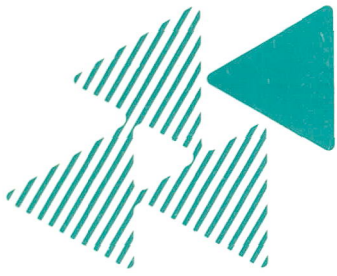


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**THE POTENTIAL FOR FRESH WATER EXTRACTION
FROM THE OLIFANTS ESTUARY**

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THE POTENTIAL FOR FRESH WATER EXTRACTION
FROM THE OLIFANTS ESTUARY

by

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ABSTRACT

The potential for the extraction of between 2 and 4 x 10⁶ m³ of water annually from the Olifants Estuary is assessed, based on available historical data and field expeditions undertaken during summer 1990. The role of seasonal variation in the hydrodynamic functioning of the system and the effects of low summer river flow, evaporation and dispersion on the upstream salinities are considered. Possible extraction rates, dependent on flow and salinity criteria, are suggested. Recommendations for future monitoring and research are made.

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1. INTRODUCTION

It was proposed that between 2 and 4 x 10⁶ m³ of water be extracted annually from the Olifants system downstream of the Lutzville bridge. However, the alteration of an estuarine inflow regime by means of water extraction or upstream impoundment can affect detrimentally the hydrodynamic functioning, the ecology and the water quality of a system.

About thirty years ago, the fresh water requirements of estuaries went unregarded. Subsequently, the release of water to balance evaporation losses and to meet flooding requirements was deemed adequate (Jezewski & Roberts 1986). Current awareness indicates that the fresh water requirements of an estuary include these and ecological needs, mouth flushing and water quality requirements (Whitfield & Bruton 1989). Studies are aimed at quantifying the effects of water removal and indicating effective management techniques. For instance, following dam construction on the Mgeni river, test releases have been conducted to establish the function of flooding in flushing open the mouth of the estuary and maintaining a reasonable water quality (CSIR 1990b). A study of the effects of impoundment on the Palmiet estuary has revealed that the mouth will probably close more often and for longer periods (CSIR 1980a) and this may have deleterious implications for the ecology of the system (Slinger & Largier 1990). Furthermore, a comprehensive investigation of the influence of the Wolwedans Dam on the Great Brak Estuary was conducted and a management plan proposed, the effectivity of which is presently being monitored (CSIR 1990a). An investigation of the possible consequences of removing a volume of between 2 and 4 x 10⁶ m³ from the Olifants system, therefore, was necessary.

A comprehensive investigation requires that data on the temperature and salinity structure (thermohaline structure) of the estuary under different inflow and tidal conditions are available. Furthermore, reliable and extensive inflow data are essential. In the absence of such information on the Olifants Estuary, a preliminary study was undertaken. The aims of the study were:

- (i) to observe the thermohaline structure and its evolution from early to late summer 1990,
- (ii) to establish an understanding of the hydrodynamic functioning of the system,

- (iii) to assess the minimum river flow condition under which water extraction can occur, and
- (iv) to identify necessary future research.

In this report, Section 2 consists of a scene-setting description of the Olifants system. Subsequently, the research methods and field work undertaken are described (Section 3), while the results of this investigation follow (Section 4). A discussion of the results, the implications of freshwater extraction and recommendations regarding extraction rates and management actions are contained in Section 5. Section 6 deals with monitoring requirements and necessary future research.

Terms which will be used frequently in the report include tidal variation and tidal/saline intrusion. These are not interchangeable. Tidal variation is the oscillation in water level which is experienced at a position in the estuary as a result of the sea tide. Thus tidal variation occurs along the full length of an estuary. Tidal/saline intrusion, however, is limited to the lower and (possibly) the middle reaches of an estuary and is associated with the influx and possible subduction of saline sea water in the estuarine system.

2. STUDY AREA

The Olifants River drains a catchment area of 46 625 km² (Heydorn & Tinley 1980), the second largest in South Africa. There are two major dams on the river, the Clanwilliam Dam with a capacity of $1,27 \times 10^8$ m³ and the Bulshoek Dam, which lies 23 km further downstream and has a capacity of $7,5 \times 10^6$ m³ (Morant 1984). The confluence of the Doring and the Olifants rivers lies 20 km below the Bulshoek Dam. This important tributary is a semi-permanent river which generally flows strongly in winter, but is reduced to a series of pools in summer. It is responsible for most of the silt load of the system as it drains from Dwyka and Ecca Group rocks, while the upper Olifants catchment consists of hard Table Mountain Group sandstones. The mean annual runoff of the Olifants River is $1,0154 \times 10^9$ m³ (Jezewski & Roberts 1986). There is a marked seasonality in flow with the highest flow rates occurring during June to September and extremely low flows occurring from December to March. This 1 080 km river system feeds the Olifants Estuary, which is located on the western seaboard of South Africa some 250 km north north west of Cape Town. The evaporative requirements of the estuary are $9,169 \times 10^6$ m³ yr⁻¹ (Jezewski & Roberts 1986).

The head of tidal influence of the estuary is marked by a causeway at Lutzville, 32 km upstream of the mouth (Figure 1). The mouth, which has a rocky bank on the north and a sand spit on the south side, is permanently open. A small flood tide delta lies within the mouth, but the main channel of between 1,5 and 4,5 m depth runs along the north side of Die Eiland. The confluence of the blind inlet and the main channel is about 2 km from the mouth. Thereafter, the channel (1,5 m to 3 m deep) extends upstream for about 5 km. An extensive sand bank exists at this point, although a narrow channel hugs the outer bend. Upstream of this bend the estuary ranges in depth from 2 to 4,5 m. The tidal variation in the estuary is large. A vertical variation of 0,8 m was observed immediately downstream of the Lutzville Bridge on 27 January 1990. The thermohaline structure of the estuary under various river and tidal conditions has not been established, although anecdotal information indicates that the upstream limit of saline intrusion lies at Ebenhaeser (Morant 1984), 16,75 km from the mouth.

3. INSTRUMENTS AND METHODS

Historical data on the hydrodynamics of the Olifants Estuary were examined. To complement the sketchy understanding of the system obtained in this way, two field exercises were undertaken. The first was designed to cover a period of seven days over a spring - (27 to 30 January) and neap (2 to 4 February) tide during summer 1990, while the second occurred over a neap tide (8, 9 April) in late summer 1990 (before the onset of the winter rains). In addition weekly measurements of the water level at the Lutzville Bridge were taken, commencing on 9 April 1990.

Data were collected at 16 hydrographic stations along the axis of the Olifants Estuary (Figure 1). During the first field expedition measurements were taken on flood - and ebb stages of the spring - and neap tidal cycles, but only on the flood stage of the neap tide during the second field investigation. Temperature and salinity were measured at 0,25 m vertical intervals using a Valeport Series 600 Mk II temperature, salinity and depth meter (accuracy 0,2°C, 0,2 ppt, 0,1 m). Current velocities were measured at 0,5 m vertical intervals using an NBA DNC-1 MK II current meter (accuracy 0,02 m.s⁻¹). The variation in water level along the estuary was established using gauge poles (accuracy 0,05 m). The inflow rates to the estuary during the first and second field excursions and at weekly intervals thereafter were estimated (using the Bernoulli equation) from water level measurements obtained at the Lutzville Bridge.

By comparing the effects on the thermohaline structure of different tidal conditions (neap/spring), an understanding of the dynamics of the system was obtained. An indication of the effect of the low summer river flow was derived by evaluating the change in thermohaline conditions from late January/ early February to 8, 9 April 1990. The potential for fresh water extraction was assessed.

4. RESULTS

4.1 Historical Information

In January 1955 staff of the Zoology Department of the University of Cape Town collected limited data on thermohaline conditions in the Olifants Estuary (Brown 1969). Salinities and temperatures, respectively, varied longitudinally at high water from 34,9 ppt¹, 14,5°C at the mouth to 5,2 ppt, 26°C at Soutpansklipheuwel. The system was stratified with a maximum vertical salinity gradient of 1,96 ppt.m⁻¹ measured about 3 km upstream of the island, that is midway between the present Stations 4 and 5 (Figure 1). The summer 1976 survey by the Marine Pollution Monitoring Group of the CSIR (CSIR 1980b) indicated that, on the flood tide, surface salinities and temperatures varied longitudinally from 34,71 ppt, 10,0°C at the mouth to 1,87 ppt, 21,5°C at Olifantsdrif. In the region of the present Station 6 20 ppt water occurred on the flood, but was present below Station 3 on the ebb, an excursion distance of about 4 km. The winter 1977 survey by CSIR (CSIR 1980c) was conducted during a river flood. Consequently, the estuary was fresh throughout (salinity less than 2,85 ppt). While such a situation periodically occurs during winter, it is not representative of the general winter condition of the Olifants Estuary. The winter 1983 survey of the CSIR (Morant 1984) indicated that tidal intrusion was limited, although the system was strongly stratified with water of 30 ppt at the bottom and fresh water (less than 2 ppt) at the surface at the present Station 3. The marked seasonality in the thermohaline structure is indicated by these data. The winter situation is characterized by high river flow, while under summer conditions of low river flow higher salinities are experienced upstream in the estuary.

4.2 Summer 1990 Field Exercise

The inflow to the Olifants Estuary was 1,2 m³.s⁻¹ (+/-0,2 m³.s⁻¹) throughout the field exercise. The riverine salinity was 1,55 ppt², while the

¹Salinity is measured in units of parts per thousand (ppt), which is equivalent to g.l⁻¹. Sea salinities off the west coast of South Africa generally are in the range 34,5 to 35,5 ppt (Shannon 1985).

