Kuantan River, Malaysia

Prediction of salinity intrusion

Report No EX 814
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Hydraulics Research Station
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ABSTRACT

A mathematical model was used to simulate the long-term movements of the high water slack longitudinal salinity profile in the estuary of the Sg Kuantan, Malaysia. The proven model was then used to predict the effects on salinity of increased abstractions from the estuary under various drought conditions. The predicted longitudinal profiles were used to estimate the restrictions on abstraction at four sites assuming different limits on the salinity of the abstracted water.

The main conclusion of the study is that, in the design drought conditions given, increased abstraction of water with tolerable salinity would not be possible for much of the year at the present intake, JKR Kobat (10.9 miles from the sea). Salinity levels would be considerably lower if the intake were moved to a point 16 miles from the sea, but for the abstracted water to be free of salinity above 0.2 ppt chlorides the intake would have to be moved at least 18.5 miles from the sea. An intake 20 miles from the sea would be affected by salinity of 0.1 ppt chlorides only for 30% of each tide on the worst 19 days of a 1 in 50 year drought.

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INTRODUCTION

1 In 1976 the Malaysian Economic Planning Unit commissioned a feasibility study of the Kuantan Water Resources to be carried out by Messrs Binnie and Partners, as part of the Kuantan Urban Development Project. New industries and an influx of population will create an increased demand for water which may be met by abstraction from either the Kuantan or Kemaman rivers or from both. In January 1977 Messrs Binnie and Partners commissioned the Hydraulics Research Station (HRS) to study the effects of increased freshwater abstraction on the salinity in the Kuantan estuary.

2 This report describes the mathematical model study undertaken to predict the salinity distribution when additional freshwater is abstracted from the river. The predictions have been made for river flows associated with 1 in 5, 1 in 20 and 1 in 50 year droughts in conjunction with various abstraction rates both for municipal water supply and agricultural use. The predicted salinity distributions have been used to calculate the number of hours per tide during which a salinity limit may be exceeded at a particular abstraction point; this gives the number of hours for which no pumping would be possible at this site. From this information the pumping capacity and storage within the supply system can be calculated.

3 The basic principles of the mathematical modelling technique are given here but a more detailed account is given in a previous HRS report(1). The dispersion coefficients for the model were found from field data collected between December 1976 and May 1977. The model was then verified by comparing the calculated salinity with further field data obtained between May and November 1977.

4 A sketch map of the river with the main tributaries and abstraction sites is shown in Fig 1. The distances in miles upstream of the river mouth are marked. The most important tributary is the Sg Belat, whose confluence with the Sg Kuantan is approximately 4 miles from the sea. The Sg Belat contributes approximately 10–15% of the total freshwater inflow. The Sg Riau has occasional floods producing 20% of the total daily inflow but in general has lower flows than the Sg Belat; typically in the dry season it gives less than 5% of the total inflow. The Sg Pandan has a flow generally less than 2% of the total and the Sg Pinang less than 1%. The flows of the Sg Panching and Sg Ah Tong have been included with the flows in the main river, Sg Kuantan at the South East Asia Mining Company at mile 25, as the inflow at the head of the estuary.

5 The main freshwater abstraction point on the estuary is the JKR intake (Kobat) at mile 10.9, this is already affected by salinity at low flows as shown by the record of chlorinity (fraction of dissolved chlorides) shown in Figs 2a and b. One of the alternatives to satisfy the increasing demand of the Kuantan area is to abstract more water at Kobat. Other options are to move the main intake upstream, eg to mile 16 or mile 20. Water for agricultural use is to be abstracted at mile 15 and one particular schedule is given in Table 1. There is to be further abstraction of 2 million gallons per day at mile 20 for water supply.

FIELD DATA

6 The data collection was carried out by Binnie Dan Rakan (BDR) to the specification given by HRS and Binnie and Partners. The data requirement for this study is very similar to earlier salinity studies; in particular a detailed account of data collection on the Rio Guayas, Ecuador, may be found in HRS report OD 8. However for the Kuantan Study modifications had to be made for the mixed type of tide. The diurnal component of the tidal motion may be completely dominant at certain times of the 14-day spring-neap cycle whereas at other times no diurnal inequality is

present and the tide appears to be semi-diurnal. The ratio of the diurnal to semi-diurnal amplitudes K_1+O_1/M_2+S_2 is 0.86/0.73. The Admiralty Tide Tables (1977) criterion for diurnal tides is that $\pi S_2 < 2(K_1+O_1)$ which certainly holds in this case since $\pi S_2 = 0.5341$ and $2(K_1+O_1) = 1.72$.

7 The field data falls into four categories: (i) geometric, (ii) tidal, (iii) salinity and (iv) freshwater inflow. The geometric and tidal data are usually collected once only, although in this case the tidal data was required for both extremes of tidal conditions, ie at a time when the diurnal component was dominant and when the tides appeared to be semi-diurnal. The geometric data may be checked for seasonal variations (in depth, cross-section etc) but in the case of the Kuantan data was available from earlier surveys to check the most recent measurements, as shown in Fig 6. The salinity and freshwater inflow were monitored as frequently as possible for 11 months.

8 The tide gauge at Kuantan jetty (mile 1.5) was used as a reference for all tidal information. At times when the tidal records at the jetty were unavailable predictions from Admiralty Tide Tables were used.

9 The geometric data consisted of:

a) cross-section areas at 14 stations from a recent survey by Binnie Dan Rakan (BDR) and some 33 other measurements from an earlier survey;

b) water depths at each of the sections.

These figures were all adjusted to the water level at mean higher high water (MHHW) or approximately 1.1 m OD.

10 Tidal velocities were measured at 10 stations for both the semi-diurnal type tides and the diurnal component dominant type of tide. Only 8 of these stations could be used because the other two had less than 23½ hours of measurement out of the 25 hour tidal period. The tidal record at Kuantan jetty was used to scale the tidal velocities, ie it was assumed that the maximum tidal velocity at a section was proportional to the tidal range at the jetty. The velocities were used to compute the horizontal displacement of a parcel of water from its higher high water position, corrected for any freshwater flow. The correction procedure ensured that a particular value of salinity returned to its original position at the end of the tidal cycle. Hence this method assumes that advection during a tide is balanced by dispersion. The computed displacements were used to correct the salinity measurements to their position at higher high water (HHW).

11 Longitudinal profiles of salinity were measured on 14 separate occasions between December 1976 and July 1977, at intervals of approximately a fortnight. A further 67 profiles were measured in two 18 day periods, 22 August to 8 September and 20 October to 7 November, to observe the monthly variation of salinity at HHW. The profiles were all measured close to the time of HHW, moving upstream at a slightly slower speed than the movement of the high water. This minimised the corrections described in the previous paragraph.

12 Freshwater inflow into the estuary was calculated by Binnie and Partners from data supplied by BDR. The flow information covered the period of data collection from December 1976 to November 1977. Further 12 month hydrographs were provided by Binnie and Partners, representing 1 in 5 year, 1 in 20 year and 1 in 50 year droughts.

EXISTING CONDITIONS

13 At present a pumped intake exists at JKR Kobat 10.9 miles upstream of the river mouth. This can be affected by excessive levels of salinity. In this case expressed as chlorinity in parts per thousand or grams per litre (Cl^- in ppt or g/l). Sea water contains approximately 19 ppt chlorides equivalent to 35 ppt total dissolved solids. Two typical records of salinity

are shown in Fig 2 for 24 hour periods on 5/6 May and 23/24 May. These show that if a limit of 0.2 ppt chloride had been imposed pumping would have to cease for 22–24 hours out of 24 and 5 hours out of 24 respectively. Increased volume of pumping would reduce the freshwater flow therefore increasing salinity intrusion from the sea and further restrict the pumping hours available. The purpose of the present work is to compute these restrictions for certain combinations of design freshwater flow, abstraction rates and salinity limits.

14 The present salinity profile is relatively steep as shown by a sample observed profile on 6 May shown in Fig 3. Even small movements of the profile upstream would severely restrict pumping at JKR Kobat. An agricultural water supply intake at mile 15, would be less affected by an upstream movement of salinity especially as the salinity limits are less severe on water for irrigation.

15 Any method of predicting the salinity distribution in the estuary must first be shown to reproduce the existing conditions to within a reasonable tolerance. The method used in this study takes the first six months of data to adjust various coefficients so that the observed salinity profiles are matched as closely as possible, then the model was run for the remaining period of observations, without adjustment, to verify that it is reproducing the behaviour of salinity in the estuary.

MATHEMATICAL MODEL

16 The mathematical model describing the movement and distribution of salinity which is used in this study is known as the "high water slack approximation". It is represented by a single unsteady equation, one-dimensional in space, representing the conservation of salt:–

$$A\frac{\partial c}{\partial t} - \frac{\partial}{\partial x}(u_f c\ A) = \frac{\partial}{\partial x}(A\ D\frac{\partial c}{\partial x}) \qquad \text{....(1)}$$

where

A is the cross-section area of the estuary at x

c is the salinity at position x at time t

u_f is the freshwater flow velocity at (x,t)

D is the longitudinal dispersion coefficient for the high water slack approximation

x is the distance upstream from the estuary mouth.

17 All quantities are taken at a particular instant during the tidal cycle, namely high water slack. Although high water does not occur simultaneously throughout an estuary we can imagine a time axis moving with the speed of high water travelling upstream. This has two advantages, (i) the boundary condition at the mouth of the estuary is just that the estuary salinity is equal to ocean salinity and (ii) the maximum salinity throughout the tidal cycle is calculated immediately.

18 The basic assumption is that the high water slack approximation represents the long-term movement of salinity and the movement of salinity within one tidal cycle can be represented by convection using measured tidal velocities (ie ignoring dispersion within one tidal cycle). However mixing is the all important mechanism by which salinity moves upstream and it dominates in the long term where variations in freshwater flow are more important than tidal fluctuations. So the solution of equation (1) would represent an envelope curve touching the real curve of salinity movement at each high water point in the case of ideal constant range semi-diurnal tides. For the real, more complex tidal situation see Fig 4.

19 In the case of rivers such as the Kuantan where the tide is of mixed type with a large diurnal component we re-define the high water slack

approximation so that equation (1) gives the salinity at higher high water (HHW).

20 Equation (1) represents a balance between the convective terms, on the left hand side, which tend to reduce salinity at a point, or push a certain salinity level downstream, and the dispersion term on the right hand side which models the mixing effects pushing salinity upstream.

21 The longitudinal dispersion coefficient, D, is modelling all the effects contributing towards the mixing. The parameters affecting the mixing are well known but the precise formulation of the dispersion coefficient is not. So we use an empirical form of D as developed in HRS report OD 2:–

$$D = D_1 \frac{Au_T}{A_o u_{T_o}} + D_2 \left[\frac{Pu_T^2}{Q_f Tgh(1-\rho/\rho_o)}\right]^n \frac{c_x L}{c_o} \qquad ....(2)$$

where

D_1, D_2 and n are empirical coefficients to be determined by fitting the solution to observations.

Also,

u_T is the maximum tidal velocity at a section

P is the tidal prism volume of sea water entering the estuary during the flood tide

Q_f is the freshwater flow

T is the tidal period

g is the acceleration due to gravity

h is the mean depth

ρ is the density of the water at a section

$c_x = \partial c/\partial x$

L is the length of the estuary

and the suffix zero denotes the value of a quantity at the estuary mouth, x = o.

22 Density is related to salinity through the approximate equation

$$\rho = \rho_o \frac{(1+\alpha c)}{(1+\alpha c_o)} \qquad ....(3)$$

where $\alpha = 1.38 \times 10^{-3}$ when c is in ppt Cl^-.

23 The mathematical problem is completed by specifying an initial condition and a boundary condition for the partial differential equation (1). The initial condition may be obtained from any measured longitudinal salinity profile and is

$$c(x,o) = f(x) \qquad ....(4)$$

where f(x) is some function describing the initial profile.

24 The boundary condition is simplified by the nature of the high water slack approximation (paragraph 18) and is simply that the salinity at the estuary mouth should be equal to oceanic salinity ie

$$c(o,t) = c_o \qquad ....(5)$$

The solution is uniquely determined by also specifying that c is bounded everywhere, ie

$$o \leqslant c(x,t) < \infty \text{ for } o \leqslant x < \infty \text{ and all } t \qquad ....(6)$$

SCHEMATIC REPRESENTATION OF THE ESTUARY

25 If the initial profile in equation (4) is split into its Fourier components then an approximate analytical solution of equation (1) is possible with

$u_f A = Q_f = \text{constant}$ ....(6)

The estuary may be split into a number of equal length sections and then the variation of geometric and tidal properties can be represented in tabular form. The initial salinity profile may be treated in the same manner. Using a numerical procedure for the Fourier analysis the solution to equation (1) can be produced in tabular form for any required time.

26 However in nature the freshwater flow does not remain constant, see for example Fig 5. It is possible to approximate the natural inflow by a stepped hydrograph as shown. The total volume of freshwater flowing into the estuary is kept the same but we now have short periods during which the flow is constant and the method outlined above may be used.

27 The estuary has been sub-divided into 22 sections and the cross-section areas at the 23 boundary points are shown in Fig 6 compared with the survey data. A similar discretisation has been used for the maximum tidal velocities and tidal excursion, interpolating between observed data.

PROVING AND VERIFICATION

28 The salinities were calculated from the solution of equation (1) using a computer program. The initial profile was taken as that observed on 14 December 1976 corrected to the HHW position. Freshwater inflow was the stepped form of the hydrograph shown in Fig 5. This comprised the sum of all tributary flows. The model considers the flows of the four lower tributaries separately, Sg Riau at mile 17, Sg Pinang at mile 14, Sg Pandan at mile 12 and Sg Belat at mile 4. These tributary flows are added to the mainstream flow at the appropriate point.

29 The model calculates an average salinity for each cross-section at higher high water slack. However the observations used for proving were taken at a depth of 5 feet below the surface, near the centre line of the river. This may not be a true average but measurements were also taken near the bed of the estuary to check the degree of stratification present. In most cases there was only slight or zero stratification. On a few occasions higher stratification was observed downstream of the confluence with the Sg Belat, but the estuary appears well mixed further upstream in the vicinity of the intake sites.

30 The longitudinal profiles observed between 14 December 1976 and 6 May 1977 were used for comparison with the calculated salinities obtained from the model for this period. The coefficients D_1 and D_2 of equation (2) were adjusted to give the best agreement with the observations. The exponent n was kept at a fixed value of 0.25. Particular attention was paid to fitting the results to observations in the lower salinity range where the limits for freshwater abstraction occur.

31 Some results from the proving runs are shown in Fig 3. This demonstrates the close fit achieved in the lower salinity range, so that the calculated profile was within 1.5 miles of the observed profile. However slightly larger discrepancies occurred in the high salinity area, near the mouth of the estuary. The calculations are relatively insensitive to variations of D_1 and D_2.

32 Fig 7 compares the observed position of the 0.5 ppt chlorinity front with the calculated movement for the final values of $D_1 = 3800$ and $D_2 = 25$.

These were found to be the best values for matching the observed profiles up to 6 May 1977.

33 After the values of D_1 and D_2 had been found the model was run for the complete period of observations with no further adjustments. Fig 7 shows that satisfactory agreement was obtained for the whole period. The average error in position is about 0.9 km. The maximum error in the position of the 0.5 ppt front was 1.75 miles downstream of the observed position. This corresponds to less than half of the measured maximum tidal excursion in this part of the estuary. At several points the calculations appear to have overestimated the distance of the 0.5 ppt front from the sea but this may be accounted for by noting that the calculated positions are all assumed to be for a maximum HHW occurring at spring tides and have not been corrected for the smaller tides which actually occurred whereas the observations were corrected for the actual tide.

34 It is considered that the model will give satisfactory predictions for the Kuantan estuary within the range of flows tested and with the maximum error in position of the 0.5 ppt front of about half the tidal excursion.

CALCULATION OF PUMPING HOURS LOST

35 The model calculates directly the salinity profiles for higher high water (HHW) slack, mid tide and lower low water (LLW) slack based on the tides at maximum diurnal inequality when the range (height at HHW minus height at LLW) is usually the greatest. So the HHW slack calculated is the upper limit for any type of tide. As it is impossible to predict how the hydrograph may be related to the variations of the tide the maximum high water slack salinity has not been reduced to an actual high water or series of high waters.

36 The situation is illustrated in Fig 4 which shows a period of generally increasing salinity intrusion. The calculated salinity intrusion at a maximum higher high water slack shows a steady increase. However, within each tidal cycle the salinity oscillates, perhaps only touching the predicted value at the beginning and end of the 14 day cycle shown. So on days where the tide is semi-diurnal in nature, the oscillation of salinity intrusion will not have such a large amplitude as at times of maximum diurnal inequality.

