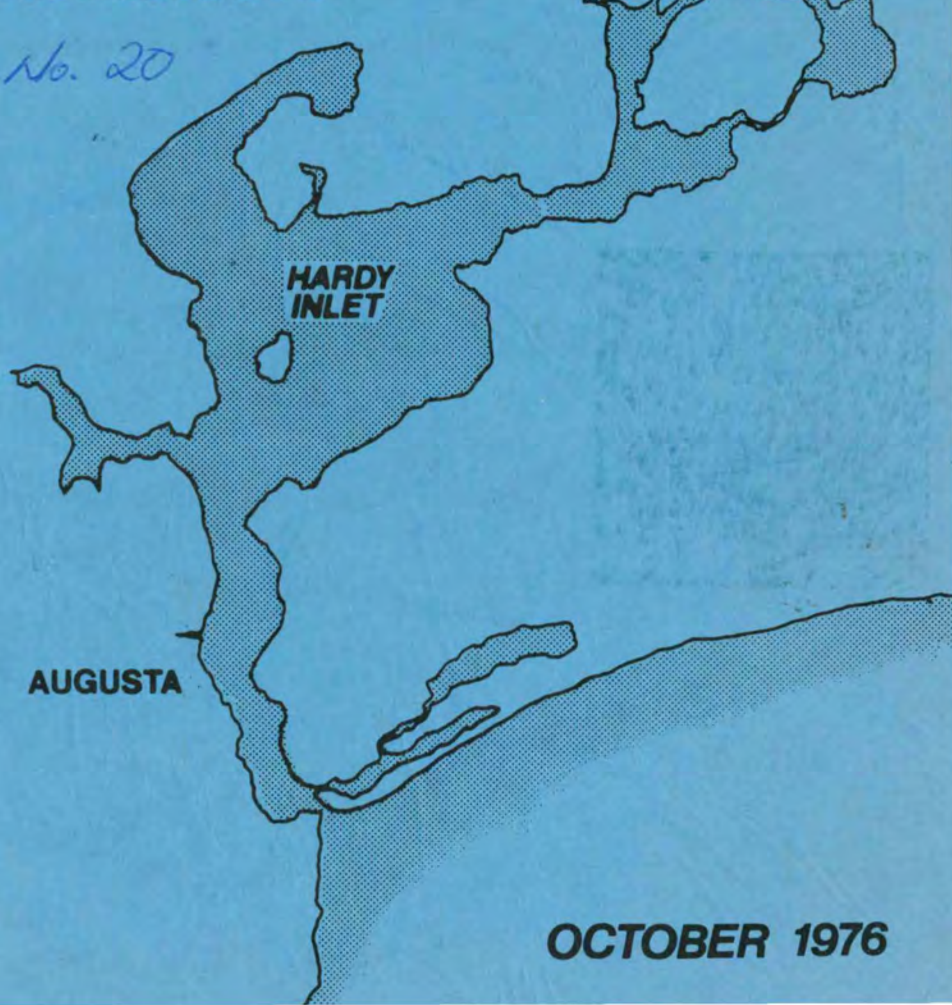
ANTICIPATED EFFECTS OF DREDGING IN THE BLACKWOOD RIVER ESTUARY

A REPORT BY THE ESTUARINE AND MARINE ADVISORY COMMITTEE TO THE ENVIRONMENTAL PROTECTION AUTHORITY

Bulletin No. 20



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1. INTRODUCTION

In June, 1973, the Western Australian Environmental Protection Authority released an interim report[1] on an application by Project Mining Corporation (PMC) for five mineral and four dredging claims in the Augusta-Blackwood River area. Subsequently one of the mineral claims was withdrawn. The report recommended, *"That no mining be allowed on these claims, and they not be listed for hearing in the Mining Warden's Court until further research has been undertaken ...."* The Hon. Minister for Mines agreed on 11 September 1973 that no further action would be taken with regard to the hearing of the claims in the Mining Warden's Court until a study of the ecology of the Blackwood River Estuary (Hardy Inlet) had been completed.

The Environmental Protection Authority requested the Estuarine and Marine Advisory Committee (EMAC), a committee established by the Authority, to undertake a detailed study of the Blackwood River estuary with the following broad terms of reference:-

> *"Such investigation should include a study of the ecology of the estuary and its environs, and lead to an assessment of the multiple uses of the estuary with respect to such factors as commercial fishing, birdlife, tourism, recreation, the mining proposal and the aesthetic effects for local residents."*

The period of study, although not precisely fixed in time, was set generally at one year of field work followed by analysis of data and presentation of technical reports.

EMAC formulated a set of inter-related research topics, and in January, 1974, appointed a Research Coordinator, Dr E.P. Hodgkin. These research topics were more precisely identified by the Research Coordinator, and personnel, some from Government departments and some from the University of Western Australia, were invited to take part in the study and submit research proposals relating to specified segments. Some financial assistance was available from limited funds allocated to the Western Australian Department of Conservation and Environment by both the Western Australian and Commonwealth Governments. For some programmes, such as the water dynamics study, the financial support was substantial whilst for others it covered only minor operating expenses such as travelling allowances.

The University research personnel were not under contract to the Government, but were undertaking individual research programmes on a cooperative basis, focusing attention on the Blackwood River Estuary. Naturally, those with substantial financial support providing a major research input, worked closely with the Research Coordinator to ensure that the programmes produced as much relevant information as was possible for EMAC, within the limited time period allowed.

Some of the studies were undertaken as part of research towards a higher degree and are continuing but without Government financial support.

The Research Coordinator had the task of encouraging and facilitating programmes of study and group discussions, coordinating the practical aspects of the programmes, and gaining a full understanding of the research results so that he could present a precise report to EMAC.

Research workers who agreed to be involved in the study were required to present to the Coordinator technical reports. These technical reports are listed in the June 1976 report of the Research Coordinator to EMAC[2]. A copy of each report is available in the library of the Western Australian Department of Conservation and Environment (DCE).

EMAC wishes to express its thanks to those who contributed to the Blackwood River Estuary Study. The committee has pleasure in presenting its appraisal of the results in terms of its task of undertaking a study and reporting on the anticipated effects of dredging in the Blackwood River Estuary. This report contains technical information, tables and figures only to the extent considered necessary for an understanding of EMAC's appraisal. For further technical information, readers are referred to the technical reports.

B.K. Bowen (Chairman)
D.A. Hancock
B.W. Logan
M.G. Anderson

2. SUMMARY OF CONCLUSIONS

* The estuaries of Western Australia are few in number and provide sheltered environments on a high energy coastline subject to continuous wave action. These protected environments are sites of high biological productivity and provide nursery areas for fish and refuges for migratory fish and birds. The sheltered nature of the estuaries attracts high levels of usage for recreation and urban development.

* The Blackwood River Estuary has a special place in the small range of Western Australian estuarine water bodies in that it is part of the largest river system in the south of the State. Seasonal river flushing and a permanent opening to the ocean are major factors in maintaining conditions attractive for human use and occupation. So far, the estuary and surrounding areas have remained relatively unaltered and it is for its unspoilt natural beauty that it is valued by residents and visitors alike.

* The mining and dredging proposals involve the processing of at least 50,000,000 tonnes of low grade ore (sediment) from both the bed of the estuary and adjacent land, to extract 1-6% of contained ilmenite. The duration of the operation has been estimated to cover 8-12 years.

* The expected consequences of dredging to the physical environment include:-

a great acceleration in natural processes of sediment erosion and deposition,

widespread shoaling in Hardy Inlet which may be accompanied by irreversible changes to the hydrology of the estuarine system,

the generation of turbid conditions throughout the greater part of the estuary over the period of up to twelve years of dredging,

possible seasonal closure of the mouth bar.

* The expected consequences of dredging to the biological environment include:-

direct destruction of the existing plant and animal communities within the dredging sites,

settlement of suspended particulate matter throughout the estuary and adverse effects on survival and behaviour of plant and animal species,

reduced light penetration and its damaging effects on aquatic plants,

depletion of the dissolved oxygen content of the water, *reduced usage of the estuary by migratory fish species such as Australian Herring, which are unable to tolerate turbid conditions,*

reduced usage of the estuary by birds as a result of depletion of food resources and changes to the feeding grounds,

diminished long term species diversity resulting from any irreversible changes creating more extreme conditions in the environmental system.

* The effects on the human community of dredging and mining are therefore likely to be:-

the disruptive effects of introducing an extractive industry into a community which is non-industrial,

the direct visual impact of the mining and dredging operations, part of which will be conducted in full view of the townsite,

discolouration of the water and its aesthetic consequences,

short term disturbance of the tranquility of the area,

reduction in the availability of fish normally popular with amateurs fishing within the estuary, during, and possibly following, dredging,

a short term reduction in the visible presence of birdlife,

a reduction of the area of navigable water due to sedimentation,

the consequences of possible drastic changes to the system resulting from closure of the mouth bar, e.g. gross variation in seasonal water levels.

3. THE MINING AND DREDGING CLAIMS

3.1 Locations of the claims

The location of the mining and dredging claims are shown in Figure 1. The mining claims (MCs 4191H - 4194H) are on land in leached Quaternary dunes to the east of the estuary, near its mouth and opposite the town of Augusta. Although they lie largely within the gazetted Augusta townsite, most of the land has not been cleared and carries coastal scrub, peppermint woodland, or jarrah/marri forest.

The dredging claims (DCs 367H, 374H - 376H) are all in the lower part of the estuary, downstream of the junction of the Blackwood and Scott Rivers. Upstream of this point, the Blackwood River is estuarine for a further 33 km. DC 375H covers two shallow basins in the southern arm of the Scott River. DCs 374H and 376H are in the estuary near Molloy Island and include both deep (5^+ m) water of the riverine channel and shallow marginal platforms. DC 367H is in the inlet channel adjacent to Augusta town and the 'potential area of interest' here also includes both deep channel and shallow platforms.

3.2 Nature of the deposits

The mining claims were cored by PMC to an average depth of 22 m per hole and the heavy mineral content assessed. Their investigations *"indicate a minimum of 1 400 000 tons of contains ilmenite, but because of the low grade, an upgrading process would be necessary for economic mining"* ([3]: PMC 17.7.1974). The workable deposits in these claims are reported to hold about 6% of recoverable ilmenite and *"it appears that the grade and tonnage of heavy minerals ... are marginal"*[1].

"The deposits in the mineral claims are relatively young and it is expected that the contained ilmenite will be 'immature'. That is, the ilmenite will be of low TiO_2 content with little or no alteration to leucoxene. The probable low TiO_2 content may be partly offset by a favourable FeO/Fe_2O_3 ratio which is usually concomitant with low TiO_2 and is also characteristic of young ilmenite deposits" ([3]: PMC 26.10.1972).

The company sampled the dredging claims by means of a 'reverse sampling device', which recovered sediments to a maximum depth of 7 metres and could not define mineralisation with any precision (the average length of recovered sediment was about 3 metres). Most samples were from shallow areas. PMC estimates *"that there may be (in the dredging claims in the Inlet and the mineral claims on land) some 3 million tonnes of contained ilmenite ..."* ([3]: PMC 17.7.1974).

3.3 Scale of the proposal

Information about the mining and dredging proposal is summarised in Table 1, and Table 2 compares this proposal with heavy mineral sand operations elsewhere in Australia.

TABLE 1

Quantitative data (approximations only) concerning the Mining Proposal (1975).

Size of Deposit[1]:	3 million tonnes, contained ilmenite
Concentration[1]:	6%
Proposed Life of Deposit[1]:	8 - 12 years
Starting Date[1]:	Approximately 5 years from present
Labour Force Proposed[1]:	65
Cost to Employer[2]:	$8,000 p.a./man
Transport of Concentrated Ilmenite to Bunbury[3]:	
Mode:	Road truck
Cost:	$6.50 - $7 per tonne
Current Price of Ilmenite[4]:	$14 - $18 per tonne, f.o.b. at 54% contained TiO_2 concentration
Possible Capital Cost[2]	Approximately $5 million

SOURCES:
1 PMC
2 Personal communication with Westralian Sands Ltd
3 Local sources at Augusta
4 Secretary, Chamber of Mines

TABLE 2

Comparison of the Proposal with other Mineral Sands Deposits

	Contained heavy mineral sands (million tonnes)	Annual production of ilmenite (thousand tonnes) 1975
This project - estimate assuming life of 10 yrs	3.0	300
Capel	29.5	389
Eneabba	33.7	277
State Total	72.9	667
Australian Total	103.0	1013

SOURCES: PMC, "The Miner", Mines Department W.A.

With the current low price of ilmenite, the profitability of mineral sand mining depends, to a considerable extent, on the production of heavy minerals other than ilmenite: rutile, monazite, zircon, leucoxene. These are present in the Hardy Inlet deposits, but no quantitative assessment is available.

3.4 Nature of the mining process

Because of the tentative nature of the proposal ([3]: PMC 17.3.1975) there is a lack of precise information about the mining and dredging procedures that would be employed in the undertaking. PMC has indicated that "*mining would be by dredging both in the estuary and on land. The dredge would be similar to the one which has been in operation at Stratham near Capel*" ([3]: PMC 17.7.1974). This dredge operates in a small closed pool with a rotary cutter which digs to a maximum depth of about 9 m. The dredged material is pumped to a floating process plant and, from there, the recovered heavy minerals are pumped to land and the spoil is used to restore the land surface. The heavy mineral sands are then upgraded at a shore-based plant before being trucked to port facilities (Figure 2).

All mining for heavy mineral sands near Capel is on land and the deposits are of two types. Those near the coast, including those at Stratham, are in Quaternary beach deposits. They are clean, well-sorted sand with only 2-4% fines (silt and clay of less than 0.6 mm) and these settle out within a day. Inland, on the edge of the Whicher scarp, the ore body is in an old shore line deposit, probably of early Pleistocene age. The sands here are poorly sorted with about 20% fines and a considerable clay fraction. The deposit is worked by open cut mining methods. However, processing involves considerable washing and the waste water, together with the suspended clay fraction, is returned to large settling ponds and is not allowed to escape to streams draining the area. Fresh water is pumped from wells and there is no contact with salt water.

3.5 Dredging in the Estuary

Operation of a dredge, and wet processing plant, may be expected to involve the following:-

(1) Disruption of the existing sediment column beneath the dredging claims.

(2) Dumping of the discarded spoil in the excavation area.

(3) Sorting and transport of the dumped sediment by currents with the different fractions being carried to varying distances before settlement, noting that -

   (a) coarse sand and gravel will settle out rapidly and only be transported by high current velocities,

   (b) fine sands and silts will also settle out rapidly under low flow conditions, but with moderate and high flow will be transported for some distance.

(4) Generation of a turbid cloud of suspended fine clay-size material. This will be sorted from the dredging spoil and remain in the water column for a long time (12 to 24 hours). The behaviour of this cloud is difficult to predict because the flocculation characteristics of this matter differ in salt water and fresh water.

(5) Foaming or formation of floating masses if the sediment is discharged above the water surface, or mixed with air.

(6) Erosion of the returned dredged spoil under high river discharge conditions because of its less cohesive character.

4. ENVIRONMENTAL CHARACTERISTICS OF THE ESTUARY

These are described in detail in the report 'Environmental Study of the Blackwood River Estuary'[2], but it is useful here to summarise the main features as background to the discussion which follows, of the anticipated effects of dredging. Topographic terms used here and the principle geomorphic features are shown in Figure 3.

4.1 Geomorphology (Figure 4)

The Blackwood River is estuarine at least as far as a rock bar 42 km from the mouth; that is to say, it is tidal and marine water penetrates to this point in summer. The Scott River is also estuarine for about 4 km from its junction with the Blackwood River.

The upper estuary, upstream of Molloy Island, is a riverine channel much of which is 5 m or more deep and 50 to 150 m wide. There are a number of deep holes in the river bed, near sharp bends, the largest of which is 22 m deep and only about 50 m in diameter; this is 13 km from the mouth. In the lower estuary, the riverine channel continues for another 3.5 km and ends abruptly where it enters Hardy Inlet at Island Point, but there are also wide, shallow, marginal platforms here. The Scott River discharges to the Blackwood River by a narrow channel 2 m deep to the north of Molloy Island and to the south of the Island, through the very small shallow Scott and Molloy Basins and a narrow channel joining them.

The estuarine basin is a Pleistocene basin, which has been infilled with estuarine and riverine sediments during the Holocene. The greater part is exposed at extreme low tide, leaving a small residual basin downstream and three natural distributary channels. The two marginal channels are now less than 0.5 m deep in places, but the central channel has been dredged as a boat channel to a depth of 2 m, first in 1956 and again in 1973.

The inlet channel between the basin and the mouth, again, has a central channel about 5 m deep and 150 m wide and extensive marginal platforms at less than 1 m (Figure 5). The mouth is somewhat constricted and there are shallow bars both inside and outside the mouth.

Two tidal lagoons, the Deadwater and Swan Lake, are connected to the inlet channel by a narrow passage, which opens just inside its mouth. Shallow bars restrict the entrance, but the Deadwater is 3 m deep in parts. Swan Lake is less than 1 m deep.

4.2 Dynamics

River discharge is strongly seasonal, with winter flow rates sufficient to keep the greater part of the estuary fresh for about 4 months each year. During this period flow rates in excess of 1 m/sec (about 2 knots) were measured at the riverine dredging site (Station 90)

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(Figure 6). In summer, there is very little river discharge, although the continued flow is important to maintenance of the hydrological conditions described below. Estuarine circulation is then dominated by ocean tides and peak velocities are about one-tenth of those of winter discharge conditions (Figure 7).