²The concentrations of calcium, sodium, potassium and magnesium in the water of the Clanwilliam Dam, at the Lutzville Bridge and at Olifantsdrif were determined. Results indicated that the salinity at the head of the estuary (1,55 ppt) was terrestrially derived.

temperature of the water was 24,86°C. The ocean salinity and temperature were 34,5 ppt and 13,7°C, respectively.

Circulation features associated with the spring - and the neap tidal cycles are subsequently described and are summarized in Table 1. On the flood tide of 28 January (spring tide) the water column was well mixed (Figure 2a & b). Salinities varied longitudinally from 34,00 ppt at the mouth to 2,95 ppt at Station 15, while the corresponding temperatures increased from 16,53°C to 24,15°C. The effect of the extensive sand bar in the sharp bend between Stations 6 and 7 was noticeable, because the maximum vertical salinity gradient (1,23 ppt.m⁻¹) and the maximum longitudinal salinity gradient (6,17 x 10⁻³ ppt.m⁻¹) were measured in the region of Station 6. The longitudinal profiles of the ebb tide of the same day (Figure 3a & b) confirmed the vertically homogeneity of the water mass and indicated that water of approximately 20 ppt salinity was located below Station 9 on the flood and below Station 3 on the ebb. This indicated that the water mass oscillated strongly with the tide and that the excursion of 20 ppt water was approximately 6,5 km. The maximum depth-averaged velocities measured were 0,65 m.s⁻¹ on the flood (Station 2) and 0,44 m.s⁻¹ on the ebb (Station 7).

On the flood tide of 4 February (neap tide) the salinities varied from 34,10 ppt at the mouth to 2,26 ppt at Station 16 and corresponding temperatures ranged from 13,69°C to 26,46°C (Figure 4a & b). The water column of the middle reaches of the estuary (Stations 4 to 10) was stratified in both temperature and salinity, while the upper and lower reaches of the estuary were vertically well mixed. The maximum vertical salinity gradient of 3,82 ppt.m⁻¹ and the maximum longitudinal salinity gradient of 8,12 x 10³ ppt.m⁻¹ occurred in the region of Station 4. The longitudinal profile measured on the previous day (3 February) indicated that the estuary was stratified in both temperature and salinity in the lower and middle reaches (Stations 1 to 10) during the ebb tide (Figure 5a & b). The greatest vertical variation occurred in the vicinity of Station 4. The surface manifestation of 20 ppt water occurred between Stations 2 and 3 on the ebb and near Station 5 on the flood. The basal 20 ppt water was located near Station 5 on the ebb and in the region of Station 9 on the flood. Thus the excursion of surface 20 ppt water was approximately 3 km, while that of the bottom water was 3,5 km on the neap tide. The difference in excursion distance between the bottom and surface water indicates that the tidal oscillation of the water varies with depth on the neap tide, unlike that of the spring tide. The maximum depth-averaged current velocities measured were

0,34 m.s⁻¹ at Station 2 on the flood tide and 0,33 m.s⁻¹ at Station 1 on the ebb tide. Thus the reduced tidal prism of the neap compared with the spring tide results in lower current velocities and more stratification.

The temperature, salinity plots of the spring flood of 28 January and the neap flood of 4 February (Figure 6a & b) indicate that the Olifants Estuary is characterized by three distinct water masses (in summer). Water influenced strongly by the river was located at the head of the estuary and had salinities below 5 ppt and temperatures higher than 22,5°C. The lower reaches of the system were subject to the influence of the sea. Consequently the salinities were high (greater than 30 ppt) and the temperatures were low (less than 18°C). The water in the middle reaches obtained its character from the mixing over time and distance of the waters of the upper and lower reaches. Thus the salinity of this water varied between 30 ppt and 5 ppt, while the temperatures were 18°C and greater.

4.3 Late Summer 1990 Field Exercise

The inflow to the estuary was estimated at 1,1 m³.s⁻¹ (+/-0,2 m³.s⁻¹), which was less than, but very similar to, the inflow during the field expedition of 27 January to 4 February 1990, estimated at 1,2 m³.s⁻¹.

The temperature of the water varied longitudinally from 16,14 °C at the mouth to 22,49 °C at Station 16. The corresponding salinities were 34,29 ppt and 4,59 ppt, respectively. The salinities at Olifantsdrif exceeded 5 ppt. Thus, in comparison with the late January / early February situation, the upstream salinities were higher, while the temperatures were lower. In general, the water column was less stratified (maximum vertical salinity gradient of 2,10 ppt.m⁻¹ in the vicinity of Station 5) than on the neap flood tide of 4 February 1990 and more stratified than on the spring flood tide of 28 January 1990 (Figures 7a & b). The temperature, salinity diagram of 8 April 1990 indicates that water influenced strongly by the river is located above Station 16 (salinity below 5 ppt, temperature greater than 22,5 °C), while water distinctly estuarine in character extends from Station 6 to Station 16 (salinity between 30 ppt and 5 ppt, temperature 18 °C and greater) (Figure 8).

During the time period from 4 February to 8 April 1990, water of distinctly estuarine character extended upstream from Station 14 to Station 16. Salinities increased at Olifantsdrif (greater than 5 ppt) and the stratification of the water column on the neap flood diminished. Although

the inflowing volume remained fairly constant (and low) throughout this period, the influence of the river flow decreased. It was insufficient to balance the evaporative losses, vegetation and flushing requirements of the system and the effects of longitudinal dispersion. Consequently, upstream salinities gradually increased over the summer season.

5. DISCUSSION

5.1 The Implications of Water Extraction

5.1.1 The salinity regime

The predominant influences on the upstream extent of saline intrusion in an estuary are tidal conditions, stream flux (river inflow) and the length of time any particular set of these conditions has persisted. For instance, if the stream flux were zero for an extended period of time, the salinity of the upstream waters would increase. In the extreme case, sea salinities or even hypersaline conditions (due to evaporation) could extend to the head of tidal influence of the estuary. In the event of a flood (extremely high stream flow) the estuary could flush completely and become a totally fresh water system for some time. The possible range of vertically averaged salinities which could occur is depicted in the family of curves of Figure 9. Estuarine biota are adapted to cope with such a range of salinity and flow conditions.

Knowledge of pre-existent inflow and tidal conditions together with an understanding of the seasonal variation of the thermohaline structure of a system enables a prediction of the salinity regime at a particular time. Without this information, recommendations about when, where and what quantity of water can be extracted, are estimates.

As no records of inflow to the Olifants Estuary exist, it is not known whether the 1989 / 1990 inflow was above or below average. Therefore, although the observed thermohaline conditions were similar to those recorded for the summers of 1955 and 1976, the reliability of the late summer 1990 state as an indication of the usual late summer condition of the estuary is not established (Section 5.3). However, both the extent of saline intrusion and the changes in stratification associated with the spring/neap tidal cycle in summer 1990 are known. These indicate that a reduction in tidal influence (under conditions of constant river flow) tends to cause increased stratification. However, the effect of increased river flow to an estuary is to reduce the tidal influence, that is to increase stratification. A decrease in fresh water inflow increases the tidal influence and reduces stratification. This can result in higher vertically averaged salinities in the upper reaches. The second field investigation established that, during the summer of 1990, the long term effects of low summer river flow, ongoing evaporation and upstream saline dispersion were noticeably, but not severely

increased upstream salinities. Thus the major possible consequence of summer water extraction from the Olifants Estuary is the elevation of upstream salinities.

The winter extraction of water is less likely to affect the stratification materially as the volume of fresh water entering the system is much larger. However, the flushing from the estuary of (1) water resident during the summer months, and (2) marine sediment, which may be deposited during the low flow summer period, may be affected. Thus the major influence of winter water extraction probably will be its effect on the role of seasonal variability in the functioning of the system.

5.1.2 The biotic regime

The biota of the Olifants system has developed in response to the strongly seasonal flow and salinity regime. In winter the fresh river water extends downstream virtually to the sea, while in summer stream flux is least and sea water may penetrate as far as Ebenhaeser. Any extraction policy must take cognisance of this regime. The *Phragmites australis* reed fringe extends downstream as far as Station 7 (Figure 1), where salinities of the order of 20 ppt were measured during the summer 1990 field excursion. Summer water extraction could raise upstream salinities. The growth of *Phragmites* in the vicinity of Stations 7 to 9 could be affected if the reeds were required to withstand high salinities for protracted periods such as occurred in Lake St Lucia in the late 1960's (Ward 1982).

5.2 Extraction Criteria

The greater the volume of fresher water extracted, the further upstream the influence of the saline intrusion will be felt. In order that the effects of water extraction be minimized (and the accompanying influences on the ecology limited), criteria of flow and salinity are proposed. It must be remembered that the selection of these criteria was influenced by (1) the observed inflow to the estuary during summer 1990 (1,2 to 1,1 $\text{m}^3 \cdot \text{s}^{-1}$), (2) the fact that salinities of 5 ppt or greater extended further upstream than Olifantsdrif by the end of summer 1990, and (3) the large tidal variation in the estuary, which means that elevated upstream salinities are a real danger.