37 If we know the characteristics of the two types of tide, semi-diurnal or equal tides, and tides with a maximum diurnal inequality, then we can calculate the movement of salinity during these extreme tides. During intermediate tides the salinity movement will be between the two extremes, so we can establish limits for the salinity intrusion.

38 The present study requires the prediction of the number of hours for which a particular salinity limit may be exceeded at a particular site for some design hydrograph. When this limit is exceeded pumping at the abstraction site will have to cease. Extra pumping capacity and storage will have to be incorporated to cope with this lost pumping time.

39 The number of hours for which the salinity limit is exceeded are calculated separately for the two extreme types of tide, within the main computer program. First the program checks if the salinity at an abstraction site exceeds the limit at maximum HHW. If it does, then the program checks that the minimum low water salinity is less than the limit. If the minimum low water salinity is also above the limit then the number of hours of salinity exceeding the limit is 25 for all tides. Otherwise the program uses the displacement versus time table, computed earlier, to convect the salinity profile up and down with the tide to find the number of hours that the limit is exceeded. This process is repeated

for the smaller, semi-diurnal tides, using the mid tide value of salinity as a starting point as this does not vary with the nature of the tide. (See Fig 4). The two figures for the number of hours lost are then plotted in Figs 14, 15 and 16 for several salinity limits at the Kobat pump site (at mile 10.9). A similar plot for the agricultural intake near mile 15 is shown in Fig 17 for run 3, the 1 in 50 year drought. Tables 2, 3, 4 and 5 show a complete list of pumping hours lost for each step of the hydrograph in each test run.

40 Figs 12 and 13 show the movement of the 0.5 ppt and 0.2 ppt chlorinity fronts respectively as calculated for maximum HHW, for the three test runs.

41 It is interesting to note that the calculation of pumping hours lost for a salinity limit of 0.2 ppt chlorides at JKR Kobat was 25 hours for 6 May 1977 and between 0 and 6 hours for 24 May 1977 out of 25 hours in the proving run when the actual record of salinity shows that this limit was exceeded for 24 hours and 5 hours out of 24 (Fig 2).

42 For the purposes of these calculations it is assumed that water is taken out of the river even if its salinity is above the limit given. In practice pumping would cease when the salinity limit was exceeded but once freshwater was available again the total volume required would be made up to recover the losses during the stoppage. Hence the average abstraction over a long period would be the same as used in these calculations.

RESULTS OF TESTS ON ABSTRACTION RATES

43 The test runs were all based on hydrographs starting in December, just before the usual period of maximum flows. In this way any inaccuracy in the initial salinity profile chosen has a negligible effect on the predicted profiles after the flow begins to decline. The given mean daily flows were converted into a step hydrograph. The step lengths were chosen to represent reasonably the variations in freshwater inflow but not so short that the assumptions made in the mathematical model become invalid. Generally for flows over 2000 cusecs time steps of 2 days could be taken but in the low flow periods the steps should preferably be at least 7 days. If the time steps taken are too long then the hydrographs become too smooth and the effects of freshwater flow variations cannot be demonstrated.

44 Initially three different hydrographs and abstraction rates were tested:

Run	*Drought return period*	*Abstractions in MGD* At mile 10.9 (Kobat)	*At mile 15 (for Agriculture)*	*At mile 20*
1	20	8	0	2
2	5	8	see Table 1	2
3	50	23	10	2

The movements of the 0.5 ppt and 0.2 ppt chlorinity fronts are plotted in Figs 12 and 13 respectively. These show that HHW salinity levels at Kobat are above 0.5 ppt chlorides for more than half the year for runs 1 and 3. The longest period for which the level of 0.5 ppt chlorides would be exceeded at HHW is

6 months for run 1 conditions
2 months for run 2 conditions
6 months for run 3 conditions

extending generally from early January to July, with the possibility of a short period (up to 7 days) in May when the 0.5 ppt chlorinity front may not reach above mile 10. If the intake were moved to mile 15 then Fig 12 shows that the level of 0.5 ppt chlorides would be exceeded at HHW for a maximum of:

1 month for run 1 conditions
never for run 2 conditions
3 months for run 3 conditions

45 Even though the maximum salinity reached during a tide may exceed the 0.5 ppt chlorides level the minimum salinity may drop below this level so that abstraction may be possible for part of the tidal cycle. Figs 14, 15 and 16 show the pumping hours lost for particular salinity limits at the JKR (Kobat) intake site under the different conditions of runs 1, 2 and 3. A band is shown for each step of the hydrograph for each salinity limit. The pumping hours lost would fall within this band, the two extremes of the band representing the extreme tidal conditions of semi-diurnal tides and the diurnal component dominant type of tide. The exact number of pumping hours lost will depend on the precise phase of the lunar monthly tide. The pumping hours lost are also given, for more salinity limits, in Tables 2, 3 and 4.

46 A considerable reduction in pumping hours lost is achieved at mile 15, the site of the intake for agricultural water. The pumping hours lost at this site are given in Table 5 for the two salinity limits of 0.5 ppt and 1.0 ppt chlorides. Fig 17 shows the results graphically for run 3, a 1 in 50 year drought.

47 The predicted movement of the 0.5 ppt and 0.2 ppt chlorides fronts (Figs 12 and 13) show the maximum intrusion of these salinities in a 1 in 50 year drought under run 3 abstraction conditions is a little less than 18.5 miles. Allowing for the errors in the prediction method it can be said that under these conditions an intake would have to be sited at or above mile 20 in order to abstract continuously water of salinity less than 0.2 ppt chlorides.

48 Later another test was carried out in run 6 with the hydrograph from a 1 in 5 year drought and abstractions of 8 MGD at Kobat and 2 MGD at mile 20. The results of this run are given in Table 9. This test differs from run 2 only in that there is no abstraction at mile 15. As can be expected this gives results only slightly different to run 2 with pumping hours lost only reduced by one or two hours at best.

RESULTS OF MOVING THE MAIN INTAKE SITE

49 Following the results of the first three runs HRS was requested to investigate the effects of moving the main intake upstream. Two possible sites were investigated, first at mile 16 in run 4, then at mile 20 in run 5 both using the hydrograph of the 1 in 50 year drought from run 3. So the tests were:

Run	*Drought return period*	*Position of main abstraction (miles)*	*Rate of main abstraction (MGD)*	*Agricultural abstraction at mile 15 (MGD)*	*Additional abstraction at mile 20 (MGD)*
4	50	16	23	10	2
5	50	20	23	10	2

50 The results of these runs are given in Tables 6, 7 and 8 in terms of pumping hours lost at the intakes. These show the considerable reduction in lost hours effected by moving the intake upstream. For instance, for a limit of 0.5 ppt chlorides an intake at mile 16 (run 4) would only be affected for 39 days with a continuous shutdown only for the days of

semi-diurnal type tides between the 12th and 31st March. For a limit of 0.2 ppt chlorides the same intake would be affected for 90 days with a complete shutdown for a maximum of 38 days (see Table 6).

51 A much greater improvement is produced by moving the intake to mile 20, (run 5). In this position the model shows that with a limit of 0.2 ppt chlorides there would be no hours lost during a 1 in 50 drought year. Even for a limit of 0.1 ppt the hours lost would be between 6 and 10 out of every 25 hours (24% to 40%) for only 19 days.

52 The effect of moving the main intake upstream increases the pumping hours lost at the agricultural intake at mile 15, as can be seen by comparing run 3 and run 4 (Tables 5 and 8). However the effect of moving the intake even further upstream is very slight as shown by the comparison of run 4 and run 5 in Table 8.

53 In order to assess the relevance of this model study to the design and siting of the proposed intake it is necessary to estimate the accuracy of the methods employed. The proving and verification runs suggest that the maximum error in the position of the profile is 1.75 miles or less than half of the total tidal excursion at mile 11, although the average error is much less, about 0.9 mi. The verification run shows a tendency to overestimate rather than underestimate the salinity at a point. However we shall assume that the error has given an underestimate, so that salinity may penetrate further upstream than predicted. Hence the 0.2 ppt chlorides level maximum intrusion which was predicted as 19.3 miles in run 5 on the 1st April may in fact be 20.3 miles. This would mean a loss of pumping hours for the 0.2 ppt limit at mile 20 of about 6 hours out of 25 hours for the 19 day period 13th March to 1st April for the 1 in 50 year drought hydrograph. The maximum hours lost for a 0.1 ppt limit at this site would increase to between 18 and 22 out of 25 hours for the same period. It should be noted that this is an estimate based upon a maximum error occurring in the method. The estimate of the number of days pumping would be restricted would not change, even allowing for the maximum error.

54 A similar analysis of the results for run 4, for an intake at mile 16 would lead to an increase of about 12 hours on all the figures other than zero in Table 6 up to the maximum of 25 hours. Again the number of days of pumping restrictions would not be affected.

CONCLUSIONS

55 The HRS one-dimensional, high water slack, model of salinity intrusion has been applied to the Sg Kuantan, Malaysia. The model was proved on 6 months' data and verified on a further 6 months' data. Satisfactory agreement was obtained.

56 The longitudinal profiles of salinity calculated by the model can be convected up and down the estuary with the tidal motion and so the length of time a prescribed salinity is exceeded at a potential abstraction site can be calculated. This has been done for various salinity levels at the Kobat intake and demonstrates that pumping will be restricted in some way for more than half the year in the conditions tested. In the case of a 1 in 20 year drought, pumping of freshwater would be impossible for continuous periods up to 35 days duration. Pumping on a restricted basis may be possible for only 5 days between periods of no pumping at all.

57 The longitudinal profile of salinity in the Kuantan is very steep, therefore moving the intake upstream would increase the pumping hours available considerably. For instance, the restrictions on pumping water at less than 0.5 ppt chlorides may be compared between Kobat (mile 10.9) and the agricultural intake at mile 15 (Table 4 and Table 8, respectively).

58 Moving the main intake site upstream to mile 16 considerably improves the situation as regards loss of pumping hours although there is still a continuous period of 3 months when pumping of water less than 0.2 ppt would be restricted but there is only a period of 19 days when no pumping at all is possible (see Table 4) in the test conditions of run 4.

59 Finally, moving the intake upstream to mile 20 in run 5 gives no restrictions at all on pumping water of 0.2 ppt chlorides and only partial restrictions on abstraction of water at 0.1 ppt for 19 days.

60 Figure 19 illustrates the effect of moving the intake upstream in some selected drought probability and salinity limits. The curves are presented for the time of maximum salinity intrusion (ie at the end of the longest recession in the hydrograph). The graph summarises the main conclusions:

a) The intake position is not very sensitive to the criteria of drought probability or salt tolerance.

b) The rate of improvement with position upstream is very rapid above mile 16.

c) Small errors in the position of a particular salinity level (either in calculations or observations) even if only 1 mile or less, could give a large error in the calculation of pumping hours lost at an intake below mile 20.

ACKNOWLEDGEMENTS

61 The investigation, of which this report is the official Hydraulics Research Station account, was carried out in Mr C L Abernethy's section of the Estuaries Division headed by Mr D R P Farleigh. The model was originally produced by Dr K Sanmuganathan and adapted for this study by Mr P J Waite. The computer programming for data preparation and the plotting of results was carried out by Mrs S E Smale.

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TABLES

TABLE 1 WATER REQUIREMENTS FOR AGRICULTURAL AREA

Period	*Area A1 cusec*	*Area A2 cusec*	*Area A3 cusec*	*Total cusec*
Mar 1–21	–	–	–	–
Mar 22–31	62.40	–	–	62.40
Apr 1–5	60.00	–	–	60.00
Apr 6–15	4.00	60.00	–	64.00
Apr 16–20	–	–	–	–
Apr 21–30	8.80	4.00	60.00	72.80
May 1–15	6.40	6.40	61.60	74.40
May 16–31	7.20	6.40	6.40	20.00
Jun 1–30	19.20	19.20	18.40	56.80
Jul 1–14	8.80	9.60	9.60	28.00
Jul 15–29	–	8.80	9.60	18.40
Jul 30–31	–	–	–	–
Aug 1–13	–	–	7.20	7.20
Aug 14–Sep 17	–	–	–	–
Sep 18–27	56.80	–	–	56.80
Sep 28–30	–	56.80	–	56.80
Oct 1–7	–	55.20	–	55.20
Oct 8–12	2.40	–	–	2.40
Oct 13–22	2.40	–	55.20	57.60
Oct 23–31	–	2.40	–	2.40
Nov 1–6	–	–	–	–
Nov 7–30	1.60	–	–	1.60
Dec 1–31	8.00	8.80	8.00	24.80
Jan 1–20	12.80	7.20	8.80	28.80
Jan 21–31	–	7.20	7.20	14.40
Feb 1–4	–	9.60	–	9.60
Feb 5–19	–	–	9.60	9.60
Feb 20–28	–	–	–	–

Maximum irrigation water requirement from river = 74.40 cusecs (40 MGD).

TABLE 2 PUMPING HOURS LOST AT KOBAT

Run 1: 1 in 20 year drought. Abstractions of 8 mGD at 10.9 miles, 2 mGD at 20.0 miles.

Chlorinity limit hours lost		*0.1 ppt*		*0.2 ppt*		*0.35 ppt*		*0.5 ppt*		*0.8 ppt*		*1.0 ppt*	
		max	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*
Date	*Time in days from 1/12*												
1/12	0												
		0	0	0	0	0	0	0	0	0	0	0	0
4/12	4												
		9	5	5	0	0	0	0	0	0	0	0	0
8/1	39												
		9	6	6	0	0	0	0	0	0	0	0	0
13/1	44												
		16	14	14	11	11	7	9	5	5	0	4	0
18/1	49												
		21	21	18	15	14	12	13	10	9	6	7	2
23/1	54												
		25	25	22	21	20	16	16	13	13	10	11	8
29/1	60												
		25	25	25	25	25	22	21	19	17	15	15	12
5/2	67												
		21	19	17	14	14	11	12	9	9	5	6	0
10/2	72												
		25	25	25	22	20	17	16	14	14	11	12	9
16/2	78												
		25	22	21	20	20	16	16	14	14	11	12	9
21/2	83												
		25	25	25	22	21	21	20	17	16	14	15	13
27/2	89												
		25	25	25	25	25	22	21	19	16	14	15	12
5/3	95												
		25	25	25	25	25	25	25	25	25	25	25	25
10/4	131												
		20	17	15	13	13	10	11	8	8	4	6	0
14/4	135												
		25	25	25	25	25	25	25	25	25	23	25	22
29/4	150												
		20	17	15	13	13	11	11	8	8	4	6	0
3/5	154												
		21	19	18	16	15	12	13	10	9	5	6	0
7/5	158												
		25	22	21	20	20	16	16	14	14	11	12	9
12/5	163												
		0	0	0	0	0	0	0	0	0	0	0	0
15/5	166												
		25	25	25	22	21	20	20	17	16	14	15	13

TABLE 2 (Continued)

Chlorinity limit hours lost		*0.1 ppt*		*0.2 ppt*		*0.35 ppt*		*0.5 ppt*		*0.8 ppt*		*1.0 ppt*	
Date	*Time in days from 1/12*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*
21/5	172	25	25	25	23	22	21	20	18	16	14	15	12
27/5	178	11	8	8	3	5	0	0	0	0	0	0	0
30/5	181	14	11	11	8	9	4	6	0	0	0	0	0
6/6	188	18	15	14	12	12	8	9	6	6	0	5	0
10/6	192	25	25	25	22	21	18	18	15	14	12	13	10
17/6	199	25	25	25	25	25	22	23	21	19	16	16	14
25/6	207	15	13	13	10	9	6	6	0	0	0	0	0
28/6	210	25	25	25	25	25	22	21	19	16	14	15	12
4/7	216	25	25	25	25	25	25	25	25	25	22	21	21
13/7	225	25	23	21	21	20	16	16	14	14	11	12	9
18/7	230	10	6	6	0	0	0	0	0	0	0	0	0
21/7	233	6	0	0	0	0	0	0	0	0	0	0	0
28/7	240	9	5	5	0	0	0	0	0	0	0	0	0
1/8	244	8	4	5	0	0	0	0	0	0	0	0	0
5/8	248	0	0	0	0	0	0	0	0	0	0	0	0
8/8	251	12	9	9	5	6	0	5	0	0	0	0	0
17/8	260	0	0	0	0	0	0	0	0	0	0	0	0
18/8	261	7	2	0	0	0	0	0	0	0	0	0	0
20/8	263	14	12	12	9	9	5	6	0	0	0	0	0
23/8	266	25	22	20	17	16	14	14	11	11	8	10	6
28/8	271	21	21	18	15	14	12	13	10	9	5	6	0

TABLE 2 (Continued)

Chlorinity limit *hours lost*		*0.1 ppt* *max*	*min*	*0.2 ppt* *max*	*min*	*0.35 ppt* *max*	*min*	*0.5 ppt* *max*	*min*	*0.8 ppt* *max*	*min*	*1.0 ppt* *max*	*min*
1/9	275												
		9	5	5	0	0	0	0	0	0	0	0	0
4/9	278												
		8	3	0	0	0	0	0	0	0	0	0	0
6/9	280												
		7	0	0	0	0	0	0	0	0	0	0	0
9/9	283												
		17	15	14	11	11	8	9	5	5	0	0	0
13/9	287												
		6	0	0	0	0	0	0	0	0	0	0	0
15/9	289												
		15	12	12	9	9	5	6	0	0	0	0	0
18/9	292												
		8	3	0	0	0	0	0	0	0	0	0	0
20/9	294												
		14	12	12	9	9	5	6	0	0	0	0	0
23/9	297												
		0	0	0	0	0	0	0	0	0	0	0	0
25/9	299												
		7	2	0	0	0	0	0	0	0	0	0	0
27/9	301												
		0	0	0	0	0	0	0	0	0	0	0	0
5/10	309												
		14	11	11	7	8	3	5	0	0	0	0	0
9/10	313												
		0	0	0	0	0	0	0	0	0	0	0	0
18/10	322												
		5	0	0	0	0	0	0	0	0	0	0	0
21/10	325												
		0	0	0	0	0	0	0	0	0	0	0	0
30/11	365												

TABLE 3 PUMPING HOURS LOST AT KOBAT

Run 2: 1 in 5 year drought. Abstractions of 8 mgD at 10.9 miles, 2 mGD at 20.0 miles. See Table 1 for abstraction at 15 miles.

