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Thurne Broads Model Using 1993 Data

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BINNIE & PARTNERS
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THURNE BROADS MODEL USING 1993 DATA

CONTENTS

1. INTRODUCTION

1.1. Background

The first detailed study of the Thurne Broads was reported by Dr. R.A. Watson, Ref. [1], in 1981. The objective of his study was mainly concerned with algal nutrients. The information he collected in terms of water quality and land drainage pump records is still a prime source of data.

In order to better understand the water exchange and salinity mixing in the Thurne Broads area, particularly at Hickling Broad and Horsey Mere the National Rivers Authority (NRA) in association with the Broads Authority and English Nature commissioned Binnie & Partners to develop a one-dimensional hydrodynamic and salinity model of the Thurne Broads system in January 1993, Ref.[2].

The hydrodynamic and salinity model was set-up on Mike 11 which is a well established river system model developed by Danish Hydraulic Institute, Ref.[3]. The model was run and calibrated using the 1976 data obtained by Watson, Ref.[1]. The predicted water levels agreed within 0.01 to 0.03m with the observed levels. The salinity at Horsey Mere was reasonably well predicted. However the predicted salinity at Hickling Broad was lower than the observations, Ref.[2].

In order to improve the model performance, a revised model was developed in 1994, Ref. [4], based on the existing model. The revised model was used to carry out additional sensitivity tests, re-examining the hydrology, evaporation and pump discharges. Taken together these changes were expected to reduce the freshwater flow and encourage salinity penetration.

The results of the revised model were better, but were still considered unreliable for predicting salinity movement mainly because of uncertainties in the input data for 1976, Ref.[4].

1.2. Objective

The unreliability of the Thurne Broads Model using 1976 data, has made it difficult to judge the model results and use the model to guide decisions on catchment management. In order to overcome the uncertainty involved in using 1976 data, the NRA commissioned Binnie & Partners in November, 1994 to re-run the model using 1993 data and make any necessary minor modifications to the model for example the representation of Heigham Sound.

The specification of this model study is included as Appendix A in this report.

2. MODEL INPUT AND CALIBRATION DATA

2.1. Hydrodynamic and Broads Topography

River and Broads Topography

The Broadland river system was taken from the Flood Alleviation Strategy for Broadlands, Ref.[5] by reducing the total number of cross-section from 114 to 62. This was accomplished with very little change in water level at Potter Heigham (less that 1.0 cm), see Ref.[2].

The Thurne Broads model topography was taken from the previous Thurne Broads model study, Ref. [4]. Heigham Sound was modified from an off line to an on line broad. This change slightly increased mixing in this area but the effect was not great.

The overall and detailed layouts of the Thurne Broads Model are shown in Figure 2.1. and Figure 2.2.

Tide and Surge Levels

The predicted hourly tide levels at Great Yarmouth from October 1, 1992 to December 31, 1993 (inclusive, 15 months) were provided by the Proudman Oceanographic Laboratory (POL).

The hourly surge residual levels for the same period were provided by POL for Lowestoft which is about 10 km to the south of Great Yarmouth. The surge levels were used to adjust the water levels at Great Yarmouth based on the assumption that the residuals at Great Yarmouth were identical to those at Lowestoft. The surge levels occurrence frequency have been analyzed and shown in Figure 2.3. For approximately 6.5% of the time, the residual levels were greater than ±0.5m.

The sea level at Great Yarmouth each hour, calculated as predicted tide level plus surge level, was used to drive the hydrodynamic model since saline intrusion into the Thurne Broads could be caused by large surges.

River Flows

The gauged mean daily river flows from gauging stations at Honing Lock (River Ant), Horstead Mill (River Bure), Needham Mill (River Waveney) and Colney (River Yare), Shotesham (River Tas), Costessey Mill (River Wensum) and Costessey Park (River Tud) are used as the base for river flow estimation at model boundaries for the River Ant (Wayford Bridge), River Bure (Wroxham Bridge), River Chet, River Waveney (Ellingham) and River Yare.