The recommended criteria for the extraction of the required volume of water (between 2 and 4 $\times 10^6 \text{ m}^3 \cdot \text{yr}^{-1}$) are:

- (1) no water be extracted if the flow at the Lutzville Bridge is $3 \text{ m}^3 \cdot \text{s}^{-1}$ or less
- (2) no more than $0,25 \text{ m}^3 \cdot \text{s}^{-1}$ be extracted if the flow is between 3 and $5 \text{ m}^3 \cdot \text{s}^{-1}$
- (3) ten per cent of the flow be extracted if the flow is $5 \text{ m}^3 \cdot \text{s}^{-1}$ or greater. This will probably occur during the winter months, but is less likely during summer.

An added condition is that the salinity at Olifantsdrif is less than 5 ppt.

These extraction criteria are regarded as "safe".

5.3 Management Considerations

The extraction of water at $0,25 \text{ m}^3 \cdot \text{s}^{-1}$ ($7,884 \times 10^6 \text{ m}^3 \cdot \text{yr}^{-1}$) for 51 % of the year would exceed the maximum demand criterion of $4 \times 10^6 \text{ m}^3 \cdot \text{yr}^{-1}$. As the mean annual run-off of the Olifants River is approximately 7,5 times that of the total capacity of dams on the system, it is likely that the flow at the Lutzville Bridge would exceed $3 \text{ m}^3 \cdot \text{s}^{-1}$ for much of the year. However, the percentage of a year during which the flow rate could be expected to exceed $3 \text{ m}^3 \cdot \text{s}^{-1}$ on average is not established. The probable source of flow during the dry summer months is drainage from the irrigated lands. The Department of Water Affairs has estimated that the flow rate due to drainage varies between $0,425$ and $0,560 \text{ m}^3 \cdot \text{s}^{-1}$. The flow rates calculated from the water level measurements taken at the Lutzville Bridge during the 1990 field expeditions indicate that the flow rate experienced during summer 1990 was somewhat greater than this (between $1,1$ and $1,2 \text{ m}^3 \cdot \text{s}^{-1}$), but below $3 \text{ m}^3 \cdot \text{s}^{-1}$. Under these management recommendations water extraction would not have occurred during this period. No removal of water would have been possible until the inflow to the estuary increased substantially and caused salinities at Olifantsdrif to drop below 5 ppt. This would have occurred at the onset of the winter rains in mid-April. Following the initial increase in flow which accompanied the start of the winter rains, the flow then remained well above $5 \text{ m}^3 \cdot \text{s}^{-1}$, except for the flow of $4,7 \text{ m}^3 \cdot \text{s}^{-1}$ estimated for 21 May 1990. Under the proposed extraction criteria, water extraction could have occurred during this time. These observations re-inforce the understanding that it is the low flow summer months that critically influence water extraction policy.

Although water may be extracted from the system upstream of the Lutzville Bridge, the extraction point, preferably, should be as far downstream in the estuary as possible as this will aid in minimizing the upstream travel of saline conditions. For instance, an extraction site located at Olifantsdrif, Ebenhaeser or Koekenaap would be suitable and would facilitate regular measurement of the salinity at Olifantsdrif. Should one of these extraction sites be selected, it is recommended that the water be pumped from the river bed.

The construction of any structure to impound fresh water and to limit the upstream migration of saline conditions is to be avoided. Such a move would affect the estuary severely, since it is strongly tidal to its head at Lutzville. The tidal variation experienced upstream of the structure and the tidal wave dynamics of the system would be altered. The weir would eliminate the regular flooding and exposure of the upstream estuary shores. This reduction in area of the intertidal zone would limit the feeding areas available to waders and other birds. The upstream migration of fish (predominantly mullet) also would be prevented. The consequences of weir construction to the ecology of the system are detrimental (P D Morant pers. comm.).

The minimum estimate of sea level increase, based on the average increase over the previous century, is 0,2 m over the next fifty years. However, there is extensive evidence that the rate of increase in sea level is increasing and the probability of a rise in sea level of 1,0 m in the next century is considered to be relatively high (Lutjeharms & Swart 1989). The implications for South Africa are considerable (Brundrit *et al* 1989). The impacts of sea level rise on the Olifants system, in particular, probably would involve inundation of low-lying areas and increased saline intrusion. Thus the potential for fresh water extraction would decrease. Monitoring of salinity levels at Olifantsdrif, therefore, is essential. As water extraction is planned only for the next 20 years, no measures additional to the recommended conditions for extraction are suggested.

6. RECOMMENDATIONS

6.1 Monitoring

1. Continuous monitoring of the inflow to the system is required. This can be achieved by the installation of a water level recorder immediately upstream of the Lutzville Bridge. However, a suitable site is difficult to find. A gauge plate at the Lutzville Bridge, read at bi-weekly intervals, presently provides adequate data. The frequency and duration of low/high river flow events then can be established. The allowed water extraction rate can be determined.
2. The salinity at Olifantsdrif must be measured in order to determine whether water extraction can be permitted to occur.
3. The actual extraction rate must be monitored continuously. Such data would be essential should any queries or complaints occur regarding the extraction of water from the estuary.

6.2 Research

1. The seasonal changes in the thermohaline structure of the estuary need to be investigated thoroughly. This would involve longitudinal and vertical measurements of temperature, salinity and current velocity over a spring/neap cycle for autumn, winter and spring. The summer situation was covered by the field investigations described in this report.
2. It is advisable to implement a hydrodynamic and transport-dispersion model on the Olifants Estuary. This would involve the following:
 - (1) a survey of the estuary
 - (2) the collection of data, that is water level recordings and salinity profiles (point 3 above)
 - (3) calibration of the model
 - (4) the simulation of various river inflow conditions and the quantification of the impact of water extraction on the hydrodynamics of the system.
 - (5) possible refinement of the extraction criteria.

3. The present study presupposes that by minimizing the influence of water extraction on the thermohaline regime of the estuary, the effects on the ecosystem will be limited. It is recommended that research be conducted to establish whether or not effects detrimental to the ecosystem are foreseen as a result of the hydrodynamic changes predicted by the model. A survey of the present ecological state of the system would provide base-line data useful for future comparisons.
4. It is recommended that a hydrological study of the lower Olifants river be conducted. This would indicate whether the 1989/1990 inflow was above or below average and place the present investigation in context. At present only hydrological data for the catchment upstream of the Clanwilliam Dam are available.

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TABLE 1: Summary of the hydrodynamical data collected during the summer 1990 field expedition

Tidal Cycle		Spring		Neap	
		Flood	Ebb	Flood	Ebb
Date		1990-01-28		1990-02-03 to 1990-02-04	
Stratification in the estuary	upper	well-mixed		well-mixed	well-mixed
	middle			stratified	stratified
	lower			well-mixed	stratified
Maximum depth-averaged velocities (m.s. ⁻¹)		0,65	0,44	0,34	0,33
position		Stn 2	Stn 7	Stn 2	Stn 1
Maximum vertical salinity gradient (ppt.m ⁻¹)		1,23		3,82	
position		near Stn 6		near Stn 4	
Maximum longitudinal salinity gradient (ppt.m ⁻¹)		6,17 x 10 ⁻³		8,12 x 10 ⁻³	
position		near Stn 6		near Stn 4	
Salinity range (ppt)	Stn 15	2,95		2,26	
	mouth	34,00		34,10	
Temperature range (°C)	Stn 16	24,15		26,46	
	mouth	13,69			
Excursion distance of 20 ppt water (km)	surface	6,5		3,0	
	bottom			3,5	