Although 1974 was a year of average rainfall, the volume of flow in July and August was above the average for the period 1965-1975. However, considerably higher rates must have been experienced during the 1964 floods and floods of similar magnitude which occurred in 1955 and 1945.

Maximum daily tidal range in the estuary is about 0.7 m, which is 70% of that in Flinders Bay. The range is little reduced along the length of the estuary and the time lag between Seine Bay and Warner Glen Bridge is only about 2 hours.

4.3 Hydrology (Figure 8)

When river flow exceeds 20 x $10^6 m^3$ per day (total flow to the estuary), the estuary is fresh throughout, with a salinity of about one part per thousand ($1^0/_{00}$). The fresh water carries a load of fine suspended particulate and dissolved organic matter which make the water turbid and light penetration is greatly reduced (Secchi disc readings 0.1 to 0.3 m).

In summer, when there is virtually no river flow the lower estuary is marine throughout (greater than $30^0/_{00}$), although lower salinity water persists in the riverine part near Molloy Island (sea water is $35^0/_{00}$). There is little suspended matter and the water is clear (Secchi disc readings of 2 to 3 m).

With decreasing flow, sea water penetrates below the outflowing fresh water and mixes with it. The distance to which this brackish water penetrates upstream is relative to the volume of flow. With increasing river discharge in autumn, saline surface water is flushed from the estuary, but high salinity water persists in deep parts of the tidal river and inlet channel until persistent high discharge rates are established.

Three dynamic/hydrologic conditions can thus be recognised:

(a) high fluvial discharge, when the whole estuary is fresh and the water turbid;

(b) low fluvial discharge, tidal dominated conditions, when the lower estuary is marine (except for brackish surface water upstream of the basin in early summer) and the water is clear;

(c) intermediate discharge conditions, when river flow is decreasing or increasing and fresh water flows over the brackish to marine water, which forms a 'salt wedge' beneath it.

The shallow regions (the mouth bars and the basin delta) play an important role in determining the hydrology. They obstruct the passage of more saline bottom water and waters of different salinity which mix in the shallows. Consequently, there is marked salinity stratification with an abrupt discontinuity (halocline) at about 2 m depth, especially in summer in the upper estuary. Under stratified conditions, dissolved oxygen levels in the bottom water may be less than 3 mg/l, but there is no significant deoxygenation elsewhere.

4.4 Sediments

The various sedimentary units which have been recognised are shown in Figure 9. In the late Pleistocene, the present estuary was a shallow basin through which the river is presumed to have flowed in a narrow channel. The soils of the basin are composed of medium to coarse leached sands, derived from the Pleistocene dunes, with a proportion of more muddy material. These Pleistocene sediments are of unknown depth, except near the western shore where they overlie granite. The Pleistocene basin was first flooded some 5-7,000 years ago and the Holocene estuarine sediments have been laid down since then. The Basin Unit is a black organic mud of estuarine origin, with about 20% fine quartz sand, but shells in the lower layers and an Oyster Unit indicates that at first conditions were more marine than now. This unit fills the present estuarine basin and probably extends upstream to Molloy Island. During the last 2-3,000 years, the Delta Unit has been laid down on top of the Basin Unit. It consists mainly of medium to coarse river sand, with sandy mud and plant debris.

Both Delta and Basin Units continue to accumulate at the present time. The Delta Unit continues to shoal, but the main area of deposition is towards its downstream face where flow velocities slacken, allowing the sediment to settle out (Figure 4). The small alluvial fan, which has formed at the downstream end of the boat channel, is visual evidence of this continued sediment transport. There is a similar, larger fan where the northern distributary debouches into North Bay.

The rate of sediment accretion on the delta is estimated at about 1,480 m^3 per year. The main source of sedimentary material, now accumulating in the delta, is probably the Pleistocene sediments, which are exposed in the bed of the riverine channel in the vicinity of Molloy Island.

In the inlet channel, the Pleistocene sediments are overlain by the Inlet Bar Unit, which is largely marine in origin and consists of beach sand mixed with reworked sand from the Pleistocene dunes. The sediments of this unit have progressively blocked the estuary entrance and this has contributed to the more extreme hydrological conditions at the present time, compared with the early Holocene.

The Pleistocene sediments are likely to be the main mineral source in DCs 374H, 375H, 376H. They are overlain by the Delta Unit and it is probable that dredging will also penetrate the Basin Unit in DC 374H. DC 367H is in the Inlet-Bar Unit, but dredging here may also penetrate the Pleistocene sediments.

The granulometric composition of the sedimentary units is shown in Figure 10. As will be seen, the Pleistocene sediments are clayey sands averaging 37% silt and clay. The Delta Unit consists mainly of quartzose sand with an average 25% silt and clay material. The Basin Unit is composed predominately of clay and clay-sized organic material. The Inlet-Bar Unit consists of rather better sorted calcareous and siliceous sand, with only 13.5% of silt and clay fractions. Core samples were taken from the deep river channel and, for the most part, penetrated Pleistocene sediments. Most samples contained a high percentage of organic material.

The sediments, especially those of the Basin Unit and Pleistocene basement, are well-packed and can be regarded as cohesive soil, resistant to the erosive forces which the water currents impose. The biota also have a binding effect on surface sediments. The cohesive nature of the sediments, which is imparted by the presence of coherent clay matrices and organic matter, is illustrated by the considerable stability in the delta sands of the banks of the dredged channel. Here current velocities in winter are high enough to transport all except the coarsest particles, but nevertheless the banks have stood up well since it was dredged in 1973. The stress required to initiate erosion of such cohesive material is considerably higher than for unconsolidated clean fine to coarse sand (0.1 to 1.0 mm grain size). The most mobile sands are those near the mouth, opposite Seine Bay. These are in constant flux, building up under flow conditions from littoral drift carried in by tidal currents and being eroded again with high river discharge in winter.

4.5 Biology

The biological productivity of the estuary is dependent largely on rushes and other plants of the marginal swamps and on extensive sea grass beds. These provide the main input of detritus to the foodchain, on which a large part of the fauna is directly or indirectly dependent. The great majority of the invertebrate species are small-particle feeders, which inhabit the surface sediments and weed beds.

The principal sea grass, *Ruppia*, grows in shallow water usually less than 1 m in depth. It has not been observed to set seed in the estuary and regrowth from seed is unlikely. Seasonal regeneration is from rhizomes and the most active period of growth was between July and September in Swan Lake, which is the most productive part of the estuary. *Potamogeton* and the alga *Lamprothamnion* form dense beds in the shallows around Molloy Island, when the water is fresh.

The invertebrate fauna (worms, molluscs, small crustaceans, and insect larvae) are associated with (a) the sea grass beds, and (b) the surface sediments. The stable, muddy sands has the richest fauna, the mud carries a less diverse and less abundant fauna, and the clean, mobile sands of the inlet bar region has only a sparse fauna. The fossil fauna of 4-5,000 years ago shows a greater diversity of molluscs than is present now and it is evident that the estuary was much more marine at that time.

The non-resident fauna, on the other hand, can avoid the seasonal salinity change and the estuary supports a considerable diversity and abundance of itinerant fish and birds. Most fish species leave the estuary when it is fresh in winter and are recruited again from coastal populations when salinity is again favourable. Few fish species spawn in the estuary, but it provides good feeding and refuge for juveniles and is a significant nursery area. Although there is a resident population of water birds, most species use the estuary mainly in summer when the shallow waters provide abundant food for both weed-eaters (swans, ducks) and the many waders, searching for the small invertebrate fauna. The waders include 18 species of transequatorial migrants.

The dominant species of waterfowl (swans and black ducks) are weed-eaters, dependent largely on *Ruppia* and other benthic plants. The Blackwood River Estuary is an important habitat for swans which use all parts of the lower estuary (Figure 11). Over 1,000 of them were sighted on a number of occasions in the summer of 1975-76; 1,200 in February. The shallows of the Molloy-Scott basins are particularly attractive to musk duck, which are divers and feed on animal food.

4.6 Man: demography and social

Four groups constitute the human population of the area: retired residents of Augusta (and holiday home owners), non-retired residents of Augusta, the rural population of the Augusta-Margaret River Shire, and visitors to the area (tourists and campers). They have different interests in and to some extent different impacts on the estuarine environment.

Augusta town has been developed as a retirement village and the resident population is biassed towards the older age groups, with 57% over 50 years of age (Table 3). A survey of the adult population of Augusta (summer 1974-75) found that 49% were retired residents, 36% non-retired residents, and 15% non-permanent residents who occupy holiday homes[2]. The small rural population of the southern part of the Shire is predominantly a farming community with a typical age distribution.

During the summer months, visitors greatly outnumber residents. They come principally from the Perth Metropolitan area, though with a substantial proportion from eastern Australia, and include both tourists who only spend a day or two at Augusta and holiday makers, who spend one to several weeks in the caravan parks or holiday cottages and in many cases some come year after year.

TABLE 3

Age Composition of the Population

	AUGUSTA URBAN				AUGUSTA RURAL		AUGUSTA-MARGARET RIVER SHIRE				W.A.
	male	female	total	%	total	%	male	female	total	%	% total
0-17	-	-	88	18.5	-	(36)[1]					35.9
18-19	9	1	10	2.1	4	1.3	636	553	1189	38.3	3.5
20-24	9	7	16	3.4	24	8.1	103	98	201	6.5	9.1
25-29	12	15	27	5.8	18	6.0	87	88	175	5.6	7.6
30-39	13	12	25	5.3	30	10.1	179	169	348	11.2	12.5
40-49	15	23	38	8.0	49	16.4	215	198	413	13.3	11.6
50-59	39	46	85	17.8	35	11.7	167	163	330	10.6	8.8
60 +	88	202	290	39.0	31	10.4	232	218	450	14.5	11.0
TOTAL	185	202	476		191		1619	1487	3106		

[1] An assumed figure on the basis of Shire and W.A. data

SOURCES: Technical Report 10, Table 1
Technical Report 11, Table 2
Census data (1971) Aust. Bureau of Statistics

The population of the Shire grew rapidly during the 1920s and has remained fairly stable since then, with small influxes to rural areas in the southern part in the 1950s. The Augusta population, on the other hand, has trebled in the last 30 years and visitors have probably increased more than tenfold.

The three groups who currently use the estuary and its surroundings (town residents, the rural population and visitors) naturally have different reasons for their involvement with and expectations for the area. For the rural community, it is a place in which to make a living, from the land. The service sector of the town population has also to earn a living there. Both these groups certainly value the area for its natural attractions.

The majority of the retired section of the population have selected Augusta for their retirement because of its natural attributes, peace and quiet and an unspoiled natural environment. The visitors too, especially those who come year after year, value Augusta for these attributes. They seek a different form of holiday from those who visit Busselton and other larger resorts and are not pressing for more sophisticated facilities.

About half the forest and bush of the southern part of the Shire has been cleared for farmland, for cattle grazing especially, but this has not as yet greatly affected the estuary itself, except where there has been clearing to the water's edge in the upper estuary.

The principal uses made of the estuary are: boating for fishing or just for relaxation, fishing from the banks, 'ferry' trips between Augusta and Alexandra Bridge, and water skiing. Amateur fishing by boat or from the shore is probably the most popular activity associated with the estuary, but clearly an aesthetic appreciation of its natural beauty is one of the principal values placed upon it by residents and visitors alike.

A small, but increasing number of houses have been built recently on the banks of the upper estuary and the associated destruction of river bank vegetation poses a threat similar to that which has already damaged banks of the Murray River (Western Australia).

As yet, the estuarine ecosystem seems to have been little modified by human activities and apart from the plastic containers, drink cans and other debris, no evidence was found of pollution or eutrophication.

5. PHYSICAL EFFECTS OF DREDGING IN THE ESTUARY

The effects of dredging in the estuary will vary with the location of the operation and the nature of the sediments to be dredged. Three locations are therefore discussed separately below, with respect to dredging:

(1) the riverine channel (DCs 374H, 376H)

(2) the Molloy-Scott basins (DC 375H)

(3) the inlet channel (DC 367H)

The contrast was made above (sections 4.2 and 4.3) between the winter - spring period when the estuary is fresh, being dominated by river flow, and the summer - autumn condition when it is tidal-dominated and salinity is high throughout the lower estuary. However, it is simplest here to consider the effects of dredging with respect to the seasonal extremes of:

(a) high fluvial discharge, and

(b) low fluvial discharge with tidal dominance,

while not forgetting the intermediate periods of decreasing, and a brief period of increasing, river discharge.

5.1 Dredging in the riverine channel (DCs 374H, 376H)

The Dredging Claims in the main riverine channel include both channel floor and the shallow marginal platforms. The river is bordered by rushes and paperbark trees and there is evidence both of erosion of the banks and sedimentation on the platforms at the present time, although both would appear to be relatively slow processes, because of the coherent nature of the sediments.

A dredge operating here, as elsewhere, would remove all the sediments wherever an ore body was located, together with all the plants and animals living there. It is presumed that every effort would be made to avoid damage to the marginal vegetation and that the dredging spoil would be returned to the river in such a way as to restore the previous contours of the river channel as far as possible. However, return of the sediments will involve sorting to various degrees, depending on current strength (Figure 12) and the returned material will be disaggregated, in contrast to the present coherent sediments. Just how long the spoil will take to consolidate will depend largely on its composition and the rate of recolonisation by plant and animal life.

The deposits to be dredged belong to the Delta Unit, the Pleistocene sediments underlying it, and probably also the muddy Basin Unit (in DC 374H), all of which have a considerable clay size fraction (Figure 10). The Basin Unit especially has a high organic content, but all three sedimentary bodies have much higher levels of available nutrients, in dissolved or particulate form, than are present in the water of the estuary.

5.1.1 High fluvial discharge

Discharge velocities in excess of 1 m/sec (2 knots) were experienced in the river channel for about 6 weeks in 1974 and must be expected to continue for an average of about 30 days during winter. Considerably higher velocities will be experienced under flood conditions such as those of 1945, 1955 and 1964 when river levels were higher than in 1974. The deep holes in the river bed are evidence of the tremendous erosive force of the river.

These high discharge velocities cause shear velocities on the river bed, which are more than adequate to erode and transport material within the size range available from the sedimentary bodies (Figure 13). Dredging is an erosive process and its principal effect will be to disaggregate the present cohesive sediments and thus greatly increase the quantity of sediment available to the river current for transport.

The results of this erosion will be :

(a) an enhanced rate of sediment accumulation, and

(b) an increased load of suspended fine particulate matter.

The geomorphic changes which sediment accumulation will cause, and the consequent hydrodynamic and hydrologic changes, cannot be predicted in any quantitative way on the basis of a one-year study. However, it is possible to draft a qualitative 'scenario' based on historical trends in the geomorphic development of the estuary and estimates of deposition and transport rates set against transport capacity and the volumes of dredge spoil.

Shoaling by sedimentation is a normal trend in estuaries and the Blackwood has been no exception, with highest rates in the delta, on marginal platforms, and at the inlet bar, during the Holocene innundation.

The net accretion rate of the delta sands during the Holocene is estimated at 1,480 m^3/year. The net accretion rate for basin muds is approximately 5,100 m^3/yr, although in the present mature state of the estuary the rate is probably considerably less. The estimated potential of the river to transport material released to it under high discharge conditions is 35,000 m^3/year, 24 times the estimated mean rate of accumulation of extra-basinal material during the Holocene.

The ancestral (Pleistocene) basin had a volume of about 22 x $10^6 m^3$ (Figure 14). Holocene sedimentation during the past 4,000 years has filled most of this with sediment (Figure 4), both by intra-basinal accumulation of clay and fine organic particulates (mainly during periods of low discharge) and by deposition of extra-basinal delta sands (in high discharge periods). The present day residual basin has a volume of only $1 \times 10^6 m^3$ available to absorb further sedimentation before the entire basin is transformed into a broad shoal exposed at low tide.

The volume of sediment which will be disturbed during the dredging process in DCs 374H, 375H, 376H is $23 \times 10^6 m^3$ (based on volume estimates of dredging down to 9 m) or $10 \times 10^6 m^3$ (PMC). Either figure is greatly in excess of the capacity of the residual basin ($1 \times 10^6 m^3$) and more than adequate to allow the river to achieve its potential transport capacity of $35{,}000 m^3$/year. Over a 12 year period this amounts to $0.4 \times 10^6 m^3$, or nearly half the total residual capacity of the basin. Most of this material will lodge on the delta face, thereby extending the delta shoals into the residual basin.

Although this high rate of sediment transport can be minimised during the dredging operation by suspending dredging while there is high fluvial discharge, this will not solve the long term problem of continued erosion of the returned disaggregated sediment. This will continue to erode for some years under high fluvial discharge conditions.

The fine particulate matter, suspended under high fluvial discharge conditions, will remain in suspension and be carried down the inlet channel and out to sea in the river plume and also into the Deadwater with tidal exchange. Settlement will occur slowly, mainly in Flinders Bay, as happens with the much smaller natural load of fine sediment carried by the river each winter, and will blanket the sea floor. This effect was observed even during the much smaller dredging operation involved in construction of the boat channel.

