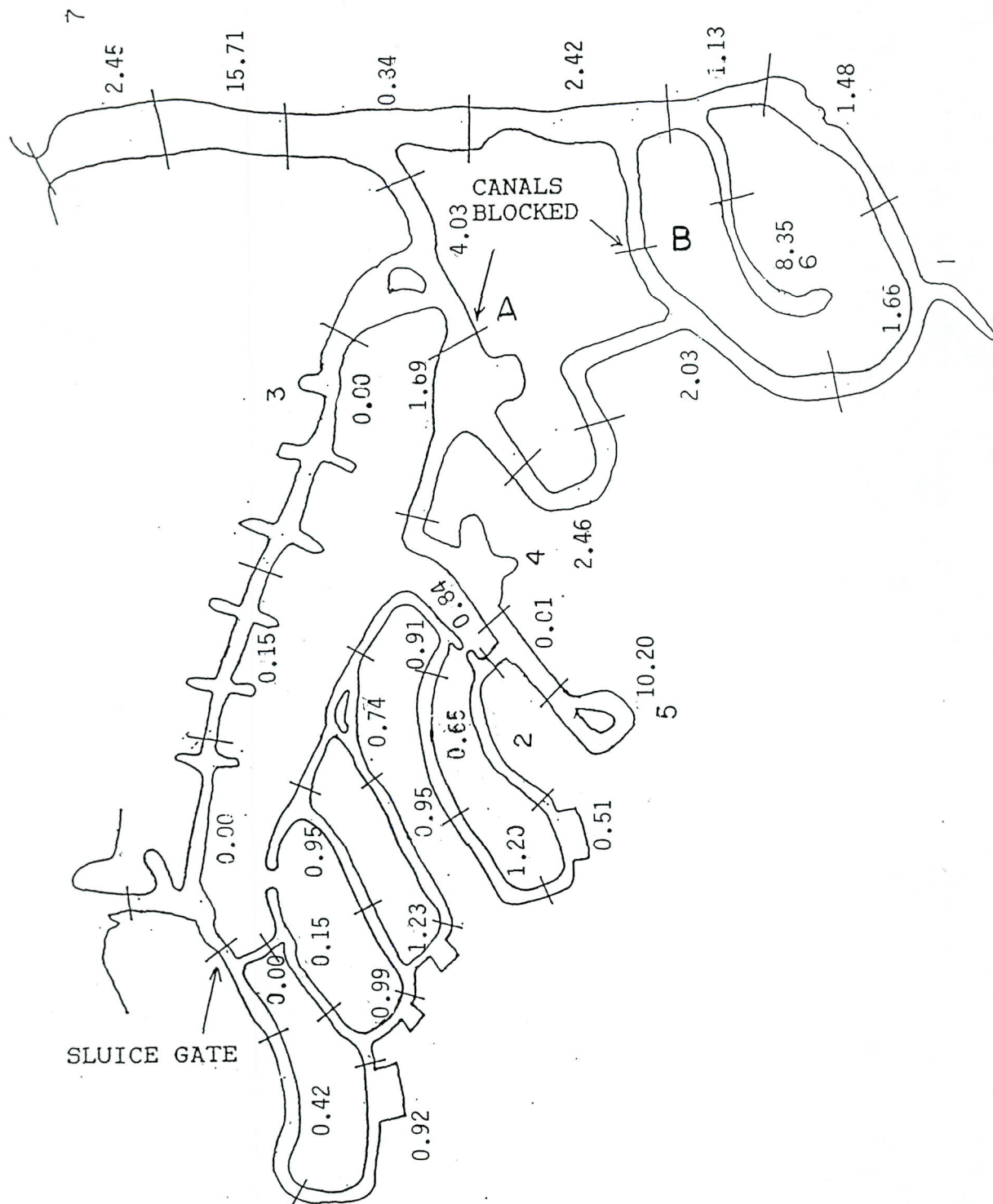


TEST 2 : MARINA AND EXTENSION
SEAWARD ENTRANCE BLOCKED; SLUICE GATE
IN OPERATION; AFTER 5,25 DAYS

FIGURE

6.5