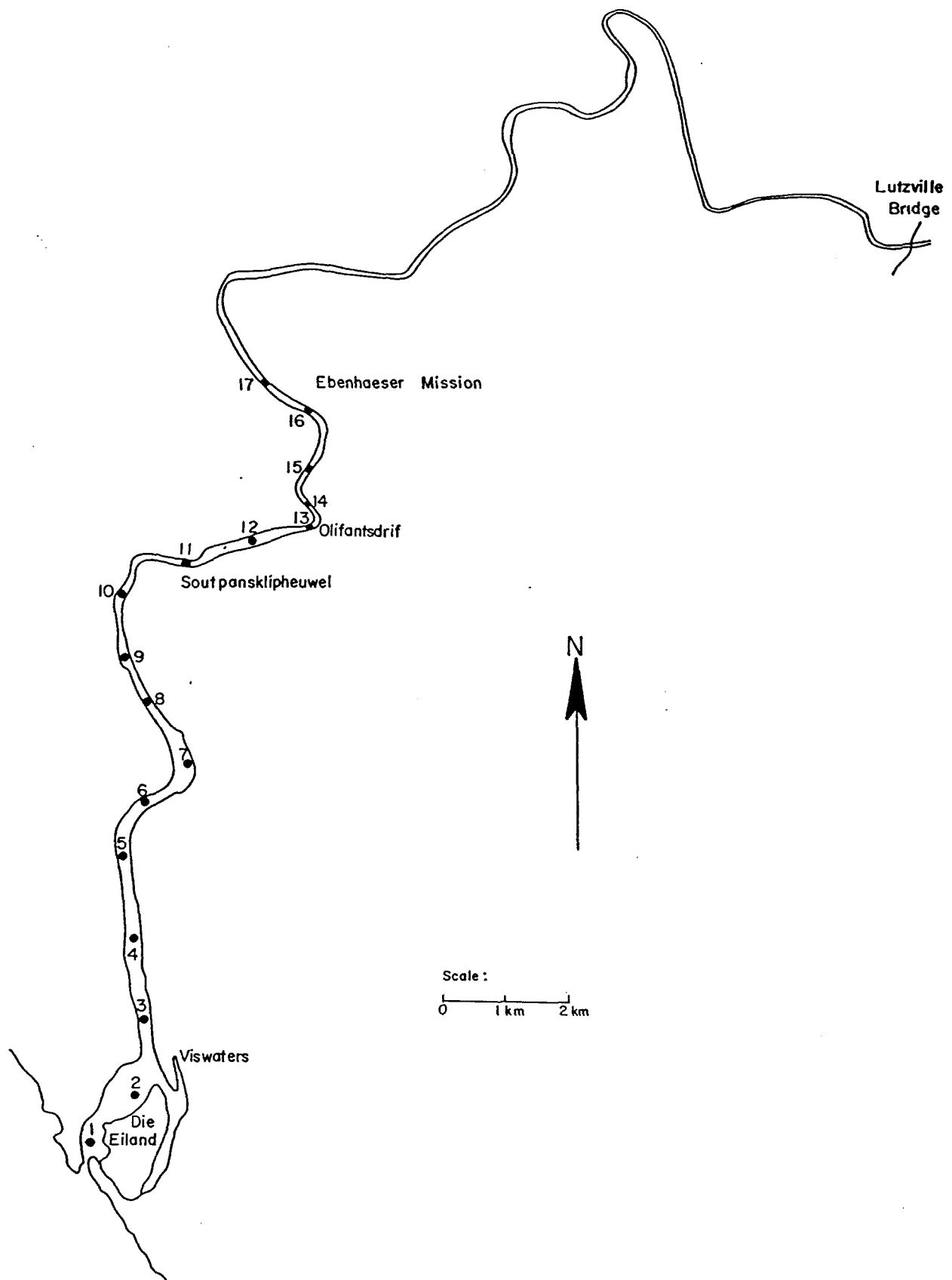


Figure 1. Map of the Olifants Estuary. Hydrographic station positions are indicated.

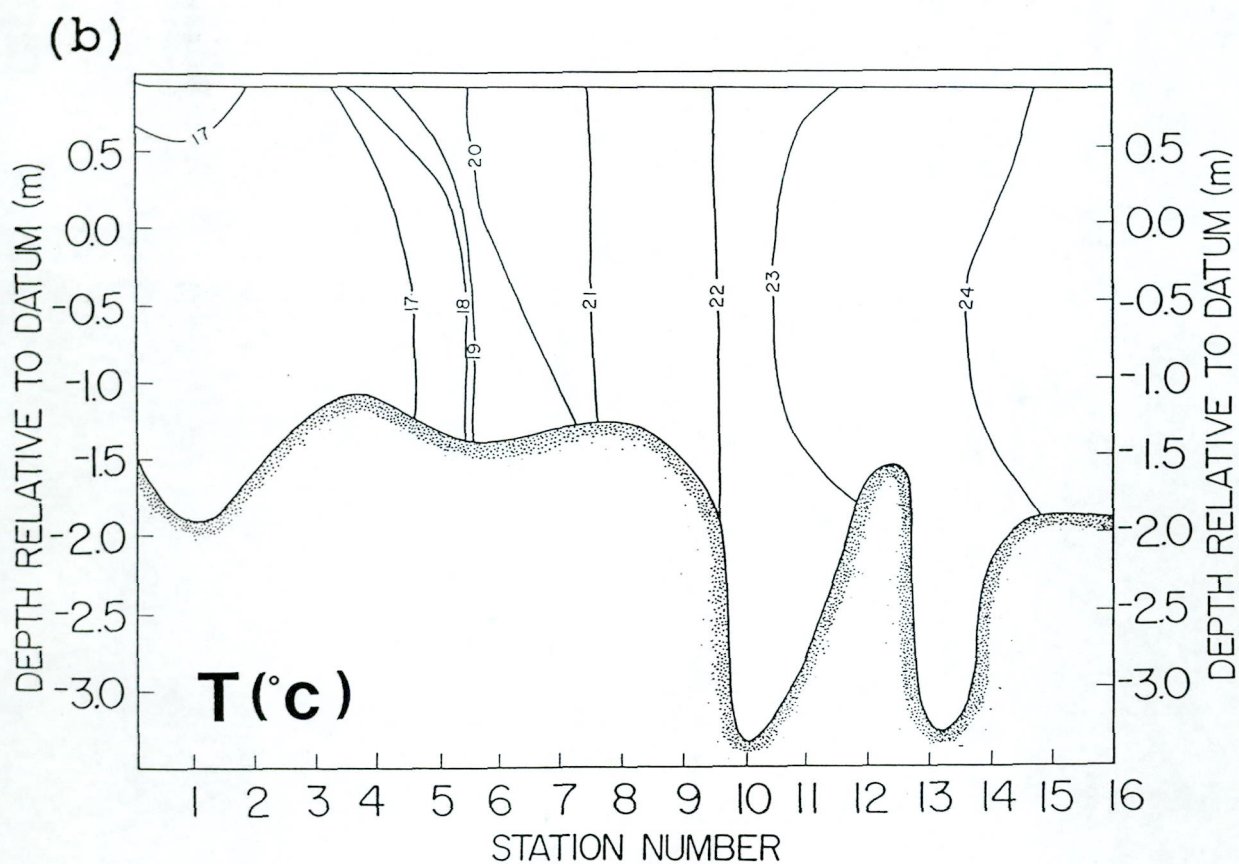
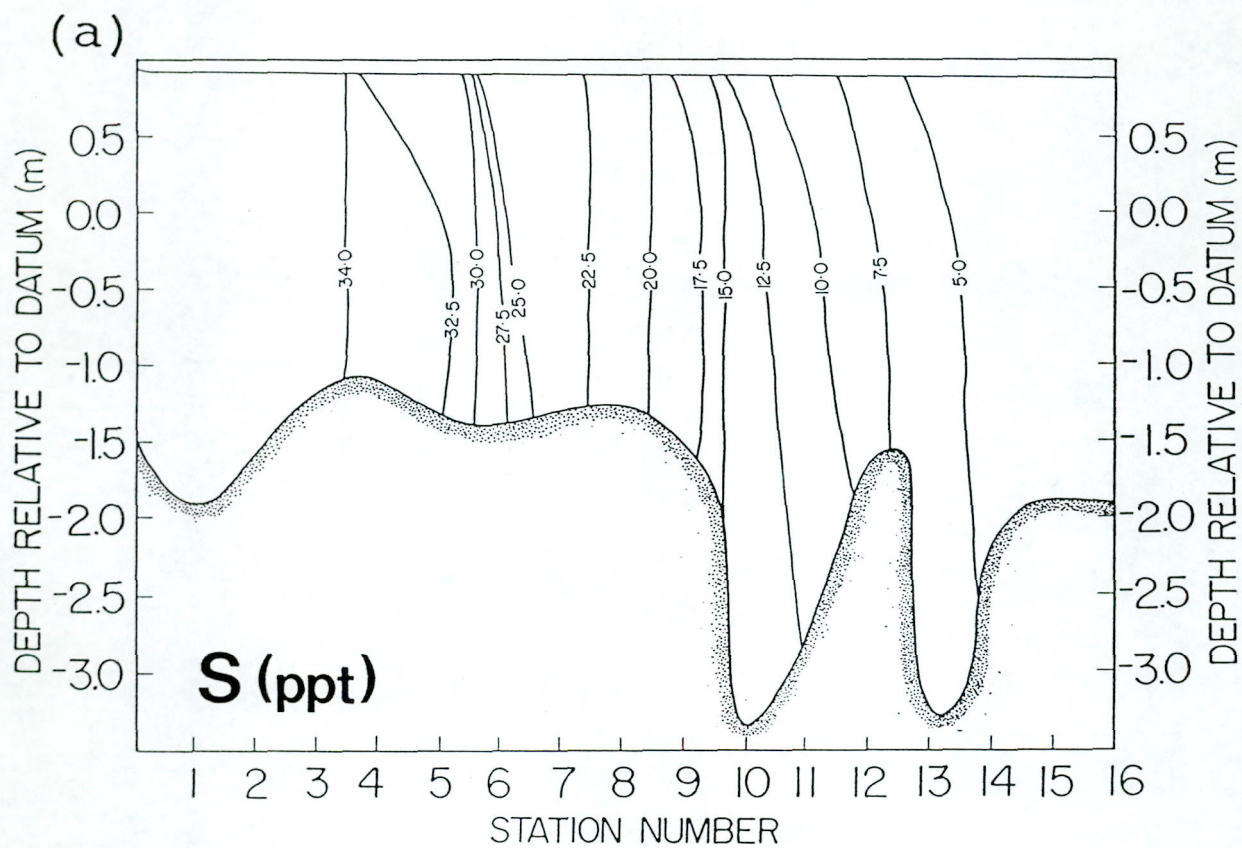


Figure 2. Longitudinal salinity (a) and temperature (b) sections of the spring flood tide of 28 January 1990.