Chlorinity limit hours lost		*0.1 ppt*		*0.2 ppt*		*0.35 ppt*		*0.5 ppt*		*0.8 ppt*		*1.0 ppt*	
Date	*Time in days after 1/12*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*
1/12	0												
		0	0	0	0	0	0	0	0	0	0	0	0
28/12	28												
		6	0	0	0	0	0	0	0	0	0	0	0
1/1	32												
		25	22	20	17	16	13	14	11	11	8	9	6
6/1	37												
		13	10	9	6	6	0	4	0	0	0	0	0
9/1	40												
		15	12	12	9	9	5	6	0	0	0	0	0
12/1	43												
		0	0	0	0	0	0	0	0	0	0	0	0
16/1	47												
		10	7	8	3	5	0	0	0	0	0	0	0
21/1	52												
		25	22	20	17	16	13	14	11	11	8	9	6
27/1	58												
		0	0	0	0	0	0	0	0	0	0	0	0
30/1	61												
		9	5	5	0	0	0	0	0	0	0	0	0
6/2	68												
		14	12	12	9	9	5	6	0	0	0	0	0
10/2	72												
		23	22	20	16	15	12	13	11	10	7	4	9
16/2	78												
		25	25	24	22	20	17	16	14	13	11	12	9
22/2	84												
		20	21	18	15	14	12	13	10	9	5	7	1
27/2	89												
		25	25	25	22	21	20	20	17	15	12	14	11
6/3	96												
		25	25	25	25	25	22	23	22	20	17	18	16
13/3	103												
		25	25	25	25	25	25	25	22	21	18	19	16
20/3	110												
		25	25	25	25	25	25	25	22	20	18	19	16
27/3	117												
		21	19	18	15	15	12	13	10	9	6	7	0
31/3	121												
		25	25	25	22	22	21	21	18	17	15	15	13

TABLE 3 (Continued)

Chlorinity limit hours lost		*0.1 ppt max*	*min*	*0.2 ppt max*	*min*	*0.35 ppt max*	*min*	*0.5 ppt max*	*min*	*0.8 ppt max*	*min*	*1.0 ppt max*	*min*
Date	*Time in days after 1/12*												
6/4	127												
		25	25	25	25	25	25	25	22	21	21	21	18
13/4	134												
		25	25	23	22	20	17	17	15	14	11	13	10
18/4	139												
		6	0	0	0	0	0	0	0	0	0	0	0
20/4	141												
		15	12	12	9	9	4	6	0	0	0	0	0
23/4	144												
		0	0	0	0	0	0	0	0	0	0	0	0
29/4	150												
		20	18	16	14	14	11	12	9	9	4	6	0
3/5	154												
		0	0	0	0	0	0	0	0	0	0	0	0
6/5	157												
		18	15	14	11	11	8	9	6	6	0	5	0
11/5	162												
		0	0	0	0	0	0	0	0	0	0	0	0
16/5	167												
		25	25	22	21	19	16	16	13	13	10	11	8
22/5	173												
		25	25	25	25	25	23	25	22	20	17	18	15
29/5	180												
		25	25	25	22	20	17	17	15	14	11	13	10
7/6	189												
		25	25	22	21	19	16	15	13	13	10	11	8
13/6	195												
		0	0	0	0	0	0	0	0	0	0	0	0
17/6	199												
		19	16	15	12	12	9	10	7	7	2	6	0
21/6	203												
		0	0	0	0	0	0	0	0	0	0	0	0
23/6	205												
		13	10	10	7	7	2	5	0	0	0	0	0
26/6	208												
		25	22	20	21	19	16	16	14	14	11	12	9
1/7	213												
		7	1	5	0	0	0	0	0	0	0	0	0
8/7	220												
		0	0	0	0	0	0	0	0	0	0	0	0
13/7	225												
		17	15	14	11	11	8	9	5	5	0	0	0

TABLE 3 (Continued)

Chlorinity limit hours lost		*0.1 pptl max*	*min*	*0.2 ppt max*	*min*	*0.35 ppt max*	*min*	*0.5 ppt max*	*min*	*0.8 ppt max*	*min*	*1.0 ppt max*	*min*
21/7	233												
		20	17	16	13	14	11	12	9	9	5	6	0
25/7	237												
		25	25	25	25	25	22	22	21	20	17	18	15
1/8	244												
		25	25	25	25	23	21	20	18	16	14	15	12
7/8	250												
		25	25	25	25	25	25	25	25	22	21	21	18
15/8	258												
		6	0	0	0	0	0	0	0	0	0	0	0
19/8	262												
		0	0	0	0	0	0	0	0	0	0	0	0
22/8	265												
		7	1	0	0	0	0	0	0	0	0	0	0
24/8	267												
		0	0	0	0	0	0	0	0	0	0	0	0
10/9	284												
		5	0	0	0	0	0	0	0	0	0	0	0
16/9	290												
		0	0	0	0	0	0	0	0	0	0	0	0
26/9	300												
		15	12	14	12	14	11	13	10	0	0	0	0
1/10	305												
		0	0	0	0	0	0	0	0	0	0	0	0
30/11	365												

TABLE 4 PUMPING HOURS LOST AT KOBAT

Run 3: 1 in 50 year drought. Abstractions of 23 mGD at 10.9 miles, 10 mGD at 15 miles, 2 mGD at 20.0 miles.

Chlorinity limit hours lost		*0.1 ppt*		*0.2 ppt*		*0.35 ppt*		*0.5 ppt*		*0.8 ppt*		*1.0 ppt*	
Date	*Days from start 1/12*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*
1/12	0	0	0	0	0	0	0	0	0	0	0	0	0
2/1	33	10	7	7	2	5	0	0	0	0	0	0	0
5/1	36	12	9	9	5	5	0	0	0	0	0	0	0
9/1	40	25	22	20	17	15	13	14	11	11	8	9	5
15/1	46	25	25	25	25	21	21	20	17	15	13	14	11
22/1	53	15	13	13	10	10	6	7	2	5	0	0	0
25/1	56	14	12	13	10	10	6	6	0	0	0	0	0
28/1	59	25	25	25	25	25	25	25	25	22	21	21	18
7/2	69	25	25	25	25	25	25	25	25	25	25	25	25
1/4	122	25	25	25	25	25	25	25	25	25	25	25	22
7/4	128	25	25	25	25	25	25	25	25	25	25	25	23
17/4	138	25	25	25	25	25	25	25	25	25	25	25	25
29/4	150	25	25	25	22	21	18	19	16	15	12	14	11
3/5	154	25	25	25	25	25	25	25	22	21	19	20	17
10/5	161	25	22	21	19	18	15	15	12	12	9	11	7
17/5	168	25	25	25	23	22	21	20	18	17	15	15	13
23/5	174	9	6	6	0	0	0	0	0	0	0	0	0
25/5	176	21	19	17	15	14	11	12	9	9	5	6	0
29/5	180	12	9	9	6	6	0	5	0	0	0	0	0
4/6	186	25	25	25	25	25	22	24	22	20	17	19	16

TABLE 4 (Continued)

Chlorinity limit hours lost		*0.1 ppt*		*0.2 ppt*		*0.35 ppt*		*0.5 ppt*		*0.8 ppt*		*1.0 ppt*	
Date	*Days from start 1/12*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*
11/6	193	25	22	21	21	20	17	17	15	14	12	13	10
16/6	198	25	25	25	25	25	25	25	25	25	25	25	22
26/6	208	25	25	25	25	25	22	21	20	18	15	15	13
3/7	215	22	21	19	16	15	12	13	10	10	6	8	3
7/7	219	25	25	25	22	20	17	16	14	14	11	12	9
12/7	224	0	0	0	0	0	0	0	0	0	0	0	0
14/7	226	15	12	12	9	9	5	6	0	0	0	0	0
17/7	229	25	22	21	20	19	16	16	13	13	10	12	9
22/7	234	25	25	23	22	20	17	18	15	14	12	13	10
27/7	239	0	0	0	0	0	0	0	0	0	0	0	0
28/7	240	25	25	25	22	20	18	16	14	13	11	12	9
2/8	245	21	20	18	15	14	12	13	10	10	6	8	3
6/8	249	0	0	0	0	0	0	0	0	0	0	0	0
7/8	250	25	22	21	19	17	15	15	12	13	10	12	9
12/8	255	0	0	0	0	0	0	0	0	0	0	0	0
14/8	257	7	2	0	0	0	0	0	0	0	0	0	0
16/8	259	0	0	0	0	0	0	0	0	0	0	0	0
17/8	260	20	17	15	13	13	10	11	8	8	3	6	0
21/8	264	0	0	0	0	0	0	0	0	0	0	0	0
24/8	267	15	12	12	9	9	5	6	0	0	0	0	0
27/8	270	21	19	17	15	14	12	13	10	9	5	6	0

TABLE 4 (Continued)

Chlorinity limit hours lost		*0.1 ppt*		*0.2 ppt*		*0.35 ppt*		*0.5 ppt*		*0.8 ppt*		*1.0 ppt*	
Date	*Days from start 1/12*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*
31/8	274												
		11	8	8	3	5	0	0	0	0	0	0	0
3/9	277												
		16	14	13	10	9	6	6	0	0	0	0	0
6/9	280												
		13	10	10	6	7	0	5	0	0	0	0	0
10/9	284												
		15	12	13	10	9	6	6	0	0	0	0	0
13/9	287												
		8	3	0	0	0	0	0	0	0	0	0	0
15/9	289												
		15	12	12	9	9	5	6	0	0	0	0	0
18/9	292												
		9	4	5	0	0	0	0	0	0	0	0	0
20/9	294												
		15	12	13	10	10	7	8	3	5	0	0	0
23/9	297												
		0	0	0	0	0	0	0	0	0	0	0	0
25/9	299												
		7	2	0	0	0	0	0	0	0	0	0	0
27/9	301												
		0	0	0	0	0	0	0	0	0	0	0	0
26/10	330												
		25	25	25	25	0	0	0	0	0	0	0	0
29/10	333												
		25	25	25	25	25	25	0	0	0	0	0	0
1/11	336												
		0	0	0	0	0	0	0	0	0	0	0	0
4/11	339												
		25	25	25	25	25	25	25	25	0	0	0	0
8/11	343												
		25	25	25	25	0	0	0	0	0	0	0	0
12/11	347												
		0	0	0	0	0	0	0	0	0	0	0	0
30/11	365												

TABLE 5 PUMPING HOURS LOST AT 15 MILE INTAKE

Run 1: 1 in 20 year drought. Abstractions of 8 mGD at 10.9 miles, 2 mGD at 20.0 miles.

Chlorinity limit hours lost		*0.5 ppt*		*1.0 ppt*	
		max	*min*	*max*	*min*
Date	*Time after 1/12 days*				
1/12	0				
		0	0	0	0
5/3	95				
		13	8	0	0
16/3	106				
		14	11	9	0
28/3	118				
		15	13	11	4
10/4	131				
		0	0	0	0
14/4	135				
		9	0	0	0
29/4	150				
		0	0	0	0
30/11	365				

Run 3: 1 in 50 year drought. Abstraction of 23 mGD at 10.9 miles, 10 mGD at 15 miles, 2 mGD at 20 miles.

Chlorinity limit hours lost		*0.5 ppt*		*1.0 ppt*	
		max	*min*	*max*	*min*
Date	*Time after 1/12 days*				
1/12	0				
		0	0	0	0
7/2	69				
		14	11	0	0
21/2	83				
		20	20	16	15
12/3	102				
		25	25	25	21
1/4	122				
		0	0	0	0
7/4	129				
		13	8	0	0
17/4	139				
		16	14	10	2
29/4	151				
		0	0	0	0
16/6	189				
		9	0	0	0
26/6	199				
		0	0	0	0
30/11	365				

NB Run 2 (1 in 5 year drought) the 0.5 ppt limit is never reached.

TABLE 6 PUMPING HOURS LOST AT AN INTAKE AT 16 MILES

Run 4 Abstractions of 10 mGD at 15 miles, 23 mGD at 16 miles, 2 mGD at 20 miles.

Chlorinity limit		*0.1 ppt*		*0.2 ppt*		*0.35 ppt*		*0.5 ppt*		*0.8 ppt*		*1.0 ppt*	
hours lost		*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*
Date	*Days after 1/12*												
1/12	0												
		0	0	0	0	0	0	0	0	0	0	0	0
28/1	59												
		10	4	0	0	0	0	0	0	0	0	0	0
7/2	69												
		16	15	14	12	13	9	11	6	8	0	0	0
21/2	83												
		25	21	20	20	18	17	16	15	15	12	14	10
12/3	102												
		25	25	25	25	25	25	25	21	21	21	20	18
1/4	122												
		18	17	14	12	10	4	0	0	0	0	0	0
17/4	138												
		25	22	20	21	20	18	18	17	16	13	15	12
10/5	161												
		0	0	0	0	0	0	0	0	0	0	0	0
4/6	186												
		9	0	0	0	0	0	0	0	0	0	0	0
11/6	193												
		0	0	0	0	0	0	0	0	0	0	0	0
16/6	198												
		13	10	10	4	0	0	0	0	0	0	0	0
26/6	208												
		0	0	0	0	0	0	0	0	0	0	0	0
17/7	229												
		16	15	14	10	9	0	0	0	0	0	0	0
27/7	239												
		0	0	0	0	0	0	0	0	0	0	0	0
30/11	365												

TABLE 7 PUMPING HOURS LOST AT AN INTAKE AT 20 MILES

Run 5: Abstractions of 10 mGD at 15 miles, 23 mGD at 20 miles + 2 mGD at 20 miles.