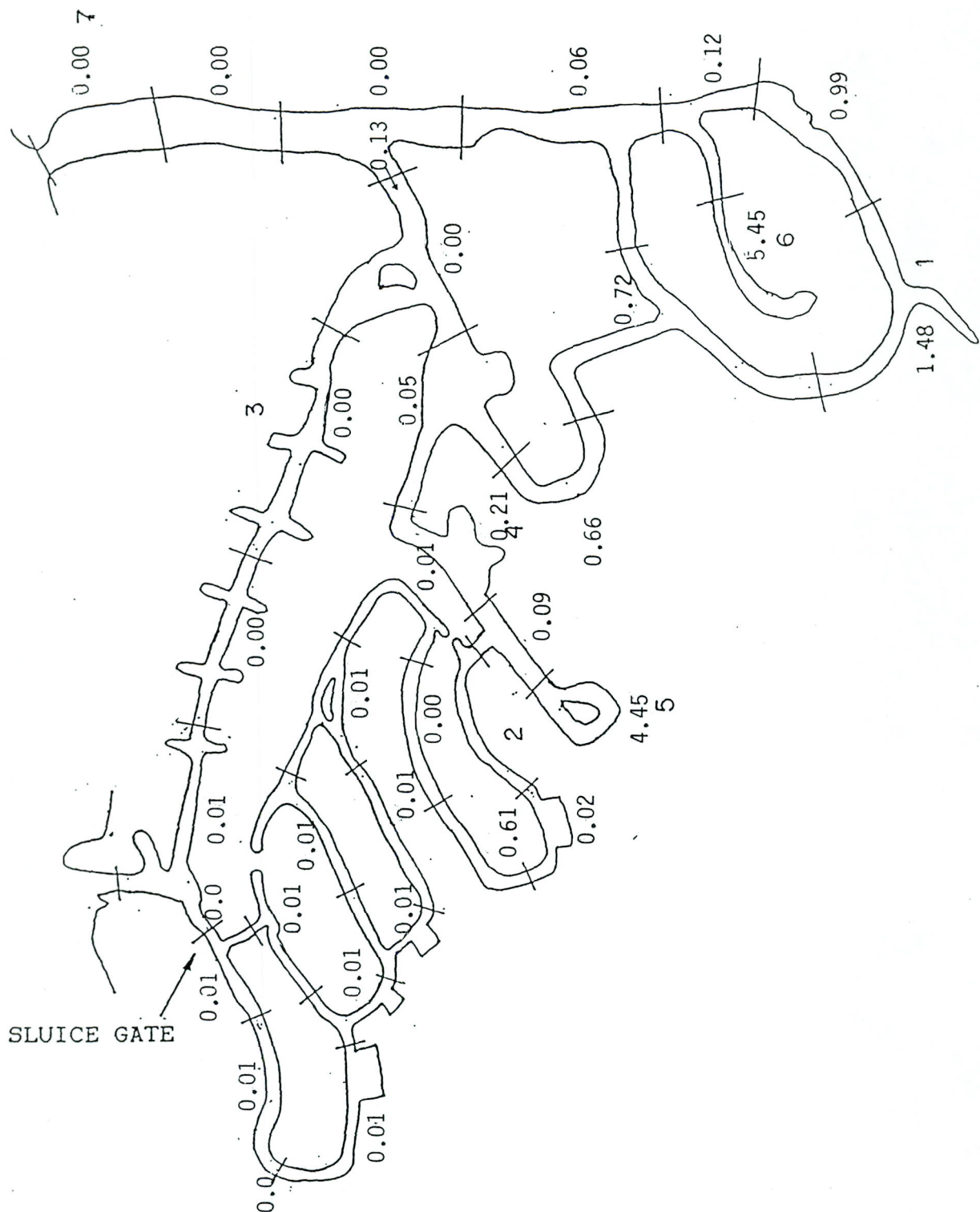


TEST 3:
MARINA AND EXTENSION; SEAWARD ACCESS BLOCKED
SLUICE GATE IN OPERATION; CANALS CUT OFF AT
A AND B; AFTER 5, 25 DAYS