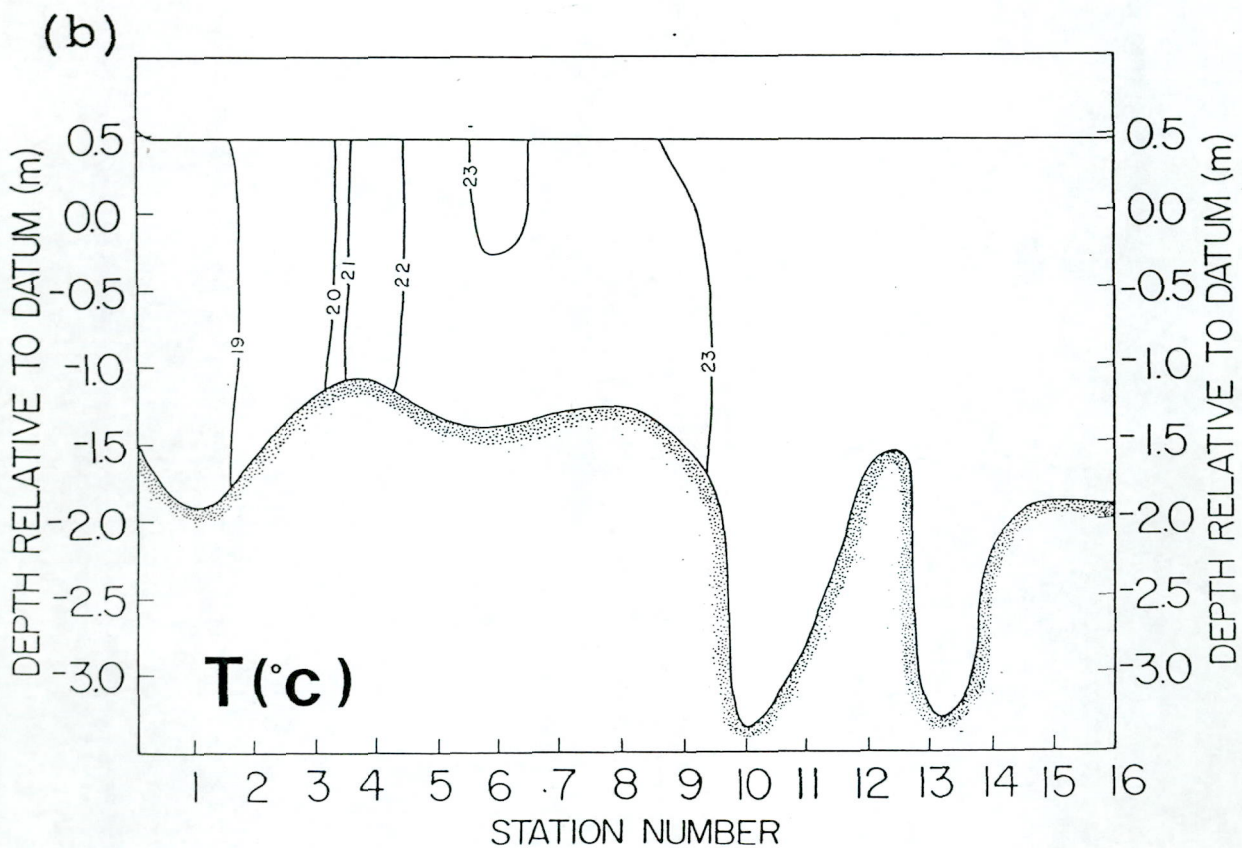
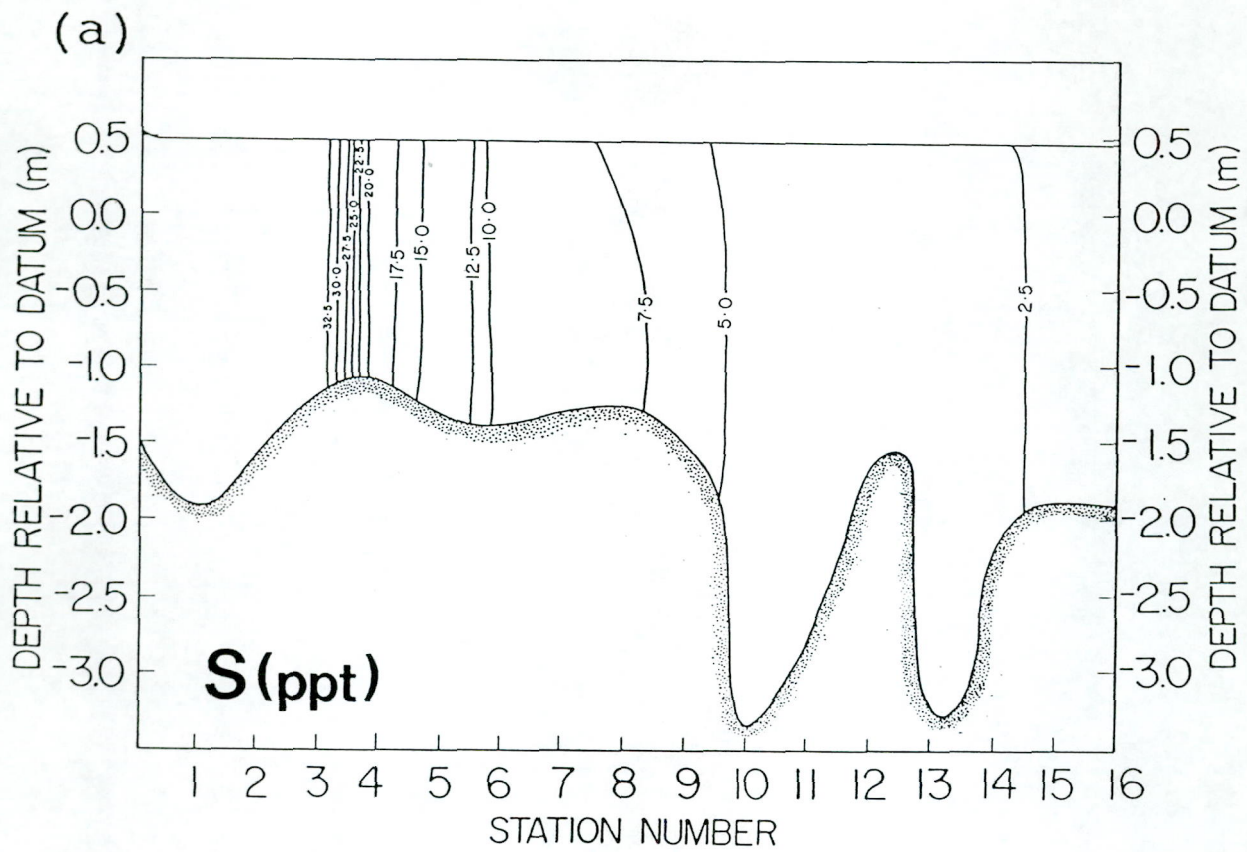


Figure 3. Longitudinal salinity (a) and temperature (b) sections of the spring ebb tide of 28 January 1990.