Chlorinity limit hours lost		*0.1 ppt*		*0.2 ppt*		*0.35 ppt*		*0.5 ppt*		*0.8 ppt*		*1.0 ppt*	
		max	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*
Date	*Days after 1/12*												
1/12	0	0	0	0	0	0	0	0	0	0	0	0	0
12/3	102	10	6	0	0	0	0	0	0	0	0	0	0
1/4	122	0	0	0	0	0	0	0	0	0	0	0	0
30/11	365	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 8 PUMPING HOURS LOST AT THE AGRICULTURAL INTAKE

Run 4

Chlorinity limit hours lost		*0.5 ppt max*	*min*	*1.0 ppt max*	*min*
Date	*Days after 1/12*				
1/12	0				
		0	0	0	0
7/2	69				
		16	14	11	5
21/2	83				
		25	21	19	17
12/3	102				
		25	25	25	25
1/4	122				
		13	8	10	1
7/4	128				
		12	7	0	0
17/4	138				
		25	22	25	25
10/5	161				
		0	0	0	0
16/6	198				
		9	0	0	0
26/6	208				
		0	0	0	0
17/7	229				
		10	2	0	0
27/7	239				
		0	0	0	0
30/11	365				

Run 5

Chlorinity limit hours lost		*0.5 ppt max*	*min*	*1.0 ppt max*	*min*
Date	*Days after 1/12*				
1/12	0				
		0	0	0	0
7/2	69				
		16	14	11	5
21/2	83				
		25	21	18	17
12/3	102				
		25	25	25	25
1/4	122				
		13	8	10	0
7/4	128				
		12	6	0	0
17/4	138				
		25	25	22	21
10/5	162				
		0	0	0	0
16/6	198				
		9	0	0	0
26/6	208				
		0	0	0	0
17/7	229				
		10	2	0	0
27/7	239				
		0	0	0	0
30/11	365				

TABLE 9 PUMPING HOURS LOST FOR INTAKE AT 10.9 MILES

Run 6: 1 in 5 year drought. Abstractions of 8 mGD at 10.9 miles, 2 mGD at 20 miles

Chlorinity limit hours lost		*0.1 ppt*		*0.2 ppt*		*0.35 ppt*		*0.5 ppt*		*0.8 ppt*		*1.0 ppt*	
		max	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*
Date	*Days after 1/12*												
1/12	0	0	0	0	0	0	0	0	0	0	0	0	0
28/12	28	5	0	0	0	0	0	0	0	0	0	0	0
1/1	32	25	22	20	17	15	13	14	11	11	7	9	6
6/1	37	13	10	9	5	6	0	0	0	0	0	0	0
9/1	40	15	12	12	9	9	5	6	0	0	0	0	0
12/1	43	0	0	0	0	0	0	0	0	0	0	0	0
16/1	47	10	7	7	0	5	0	0	0	0	0	0	0
21/1	52	25	22	20	17	15	13	14	11	11	7	9	5
27/1	58	0	0	0	0	0	0	0	0	0	0	0	0
30/1	61	9	5	5	0	0	0	0	0	0	0	0	0
6/2	68	14	12	12	8	9	5	6	0	0	0	0	0
10/2	72	22	21	19	16	15	12	13	10	10	6	9	4
16/2	78	25	25	23	22	20	17	16	14	13	10	12	9
22/2	84	21	20	18	15	14	12	13	10	9	5	7	1
27/2	89	25	25	25	22	21	20	20	17	15	12	14	11
6/3	96	25	25	25	25	25	22	23	22	20	17	18	16
13/3	103	25	25	25	25	25	25	25	22	21	18	19	16
20/3	110	25	25	25	25	25	23	25	22	20	18	19	16
27/3	117	20	17	15	13	14	11	12	9	9	5	6	0
31/3	121	25	25	25	25	21	21	20	17	16	13	14	12

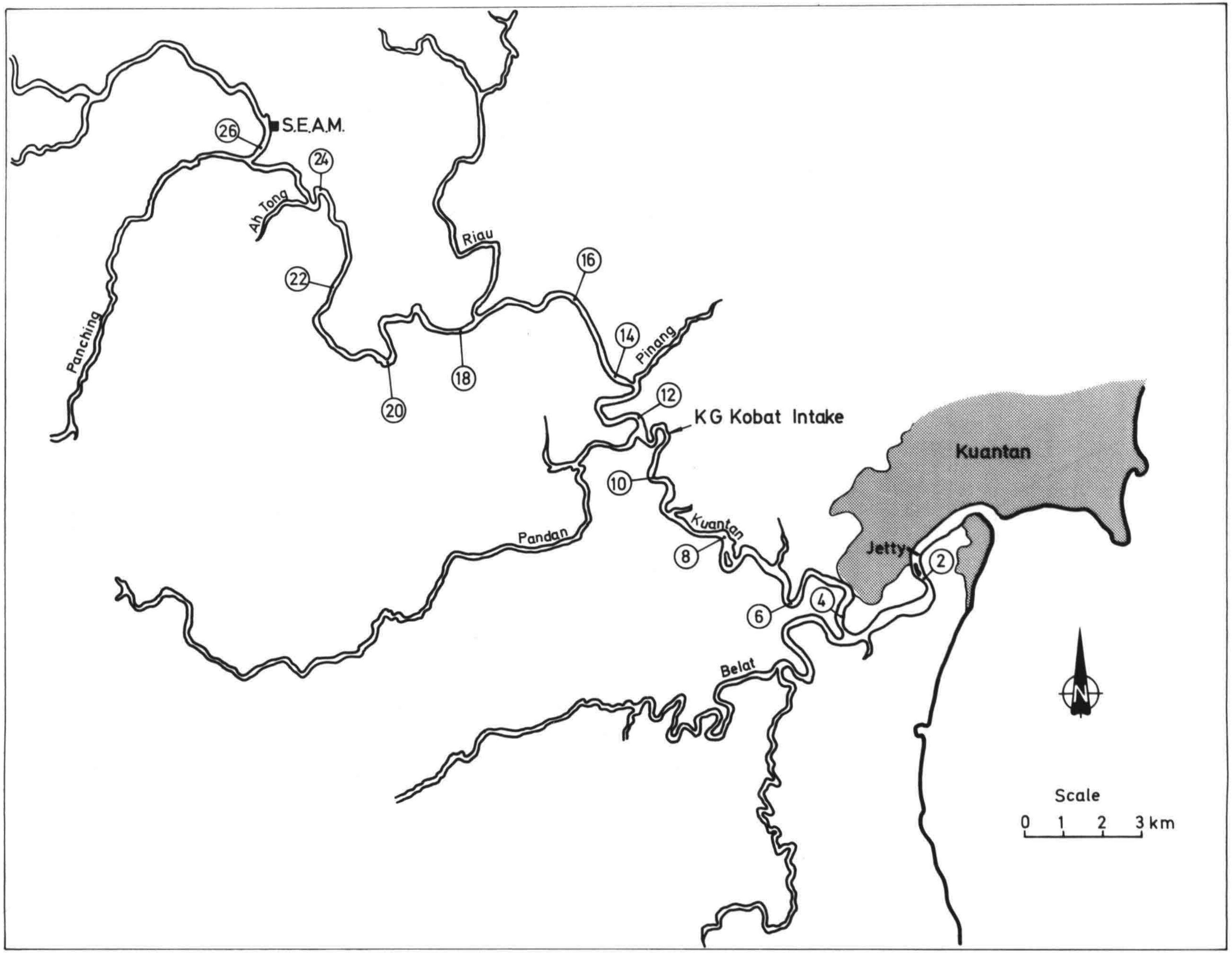
TABLE 9 (Continued)

Chlorinity limit hours lost		*0.1 ppt*		*0.2 ppt*		*0.35 ppt*		*0.5 ppt*		*0.8 ppt*		*1.0 ppt*	
Date	*Days after 1/12*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*
6/4	127	25	25	25	25	25	22	25	22	20	17	18	16
13/4	134	25	25	22	21	20	17	16	14	14	11	12	9
18/4	139	25	25	0	0	0	0	0	0	0	0	0	0
20/4	141	15	12	12	9	9	5	6	0	0	0	0	0
23/4	144	0	0	0	0	0	0	0	0	0	0	0	0
29/4	150	21	20	17	15	14	11	12	9	8	4	6	0
3/5	154	0	0	0	0	0	0	0	0	0	0	0	0
6/5	157	15	13	13	10	10	7	8	4	5	0	0	0
11/5	162	0	0	0	0	0	0	0	0	0	0	0	0
16/5	167	25	25	21	21	19	16	15	13	13	10	11	8
22/5	173	25	25	25	25	25	25	25	22	21	18	19	16
29/5	180	25	22	21	20	18	16	15	13	13	10	11	8
7/6	189	25	22	21	19	17	15	15	12	12	9	10	7
13/6	195	0	0	0	0	0	0	0	0	0	0	0	0
17/6	199	18	15	14	11	11	8	9	6	5	0	4	0
21/6	203	0	0	0	0	0	0	0	0	0	0	0	0
23/6	205	13	10	10	6	8	3	6	0	0	0	0	0
26/6	208	25	22	21	18	16	14	15	12	13	10	12	9
1/7	213	6	0	0	0	0	0	0	0	0	0	0	0
8/7	220	0	0	0	0	0	0	0	0	0	0	0	0
13/7	225	16	14	14	11	11	7	9	4	5	0	0	0

TABLE 9 (Continued)

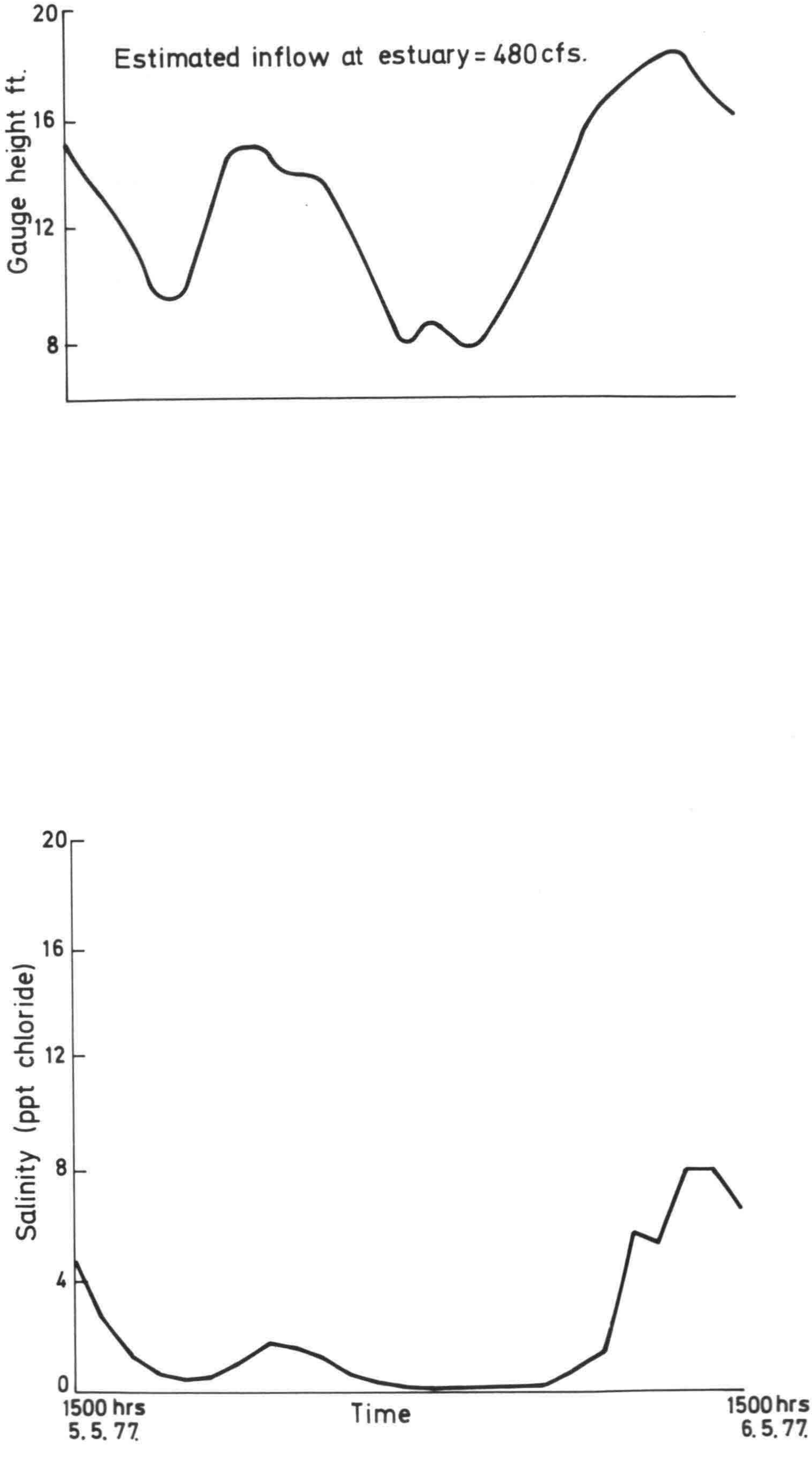
Chlorinity limit hours lost		*0.1 ppt*		*0.2 ppt*		*0.35 ppt*		*0.5 ppt*		*0.8 ppt*		*1.0 ppt*	
Date	*Days after 1/12*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*
17/7	229												
		17	14	14	11	11	8	9	5	5	0	0	0
21/7	233												
		20	17	15	13	14	11	12	9	9	5	6	0
25/7	237												
		25	25	25	25	25	22	22	21	20	17	18	15
1/8	244												
		25	25	25	25	23	22	21	18	16	14	15	12
7/8	250												
		25	25	25	25	25	25	25	25	23	22	21	19
15/8	258												
		6	0	0	0	0	0	0	0	0	0	0	0
19/8	262												
		0	0	0	0	0	0	0	0	0	0	0	0
22/8	265												
		7	1	0	0	0	0	0	0	0	0	0	0
24/8	267												
		0	0	0	0	0	0	0	0	0	0	0	0
10/9	284												
		5	0	0	0	0	0	0	0	0	0	0	0
16/9	290												
		0	0	0	0	0	0	0	0	0	0	0	0
26/9	300												
		11	8	9	5	5	0	0	0	0	0	0	0
1/10	305												
		0	0	0	0	0	0	0	0	0	0	0	0
30/11	365												