FIGURE

6.6



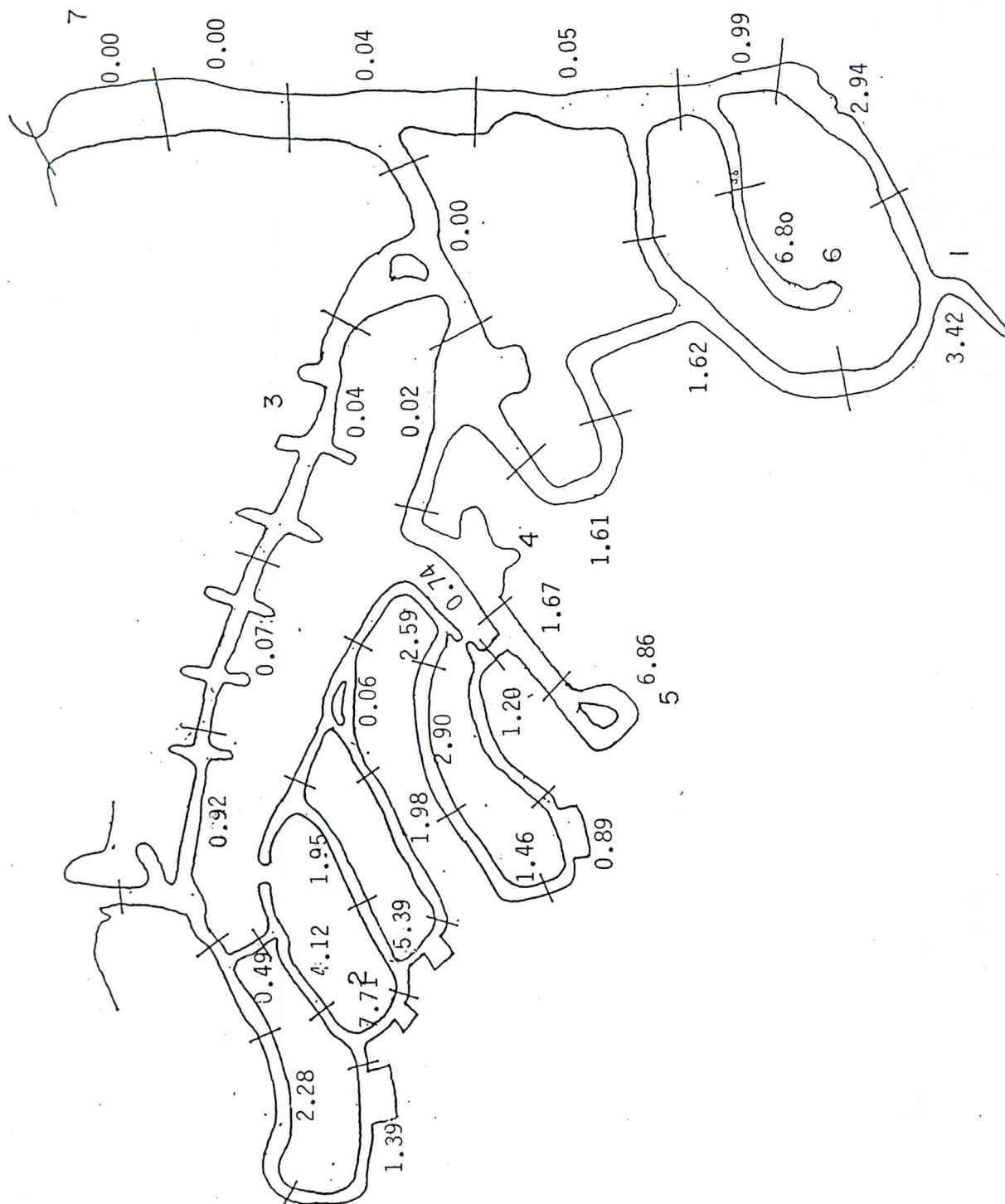


TEST 6: MARINA AND EXTENSION
SLUICE GATE IN OPERATION
SEAWARD ACCESS OPEN
AFTER 5, 25 DAYS

FIGURE



6.9



TEST 7 :
MARINA AND EXTENSION
SEAWARD ACCESS OPEN AND SLUICE GATE NOT IN
OPERATION AFTER 5.25 DAYS

FIGURE
6.10

7. PUBLIC OPINION

In order to obtain input from the public, a public meeting was held, and a questionnaire (in Appendix 1 at the end of this chapter) was distributed. A summary of the public meeting, and a detailed report on the results of the questionnaire survey are included in this chapter.

KROMME PUBLIC MEETING - 9 APRIL 1990

The meeting was held to obtain input from the public for the Kromme siltation study, with regard to sedimentation in the estuary mouth, sedimentation of the seaward marina access canal, and sedimentation in the estuary in general.

The general opinion of the public was that sedimentation had occurred in the estuary in recent years, and that this is due to a decrease in flood scouring. There were, however, exceptions to this. In addition, the following pertinent aspects were mentioned by the public:

(i) Mouth sedimentation:

- Mouth access has deteriorated due to decreased flood action.
- The position of the mouth moves considerably. This is confirmed by aerial photograph observations.
- Extensive accretion occurred at the mouth in the past; at times it was possible to walk across the inlet with ease.

(ii) Sedimentation of the marina access canal:

- The use of sluices, to improve circulation, was suggested. (Chapter 6)
- Sedimentation has also occurred at the western access.
- Water quality deteriorates when the access canal is closed. This is confirmed by the results of model simulations (Chapter 6).

- The berm wall is successful in helping to maintain the seaward access canal.

(iii) Sedimentation in the estuary in general:

- In general, the estuary is perceived to be sanding up.
- The release of water using sluice gates at C W Malan Dam were queried. These allow a flow of $15,6 \text{ m}^3/\text{s}$, which is insufficient to cause any significant scour of the lower estuary.