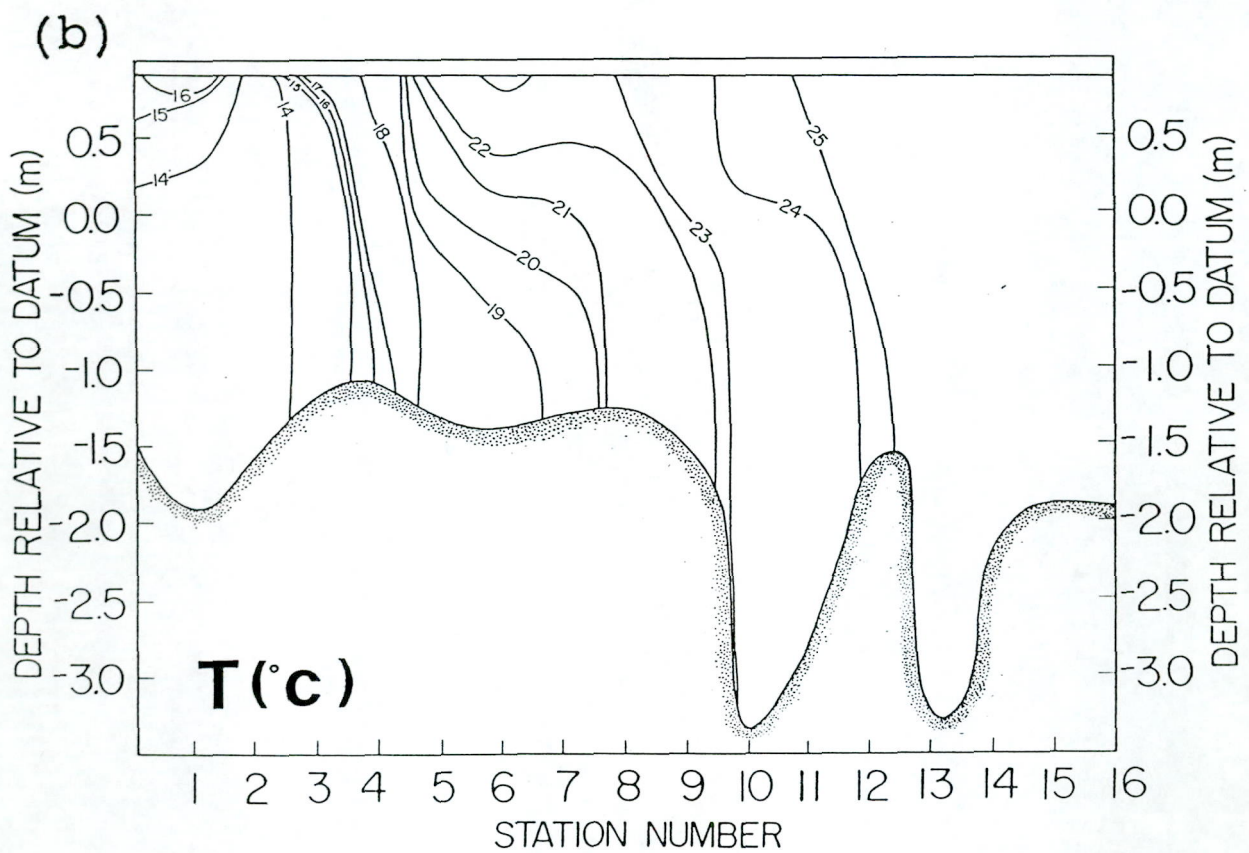
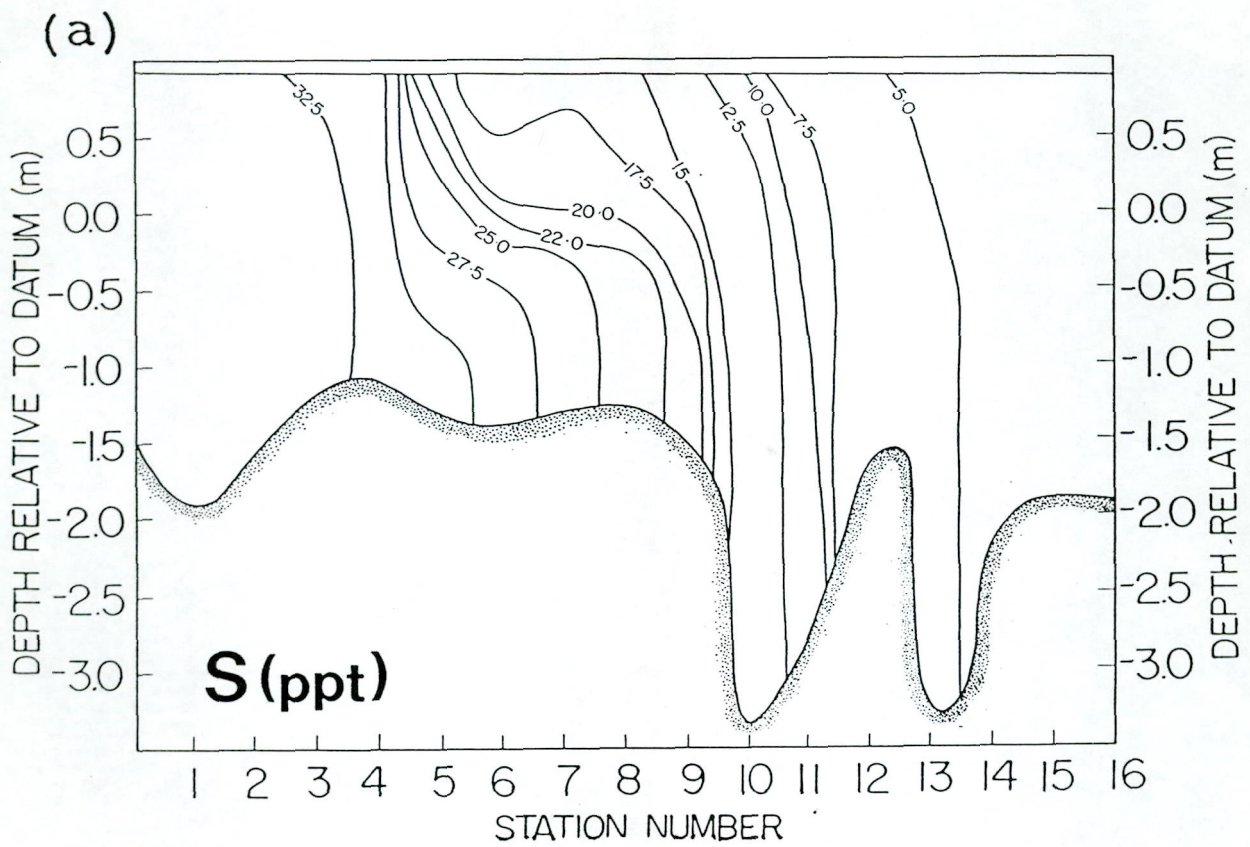


Figure 4. Longitudinal salinity (a) and temperature (b) sections of the neap flood tide of 4 February 1990.

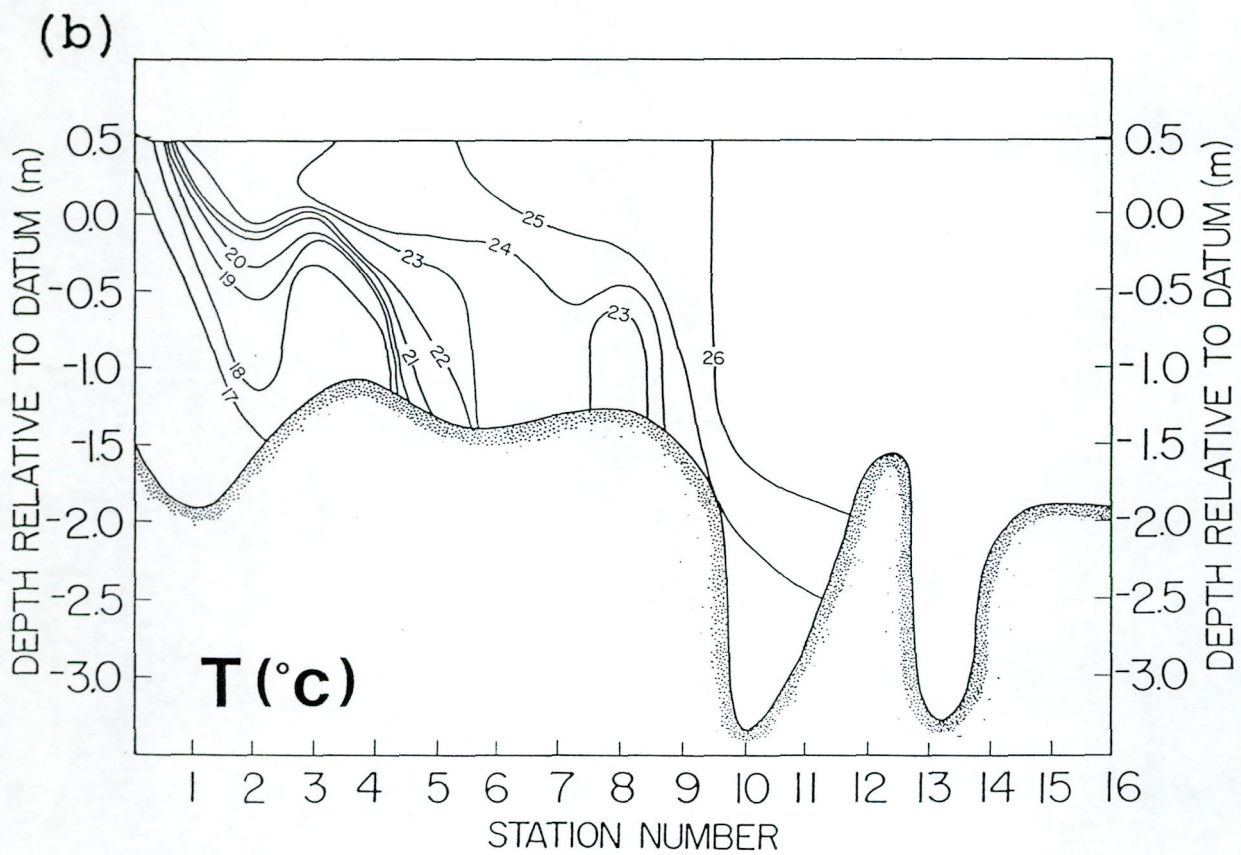
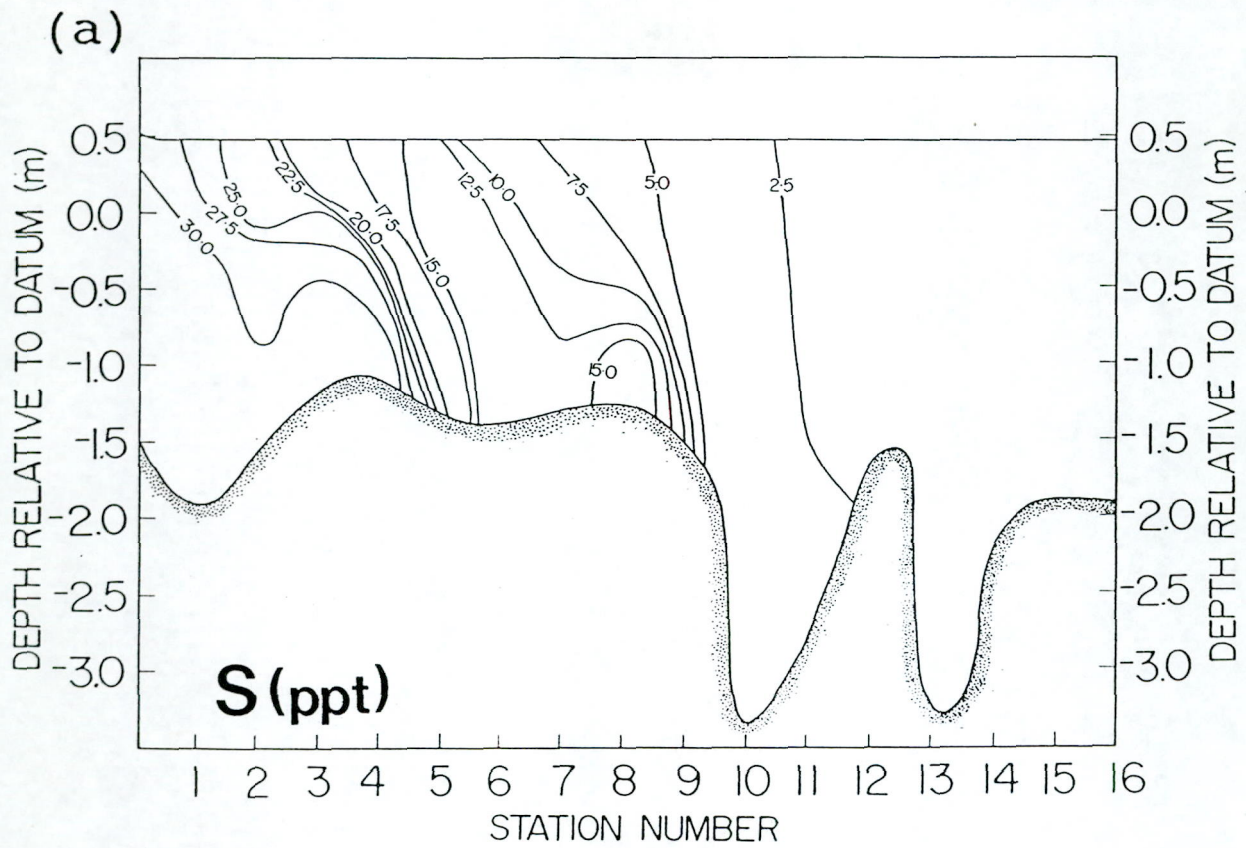


Figure 5. Longitudinal salinity (a) and temperature (b) sections of the neap ebb tide of 3 February 1990.