FIGURES



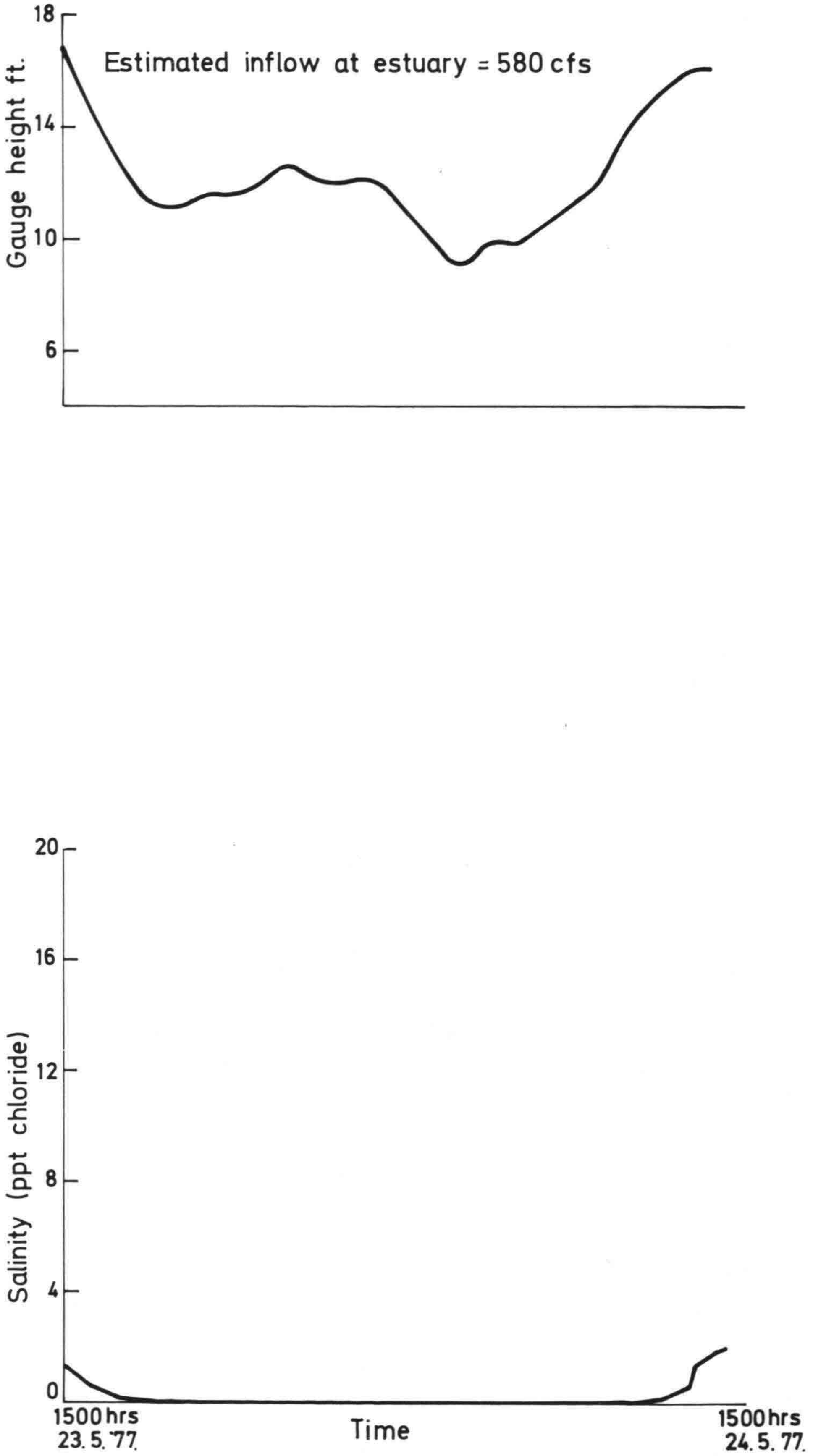
Sketch map of SG. Kuantan

Fig.1



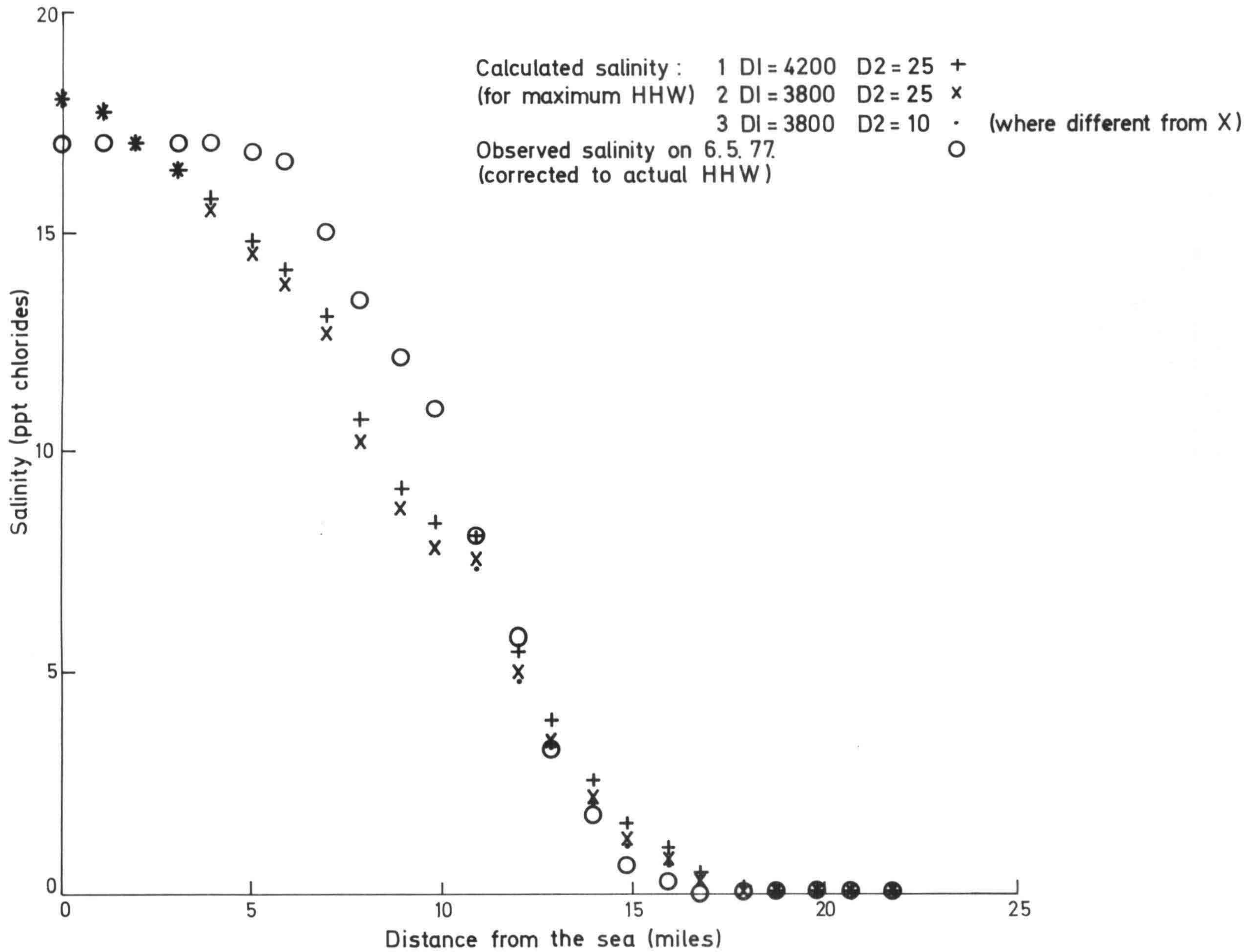
Existing salinity at JKR Kobat intake

Fig 2a



Existing salinity at JKR Kobat intake

Fig.2b



Longitudinal salinity profile

Fig.3

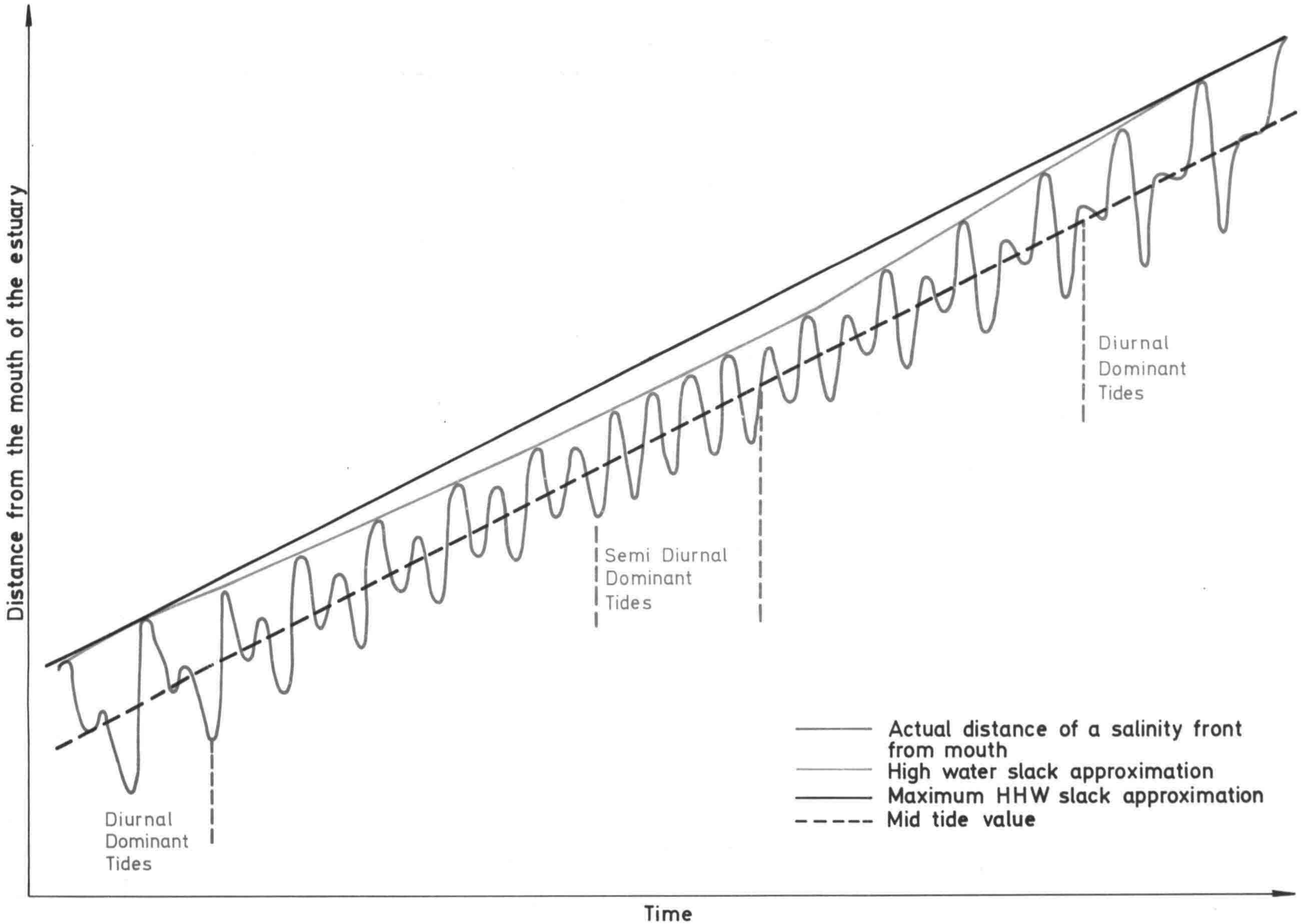


Fig.4

Movement of salinity by the high water slack approximation

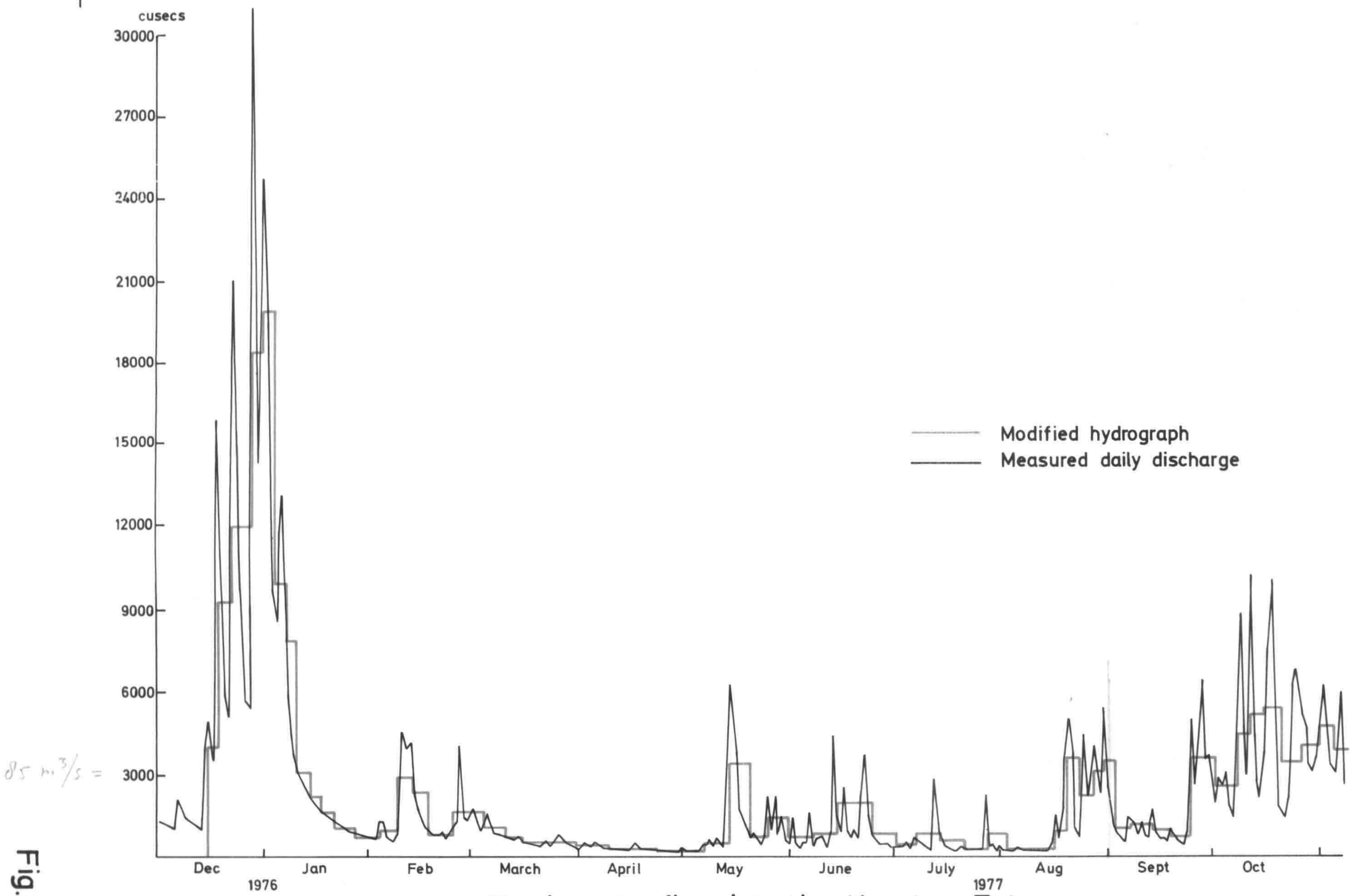
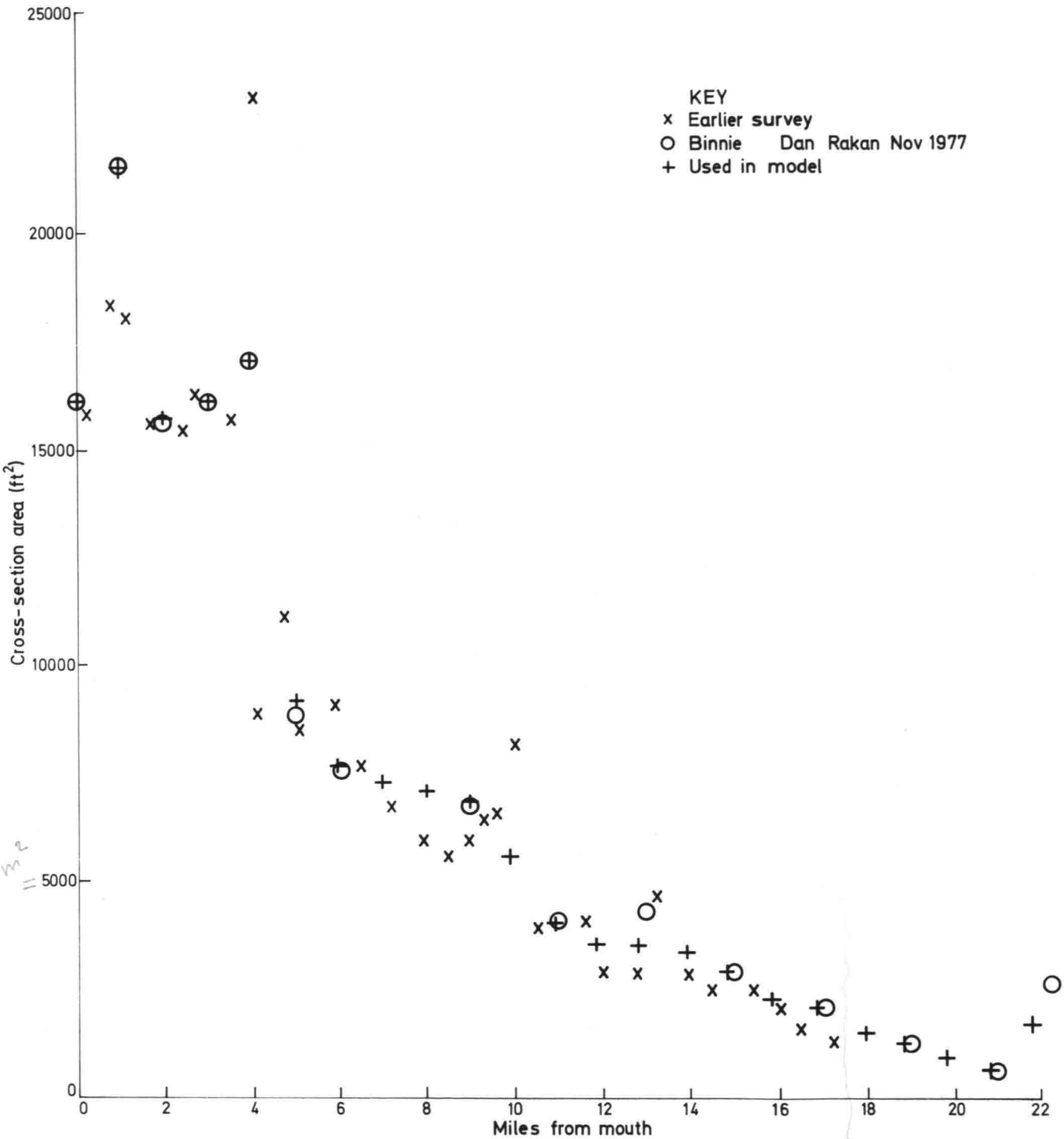