5.1.2 Low fluvial discharge, tidal-dominated conditions

These conditions were fully developed for about six months in the summer of 1974-75. With the slow speeds of tidal currents then experienced (Figure 7) the heavier sediment fractions will settle out quickly, close to the dredging operation, but much of the finer material will remain in suspension for some hours, and be transported by the tidal currents. Peak current velocities are only about 0.04 m/sec, a speed at which a single charge of silt clay material will settle out in about 12 hours leaving the water clear. However, because dredging will be a continuous operation and fresh sediment will be added to the water body continuously the resulting turbid cloud must be expected to be present for the full duration of the dredging operation.

The suspended matter will be carried up and down the estuary by tidal currents and must be expected to be distributed through it in the same way as dye carried in the dye release experiment made in February 1975, and so fill the whole lower estuary (Figure 16). Upstream of the dredging site the cloud will be transported mainly in the sub-halocline flow, which is characteristic of summer salt-wedge conditions, and again on the experience of the summer dye release experiment, clay size material can be expected to be transported upstream as far as Alexandra Bridge. The anticipated distribution of the turbid cloud under tidal-dominated conditions is shown in Figure 16.

Apart from the obviously undesirable aesthetic result of having the water turned brown or black, the turbid cloud will have two principal effects:

(a) the particulate matter will fall out of suspension and blanket the bottom and sea grasses and other plants, and

(b) reduce light penetration to a few centimetres.

Both these will seriously affect the plant and animal life and the anticipated results are discussed in section 5.4.

The behaviour of fine suspended material, even in homogeneous freshwater or seawater, is not well understood. Flocculation tends to bind clay into larger particles, especially where fresh and salt water mix, and electrostatic forces tend to hold clay particles at a surface once contact has been made. However, much of the fine material is organic in origin and is not electrostatically charged. Also, it has a specific gravity little greater than that of the water, even when bound into faecal pellets with a particle size of the order of 0.1 mm.

Dredging operations commonly create floating masses of foam which can blanket the surface of the water. The possibility of this happening in this estuary, as a result of dredging, has not been investigated, but with the high level of dissolved organic matter expected, it is a serious possibility.

5.1.3 Intermediate river discharge conditions

Between winter high river discharge and summer tidal-dominated conditions, there is a period of several months of declining river discharge and consequently conditions intermediate between those discussed above. Erosion and transport of suspended matter will be intermediate between the two extremes described, the particle size and distance carried decreasing with decreasing river flow. The turbid cloud of fine sediment will fill the lower estuary, but will not penetrate far upstream until the salt-wedge system becomes established.

A shorter transitional period may be experienced in late autumn or early winter, depending on the rainfall pattern. In 1974, a short period of high river flow occurred in early June, followed by a dry spell during which flow decreased and allowed salt-wedge conditions to be re-established in the lower estuary before onset of winter rains in July.

5.2 Dredging in the Molloy - Scott basins (DC 375H)

The shallow Molloy and Scott basins are connected by a narrow winding channel. Large areas of both basins are exposed at extreme low tide. The banks are rush covered in most parts and there are some extensive swampy areas. Laterite is exposed on Molloy Island and in the Scott River within the claim area.

The basins are outside the main Blackwood River channel and current speeds in them are not likely to approach the velocities in the main riverine channel, at any time. Flow rates were not measured in the Scott River in winter, although tidal currents were found to circulate around Molloy Island in summer.

The sediments here are of the same nature as those in DCs 374H and 376H, with high silt-clay fractions and these will behave similarly when released into suspension as in the other dredging locations. Some coarse sediment must be expected to enter the river flow under high discharge conditions and the turbid cloud will be carried freely, by tidal currents, into the lower estuary.

5.3 Dredging in the inlet channel (DC 367H)

The inlet channel has a deep central section of 4 to 8 m and wide shallow marginal platforms on both sides. Granite is exposed on both banks and on Lion Islands, and was contacted in holes drilled near the west bank. There are rushes along the banks and these cover wide swampy areas in some parts of the east bank.

The principal mineral source is likely to be the Inlet-Bar Unit. However, both the Pleistocene sediments and the Oyster Unit are also likely to be involved. In the part of the inlet channel indicated as a 'potential area of interest', the 1974 bottom contours are not greatly different from those of 1925 and the sediments appear to be stable. However, near the mouth, the sediments of the east side of the main channel are highly mobile and the banks change seasonally.

It will be seen from Figure 10 that sediments of the Inlet-Bar Unit are better sorted than those of other units and the silt-clay content averages only 13.5%. The Pleistocene sediments here are likely to be of similar composition to those around Molloy Island, although clay layers could be penetrated towards the west bank. The Oyster Unit contains much shelly material embedded in a muddy matrix.

5.3.1 High fluvial discharge

The current speeds of 1 to 1.5 m/sec are capable of transporting all sediment particles made available by the dredging process. The physical effects of sediment suspension here will be the same as in claims in the riverine channel (see section 3.1.1), although the area where the sediments will settle will be different. Much of it will be carried through the mouth and deposited in Flinders Bay, the first point at which flow slackens at this time. This will add to material available in littoral drift and be carried back into the inlet by tidal currents under low discharge conditions. During the period of decreasing river flow, in spring especially, sediment of sand size will be carried down the inlet channel and settle where flow rates are least; along the marginal shallows and particularly near the mouth on the bank of mobile sand, which accumulates here each year with slackening flow. It seems probable that at the present time the spring - summer growth of this inlet mouth bar is in balance with the erosion which occurs in winter under high flow conditions. If there is a net accumulation of sediment here, this is certainly a slow process.

Dredging in the inlet must be expected to cause a great acceleration of this natural process.

Growth of the inlet mouth bar will reduce tidal flow and allow growth of the sea bar. Such a situation developed during 1930-45 with formation of a sand spit from Dukes Head. This resulted in diversion of the river through what is now the Deadwater and progressive shallowing of the sea bar at the entrance to the new channel, and finally its closure in the summer of 1945 (Figure 17). There was a rise of water level of over a metre in the estuary and flooding of the caravan park and other low lying areas. A cut was then made at the original/present site of the mouth and the force of the water scoured out the sand spit. A similar or even more drastic change of form of the estuary mouth could result from mobilisation of the quantities of sediment likely to be involved in dredging DC 367H.

5.3.2 Tidal-dominated conditions

Current speeds observed at Point Irwin were similar to those at Station 90 (0.04 m/sec at the surface and 0.01 m/sec near the bottom) and considerably higher at the mouth (0.08 to 0.06 m/sec) - speeds which are adequate to carry silt and clay in suspension.

The effect of dredging will be similar to that described above (5.1.2), in producing a turbid cloud which will be distributed throughout the lower estuary. It will not be carried so far up the tidal river but will be more effectively spread through the Deadwater and Swan Lake; it will also be carried out to sea. The aesthetic effect here will also be obvious. The biological effects are considered in section 6.4.

5.4 Summary

At the present time the river carries little sediment and there is only slow growth of the estuarine delta and mouth bars. The sediments of the dredging claims are well consolidated and only subject to slow erosion, even at times of high river discharge.

Dredging in the estuary will result in disaggregation of the sediments and their suspension in the water body, thus enhancing the supply and greatly accelerating the natural sedimentary process. This will have the following principal effects:

(1) Fine, clay size, sediments will remain in suspension for about 12 hours and be transported by both river flow and tidal currents, forming a turbid cloud which will persist throughout the dredging operation. The 'short term' effects of this on the life of the estuary are discussed in section 6.4.

(2) Suspended sand size material will be transported downstream by high river discharge in winter and deposited again where flow slackens.

(3) The returned, unconsolidated sediments will be more subject to erosion than are the present sediments.

The long term changes, beyond the duration of dredging, anticipated as the result of (2) and (3) will be:

(a) a general shoaling of the delta and its rapid advance into the remaining estuarine basin south and west of Thomas Island, eventually filling it;

(b) growth of the distributary fans and shoaling of the channels;

(c) confinement of river flow to one distributary in its passage to the inlet channel and consequent enlargement of this by erosion;

(d) when the estuarine basin has filled, resuspended delta sediments will be carried down the inlet channel and increase sedimentation in the inlet bar area. Sediment dredging in DC 367H will also be deposited here;

(e) sedimentation here could result in changes in topography of equal or greater magnitude than those of 1930 to 1945;

(f) obstruction of tidal flow by the delta or mouth bars would change hydrologic conditions in the estuary, probably making the water fresher.

There is little basis for predicting how rapidly the dredged sediments will again compact, but it is anticipated that they will continue to be subject to rapid erosion during periods of high discharge for a period of ten or more years after dredging ceases. Both during the life of the dredging operation and subsequently, any change in the contours of the river channel could result in rapid erosion of the banks, which would affect even the existing consolidated sediments. Major floods are experienced on the average every ten years and such a flood could result in considerable and quite unpredictable changes to the course of the river.

6. DREDGING AND THE BIOLOGY OF THE ESTUARY

The literature on the biological effects of the dredging is fairly extensive and relates to many parts of the world. This has been reviewed but has been of limited value in respect of the present proposal. Most studies relate to short term dredging operations and no data has been found on the effects of dredging in estuaries continued over a number of years, or of deep dredging; also the experience and conclusions recorded in the literature are often at variance with one another and it is evident that some studies lack objectivity, reflecting the interests of the persons reporting them. The hydrological characteristics of the estuaries of south-western Australia are almost unique and no references have been found to studies made in estuaries with such great seasonal extremes.

When an estuary is dredged, changes in the biological systems may result from any one of the following physical and chemical causes:

(a) Destruction of the existing flora and fauna, especially the marginal vegetation and aquatic macrophytes (algae and sea grasses).

(b) Alteration of the physical dimensions of the estuary as discussed above (5.1.1).

(c) Changes in dynamics of river discharge and tidal exchange with the sea.

(d) Changes in the salinity regime consequent upon (b) and (c).

(e) Destruction of habitats and creation of new ones, especially marginal and shallow water habitats.

(f) Sorting of dredged material with consequent physical and chemical changes in composition of surface sediments, their granulometric composition and organic content.

(g) Suspension of fine particulate matter with direct effects on both fauna and flora.

(h) Turbidity of the water with reduced light penetration.

(i) Deoxygenation of the water as a result of resuspension of organic matter, resulting in increased bacterial activity and biochemical oxygen demand (BOD) and in reduced photosynthesis because of the turbidity.

(j) Nutrient release from the suspended sediments.

(k) Changes in water chemistry; e.g. release of herbicides, insecticides, dissolved heavy metals, hydrogen sulphide and other toxic substances.

The effects of (a) are immediate, and are the direct results of the dredging process; they will be discussed in 6.1. The effects of (b) are long term and are largely irreversible as are (c), (d) and (e) which are consequent upon (b), also (f); these are discussed in 6.2 and 6.3. The rest are short term, limited to the period of the dredging operation and for some time thereafter, depending on the stability of the dredging spoil returned to the substrate. They result mainly from production of the turbid cloud of fine particulate matter, the physical effects of which were considered above (5.1.2); the biological effects are discussed below in 6.4, from which it will be clear that the consequences of the cloud will be of fundamental significance to the estuary.

The effects of dredging need to be considered both from the point of view of the immediate impact, during the dredging, and of subsequent recovery and as far as possible this has been done here.

One further general point needs to be made. Beyond the area where the dredging process will cause total destruction of habitats and plant and animal life, there will be a gradient of disturbance to the ecosystem, the effects of which will gradually decrease with distance from the dredged area. Close to the dredging operation, the bottom will be blanketed by sediment at a rate which will destroy most plant and animal life. Some organisms are more resilient, or less affected by the more pervasive effects of dredging, such as turbidity and fine suspended matter. Species diversity and productivity will be less affected with increasing distance from the dredging site. However, there is little basis for predicting the dimensions of this sequence or how individual species of plants and animals will respond.

6.1 Direct destruction of habitats, plants and animals

The shallows of the dredging claims provide rich feeding for fish and waterfowl. Destruction of the aquatic plants and the invertebrate fauna will render these areas unsuitable for fish and birds, until the flora and fauna is re-established. Regrowth of the dominant seagrass, *Ruppia*, will almost certainly depend on the success of vegetative regeneration from rhizomes or other plant fragments. No record has been found of any attempts to propagate *Ruppia*.

Other aquatic plants, such as the less salt tolerant *Potomgeton* and *Lamprothamnion*, which do produce seed, may be expected to re-establish more quickly, during the fresh phase of the estuary They die back in summer under the influence of salt water.

Swans and ducks are the principal herbivorous animals of the estuary. The maximum depth at which a swan can feed is 1 m, the length of its neck, and it would be necessary to restore the shallows to this depth if they are to continue to be feeding grounds for swans.

Recolonisation of dredged areas and of new sediment by the bottom living invertebrate fauna will be progressive and, as experienced elsewhere, it may be expected that populations will be re-established fairly rapidly, within two to four years. The species composition may differ from that at present, as discussed later. Usage by fish will depend largely on re-establishment of this invertebrate fauna as a food resource.

6.2 Sedimentary infilling

This will reduce the area of open water and therefore of available feeding grounds for fish and birds. Areas above low water level will be unsuitable for aquatic plants and above about mean water level for benthic invertebrates. This would result in reduced fish and bird populations and possibly the disappearance of some of the less common species.

Swamp plants, rushes *(Juncus)* and samphire, will eventually colonise the higher areas, though this is likely to be a slow process. *Juncus* advances to new areas either by rhizomes from existing stands or by seed dispersal and both are seen in shallow, enclosed water at Point Pedder. However, there seems to be little successful establishment of seedlings and there appears to have been only slow advance here in the last 150 years. This can be expected to accelerate with new sediment deposition. Such encroachment will, of course, further reduce the area of open water.

6.3 Hydrologic changes

Any significant change in topography, particularly obstruction of tidal currents by enlargement of the delta, will change the hydrological conditions in the estuary. Lower salinities, or more prolonged exposure to low salinities, will result both in reduced diversity of bottom living invertebrates and of immigrant fish, and probably decreased production of these. On the other hand, if a deep channel was scoured through the delta, increased penetration of salt water into the upper estuary would permit its better utilisation by a few species of fish.

In the event of obstruction of the mouth or closure of the bar, as envisaged in section 5.3.1, there would be a gross change in the hydrology of the estuary, with poor penetration of salt water. This would result in an impoverished fauna and poor recruitment of fish to the estuary, as is reported to have happened with the build up and closure of the bar in the early 1940s.

6.4 Fine particulate matter

The Pleistocene sediments contain 36% and the Delta Unit 25% silt-clay material (Figure 10). This is both organic and inorganic in nature but there is no measure of the proportions of these or of the nature of the organic matter. As shown above, this material will be thrown into suspension by the dredging operation and form a turbid cloud throughout the lower estuary during the greater part of the dredging operation, especially under tidal-dominated conditions (Figure 16) and will settle slowly to the bottom.

Although all suspended sediment will be carried from the estuary with the first high river discharge after dredging ceases and the water body can be expected to clear within 12 hours after dredging stops, the various effects it will have pose a serious threat to the life of the estuary. The anticipated effects of this turbid cloud are:

(1) Direct effects of the suspended and settled particulate matter on the plants and animals.

(2) Reduced light penetration consequent upon the turbidity.

(3) Depletion of the dissolved oxygen content of the water.

(4) Supply of additional plant nutrients derived from the organic matter.

(5) The aesthetic effects of brown or black turbid water replacing the clean oceanic water, which fills the lower estuary through the summer months, are considered in section 8.3.

6.4.1 Direct effects

When the suspended particulate matter sediments out it will blanket the benthic plants, occluding the light and thus preventing photosynthesis. At low concentrations, farther from the dredging operations or during the recovery period after dredging finishes, the organic content might act as a fertilizer and increase plant growth, particularly that of rooted plants.

High concentrations will overload suspension feeders, such as mussels, but the organic content will provide a detrital source, which may be advantageous to some species of sediment feeders. The net effect must be that a few species will survive near the dredging site and some disruption of species composition of the benthic fauna must be anticipated throughout the lower estuary.

Recovery after dredging ceases, will depend largely on the composition and thickness of sediment deposited. A muddy bottom is likely to support a low diversity of fauna, but on a sandy mud the benthic fauna may be expected to recover rapidly. It is possible that some individual species will be eliminated as appears to have happened recently in the Swan estuary following dredging and shore reclamation. However, a return to previous levels of productivity can be expected on suitable bottom types, if there are no other adverse effects.

No generalisations can be made about the direct effects of suspended matter on fish. Specific differences are great and overseas studies have shown that while some species are little affected by the fine particulate matter, others avoid turbid water. Such species may be expected to leave the estuary during the dredging operation. Clogging of the gills has been reported with some species. Reduced visibility will adversely affect the feeding of bottom feeding and predatory fish, although for a few (e.g. cobbler), this could be offset by the protection afforded from attack by predators.

In the absence of information on currents in Flinders Bay it is difficult to predict what effect the accumulation of fine sediment will have there. Local fishermen are adamant that the turbid cloud, caused by dredging the boat channel in 1973, blanketed the bottom with a layer of such sediment. This activity was on a much smaller scale and for a much briefer period than the proposed operation.

The dramatic effect of even a brief inundation with a silt load is illustrated by the following experience. An instructive study was conducted by the Australian Littoral Society in the estuary of the Tweed River in northern New South Wales. Periodic underwater observations were made before and after pollution by silt from a sand-dredging operation lasting for four weeks. Three weeks after the completion of dredging, the river bottom was covered with silt up to 1.5 metres deep and was devoid of almost all sessile animals and algae. Counts of fish, taken over fixed transect lines, indicated that immediately before dredging sixteen species were abundant whereas after dredging a drop in number of species and of fish occurred, with the recording of a minimum of five species on one occasion. A steady biological improvement was noted in the following weeks and after twenty-nine weeks recovery was apparently complete.