The flows of Rivers Ant, Bure, Chet, Waveney and Yare at the model boundaries are factored up to take into account the catchment area between the gauging stations and the model boundaries. The mean monthly flows at the model boundaries are listed in Table 2.1 and plotted in Fig.2.4. The flows in the River Bure were reduced by the quantity abstracted by Suffolk Water around Wroxham from both surface and groundwater sources.

Table. 2.1. Mean Monthly River Flows at Model Boundaries (m^3/s)

Month	River Flows (m^3/s)				
(-)	Ant (Wayford Bridge)	Bure (Wroxham Bridge)	Chet (-)	Waveney (Ellingham)	Yare (-)
Oct. 1992	0.71	1.85	0.17	1.65	3.88
Nov.	0.95	3.21	0.47	6.79	8.31
Dec.	0.97	3.44	0.55	6.41	10.16
Jan. 1993	1.02	3.36	0.37	7.17	9.11
Feb.	0.75	2.45	0.22	2.25	5.54
Mar.	0.75	2.39	0.23	2.69	5.67
Apr.	0.73	2.35	0.20	2.01	4.93
May	0.61	1.88	0.13	1.07	3.63
Jun.	0.50	1.46	0.09	0.83	2.42
Jul.	0.67	1.60	0.06	0.75	2.17
Aug.	0.65	1.53	0.06	0.64	2.11
Sep.	1.01	2.81	0.14	1.25	4.01
Oct.	1.27	5.57	0.31	6.59	12.18
Nov.	1.15	4.47	0.41	6.50	13.31
Dec.	1.32	5.55	0.86	14.88	19.37

Note: The following assumptions are made in flow input calculations:

(1). Ant at Wayford Bridge = Ant at Honing Lock x 2.97;
(2). Bure at Wroxham Bridge = Bure at Horstead Mill x 1.47 - Suffolk Water Abstraction;
(3). Chet = Yare at Colney x 0.174;
(4). Waveney at Ellingham = Waveney at Needham Mill x 1.81;
(5). Yare = Yare at Colney + Tas + Wensum + Tud.

Table 2.3. Mean Monthly Pump Flow and Chloride Concentration

Q: flow (m^3/s); C: Chloride Concentration (g/l);

Month	Catfield		Horsey Mill		Eastfield		Stubb Mill		Brograve		W. Somerton		N. Somerton	
	Q	C	Q	C	Q	C	Q	C	Q	C	Q	C	Q	C
	m^3/s	g/l	m^3/s	g/l	m^3/s	g/l	m^3/s	g/l	m^3/s	g/l	m^3/s	g/l	m^3/s	g/l
Oct 92	0.03	0.16	0.02	1.87	0.22	0.68	0.16	2.00	0.25	3.80	0.10	0.96	0.06	6.89
Nov	0.03	0.13	0.09	1.30	0.25	0.53	0.16	1.56	0.11	1.95	0.10	1.41	0.06	0.89
Dec	0.02	0.15	0.13	1.70	0.24	0.89	0.14	1.24	0.37	1.04	0.09	1.06	0.05	1.77
Jan 93	0.01	0.12	0.10	2.13	0.15	0.92	0.09	1.40	0.28	0.88	0.06	2.36	0.04	1.34
Feb	0.01	0.14	0.06	1.62	0.08	0.26	0.14	1.85	0.19	3.42	0.10	0.72	0.10	2.46
Mar	0.01	0.15	0.02	1.98	0.06	0.29	0.10	2.02	0.15	3.63	0.07	1.17	0.07	2.53
Apr	0.00	0.09	0.01	2.77	0.05	0.23	0.08	1.98	0.13	3.45	0.06	1.07	0.06	2.47
May	0.00	0.12	0.00	2.59	0.03	0.41	0.10	2.27	0.10	4.31	0.04	1.34	0.01	2.46
Jun	0.00	0.09	0.00	2.75	0.02	0.25	0.06	2.56	0.07	4.20	0.02	1.09	0.01	3.29
Jul	0.00	0.10	0.00	2.90	0.01	0.59	0.03	2.34	0.02	4.81	0.01	0.86	0.00	3.06
Aug	0.00	0.09	0.00	3.04	0.01	0.74	0.00	2.10	0.03	4.82	0.01	1.49	0.01	2.83
Sep	0.01	0.16	0.03	1.99	0.03	0.32	0.01	2.33	0.06	5.36	0.02	0.87	0.02	2.39
Oct	0.04	0.13	0.25	0.94	0.22	0.12	0.06	0.94	0.25	1.32	0.19	0.84	0.16	1.59
Nov	0.05	0.12	0.13	1.04	0.25	0.55	0.08	0.94	0.11	0.91	0.12	0.50	0.14	1.30
Dec	0.05	0.12	0.15	1.26	0.24	0.67	0.07	0.84	0.13	1.91	0.11	0.78	0.13	1.61