Fig.5

Fresh water flow into the Kuantan Estuary
December 1976 to November 1977



Cross-sectional areas

Fig.6

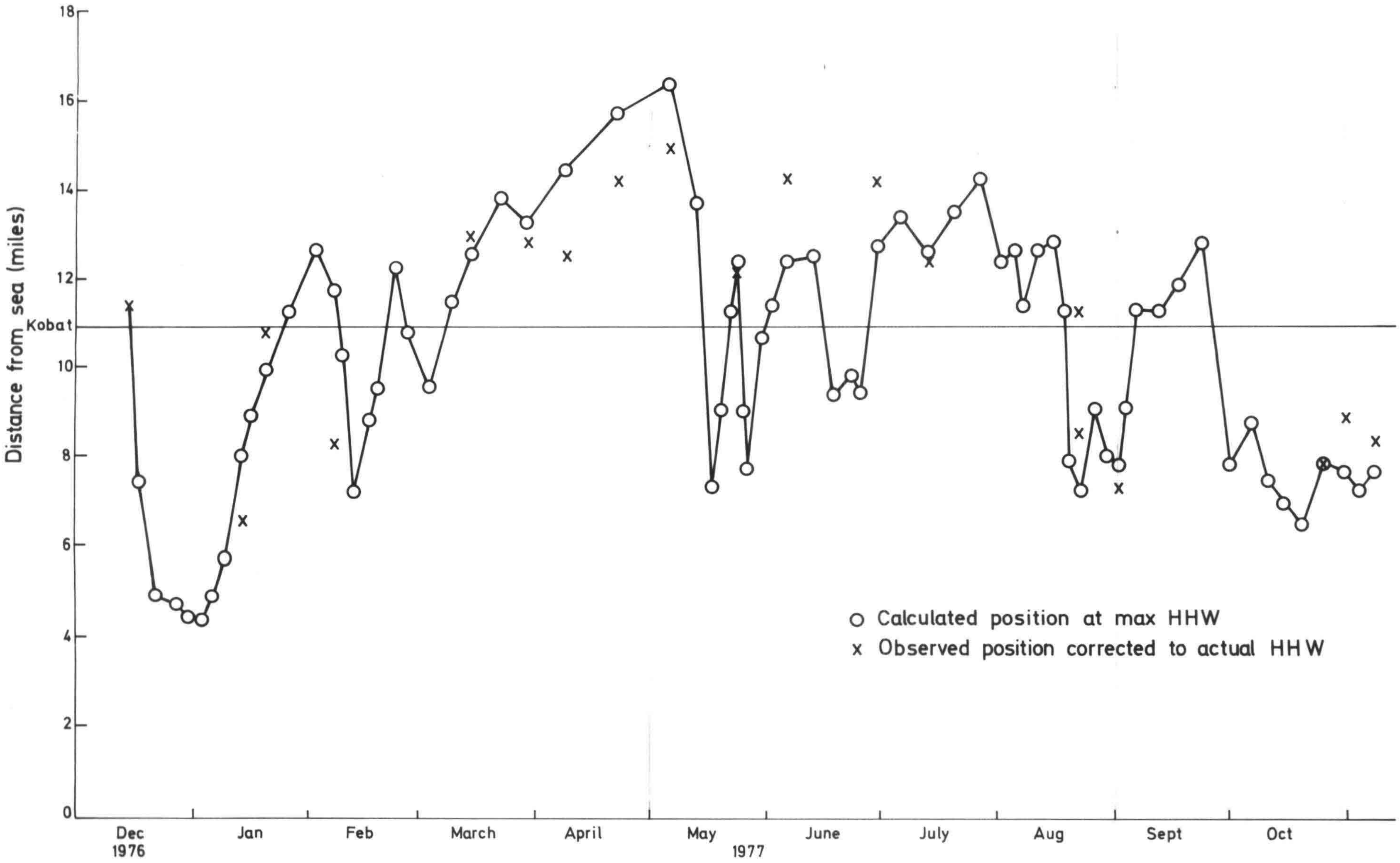


Fig.7

Movement of the 0·5ppt chlorinity front, proving

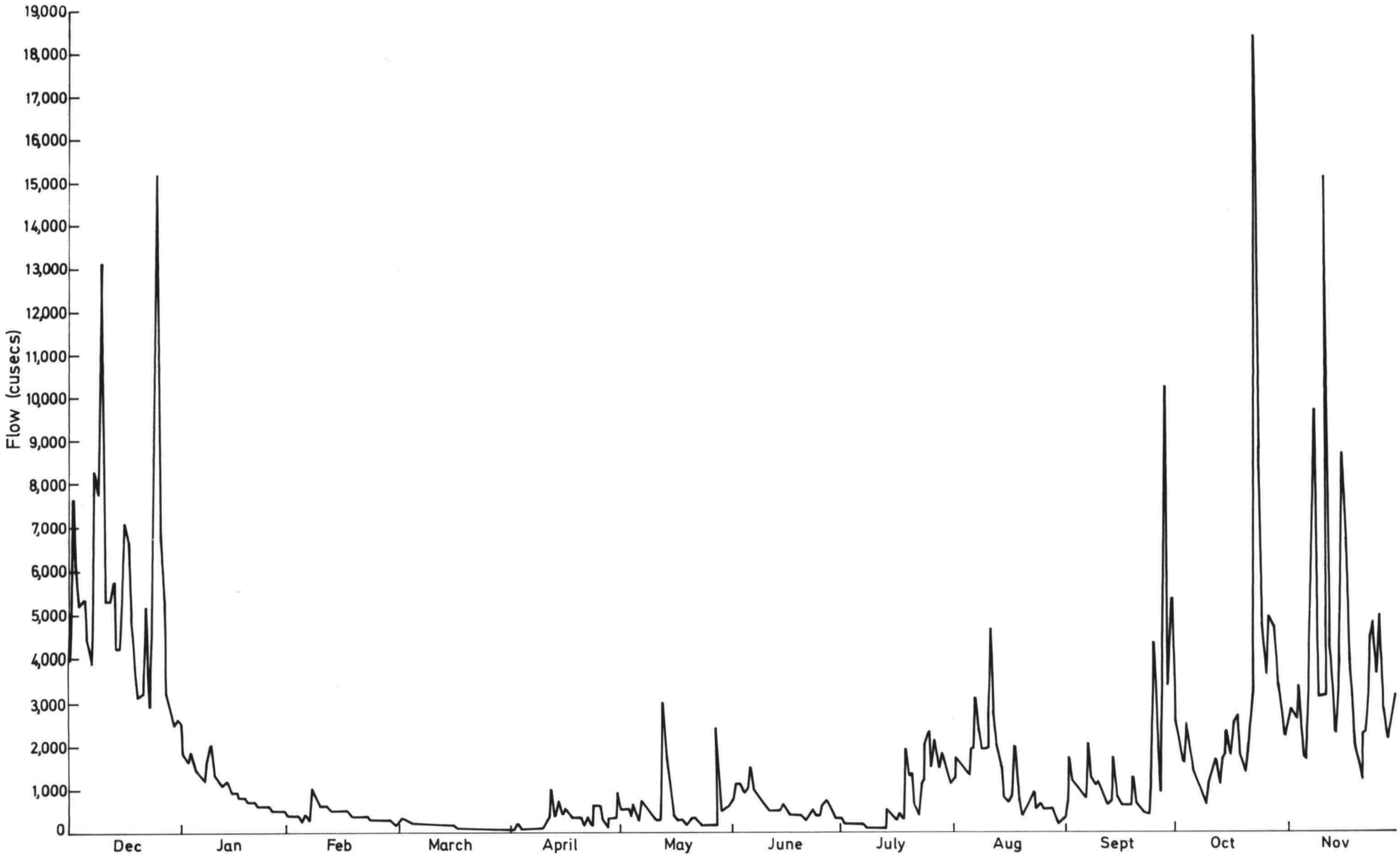
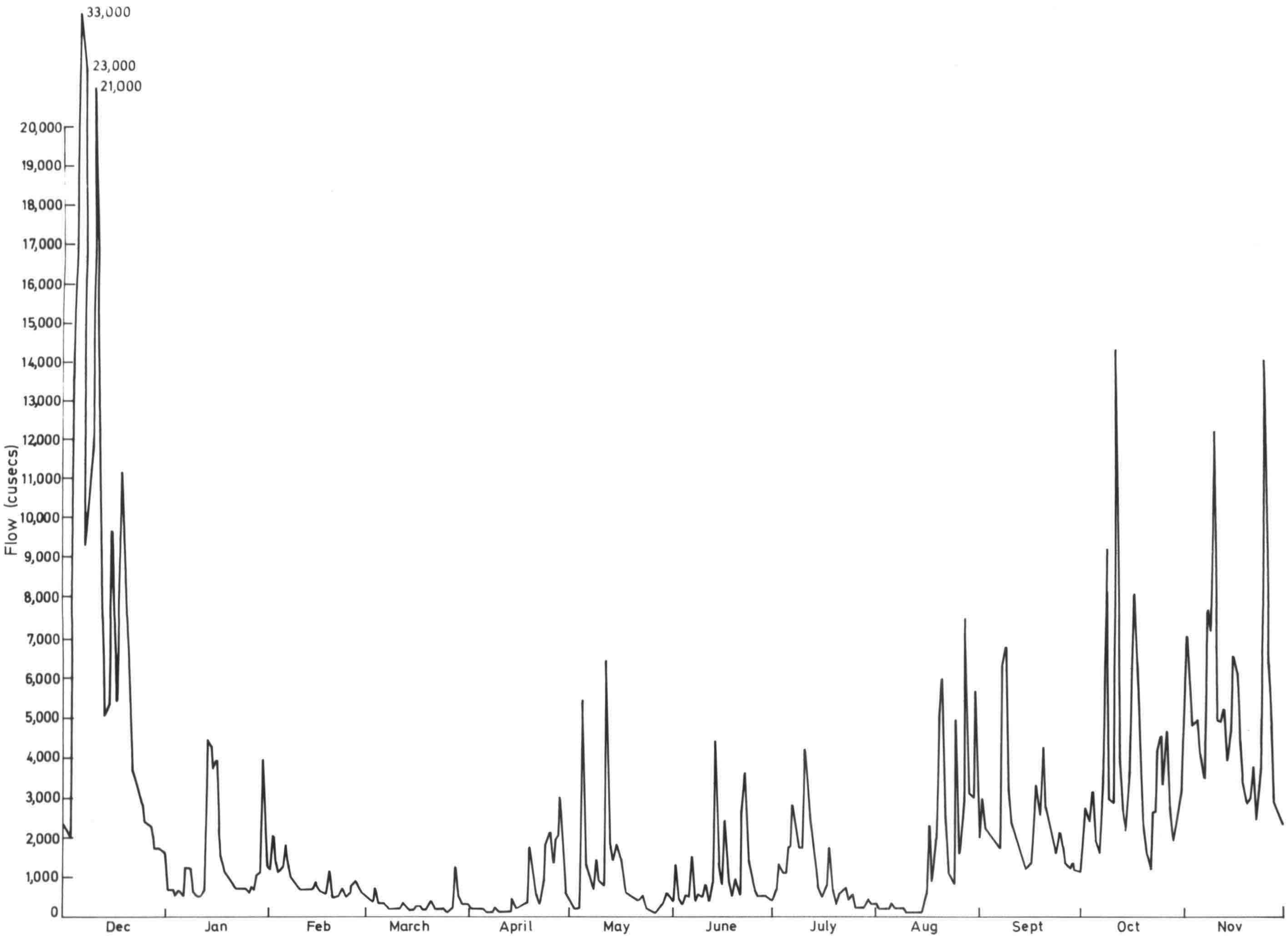


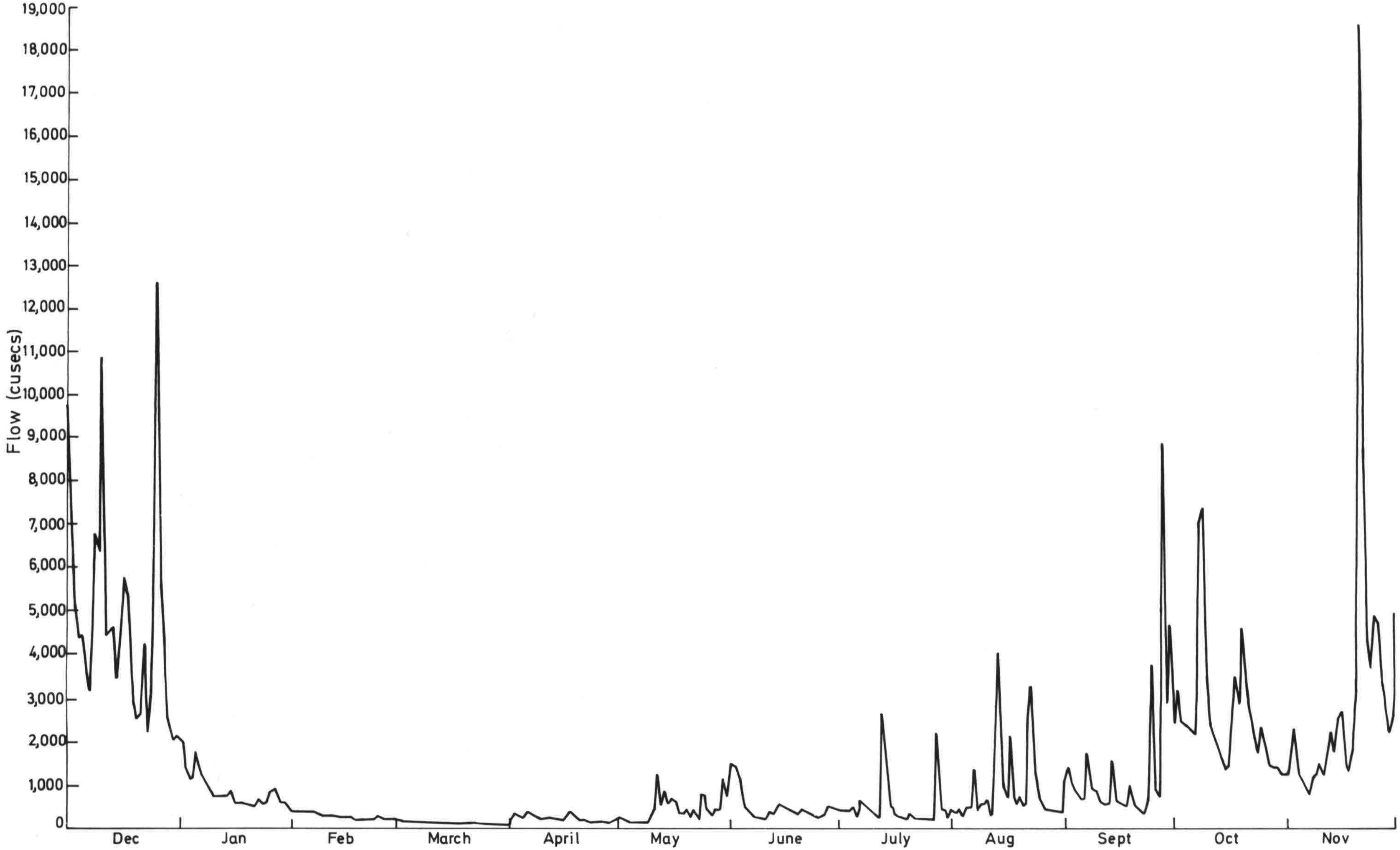
Fig. 8

Hydrograph for 1 in 20yr. drought (Total inflow)



Hydrograph for a 1 in 5yr. drought (Total inflow)

Fig.9



Hydrograph for 1 in 50yr drought (Total inflow)