- The effect of the bridge on floods was queried. In an investigation (Chapter 4), it is found that the bridge has no effect on flood flows.
- Changes in ecology were mentioned e.g. less bird life, and the disappearance of flamingoes. (This does not have direct relevance to the study)
- It was mentioned that sand banks were a hindrance to boating previously, as they are now.

RESULTS OF THE QUESTIONNAIRE SURVEY

The results of the questionnaire survey conducted in April 1990 are contained in Appendix 1.

KROMME RIVER ESTUARY SEDIMENTATION STUDY
RESULTS OF THE QUESTIONNAIRE SURVEY CONDUCTED APRIL 1990

1 PURPOSE OF THE SURVEY

The purpose of the survey was:

1. to gauge public perceptions of the sedimentation problems in and around the Kromme River estuary;
2. to glean additional information about problems in the estuary from people familiar with it, as an addition to the scientific studies;
3. to gauge public support for, or opposition to, potential solutions.

2 DESIGN OF THE SURVEY

2.1 Administration of the survey

The sampling universe was all regular users of and people with a direct stake in the Kromme River estuary and St Francis Bay area. The sampling population was all ratepayers (present or absent) in the St Francis area, that is, the Marina Glades, properties along the Kromme River, St Francis Bay and Santareme Bay, and people present in the area over the period 3-8 April 1990.

A variable strategy was adopted to ensure saturation coverage of the entire sample population, that is, while the vast bulk of questionnaires were distributed by post, a small number were distributed by other means where postage could not reach potential respondents. Details of the distribution are given below in Table 1.

The composition of returns reflected this distribution pattern: 93.4% were received by mail, while 1.7% reported receipt of the questionnaire by personal delivery (hand delivery in fact amounted to 3.8% of the total sample, but 31 were left under house doors, from which a low response rate could be expected).