6.4.2 The turbid cloud and light penetration

Growth of aquatic plants is dependent on penetration of sufficient light to the level at which plants are growing. At about 5% of surface light, the rate of respiration of such aquatic plants as sea grasses equals the rate of photosynthesis and there is no net production (this is about the level at which a white Secchi disc ceases to be visible).

The turbid cloud will greatly reduce light penetration throughout the lower estuary, probably to even less than under high river discharge conditions at present, when Secchi disc readings are 0.1 to 0.3 m.

Field experiments have shown that when light intensity is reduced to 20% of that in a control situation, the growth of *Ruppia* is markedly reduced. Moreover, productivity decreases with increased time at low light intensities and even at 50% of the normal light level, productivity was found to be greatly reduced after a period of five months. With prolonged exposure to such reduced light intensities the sea grass meadows will die out altogether.

Disappearance of the sea grass meadows will result in the elimination of other biotic elements which use the grasses as a habitat, notably the epiphytic algae which are themselves important primary producers and a variety of invertebrate fauna, especially the shrimp *Palaemonetes*. Also the juvenile fish populations which use the *Ruppia* meadows as nurseries will be deprived of a major habitat.

Turbidity will also reduce productivity of another element of the flora, the benthic diatoms, although they require lower light intensities than sea grasses. These have an important role in the estuarine food chain, being eaten by suspension and sediment feeding invertebrates, possibly also by some fish.

6.4.3 Dissolved oxygen

The decreased photosynthesis resulting from the turbid cloud and increased BOD of particulate organic matter will cause a reduction in dissolved oxygen. This is likely to be severe in the immediate vicinity of the dredging operation and below the halocline, under stratified conditions. Oxygen levels less than about 3 mg/l are unsuitable for fish and prolonged exposure will affect survival. There is not likely to be significant depletion of oxygen in shallow water of the basin or surface water elsewhere.

6.4.4 Nutrients

The sediments are rich in plant nutrients, and contain dissolved organic matter in a form available to plants in much higher concentration than is present in the estuarine water. Nutrients will also be rapidly made available by bacterial action from particulate organic matter. These will, therefore, add to the nutrient content of the water and may result in some degree of eutrophication under tidal-dominated flow, with resulting phytoplankton and other algal blooms. This will be offset by reduced light penetration. It is not possible to predict what level of eutrophication may result. Increase in phytoplankton productivity outside the estuary could be beneficial, though there is also the possibility of blooms of toxic species.

6.5 Review of the anticipated response of different types of organisms

It is useful to summarise the foregoing sections, from the point of view of the anticipated effects of dredging on the several elements of the biota. Before doing so, it is well to reiterate some general points with respect to dredging First, there is no basis of experience as to the effects of dredging in such an estuary as the Blackwood. Resident plants and animals are very resilient and are well adapted to the great environmental extremes to which they are subjected, extremes which normally persist for a relatively short duration of no more than half a year. However, dredging will expose them to additional hazards for a prolonged period, so that the disturbance to the environment will be a chronic, long term disturbance rather than a short, acute disturbance. Second, while destruction of the biota will be total in the dredged area, there will be a gradient away from it of coarse sediment deposition, fine sediment settlement, turbidity, release of nutrients, and no doubt others. These will have different effects on particular elements of the biota and to predict, with any precision, how they will respond to all of them is clearly impossible. Third, there is every reason to believe that when dredging ceases, an estuarine ecosystem will be re-established with a species diversity not greatly different from that at the present time. However, there is little experience from which to predict either how long this will take or what will be the ultimate composition of the estuarine flora and fauna.

The comments here relate primarily to the lower estuary, the part of the estuary likely to be most affected by dredging in PMC's claims.

Algae. At present, phytoplankton is a relatively unimportant element of the ecosystem. Turbidity must be expected to further reduce productivity, but release of nutrients could result in localised blooms under low flow conditions. Macroscopic algae may be expected to respond similarly to turbidity, with poor growth of most attached species, but nutrient enrichment could cause excessive growth of a green alga, such as *Rhizoclonium*, and accumulation of decomposing masses in the shallows, as occurs in Peel Inlet. Both types of algae can be expected to return to present levels of production within a few years after dredging ceases.

Vascular aquatic plants. The sea grass *Ruppia* must be expected to be eliminated by the actual dredging and killed by the rain of coarse or fine sediment in the immediate vicinity of the operation. Farther away, the reduced light resulting from the turbid cloud will probably result in death of the sea grass meadows.

The experimental dye cloud penetrated Swan Lake and the turbid cloud may be expected to behave similarly, although attenuated by settlement during its passage to the lake. It seems unlikely that all *Ruppia* will be killed in the shallow water of the lake, and it would be an important refuge for *Ruppia* and its epiphytes and the associated fauna. There could be an increase in productivity as a result of the added nutrients.

Fringing Vegetation. The rate at which rushes *(Juncus)* invade the open water will increase with the deposition of sediments and result in the type of encroachment into the estuary, seen on the northern shore of Hardy Inlet. Here *Juncus* traps sand, which builds up into a ridge and a salt marsh forms behind with samphire and paperbark trees and other plants colonising more slowly as salinity decreases. Most of the plant biomass of the estuary is in the fringing vegetation, which traps and recycles nutrients, and constitutes the largest pool of nutrients in the ecosystem. Clearly for this reason, and because of the binding effect of *Juncus* on the marginal sediments, its destruction will be harmful to the system.

Benthic invertebrate fauna. These inconspicuous worms, molluscs, small crustaceans, and insect larvae are essential elements in the food chain, being the food of most species of estuarine fish and birds. In the immediate vicinity of the dredging operation, all elements of this fauna are likely to be adversely affected by sediment accumulation. With increasing distance from the dredging site both diversity of species and biomass will progressively approach normal, but there are insufficient data on which to base predictions about the response of individual species. Filter-feeding animals, mussels and barnacles, can be expected to be the worst affected and burrowing worms and molluscs, which constitute the bulk of the bottom fauna, will probably be less badly affected, while some species may benefit from the particulate organic matter.

From the experience of short term dredging elsehwere, a period of 2 to 4 years may be expected for most invertebrate species to return to full productivity - once there are stable sediments for recolonisation. If, however, there is any substantial change in composition of the sediments, the relative and absolute abundance of species may change considerably. For example, the muddy bottom of the dredged boat channel still has both a lower species diversity and lower biomass than the adjacent sandflats, probably because of the different more muddy, character of the substrate following dredging.

Fish. Fish will be adversely affected both directly by suspended sediment, the turbid water, and any significant oxygen depletion, and indirectly by reduction in aquatic plants, the plant habitat, and their invertebrate food. Populations of the resident species, black bream, hardyheads, and gobies, which breed in the estuary, may well be expected to be depleted during the dredging operation, but insufficient is known about their biology for valid predictions to be made about long term effects on them. Black bream are among the most popular fish with amateur fishermen and hardyheads and gobies are eaten by predatory fish and birds.

The great majority of fish species leave the estuary during the fresh phase and are recruited annually from coastal populations. Numbers of most species must be expected to be severely depleted in the estuary during the dredging operation and some species, such as herring, may avoid the estuary altogether throughout the dredging operation. There is no reason to think they will not return to it when conditions are again favourable, but the time taken for recovery of the estuarine populations must depend mainly on the recovery of food and habitat resources.

Ruppia beds are especially important to juvenile fish and destruction of these will reduce use of the estuary as a nursery until these beds recover. In this respect, the Deadwater is particularly important and any serious depletion of *Ruppia* here must be damaging to fish populations in the estuary.

Waterbirds. The shallows of the dredging sites are feeding and loafing grounds for waterfowl (swans and ducks) and dredging will deprive the birds of them. The anticipated destruction of *Ruppia* by sediment accumulation and turbidity will also reduce available feeding grounds throughout the lower estuary, so that waterfowl populations are likely to decrease greatly during dredging. Recovery after this ceases will depend mainly on re-establishment of sea grass beds.

Reduction of the area of shallows from any cause, or of the invertebrate fauna of them, must reduce the food available for the many species of wading birds. Cormorants fish by sight and any increase in turbidity will be disadvantageous to them. Silver gulls and possibly some other species may take advantage of small fish and benthic invertebrates disturbed by the dredge.

Long term effects on waterbird populations using the estuary must to a large extent depend on how the bottom contours are altered by the dredging; waders are dependent on shallow intertidal flats and waterfowl (except musk duck) on water of less than one metre depth that can support aquatic plants and a diversity of invertebrate fauna. These are the same habitats on which most fish species depend; the deeper water is much less productive for both plant and animal food. Swan Lake, with its extensive *Ruppia* meadows, is of particular importance to the continued use of the estuary by waterbirds.

6.6 Summary

The actual dredging operation will cause destruction of plant and animal life at the dredging site. Beyond the dredged area there will be a gradient of sediment accumulation and the adverse effects will decrease in severity with distance from the dredging operation. The dimensions cannot be predicted with any accuracy. However, it is clear that the release of of sediment into the estuary, under high flow conditions, must result in destruction of a considerable part of the flora and fauna downstream from the dredging activity.

Under tidal dominance conditions, the turbid cloud must be expected to greatly reduce productivity of sea grasses and other plant life throughout the estuary, and consequently the animal life dependent on them. It may well result in elimination of all plant life in the lower estuary, within one year.

Most fish, especially 'commercial' species which are fished by both amateurs and professionals, enter the estuary from the sea. Almost all species must be expected to be adversely affected and some will probably avoid the estuary during the dredging.

The sea grass beds are the principal feeding grounds of swans and their destruction from whatever cause must almost certainly reduce swan numbers, even if Swan Lake remains little affected. Wading birds, most of them transequatorial migrants, feed indiscriminately on the invertebrate fauna of the tidal flats. The area of these flats could either be increased or greatly reduced as the result of sediment deposition in the basin, depending on the pattern of sedimentation.

After dredging ceases, there will be a recovery period during which various elements of the fauna and flora will re-establish themselves. There is no basis in experience for predicting the rate at which this will take place, after such a prolonged disruption to the life of the estuary.

However, an ecosystem which approaches the present one in productivity and complexity, though possibly with a different species composition, can be expected to be re-established within four years, but only if there is:

(a) no great change in the physical dimensions of the estuary;

(b) an immediate consolidation of the dredged sediments, and;

(c) regrowth of *Ruppia* and other aquatic plants in the denuded areas.

If any of the long term changes envisaged in section 5.4 supervene, then obviously there will be a different, much longer, time scale for recovery about which it is exceedingly difficult to make predictions.

Discharge of the fine sediment plume into Flinders Bay, and the consequent smothering of the bottom with a layer of silt-clay and organic material, may have disruptive effects on the fauna. It is not possible to predict the nature of these effects. How long this will persist when dredging ceases will depend on transport by currents in the Bay.

7. MINING THE MINERAL CLAIMS (MCS 4191H - 4194H)

It has been stated by PMC that both the mineral and dredging claims are an integral part of the one operation and neither would be a viable venture on its own. Therefore, although our investigation focussed principally on the estuary itself and the effects of dredging within it, some mention needs to be made of the proposed operation on the adjacent mineral claims. The deposits which it is proposed to mine here are Pleistocene dunal sands. These have been cored by PMC but no information is available about their granulometric composition. The proposed extraction technique involves clearing the land, followed by cutter suction dredging in ponds, using a dredge similar to that employed in the estuary. If the sediments to be mined contain a high proportion of fines, the operation of a processing plant, within the confines of a small pool, would pose a difficult problem of silt disposal. In this case a *"dry mining method would be employed, using bulldozers and loaders and a dry concentrating plant"*[1].

The principal objections to mining these claims are with respect to land use and the aesthetic effects. The area involved is immediately opposite Augusta in full view of the town. Some of it is gazetted as town land and has been so described since 1830. It may yet be developed for residential purposes, although there are no plans for such development at present.

It is evident that the mining operation will totally destroy the present natural vegetation, mainly of peppermint and poor jarrah/marri woodland, and that the native fauna will be eliminated from the areas involved in the operation. Experience at Capel has shown that such mined land could be developed for pasture.

"The Company will undertake to restore all mined areas as nearly as possible to conditions prevailing before mining commences and to this end is prepared to seek advice from Government departments and experts in relative scientific fields"[1]. The feasibility and cost of this restoration has not been determined.

The claims abut on Hardy Inlet and Swan Lake and destruction of marginal vegetation could result in serious erosion of the foreshore and release of silt into the estuary or Lake.

The aesthetic objections are discussed in section 8.3 below.

8. EFFECTS ON THE COMMUNITY

The various components of the community, which would be affected by the proposed mineral sand mining at Augusta, can be grouped into four reasonable homogeneous categories: retired residents, non-retired residents, rural residents, and visitors (section 4.6). To some extent, these groups have different interests and their attitudes to the estuary and the value they place upon it and its environs, inevitably differ. It is not possible to make a completely objective study of the views of the community and of the effects of mining and dredging on it and all that can be done here is to:

(a) summarise the expressed attitudes of the local community to the proposed mining and dredging operation;

(b) state the values known to be placed on the area by this community;

(c) assess as objectively as possible the impact of the operation on these values and on the community itself; and

(d) finally to try to assess the impact of the proposal on the wider community of W.A.

8.1 Community attitudes to the mining and dredging proposal

Community attitudes were clearly stated by various local bodies in objections lodged in 1971, 1972, and 1973[1] and they were further investigated by questionnaires during the Environmental Study. In the town 80% of respondents agreed with the statement "under no circumstances at present should there be mining and dredging in Hardy Inlet" (7.5% disagreed, 12% no response or not sure). In the rural area, a similar question elicited the response of 42% in favour of mining and 48% opposed to it (10% no response). Both mining and dredging would of course have an immediate impact on the townspeople, who in many cases would see the operations from their front windows. The impact on the rural community would be more remote.

The concepts 'dredging' and 'mining' are inevitably confused in people's minds and it is often difficult to know whether expressed attitudes relate specifically to the dredging operation in the estuary, or to the whole mining process. Also the anticipated immediate impact that the dredging operation may have is not clearly separated, in people's minds, from possible long term effects of such an industrial activity on Augusta and its community. Moreover, it is realised that judgements based on attitudes expressed in anticipation of an event do not always give a reliable guide to the behaviour of individuals on its realisation.

Information as to the nature of residents' involvement with the estuary and its surroundings was obtained during the course of the Study and is summarised in 8.2.

8.2 Human values

The attributes of the Augusta area which residents are known to value have been stated: (a) in response to questionnaires with open-ended questions[2], (b) in objections made to the mining and dredging claims by community groups summarised in the EPA Report[1], and (c) in private discussion and at public meetings held at Augusta. The views of holidaymakers are only known from discussion with proprietors of holiday accommodation and private conservation with regular visitors.

In answers to the questionnaires, the estuary itself rated as the principal attractive feature of the Augusta environment. Other aspects of the area nominated by residents were as follows:

Climate. The mild, uniform climate with relatively high rainfall is particularly attractive to the farming community and it is also a reason why many people have retired to Augusta.

Clean ocean air. This was stated by some residents to be one of the attractions.

Peace and quiet. Peace, quiet, and tranquility were given by many residents as the most important reason for selecting Augusta for retirement.

Natural beauty. This is repeatedly cited as one of the principal attractions of Augusta. The quiet beauty of the wide river and the big timber along its banks and the expanse of open water in Hardy Inlet are appreciated by all. The residential area of Augusta is high and overlooks the river and the beautiful groves of peppermint and forest trees on the east bank, with views of Swan Lake and the coastline are greatly appreciated.

Waterbirds. These are regarded as an attraction by tourists and are also valued by residents. A surprisingly large number of visitors gave "ornithology" as one of their activities at Augusta.

Fishing. Fishing in the estuary, from the shore or boats, is one of the most popular pastimes for residents and visitors alike. It is an important part of the life of many retired people.

Boating. Whether for fishing or just for pleasure, boating is a favourite occupation for many visitors. The estuary itself is not suitable for yachting because of the limited area of open water, but motor boats, row boats, and canoes are used frequently and there is skiing in the tidal river. Scenic cruises by 'ferry' from the town to Alexandra Bridge are an important tourist attraction.

Historic sites. There is an active branch of the Royal Western Australian Historical Society at Augusta and plaques have been erected to commemorate the history of the area and the early pioneers. Many of the historical sites, including the lighthouse, water wheel, and memorials to pioneers are visited by tourists.

The village atmosphere. People who have visited the area for many years find that the village atmosphere is disappearing as a result of the growth of the town. Nevertheless, there is a friendly community spirit in the town which is greatly valued by many residents.

Absence of commercialism and industrialisation. Most people see this as one of the greatest attractions of Augusta and are content to go to Busselton or Perth for all except their day to day needs. Margaret River is a more important centre for the farming community. A minotiry of residents find Augusta altogether too quiet and would like to see the place 'get up and go'.

A good place to make a living. This is, of course, how the farming community sees the area, as do people in business or employment in the town. The area is being promoted as a place for small hobby farms, but without much success as yet.

8.3 The impact of mining on the local community

The investigations have made it possible to assess with some objectivity the likely impact of mining and dredging on the community.

Peace and quiet. The sound of a dredge working day and night will be heard in the town and heavy trucks moving through the region would be disturbing.