Fig 10

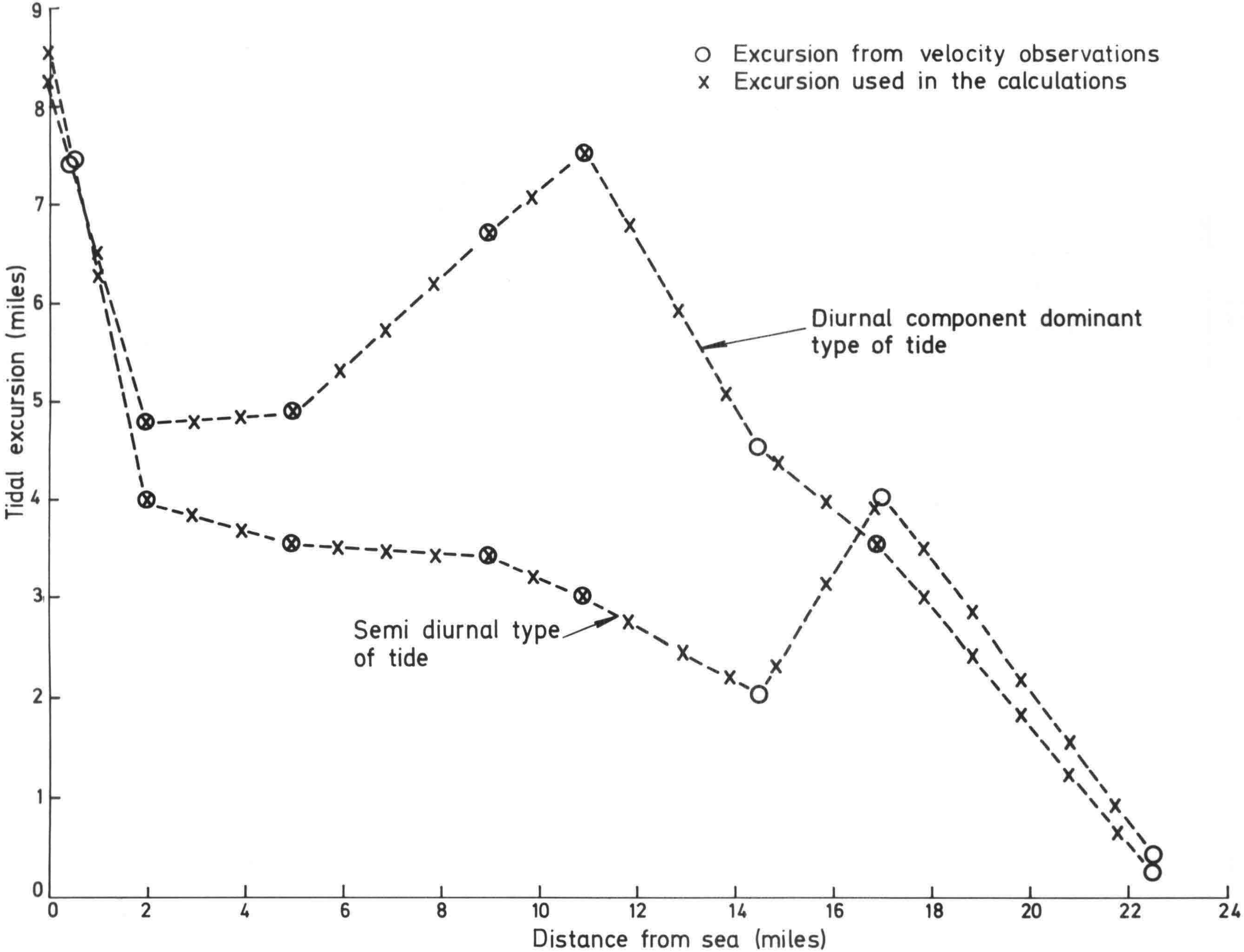


Fig.11

Variation of tidal excursion along the estuary

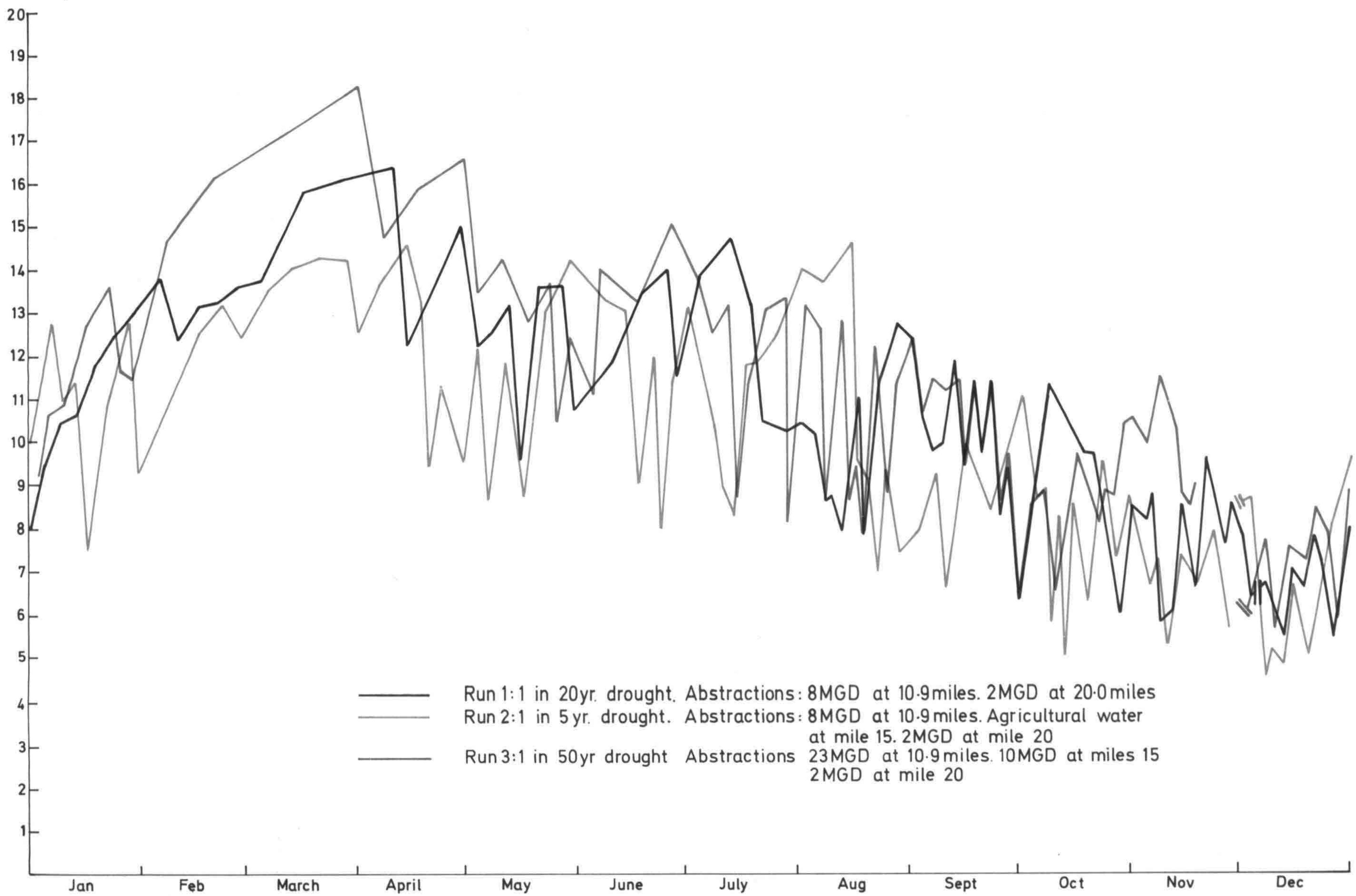


Fig.12

Movement of 0·5ppt. salinity front at maximum HHW

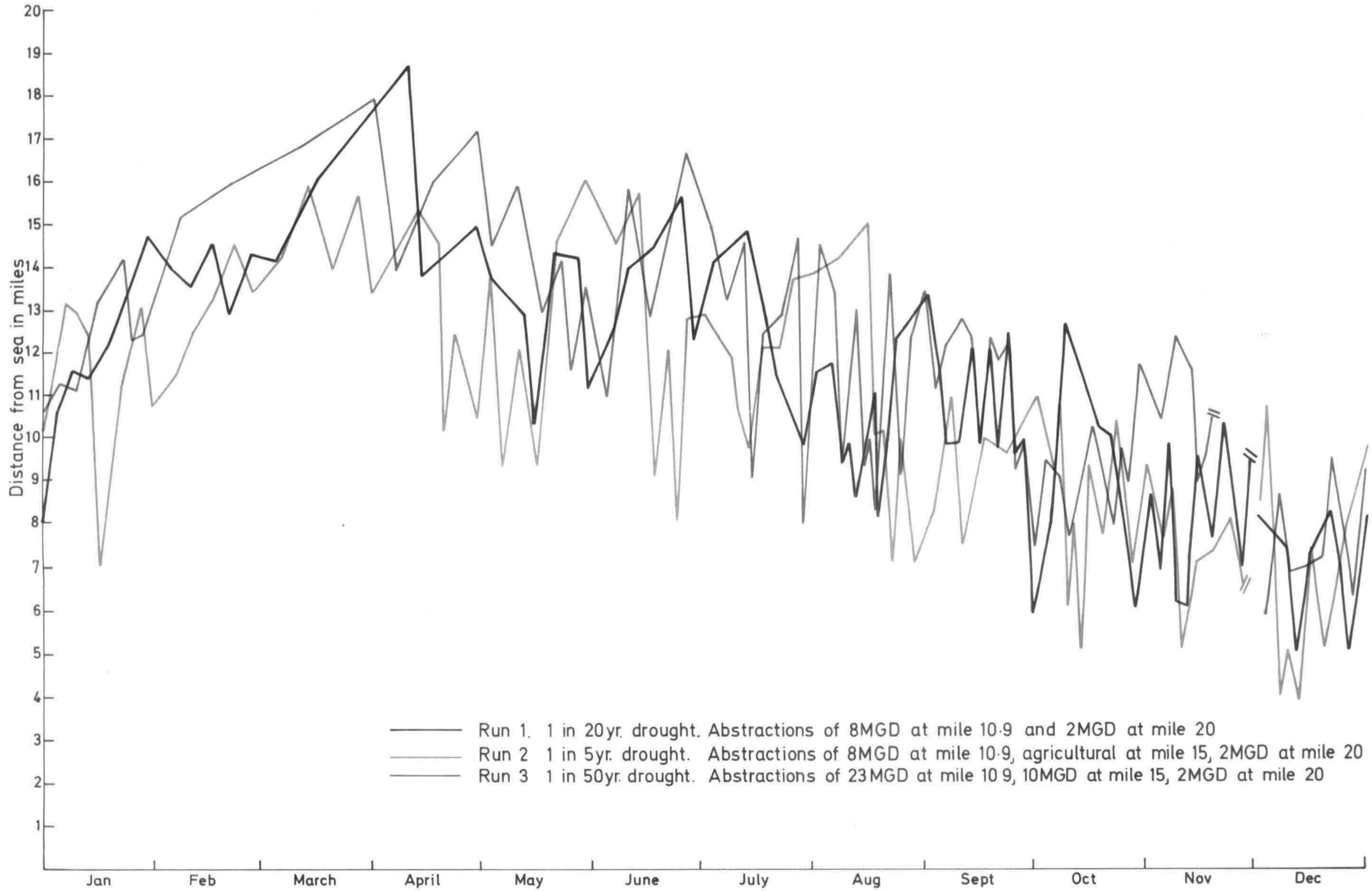


Fig 13

Movement of 0·2ppt salinity front at maximum HHW

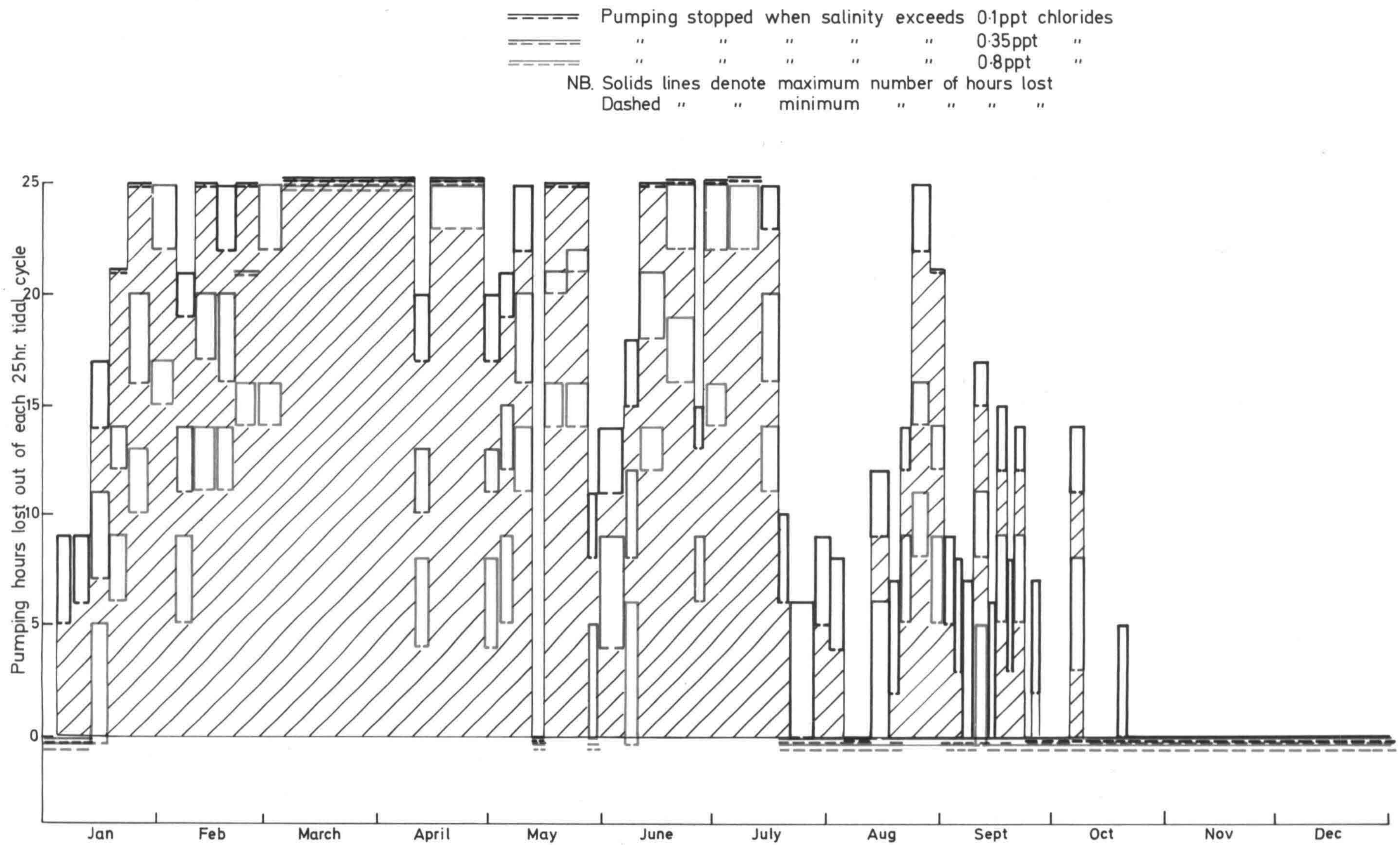
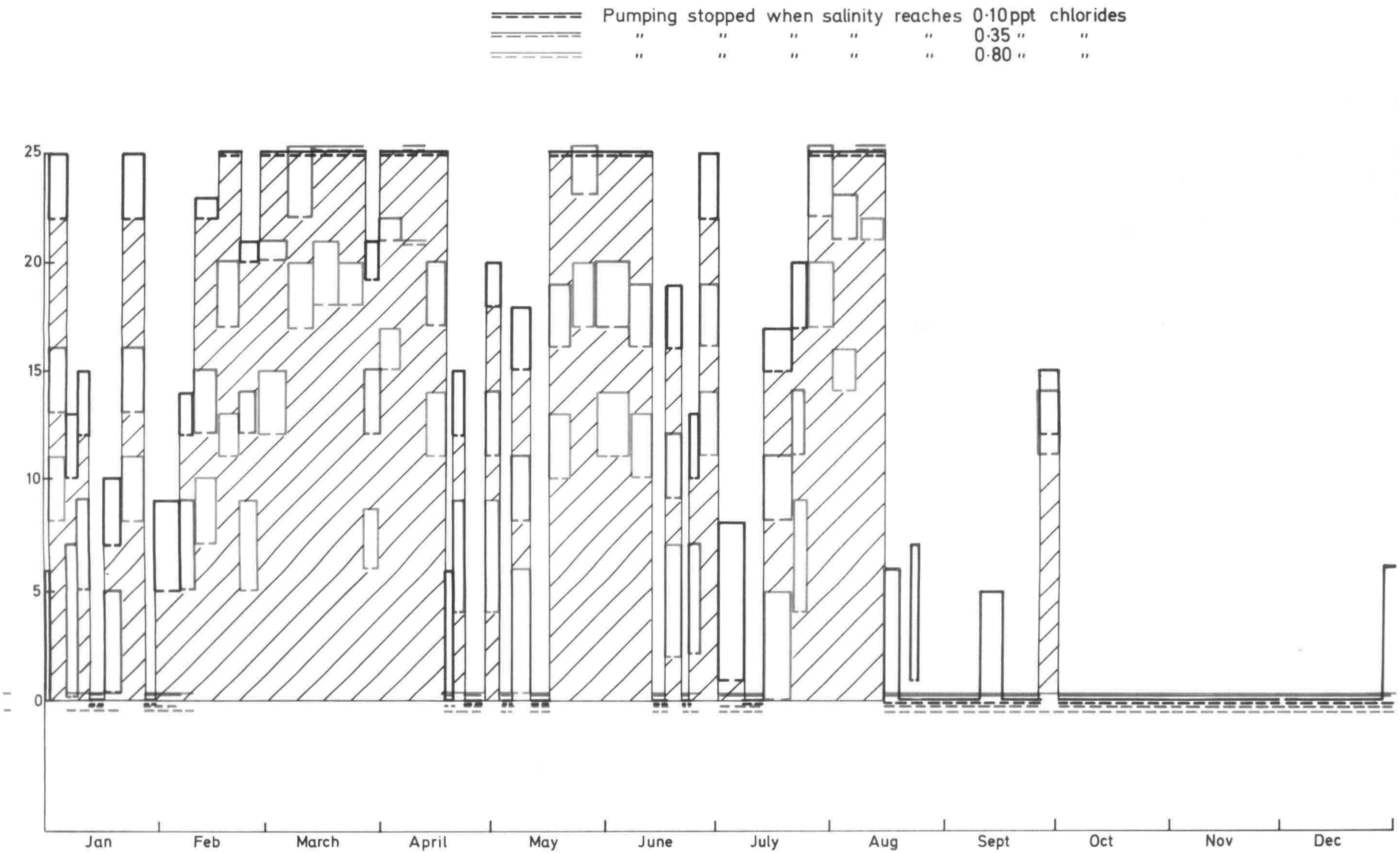