DATE	SENT TO	METHOD	NO.
28 March	St Francis Bay property owners	posted	1409
8 April	Cottages upstream of the bridge (on both sides), and on north side near the mouth	personal delivery posted under doors	15 31
3,4 April	Fishermen	personal delivery to all bar 2, to whom posted	10
TOTAL:			1465

TABLE 1: Survey Administration

2.2 Questionnaire Design

The questionnaire was divided into three parts, each part focussing on a different area of concern. These were sedimentation in the Kromme River estuary and its effects on boating (Part 1), access problems to the Marina Glades canals (Part 2), and beach erosion at St Francis Bay (Part 3).

While most questions were formatted as closed questions, a few were left open-ended (questions 11, 12, 17, 20(b) and 22(b)). The intention was two-fold: open-ended questions are necessary at times to obtain specific details which would be lost in a closed question, and sometimes they are used in order not to pre-empt and limit responses.

3 SURVEY RESULTS

3.1 Return Rate

A response rate of 20.68% (303 returns were suitable for analysis, out of the 1465 questionnaires distributed) was obtained. However, it was subsequently found that a substantial number of households received more than one questionnaire, because of errors in the mailing list. The number involved, however, has not been ascertained, although it has been established that there were no duplicated responses.

In an earlier survey conducted at the Kromme River estuary in 1986, a 70 percent response rate was obtained (Sowman 1986). There are, however, important differences between the surveys: Sowman's survey was conducted at the height of the summer holiday season when most property owners are resident at Kromme River, and the questionnaires were distributed by door to door delivery by the researchers. There is no doubt that this method of distribution elicits a far higher response rate than mailed questionnaires.

The percentage composition of the responding sample in terms of their association with the area is shown below in Tables 3.1 and 3.2. While Table 3.1 suggests that no commercial fishermen returned the questionnaire, what appears to have happened is that the boat owners do not consider themselves "fishermen", and included themselves probably in the resident category, since in question 6(a) 10 respondents answered that they were commercial fishing boat owners.

permanent resident of the area	18.5%
visitor (staying for at least one night)	1.3%
fisherman working from the area	
absentee homeowner/ratepayer of St Francis area	78.2%
no response to the question	2.0%

TABLE 3.1: Residential status of survey respondents

before 1970	21.8%	
1970-1979	23.8%	(>10 years) 45.6%
1980-1984	23.4%	
1985-1990	17.2%	

TABLE 3.2: Length of association with St Francis Bay area.

It is equally interesting to note the high percentage response from absent ratepayers, indicating a high degree of interest in the subject. It would be interesting to see whether the relative proportions of resident to non-resident respondents is mirrored in the actual proportional composition of property owners/ratepayers in the area, or whether residents are disproportionately well represented in the survey sample, since one might expect residents to have a greater stake in the outcome of such matters.

<u>AGE (% COMPOSITION BY YEAR CATEGORIES)</u>				
15- 30	31-40	41-50	51-60	>60
3.6%	19.5%	32.7%	24.4%	17.8%
<u>EDUCATION</u>				
SECONDARY	MATRIC	DEGREE/DIPLOMA		
0.7%	18.5%	71.6%		
<u>OCCUPATION</u>				
STUDENT	EMPLOYED	RETIRED		
0.7%	82.2	14.9		

TABLE 3.3 Characteristics of St Francis Bay respondents

The population we are dealing with is a well educated group, the majority of property owners probably being successful, relatively affluent professionals or white collar workers, mature family men aged between 40 and 60, with a few in the 30-40 age category. No attempt was made to sample race groups other than white: in Sowman's (1986) survey in the area, the response rate from the "coloured" township was 3 percent!

As in the Aston Bay/Paradise Beach survey, most respondents have had a relatively long association with the area, 45.6 percent of Kromme River respondents having been associated with the area for over 10 years.