Natural beauty. A dredge and processing plant working in DC 367H would be visually out of character with its surroundings during the period of their operation there (1 to 2 years). They would also be seen while working the Mining Claims, for a longer period. In DCs 374H, 375H and 376H they would not be seen from the town for most of the time, but would certainly detract from the natural beauty of the river for all who use it. The dark turbid water would be a most unaesthetic feature at all times, and especially during the tourist season in summer when normally the clear, blue water which fills the lower estuary contrasts with the dark green of the peppermint woodland on the east bank.

If sedimentation resulted in any of the long term changes to the basin or bar envisaged above (section 5.4), then the whole nature of the estuary would be changed more or less permanently.

Waterbirds. It is expected that there will be a reduction in waterfowl during the dredging operation. The effect on wading birds and the long term effects consequent upon changes to the physical and biological environment, are unpredictable.

Fish and fishing. The anticipated reduction in fish populations during dredging will reduce the attractiveness of the estuary to residents and holiday makers alike. Some recovery after dredging ceases may be expected if there are no drastic changes of topography.

Boating. The turbid water and poor fishing will render boating less attractive during dredging. Growth of the delta and infilling of the basin will reduce the area suitable for recreational use. Sedimentation near the mouth of the estuary, resulting especially from dredging in DC 367H, could alter the pattern of boat usage and make access to the ocean even more hazardous than at present.

Population. PMC envisages a labour force of about 65 - 15 to operate the floating wet plant and some 50 on the shore based processing plant[1] and state their wish to employ local labour. It is probable that sufficient unskilled labour could be recruited locally, on a casual basis, and that such a labour opportunity would be welcomed, especially with the present recession in the farming industry. On the other hand, the view was expressed that any influx of labour would be disruptive to the community and of no long term benefit to the town. The short duration of the mining project means that it will not be useful in solving the region's employment and development problems in the medium to long term.

Revenue. Mining offers immediate benefits to a rural Council, which is hard pressed for funds to maintain facilities that benefit a non-resident community (tourists and holiday makers), who contribute little by way of revenue to the Shire. EMAC did not attempt to gain a full understanding of the economic consequences of the mining and dredging venture, but it is clear that the income created by tourism, both in the town and outside, is of the same order as that which would be generated by the proposed mining, even in the short term. If, as is expected, tourism and residential development are discouraged in anticipation of and during the operation of the mining and dredging, then there would be a long term loss to the community.

8.5 Impact on the W.A. community

It is not the purpose of this report to evaluate the economic gains or losses to Australia or Western Australia in particular. All that can be done here is to note some of the probable areas of advantage or disadvantage which may accrue from the proposed mining and dredging at Augusta.

The concentration of heavy mineral sands believed to be present in the deposits is small in comparison with the deposits being worked at Capel and Eneabba and elsewhere in Australia. Moreover, it is a low grade deposit which would be uneconomic to mine at the present time. Even the Capel mines with their much higher percentage of contained heavy minerals, probably higher zircon content, established facilities, and much shorter haul to port, are now only reasonably profitable.

The argument has been advanced that the mining claims should be worked before residential development takes place on the eastern shore. There is no immediate prospect of the latter happening and it would be more advantageous to retain the whole of this area as park land, to ensure the continued beauty of the setting of Augusta.

Augusta has come to be recognised as a holiday resort and centre for one of the most attractive and unspoilt areas of Western Australia - the southern part of the Naturaliste-Leeuwin ridge and its hinterland - and one which is rapidly becoming more popular. It appeals especially to those who enjoy a less sophisticated atmosphere than is provided by the larger holiday resorts, such as Busselton and Mandurah. With greater leisure, there is an increasing demand for just the sort of facilities which are offered by Augusta. It has been suggested that the mining operation itself would be a tourist attraction, but it is likely that any such attraction would be more than offset by the associated disadvantages noted above.

Desirable as the growth of tourism may be, human usage can easily destroy just those things for which the estuary and its surroundings are valued and it is important to plan carefully the type of development suitable for Augusta in order to retain its present character as far as possible. Increasing use of the estuary will make it necessary to ensure its proper management, in order to prevent indiscriminate damage to the natural vegetation and to conserve the river itself.

Attention has been drawn to the possibility that the expected increase in sedimentation rate could result in major changes in the topography of the estuary and in particular to the mouth and sea bar. The experience at Peel and Wilson Inlets is relevant and it is evident that closure of the bar would require costly works to reopen it and possibly training walls to keep the mouth open.

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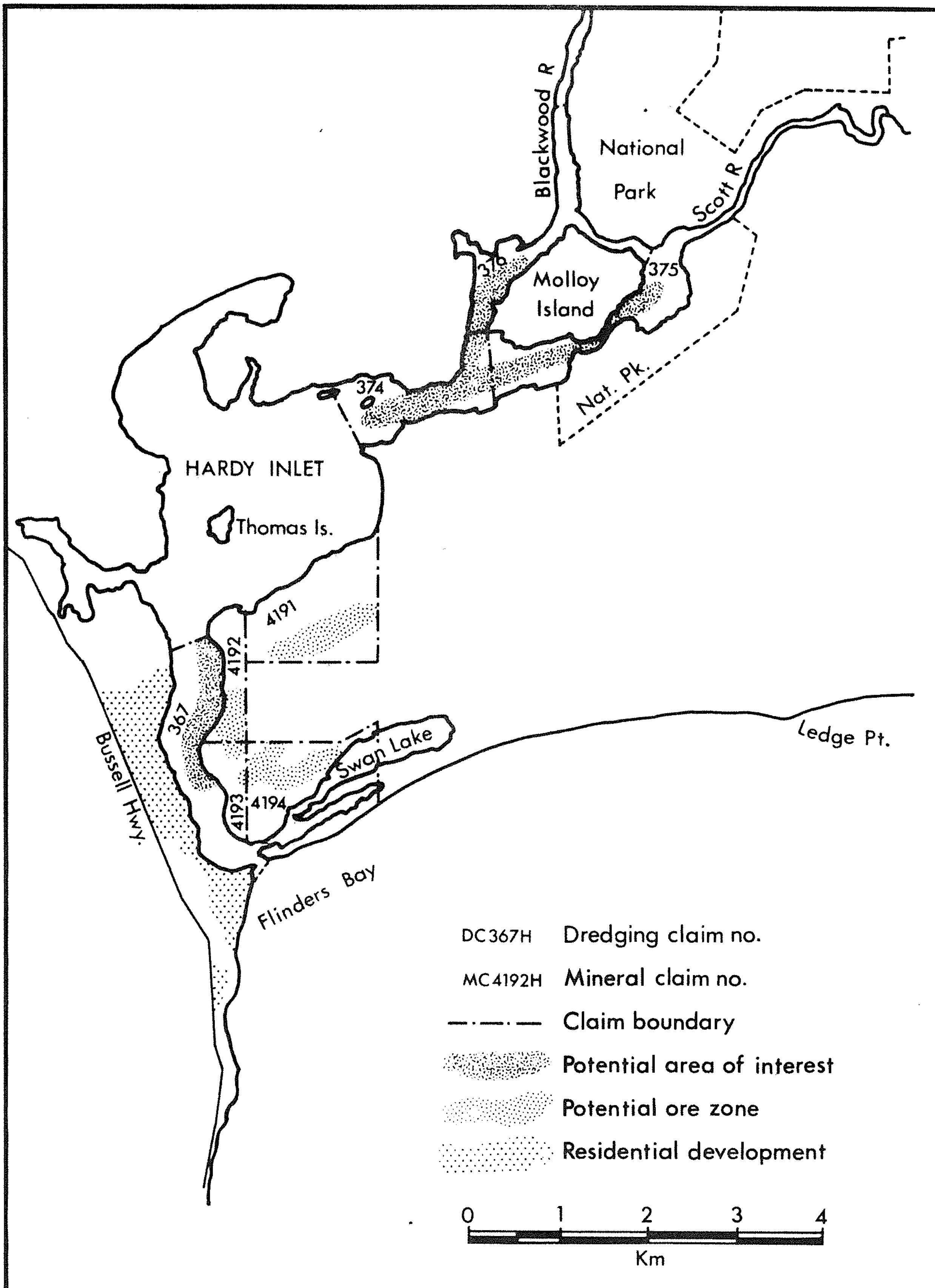

FIG. 1 Mineral and dredging claims at Augusta, as at 3 September 197[illegible]

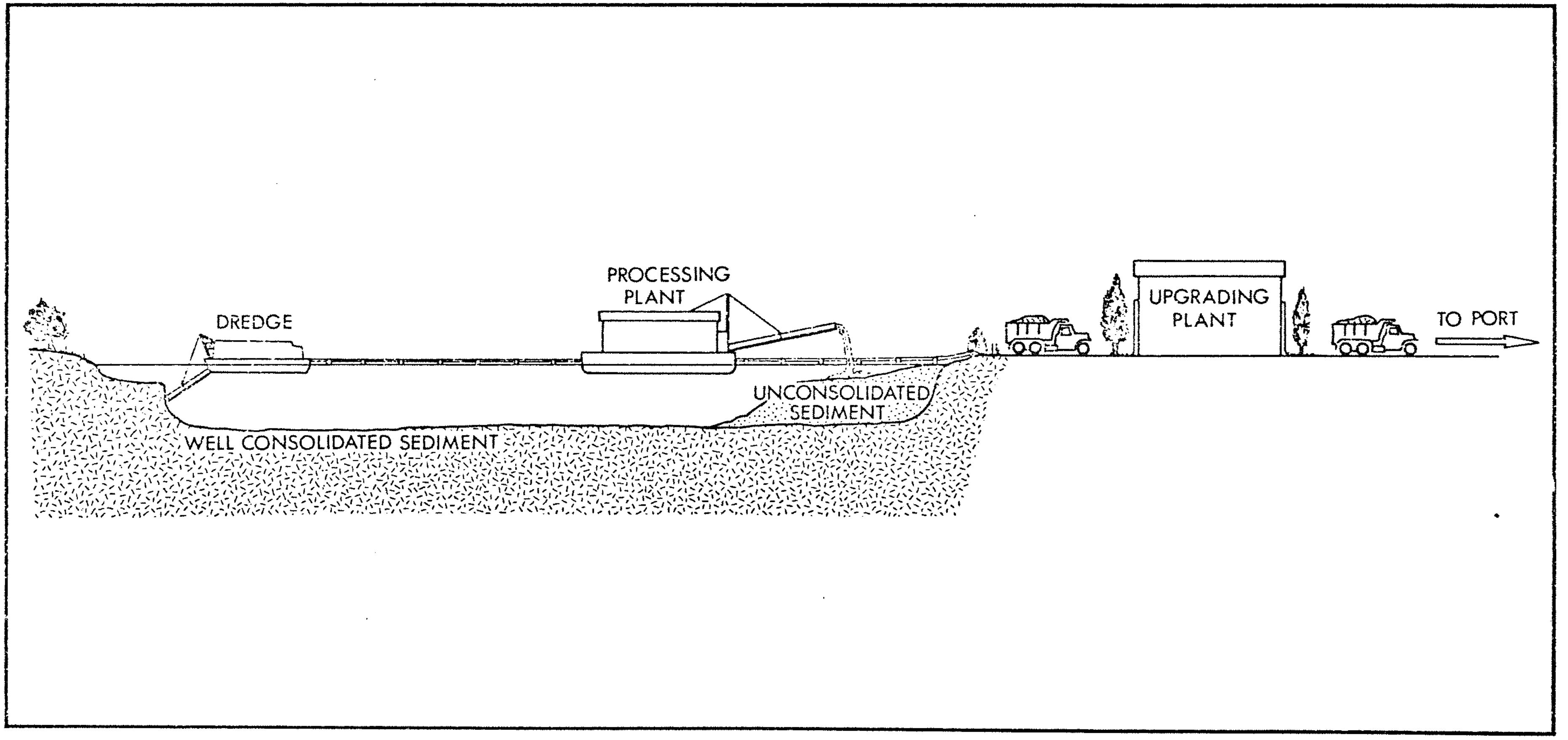

FIG. 2 Diagramatic representation of the dredging operation.

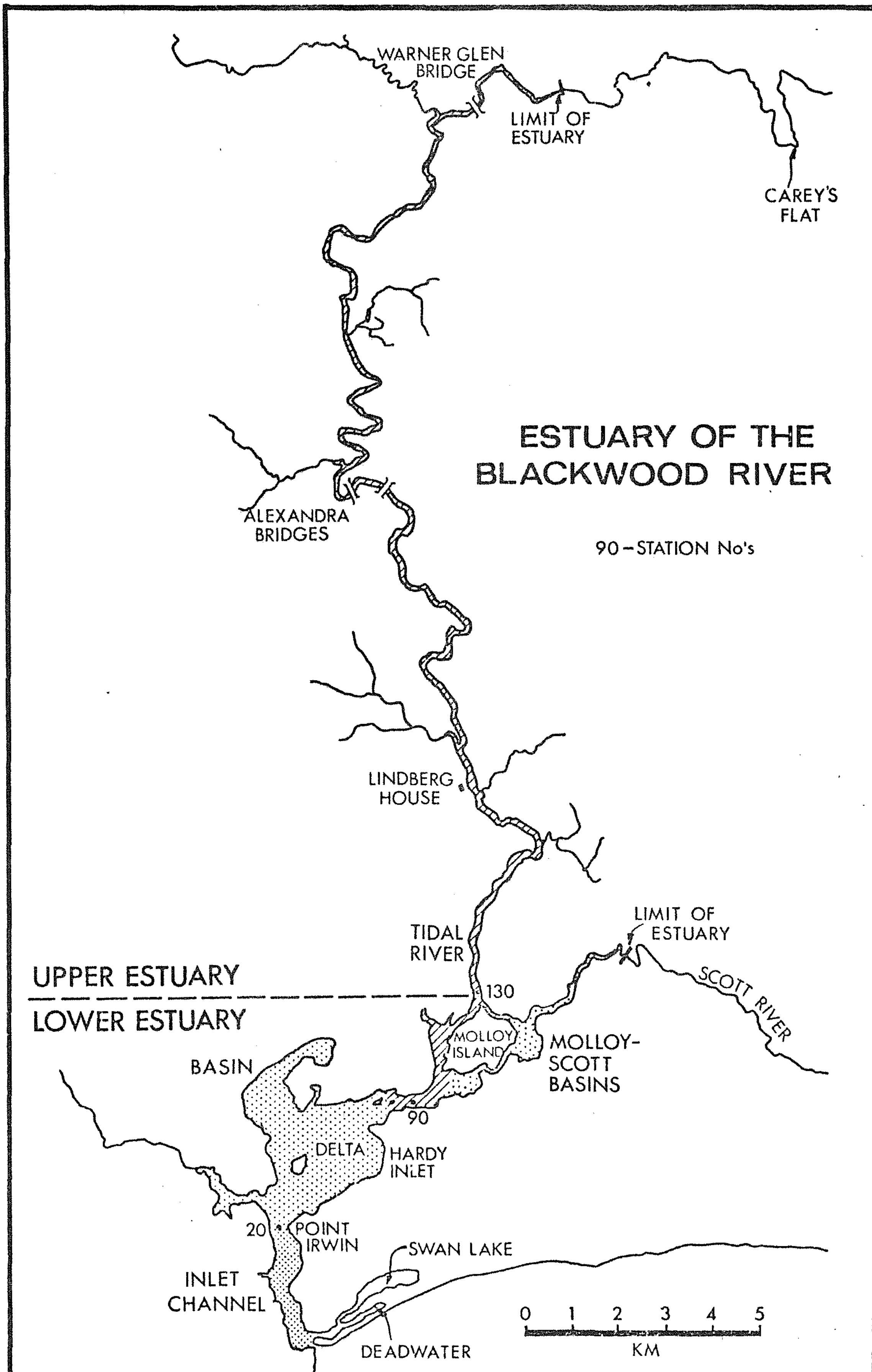

FIG. 3 Topographic terminology adopted in this report.