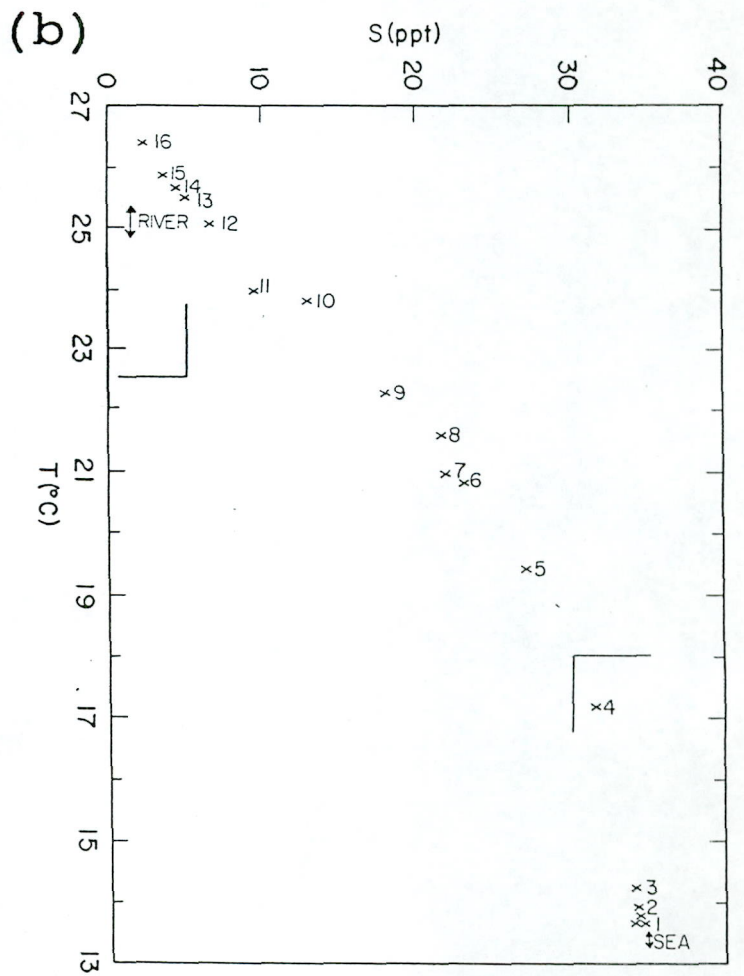
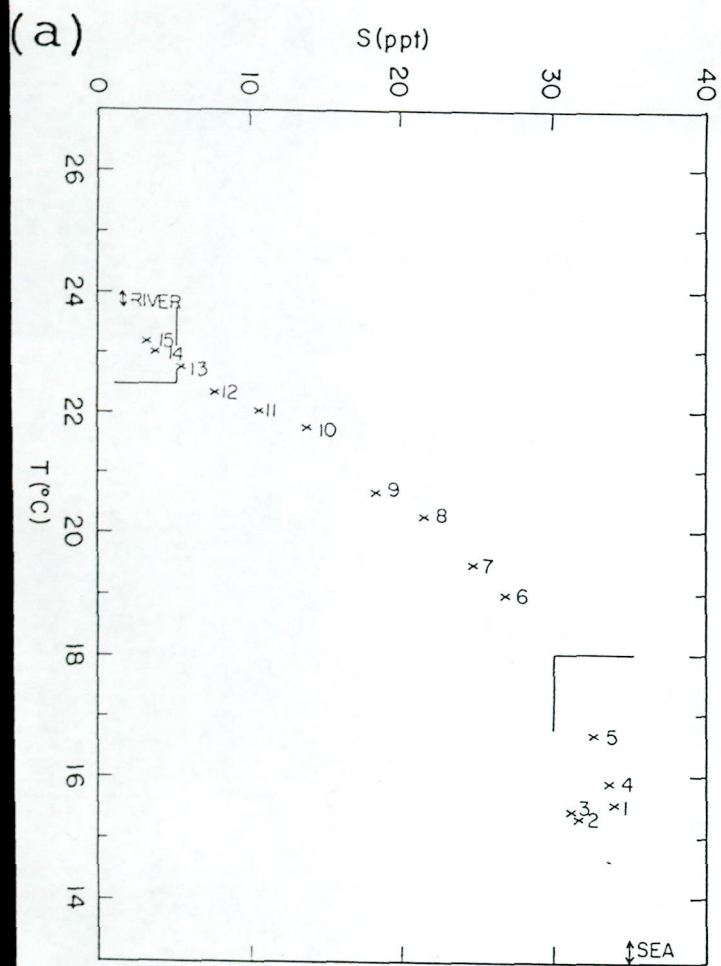


Figure 6. Temperature salinity diagrams of the spring flood tide of 28 January 1990 (a) and the neap flood tide of 4 February 1990 (b).

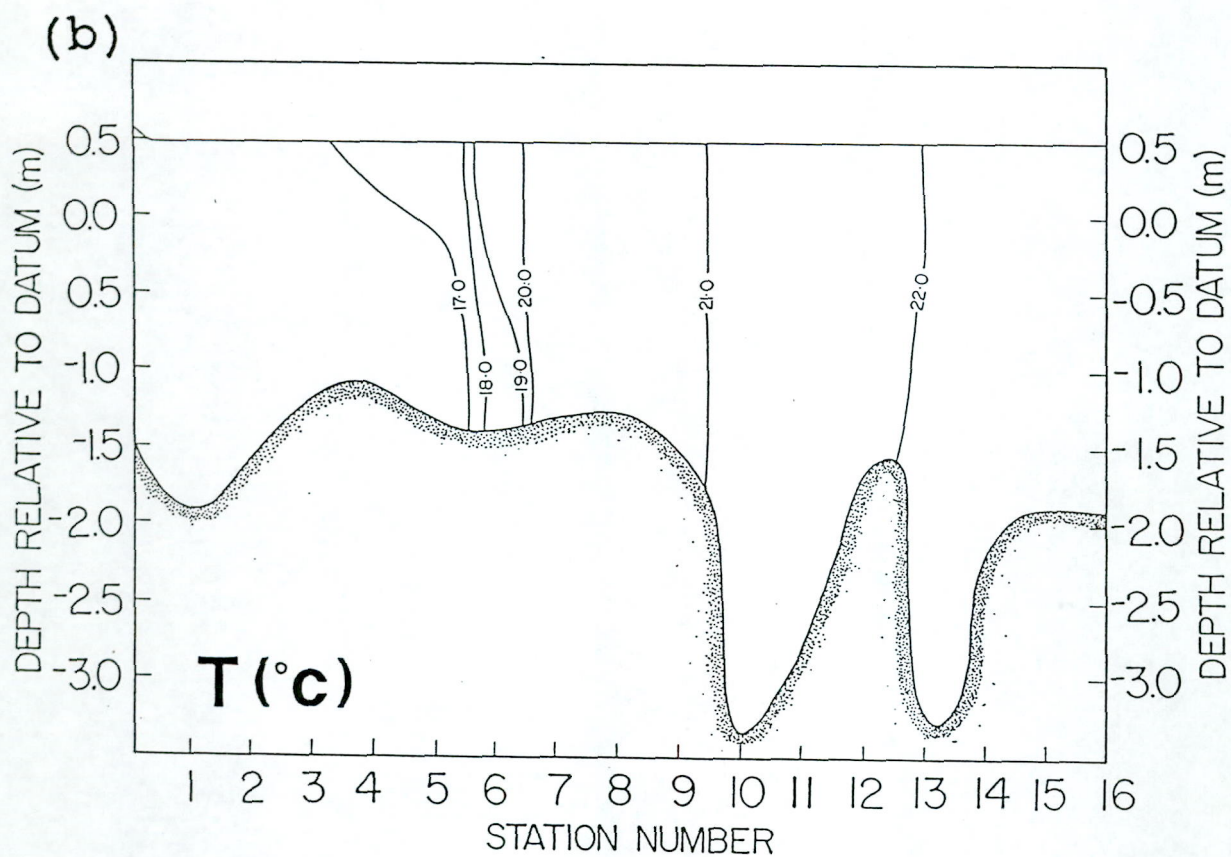
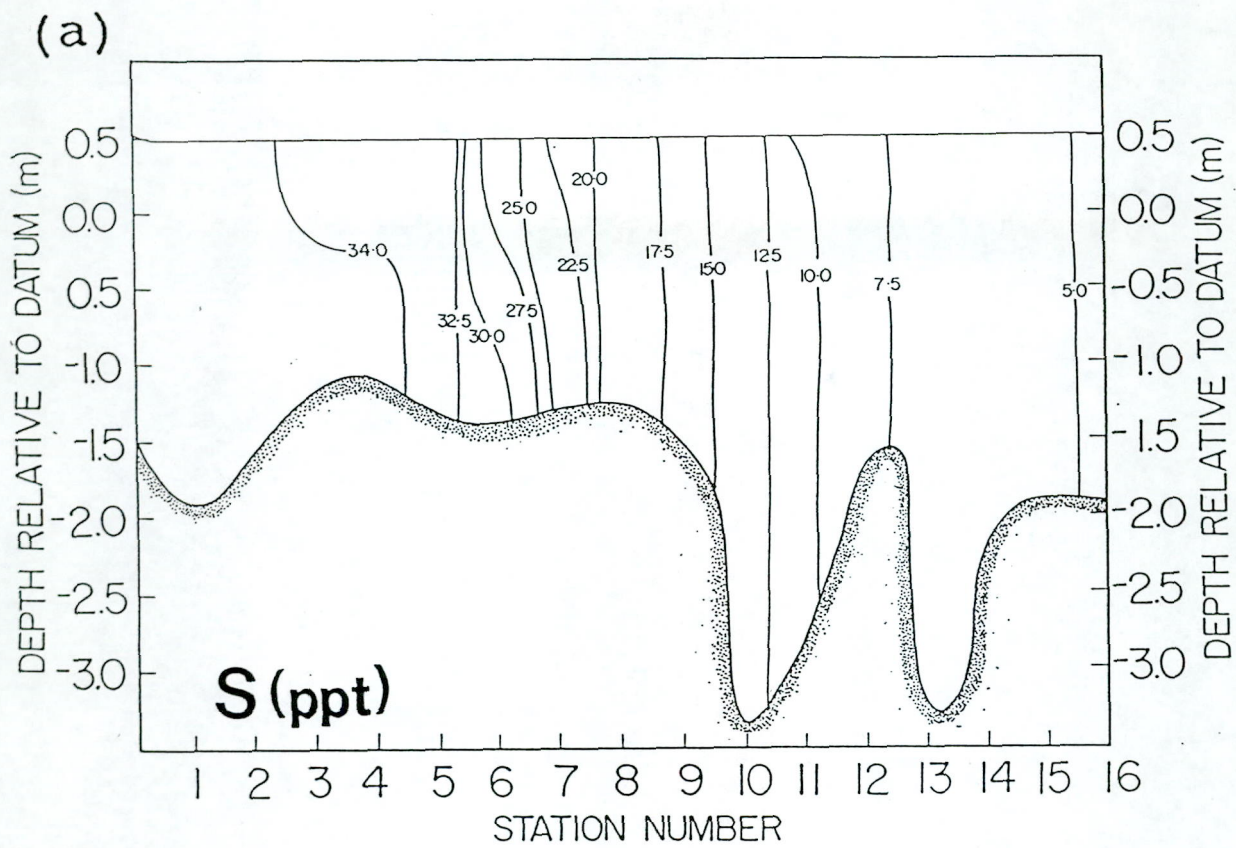