Drainage Pump Flows

There are altogether thirteen drainage pumps in the model area. Electricity readings were available for seven of these pumps. The drainage pump flows were estimated from pump electricity readings using a conversion between quantity pumped and electricity consumed determined from a recent calibration carried out by NRA. Table 2.2 shows the availability of the drainage pump flows. The mean monthly pump flows are listed in Table 2.3 and plotted in Fig. 2.5 (a)-(g), which show that pump flows at Brograve,Horsey Mill, Eastfield and West Somerton are around 0.00 - 0.25 m^3/s, but flows of the other pumps are only in the range of 0.00 - 0.10 m^3/s.

For Eastfield, Brograve and Horsey pumps, electricity readings were taken monthly. For the remaining pumps there were only quarterly readings available and some of those were estimated. For these remaining pumps, the distribution of the electricity consumed each quarter into individual months used Eastfield pump's monthly readings to estimate the number of units used in individual months by the other pumps.

As electricity meters were only read at intervals(monthly or quarterly), it is not possible to estimate short term changes in pumping flow arising from rainfall or other factors, Ref.[2].

Rainfall and Evaporation

Daily rainfall data were collected from the Meteorological Office records at Hickling Broad for the whole modelling period of January - December 1993.

Evaporation rates have been derived from the Met. Office MOREC cell 121 which provides average weekly potential grass evaporation from a 40 x 40 km2 area of land including the Thurne Broads for the whole of 1993. The last three months of 1993 were used in place of the last three months of 1992 to estimate the evaporation for the first three months of the model run time.

It has been assumed that the evaporation rate for open water, reedbed and woodland is 1.2 times that for grass. Evaporation from the reedbed may vary seasonally as discussed previously, Ref. [2].

The net gain or loss of water from rainfall and evaporation was calculated based on the above evaporation assumption for open water and reedbed using the catchment area and vegetation cover of the Thurne Broads system. This net flow was input into the Mike 11 hydrodynamic model as lateral inflow at cells which have a significant surface area. Rainfall and evaporation directly to or from the river channels were grouped with nearby Broads, Ref.[3].

The calculated net weekly rainfall and evaporation is shown in Figure 2.6. This indicates that:

(a) the water gain or loss due to rainfall and evaporation are more or less balanced during the whole simulation period;

(b) rainfall and evaporation flows are of the order of magnitude of 1.0 m3/s, with the exception that the net flow was close to zero in the period of Jan - Mar 1993. The heavy rainfall in Oct and Nov 1993 which were associated with the two flood events (see Section 3.3 for discussion) caused an inflow of up to $3m^3/s$;

(c) the order of magnitude of the flow from all evaporation cells is roughly the same as the flow of the River Ant, but a third of the River Bure flow at the model boundaries.