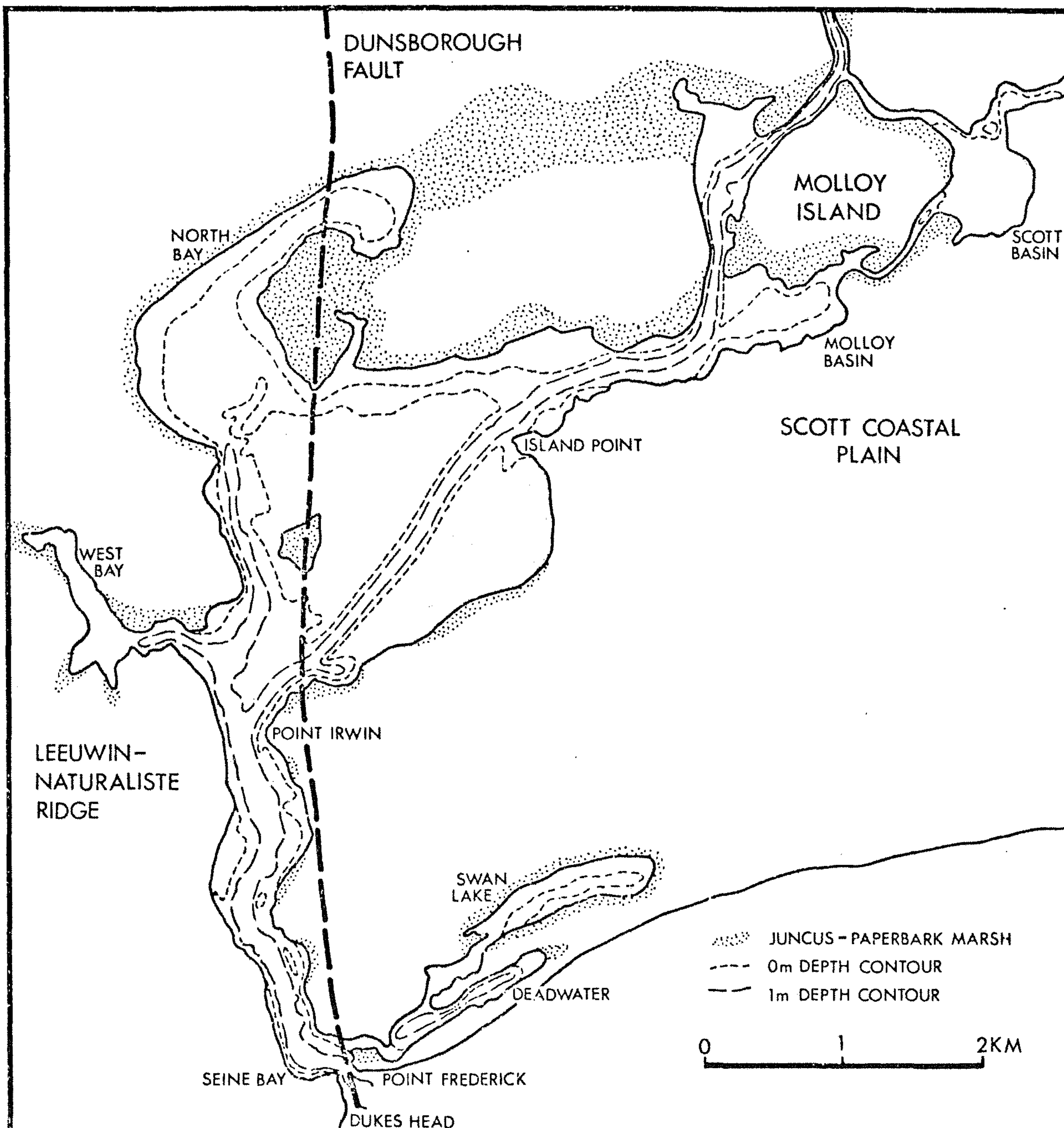

FIG. 4 Geomorphology of the estuary of the Blackwood River

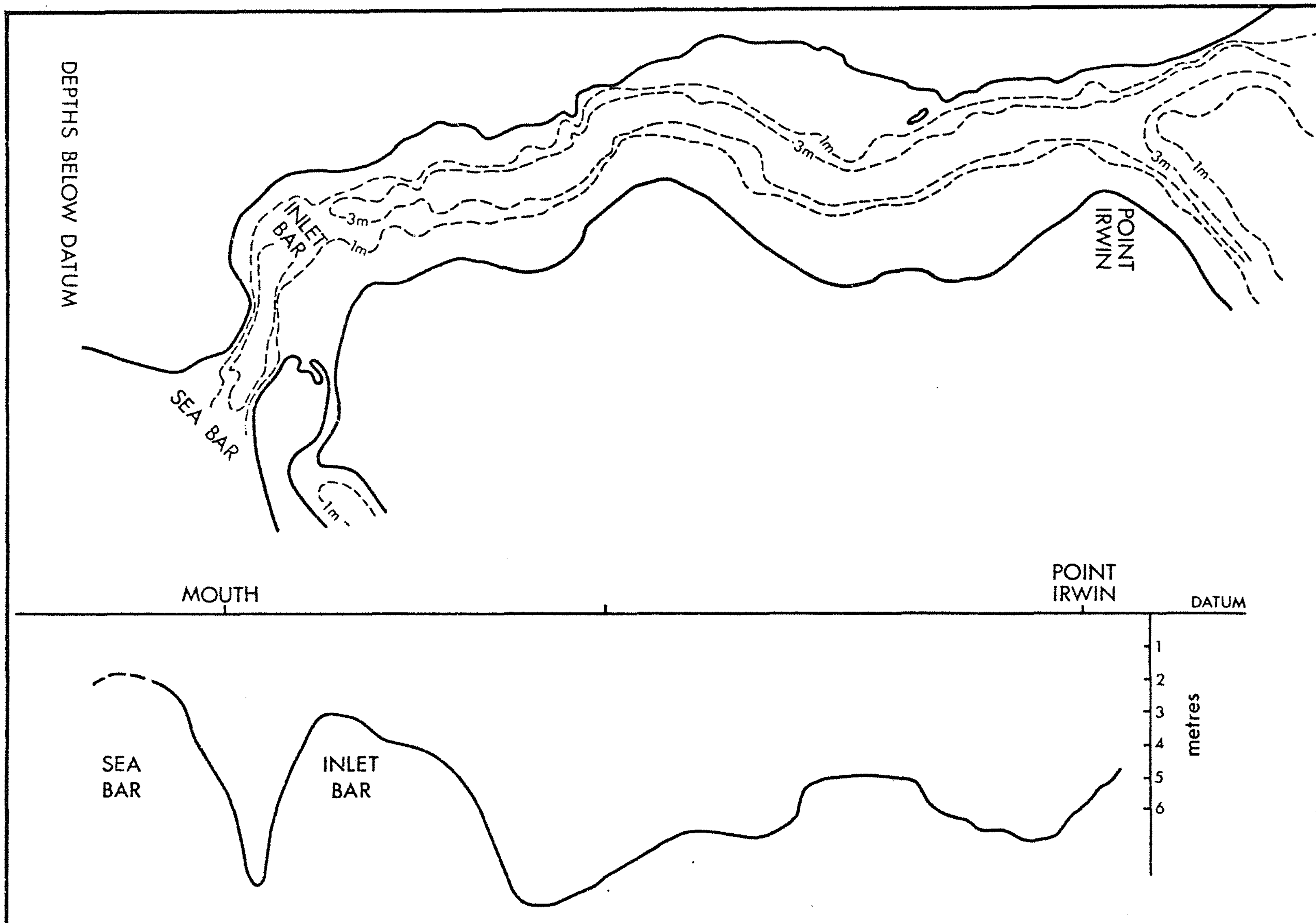

FIG. 5 Plan and profile of the inlet channel

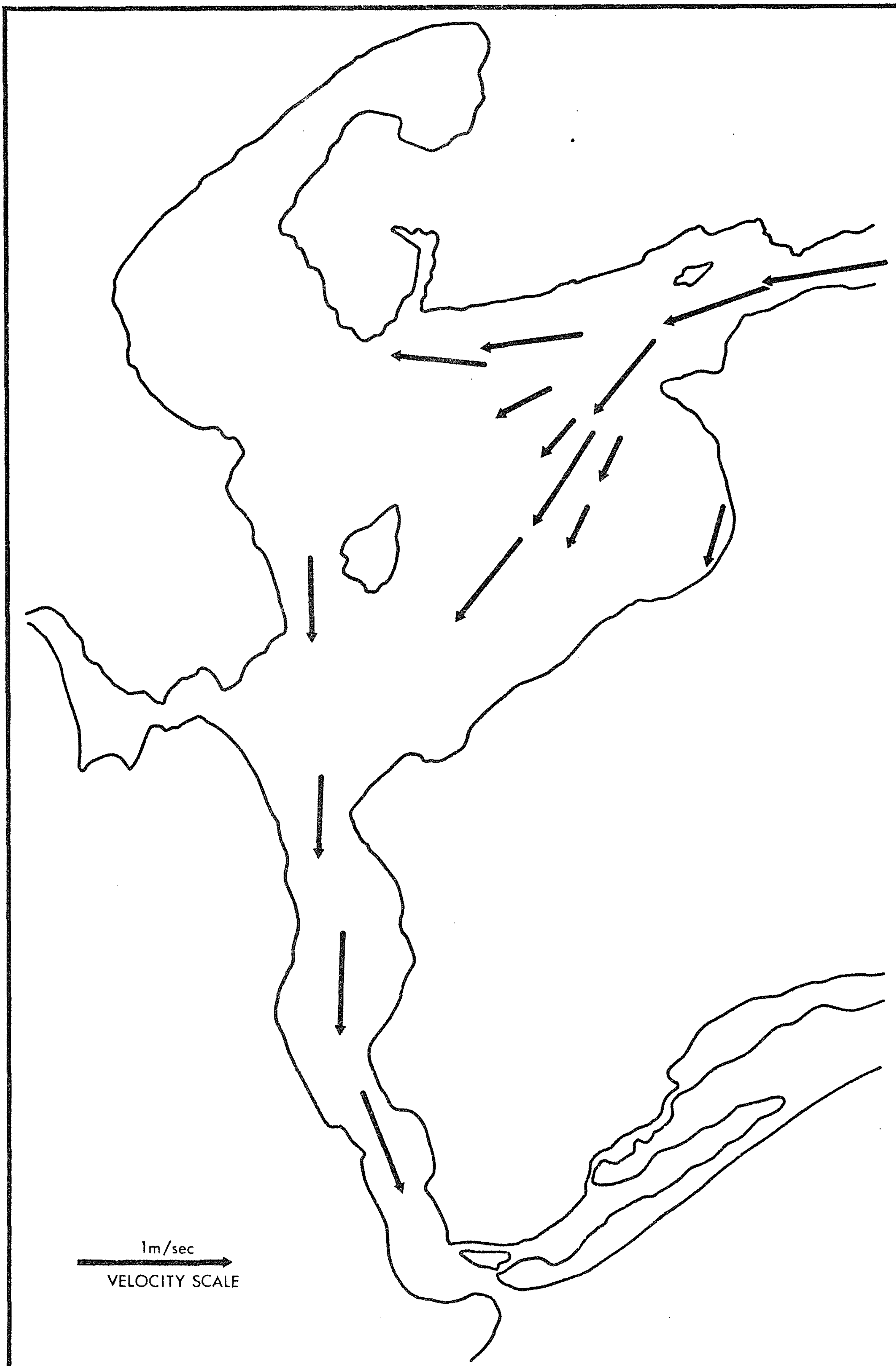

FIG. 6 Flow velocities in the lower estuary under high discharge conditions on 13 August 1974.

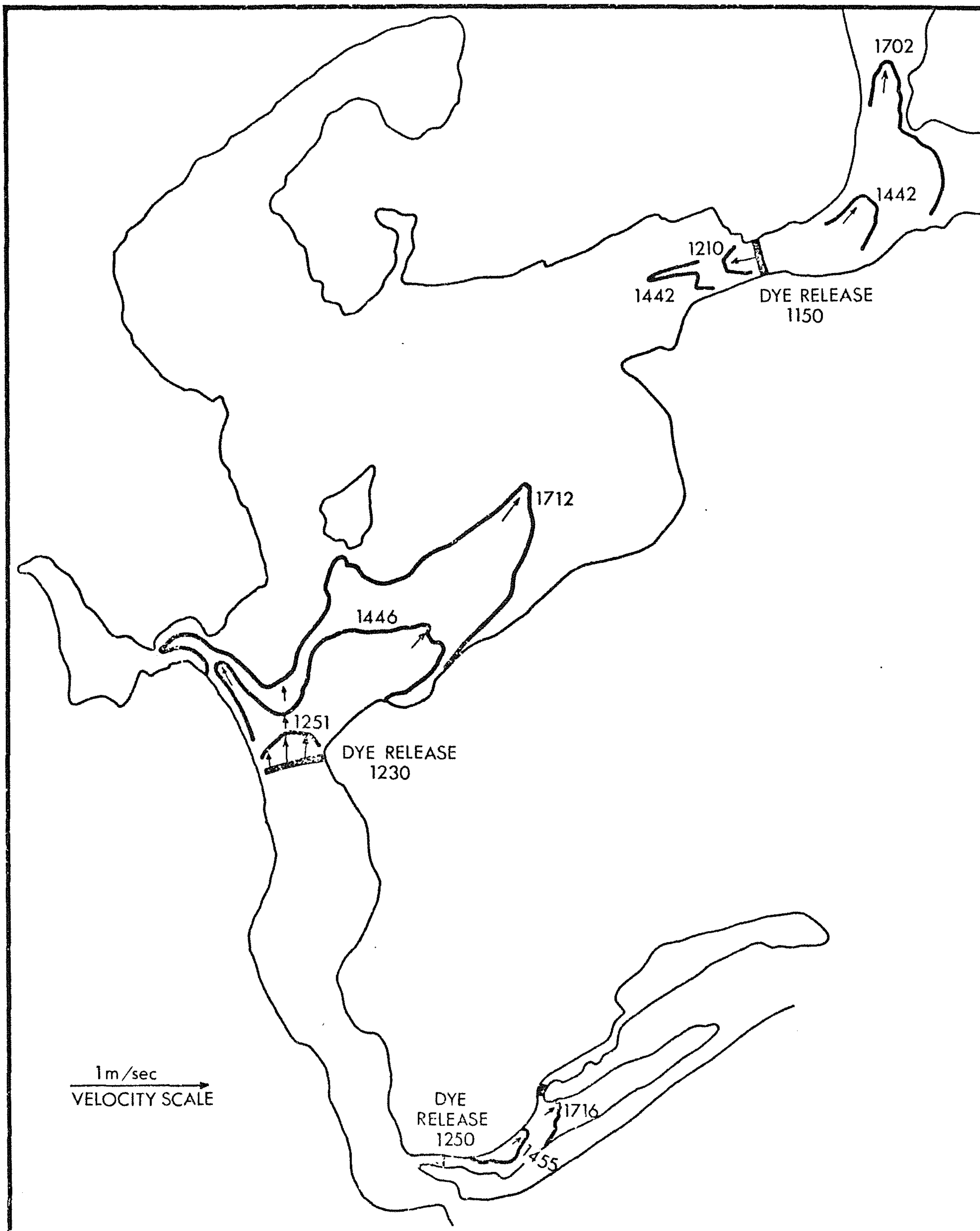

FIG. 7 Flow velocities and dye transport under tidal circulation conditions on 23 February 1975. Figures show times of observations of dye streaks.

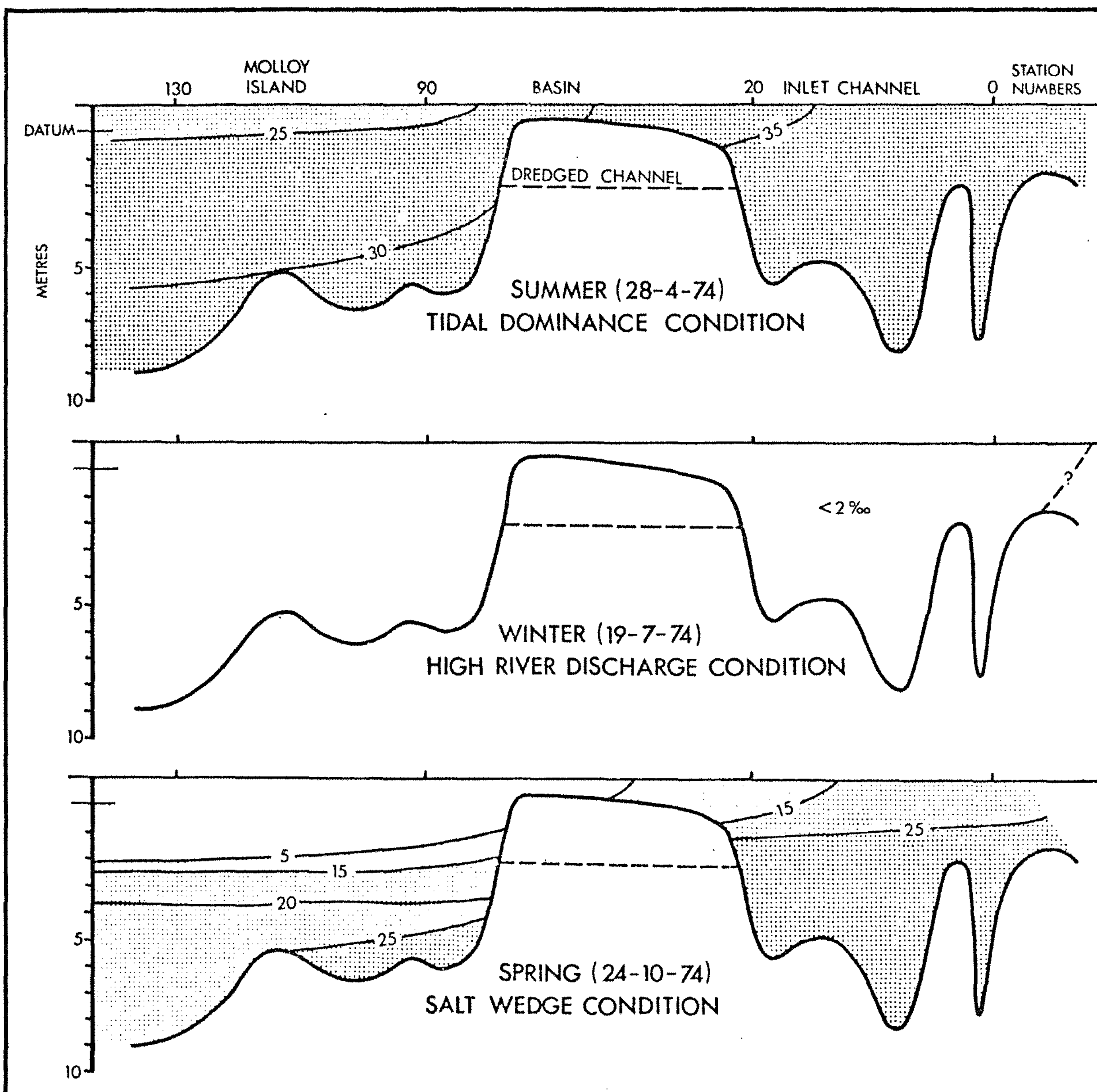

FIG. 8 Hydrology of the Blackwood River Estuary. Salinity in parts per thousand ($^{o}/oo$)