Fig.14

Run 1. Pumping hours lost at Kobat (10·9) miles 1 in 20yr. drought



Run 2. Pumping hours lost at Kobat (10·9 miles)

Fig.15

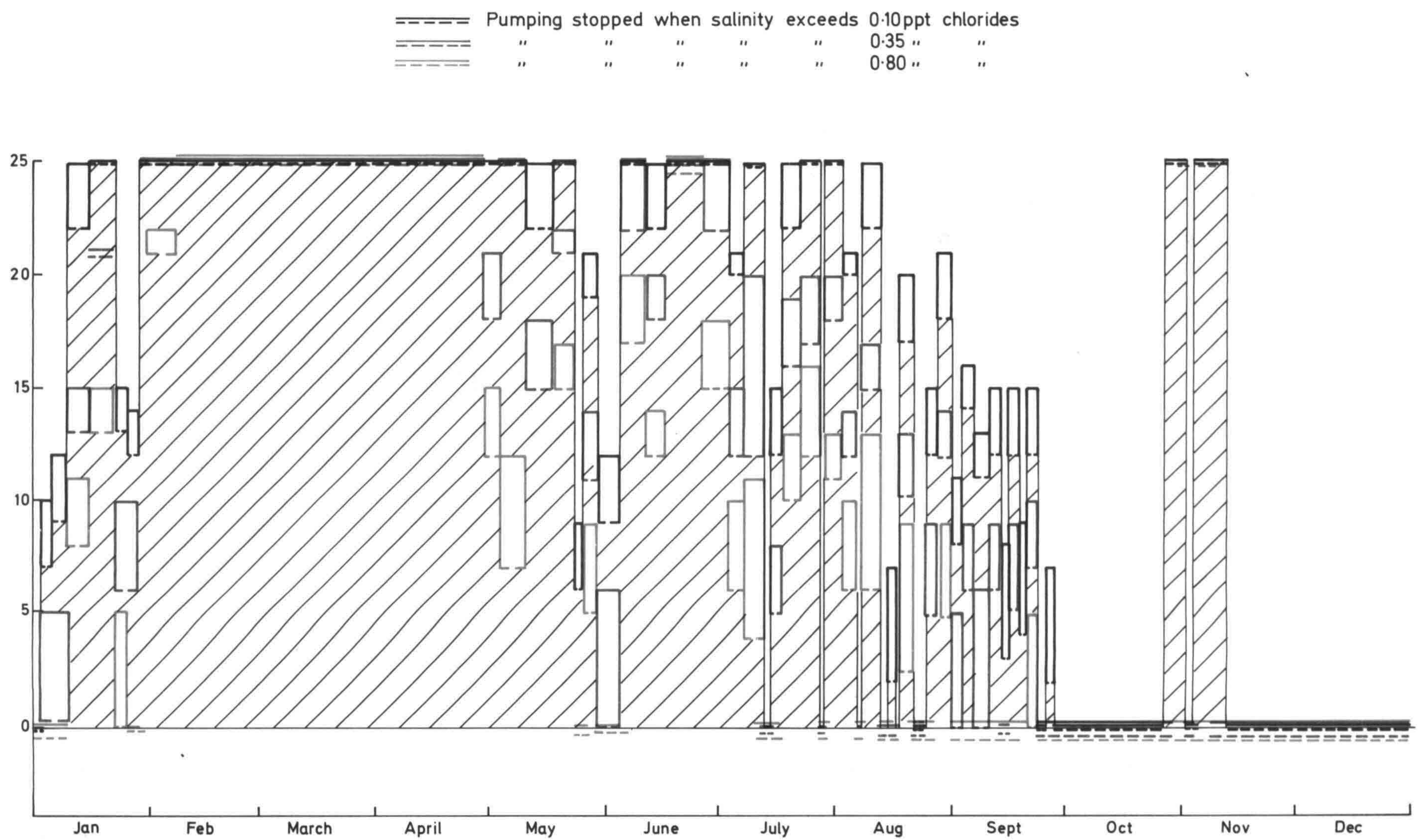
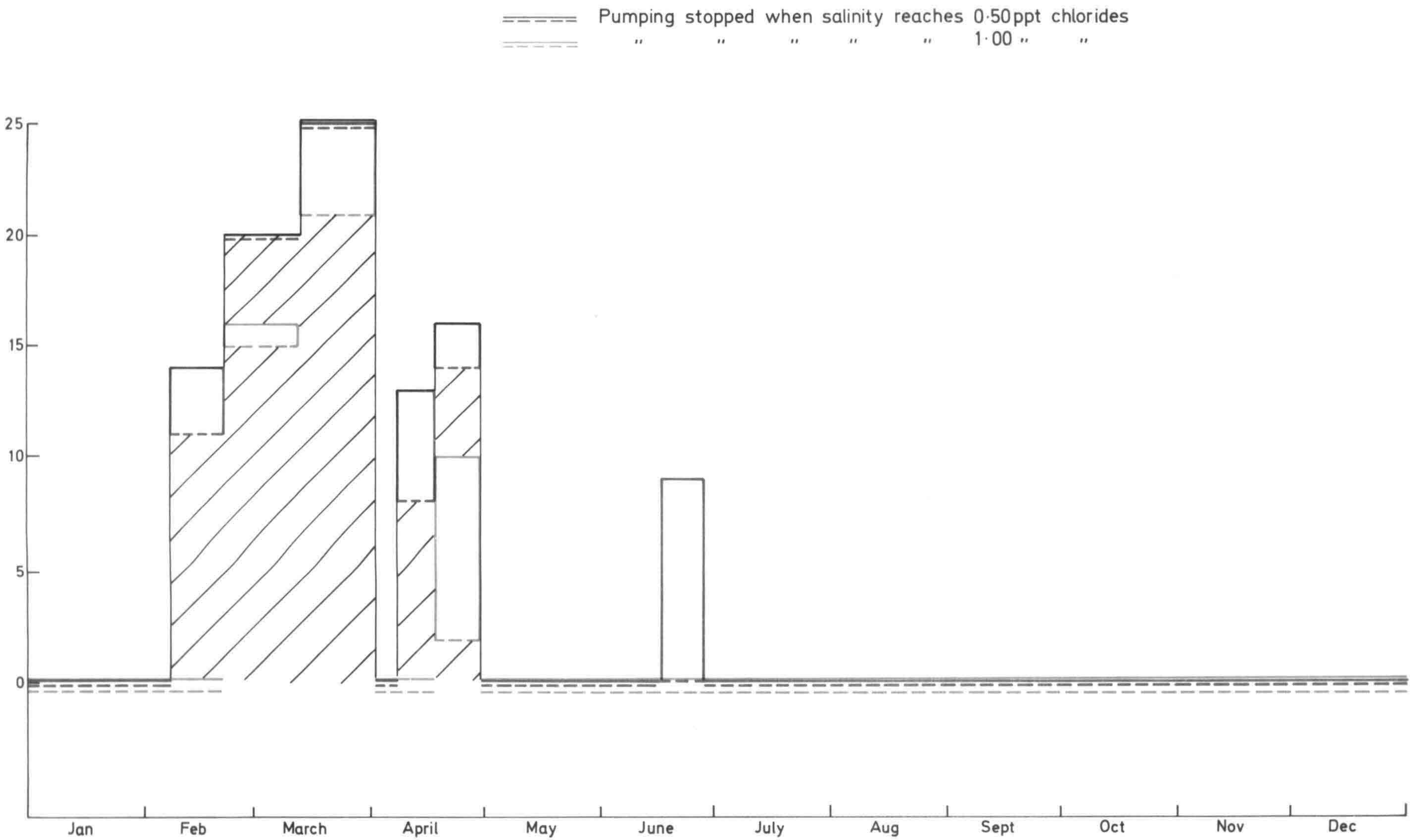


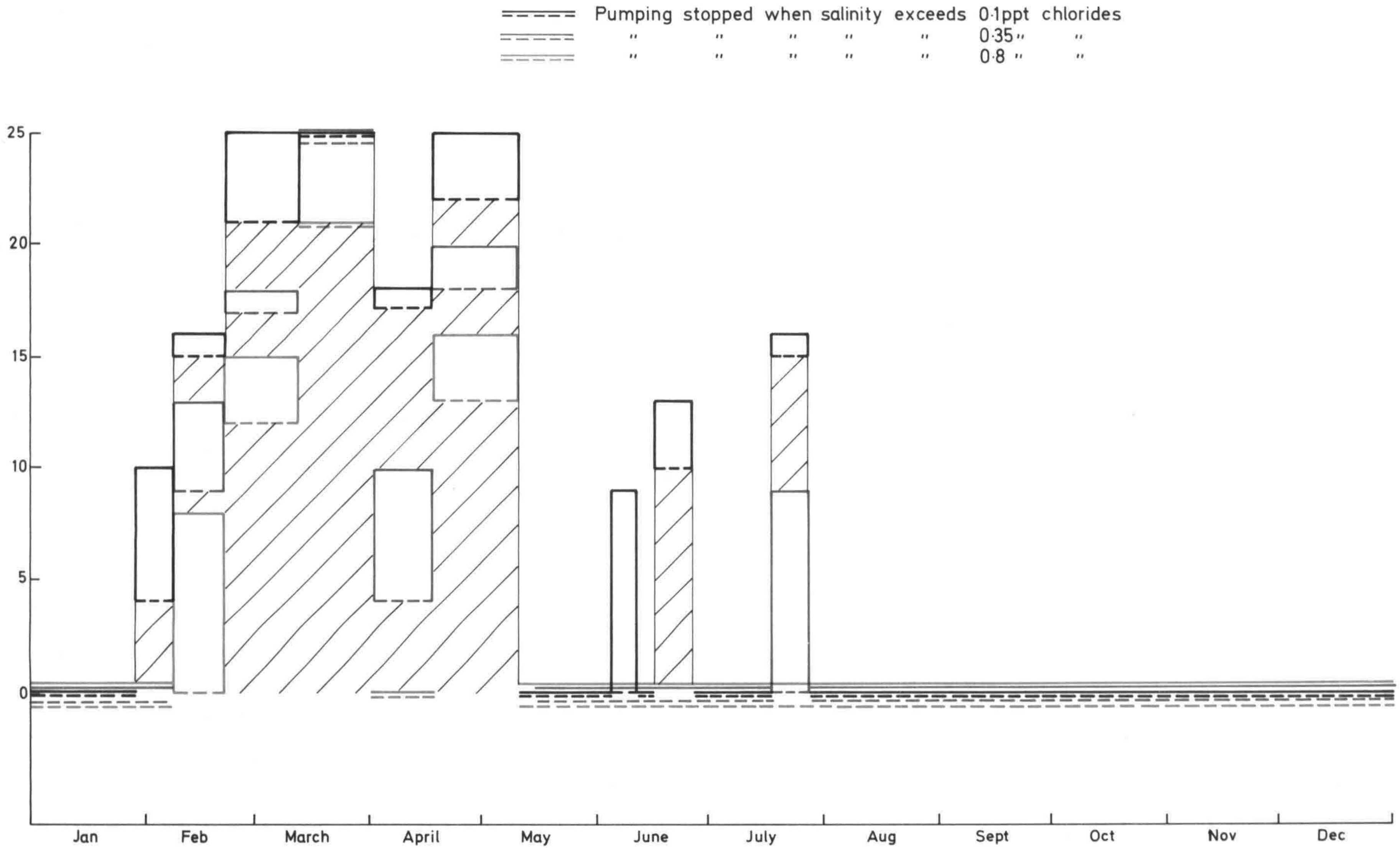
Fig 16

Run 3. Pumping hours lost at Kobat (10·9miles)



Run 3. Pumping hours lost at mile 15

Fig.17



Pumping hours lost at mile 16

Fig.18

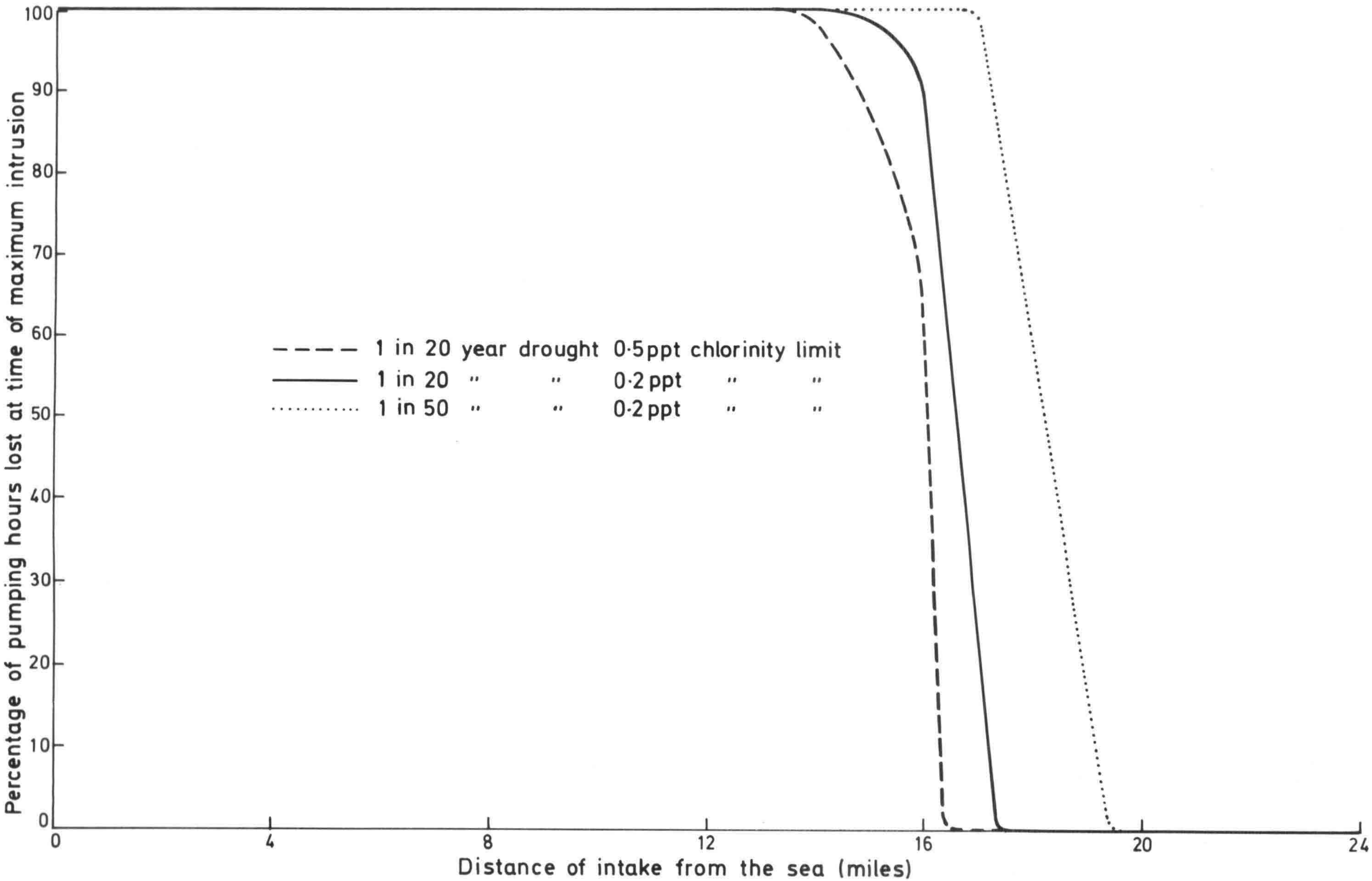


Fig. 19

Variation of pumping hours lost with position of intake