Figure 7. Longitudinal salinity (a) and temperature (b) sections of the neap flood tide of 8 April 1990.

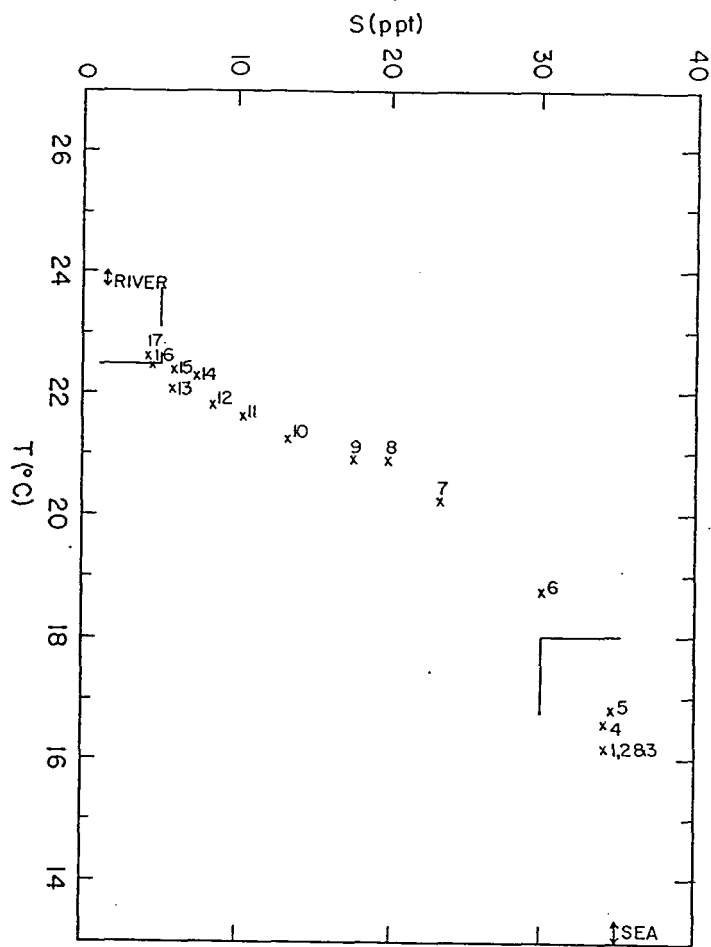


Figure 8. Temperature salinity diagram of the neap flood tide of 8 April 1990.

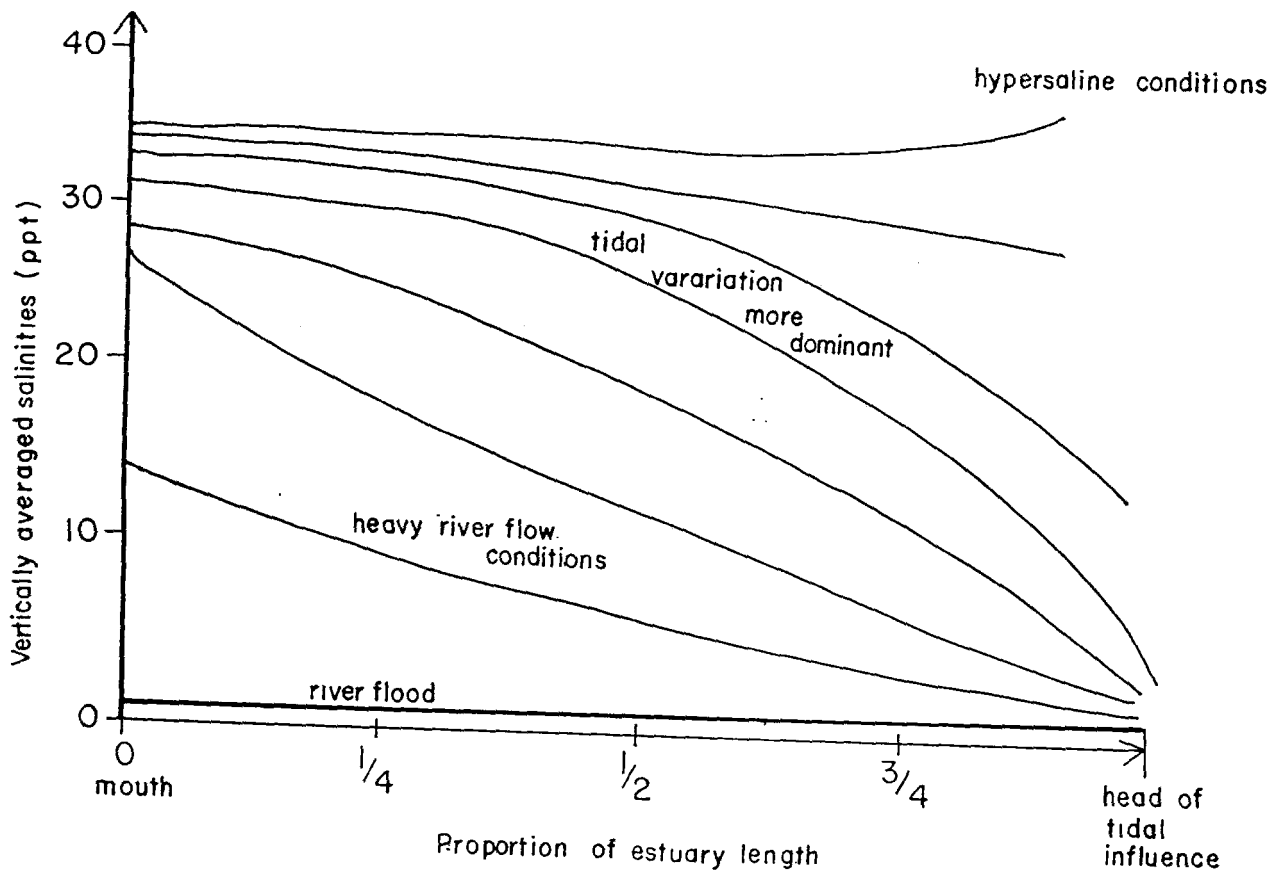


Figure 9. The possible range of vertically averaged salinities which can occur along the length of an estuary.