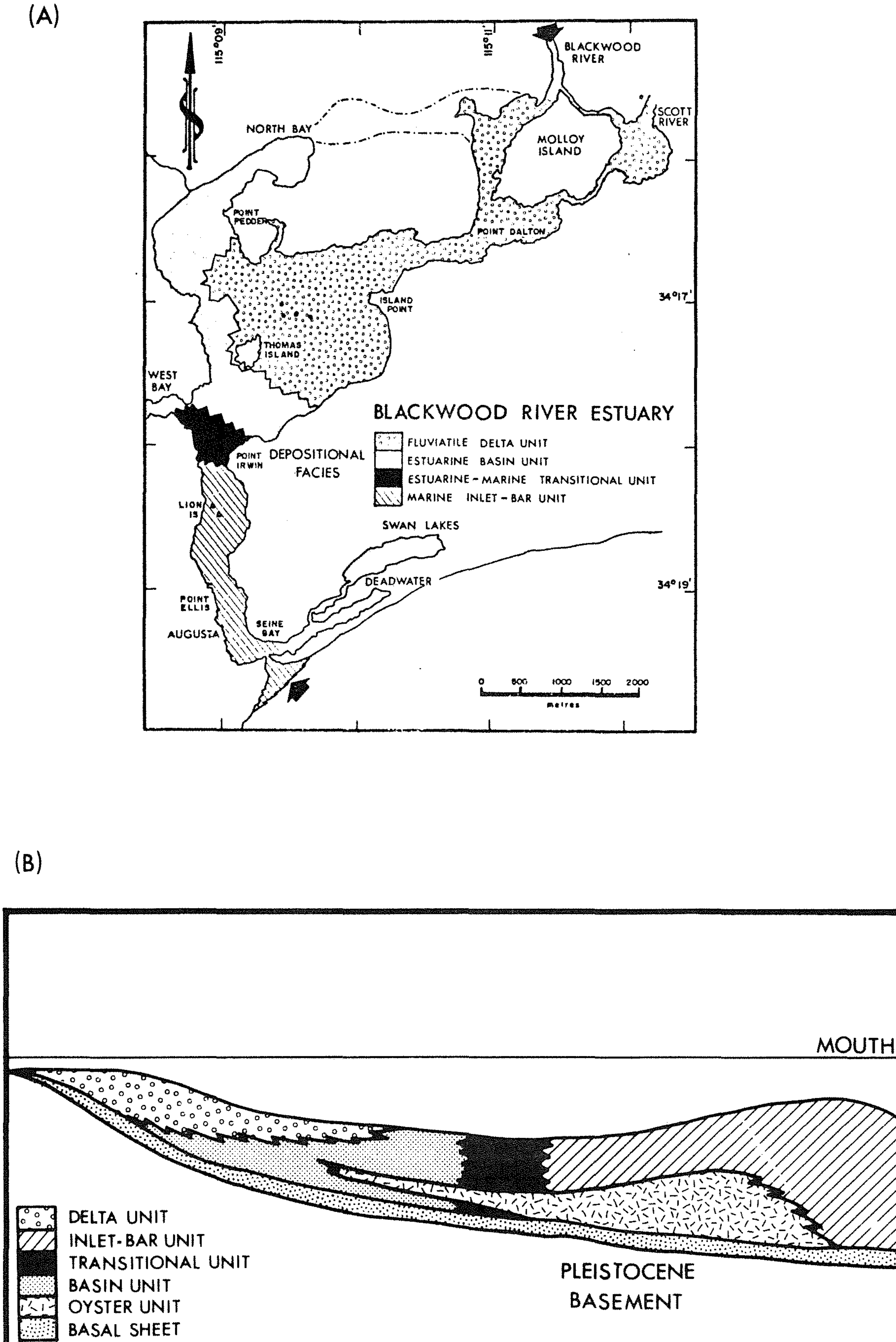

FIG. 9 Sediments of the Blackwood River estuary.
(A) Composition of the sediments
(B) Idealised stratigraphic section

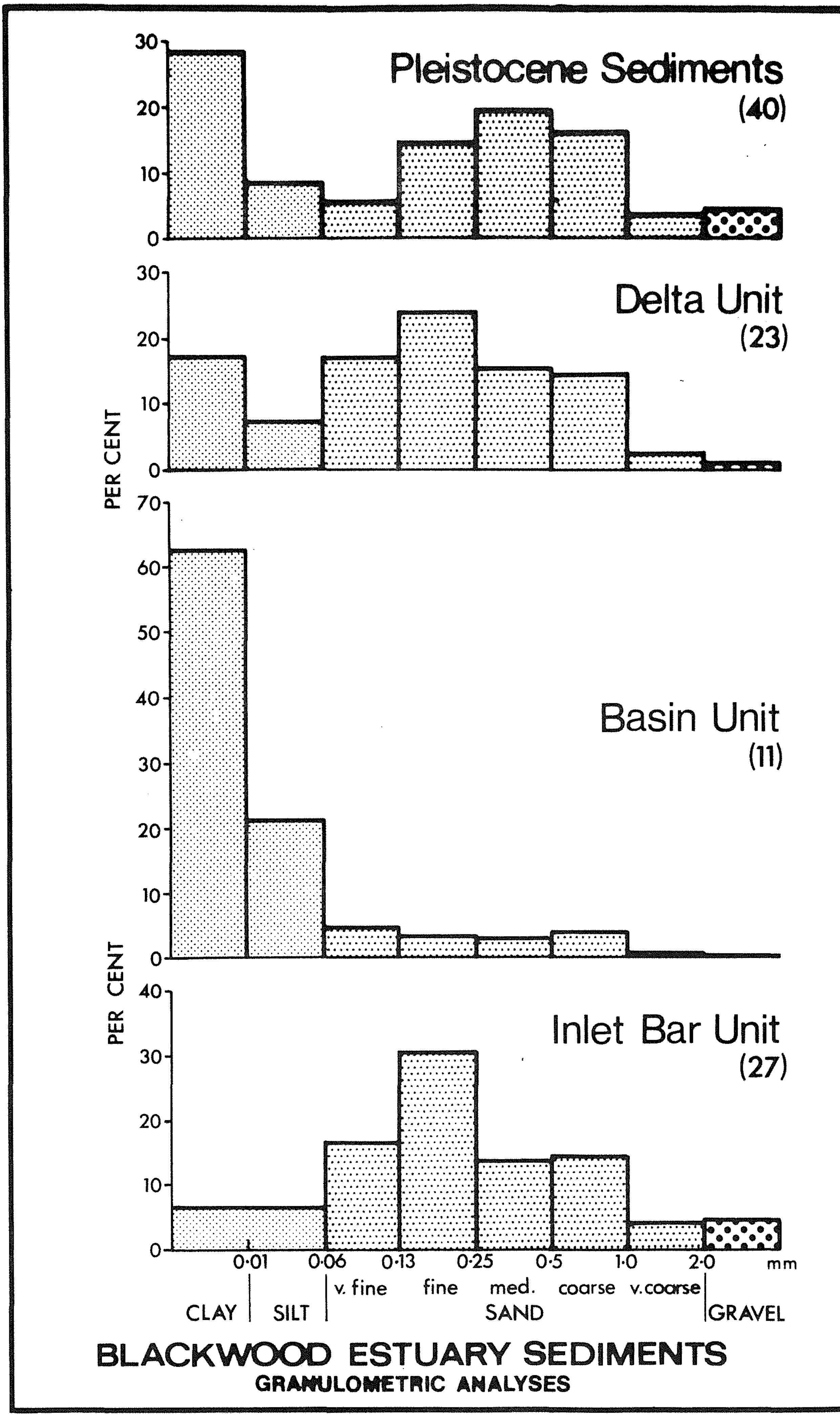

FIG. 10 Granulometric analyses of Blackwood River estuary sediments

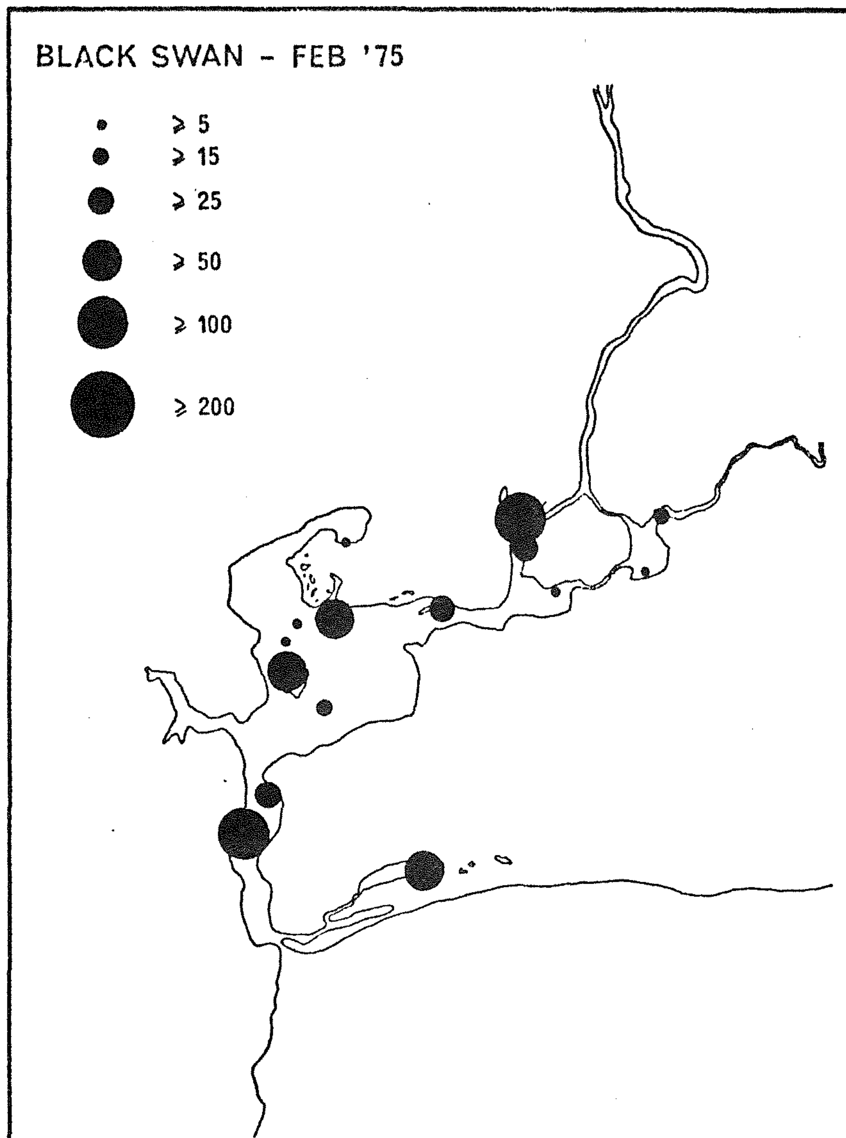

FIG. 11 Numbers and distributions of Black Swans on 25 February 1975

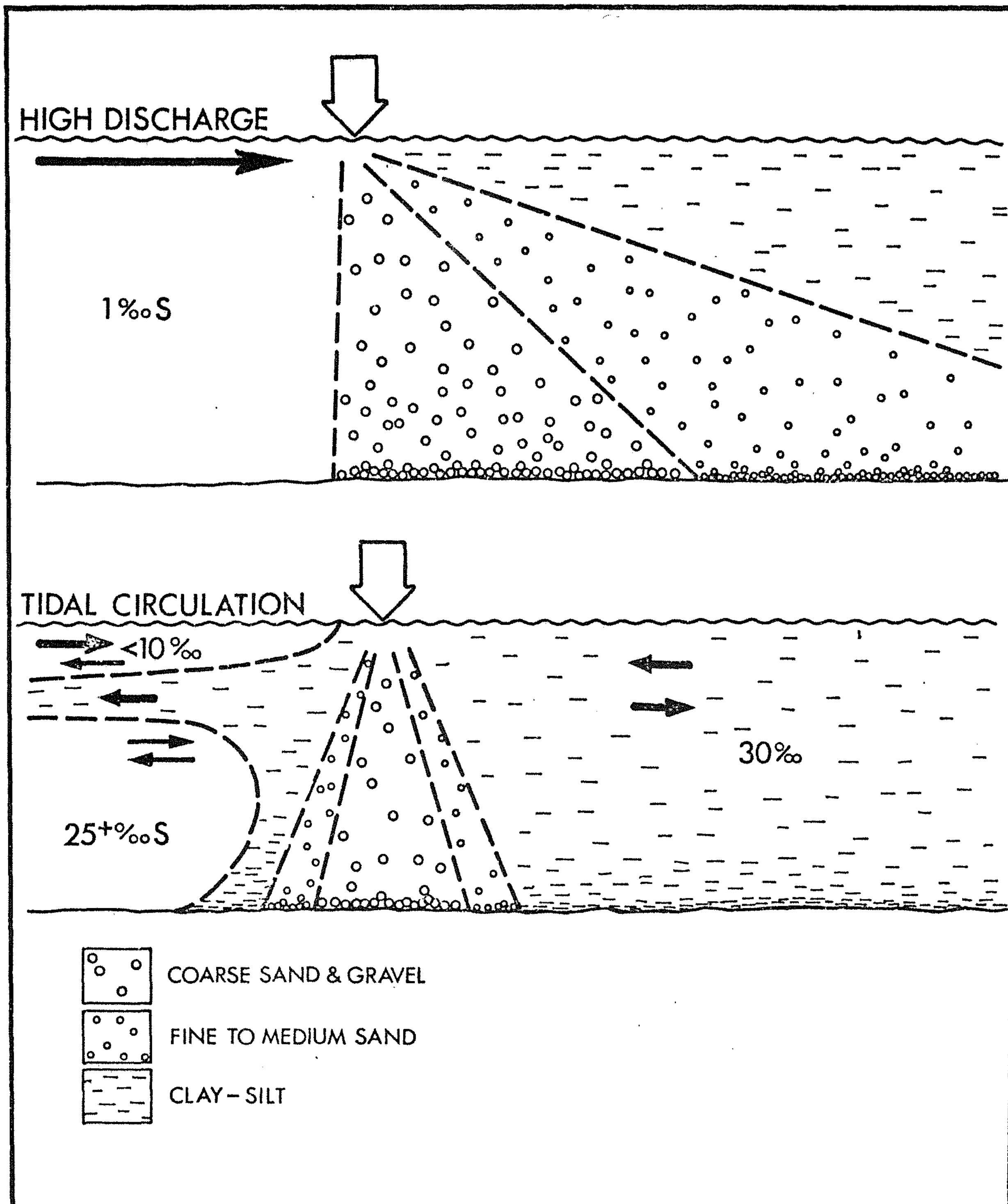

FIG. 12 Sorting and transport of dredging material under high river discharge and tidal circulation conditions.

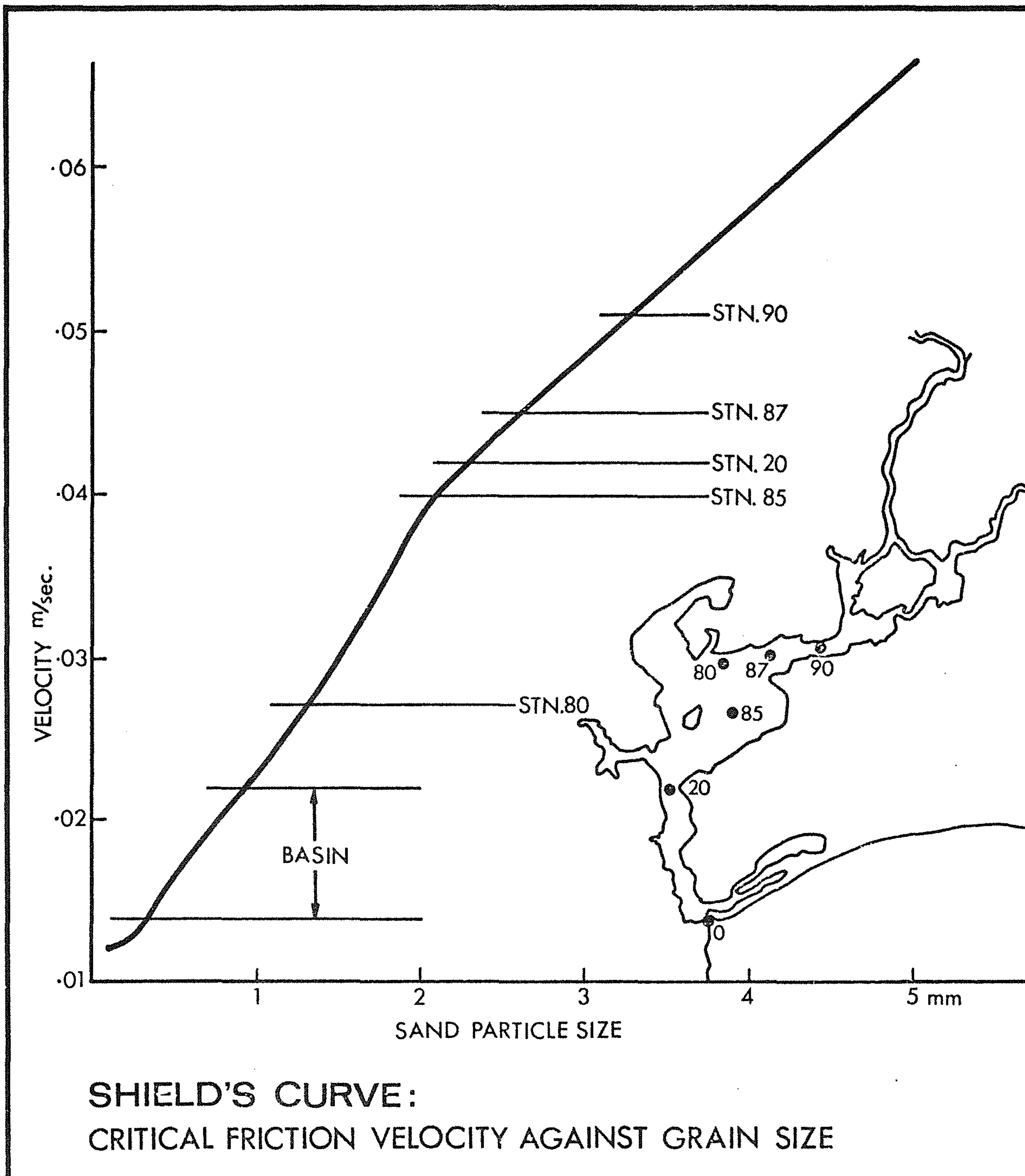

FIG. 13 Shield's curve: critical friction velocity against grain size.