Unfortunately a mistake was made in the way in which question 3 was typed up, so that the first two options, *by post* and *delivered by hand*, instead of forming the columns of a matrix, became options in a list. The result was that this question was not correctly answered, with the majority of respondents not indicating which particular locality in the St Francis Bay area they came from or in which they had property. The distribution of responses between the

different settlements in the area could not be deduced from the survey results.

3.2 Sedimentation and its Effects on Boating on the Kromme River Estuary

Questions 4 and 5 were intended, respectively, to identify to what extent respondents were active users of the estuary in terms of boating, and to gauge the number of boats potentially active in the area.

Boat owners comprised 29.7 percent of respondents (non-owners were 68.0 percent). Some 13 percent of all respondents had access to or the use of someone else's boat, but 59.7 percent reported that they do not have access to a boat. This seems to be a surprisingly high proportion of non-boating people, particularly in view of the number of boats specified in question 5: 263 boats were described. If we project the survey results to the total survey population, namely 1455 households (questionnaire total less 10 fishermen), then there would seem to be over 1200 boats potentially using the area. However, these are not all based on the Kromme River and do not all necessarily use the estuary. Nevertheless, it is clear that powerboating is a popular activity in the area.

Most boats were moderately sized powerboats: 69.6 percent had a length of 4-6 m. Ten commercial fishing or chokka boat owners responded to the questionnaire.

Patterns of estuary use

Question 7 indicates that some 20 percent of respondents never use the Kromme River estuary. The period of most intense use is in summer, as would be expected, but there is a fairly even and significant utilization throughout the rest of the year.

The proportional use of the estuary for different purposes is shown in Table 3.4. Powerboating is generally the dominant use, with waterskiing, cruising and fishing being the most significant activities. Use of the mouth for access to the sea is also significant, being undertaken by a quarter of estuary users.

skiboat launching	(%)	15.5
waterskiing		41.3
fishing from a skiboat in the river		35.0
cruising on the river		57.8
mooring chokka boat	(10 respondents)	3.3
mooring skiboat		6.9
access to the sea via river mouth (78 responses)		25.7
swimming		12.2
canoeing and sailing		15.2
birdwatching		1.7

TABLE 3.4: Use of the estuary in terms of percentage participation in different pursuits.

Perceptions of sedimentation in the estuary

There is strong agreement amongst respondents that the mouth area of the estuary is more sanded up than in the past, with 71.3 percent stating that the situation is worse now than two years ago, and a slightly lower number, 63.7 percent, declaring this to be the case in comparison with 10 years ago. When asked whether they thought the entire estuary was now more silted up than previously, there was even greater unanimity: 80.2 percent responded to this effect.

leave everything as it is	(%)	9.9
build artificial mouth channel		22.4
dredge the mouth area		43.2
build a harbour in the estuary		6.3
build more slipways on St Francis Bay		5.3
build a harbour on St Francis Bay		13.9
dredge marina canal and put in groins		6.4
remove dam wall/ have sluice gates		20.3
do a study of chokka boats		7.3

TABLE 3.5 Public opinion at St Francis Bay regarding possible remedial action to be taken against increasing sedimentation of the Kromme River estuary

On the question of potential remedial measures, dredging the mouth area was the most popular option, with 43.2 percent of

respondents supporting it. The distribution of opinions regarding solutions to sedimentation in the estuary are given above in Table 3.5.

There are three separate issues here which have significant support: the first is the manipulation of the mouth area, the second is river management, particularly the release of sufficient water (by removing the dam or using sluice gates) to scour out the estuary, and, lastly, the creation of a proper facility for chokka boats (which have been reported to be problematic to other users of the Kromme River estuary). Clearly, the option of building a harbour on the Bay rather than in the estuary, is a more popular one.

Opinions on options for paying for such action is marginally in favour of applying a levy for the use of the estuary (42.9%), as opposed to seeing it as a government responsibility (33.7%).

In attempting to compare the estuary with the launching ramp at Santareme Bay it is clear that only a small proportion of people in the area use that facility; 79.9 percent of respondents said that they did not, and of those who reported that they do use the Santareme Bay ramp, a majority said they did not prefer it to the estuary.