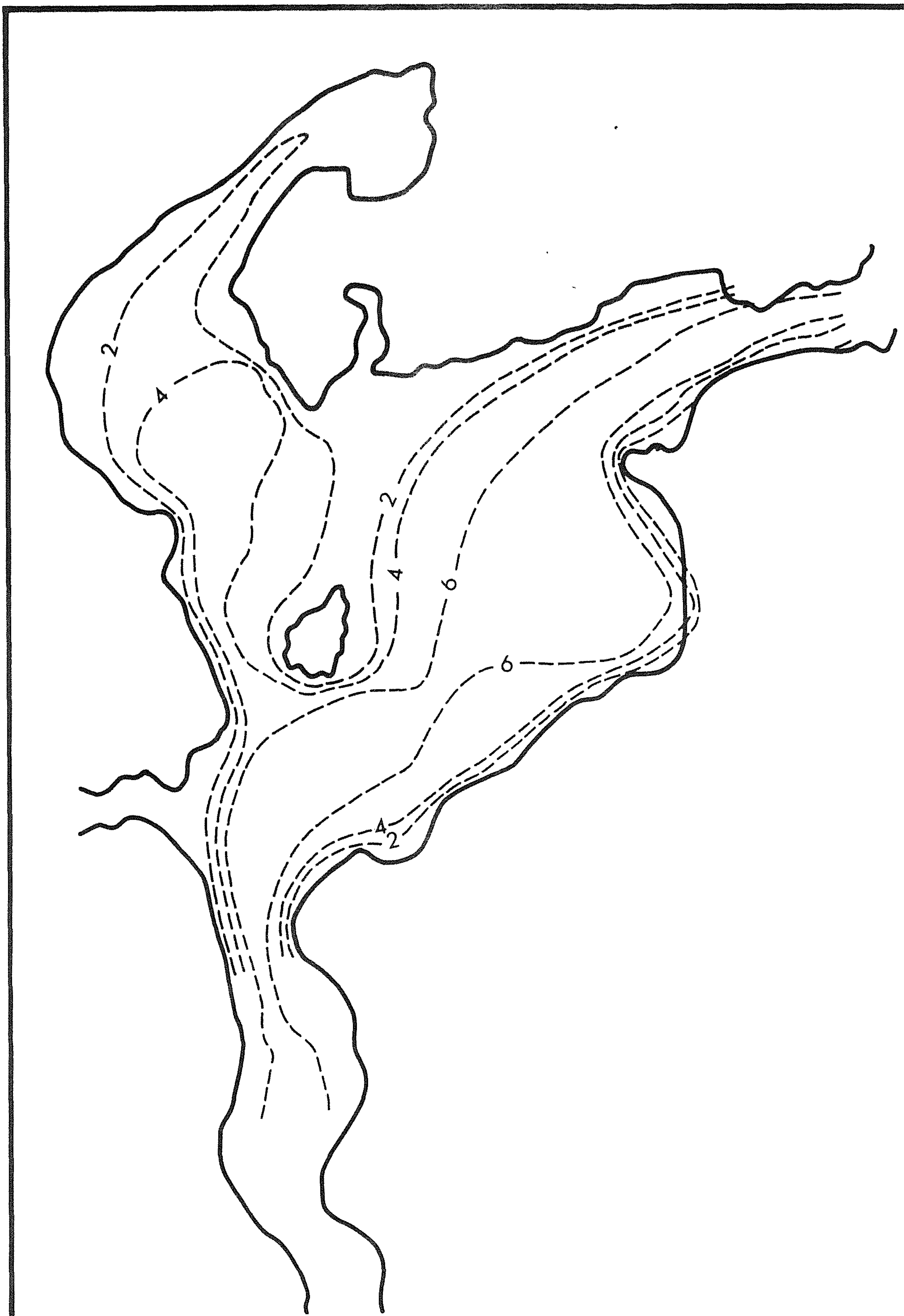

FIG. 14 Contours of the ancestral (Pleistocene) basin.
Depths in metres below the present datum.

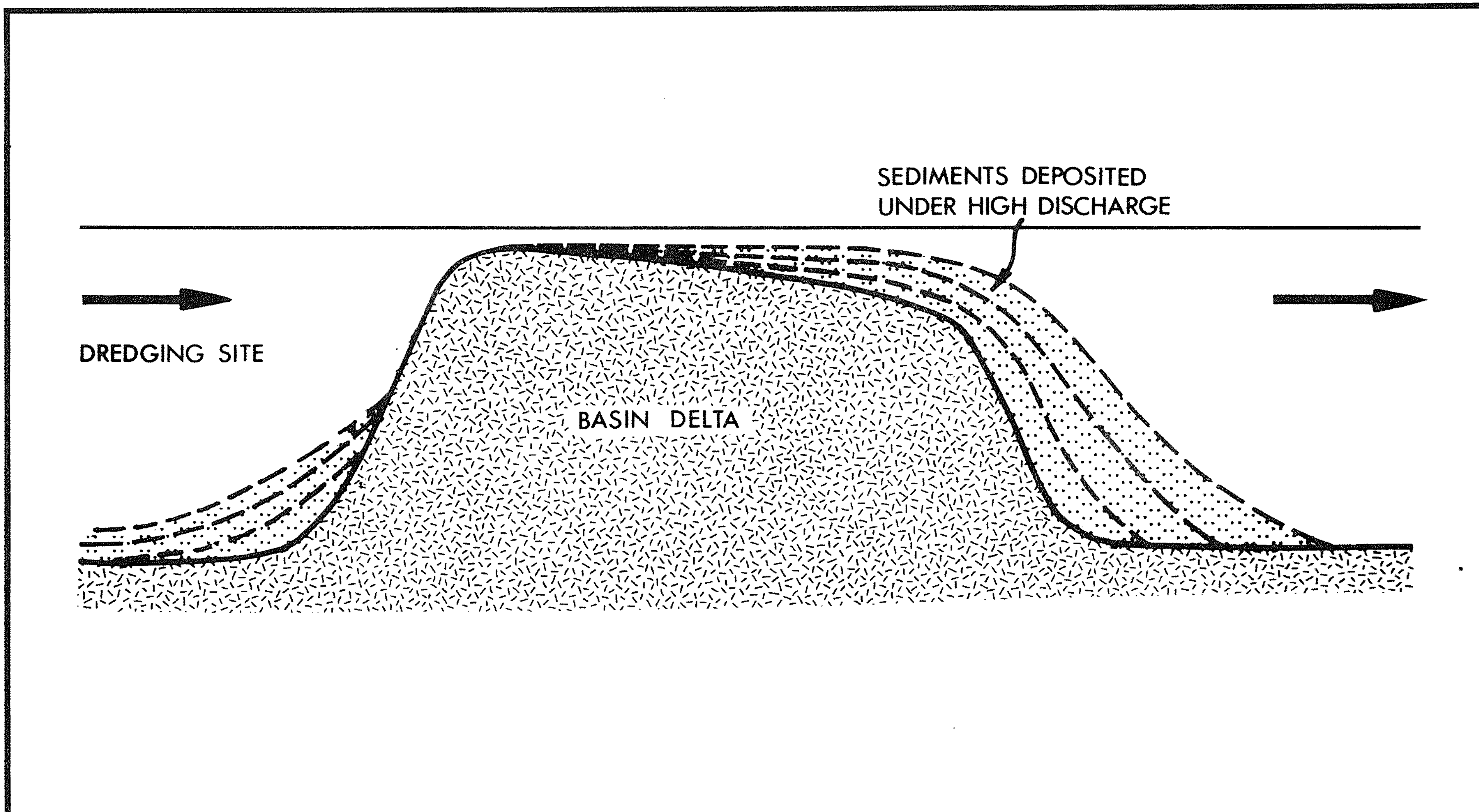

FIG. 15 Anticipated pattern of sedimentation following remobilisation of sediments by dredging in DCs 374, 375, 376. Not to scale.

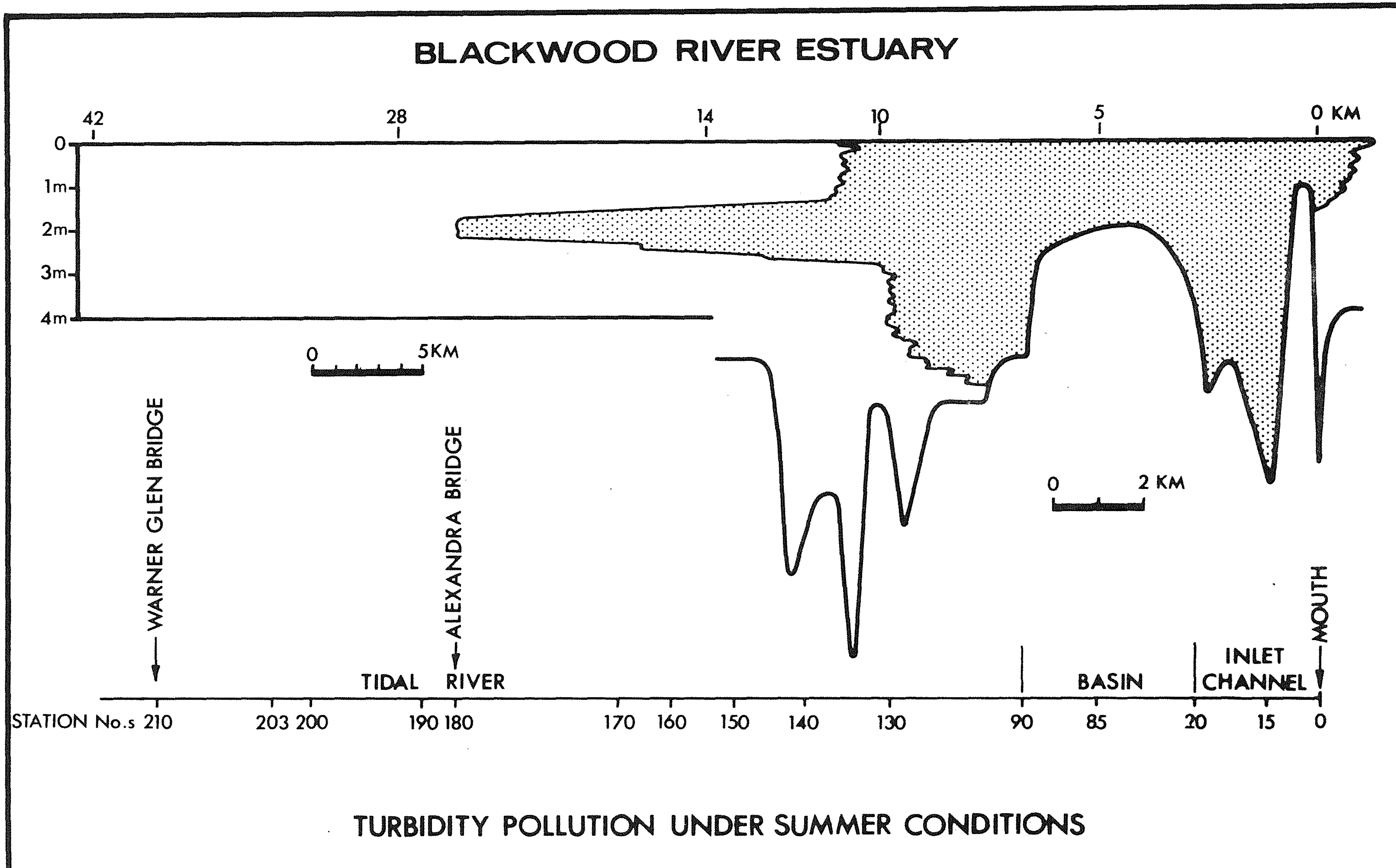

FIG. 16 Turbidity pollution under summer conditions

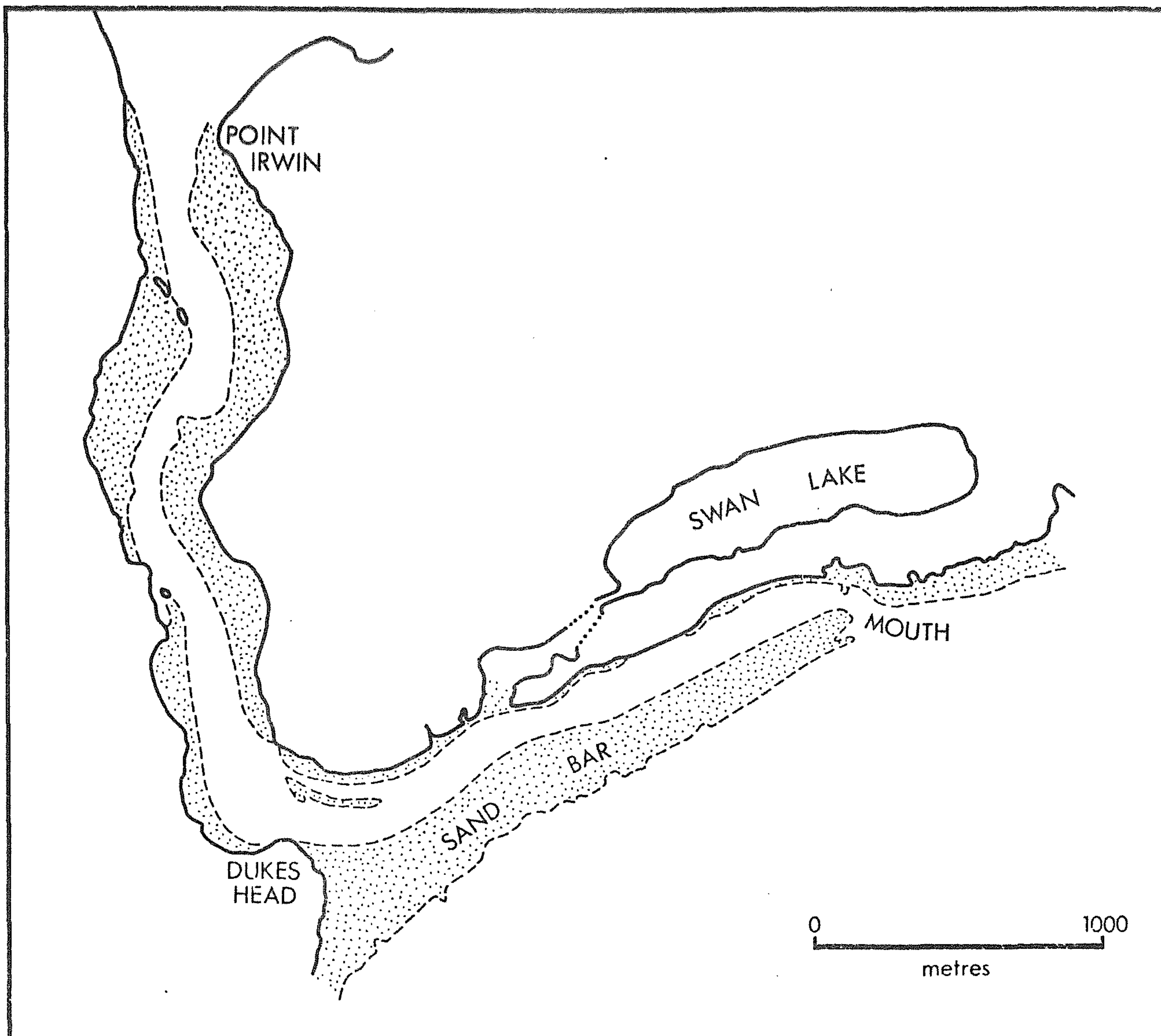

FIG. 17 The inlet channel, sand bar, and mouth in 1943. Tracing from air photo of 20 November 1943.