3.3 Marina Glades: Access Problems

The public slipway situated on Shore Road is evidently not used by many respondents - 77.6 percent do not use it at all and of those that do use it, most (18.2% of total) use it only occasionally.

By contrast 33.7 percent of all respondents stated that they used the East channel entrance to Marina Glades and 24.4 percent used the West channel. (38.9% did not respond to this question). Furthermore, a majority thought that there would be problems in using the West entrance only, should the East channel be permanently closed: 46.5% foresaw problems in closing the East channel, while 21.5% replied negatively to this question (question 20(a)).

The chief concern of those against closing the East channel was congestion due to the increased traffic this would generate in the West channel (22.1%). The consequent lack of circulation in the marina channels by such closure was raised by 9.6 percent of respondents, while problems associated with tidal exchange and the lowness of the bridge

concerned 5.3 percent of respondents. A further 6.9 percent raised all these issues, but only 3.3 percent of respondents complained that the West channel was "too far away" (presumably from their homes or the mouth).

Marina canals: sedimentation and water quality

Again, the dominant public opinion is that increased sedimentation has occurred, in this case, in the marina canals: 45.9 percent agreed, 18.2 percent did not.

The public appears to be in general agreement with scientists on the subject of marina canal water quality, with only 8.3 percent judging water quality all year round to be less than *fair*, that is, *poor* or *very bad*, although this proportion increased considerably with respect to the peak holiday season, during which, 22.1 percent claimed, water quality was *poor* or *very bad*. By contrast, 45.9 percent judged it to be *good* or *fair* during the peak season, and 53.8% concurred regarding the year round situation. Poor circulation (24.1%) and pollution (14.2%) were the main causes of water quality problems, according to responses to question 22(b).

Clearly, marina canal water quality is not a major concern of St Francis Bay ratepayers and users.

3.4 Beach Erosion at St Francis Bay

The majority of respondents have observed beach erosion at St Francis Bay, with fully 34 percent rating it as *severe*, 30 percent rating it *moderate*, 15.5 percent as *minor*, and only 10.6 percent reporting that they have not observed beach erosion at all.

Observations by respondents of the impacts of beach erosion are detailed in Table 3.6. Loss of beach area and destabilisation of the foredune are the most serious consequences of beach erosion. But when asked if they thought the situation demanded artificial intervention, 55.4 percent of respondents were against intervention, while 23.4 percent believed intervention to be justified (18.8% did not reply to this question).

damage to beachfront properties	(%)	10.9
loss of beach area		57.4
destabilisation of the foredune		50.5
increased beach steepness - dangerous batheing		20.1

TABLE 3.6: Public perceptions of damage caused by beach erosion on St Francis Bay.

4 CONCLUSIONS

1. The survey population was white, affluent, well educated and interested in the problem.
2. The estuary is popular for powerboating activities including waterskiing and fishing, and the mouth is used by significant numbers of powerboats for access to the sea.
3. There is strong agreement amongst the public that increased sedimentation of the Kromme River estuary has occurred. (This would have serious implications for the activities mentioned above.)
4. Almost half the respondents favoured dredging the mouth area of the estuary as a solution, while some 20 percent, respectively, thought creating a new mouth channel, or removing the dam/using sluice gates to release more water to the estuary, to be the appropriate options.
5. Of those using the Marina Glades, a majority use the East channel for access to the estuary, and are not in favour of closing it despite silting problems. Respondents foresaw problems, mostly related to congestion, in permanently closing the East channel.
6. Water quality in the marina canals is generally perceived to be fairly good, with some problems occurring during the peak holiday season. However, this does not appear to be a major issue with the local population.
7. Respondents strongly agreed that beach erosion on St Francis Bay is bad (moderate to severe), but the majority were not in favour of artificial intervention

(such as sand importation) to solve the problem. Only 10 percent mentioned damage to beachfront properties as a problem.

Compiled by C M Henderson
Institute of Natural Resources
Pietermaritzburg

July 1990