Table 2.2 DATA AVAILABILITY

	1992 Oct	Nov	Dec	1993 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FOR DATABASE INPUT:															
River Flows															
Bure (Horstead)	***	***	***	***	***				***	***	***	***	***	***	***
Ant (Honing Lock)	***	***	***	***						***	***	***	***	***	***
Yare (Colney)	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Tas (Shotesham)				***	***	***	***	***	***	***	***	***	***	***	***
Wensum (Costessey Mill)	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Tud (CostesseyPark)	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Waveney (Needham Mill)	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Pump readings															
Catfield		***	***	***	***	***	***	***	***	***	***	***	***	***	***
Horsey Mill		***	***	***	***	***	***	***	***	***	***	***	***	***	***
Eastfield				***	***	***	***	***	***	***	***	***	***	***	***
Stubb Mill		***	***	***	***	***	***	***	***	***	***	***	***	***	***
Brograve			***	***	***	***	***	***	***	***	***	***	***	***	***
West Somerton		***	***	***	***	***	***	***	***	***	***	***	***	***	***
New Somerton		***	***	***	***	***	***	***	***	***	***	***	***	***	***
Pump salinities															
Catfield	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Horsey Mill	***	***	***	***	***	***	***	***	***		***		***	***	***
Eastfield	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Stubb Mill	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Brograve	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
West Somerton	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
New Somerton		***	***	***	***	***	***	***	***		***	***	***	***	***
Hickling Rain	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Potential Evap				***	***	***	***	***	***	***	***	***	***	***	***
Predicted Tides	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Residual Levels	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
FOR CALIBRATION:															
Water levels															
Hickling Broad	***	***			***	***	***	***	***	***	***	***	***	***	***
Wayford Bridge			***	***	***	***									
Salinities															
Hickling Broad	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Horsey Mere	***	***	***	***	***	***	***	***	***		***		***	***	***
HeighamSound	***	***	***	***	***	***	***		***	***	***	***	***	***	***
by Repps pump	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
River Thurne (Candle Dyke)	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***

Broads Water Levels

The water levels were recorded hourly at Hickling Broads from January 1 - December 31 1993, with a missing period from January 1 to March 10. The maximum and minimum daily water level were abstracted and used later to calibrate and validate the model performance. In order to compensate for the missing data at Hickling Broad, the recorded water levels at Wayford Bridge were used to calibrate the hydrodynamic model in the period of missing data.

2.2. Salinity Data

Drainage Pump Salinities

In the Thurne Broads system there are altogether thirteen drainage pumps. At seven of these pumps, chloride concentrations in the pump discharge were measured in 1993. There are some small data gaps at Horsey Mill and New Somerton pumps (see Table 2.2).

The availability of the chloride data at each pumping station are listed in Table. 2.2. The mean monthly pump salinity are listed in Table 2.3 and plotted in Fig. 2.5 (a)-(g). The data show that the chloride concentrations at Brograve, New Somerton and Stubb Mill and Horsey Mill pumps are many times higher than at Catfield and Eastfield pumps. The drainage pump chloride mass pumped into the river system is the product of pump flow and salinity. The mass of chloride introduced by each pump is calculated and plotted in Fig. 2.5 (a)-(g). This indicates that Brograve pump is the most significant source of chloride (approximately 100 times Catfield pump which was the smallest source identified).

Sea Water Salinity

The seawater salinity at Great Yarmouth is estimated as 34 g/l which is assumed equivalent to a chloride concentration of 20.6 g/l in the model simulations.

Broads Salinities

The recorded chloride concentration at Candle Dyke and Hickling Broad (fortnightly), Horsey Mere and Heigham Sound (monthly) and Repps (hourly) for the period October 1992 - December 1993 are available. The data have been used to check the performance of the salinity model. The recorded salinity data at Repps were converted to chloride by assuming 1.65 g/l salinity is equivalent to 1.0 g/l chloride.

Rainfall and Evaporation Salinity

It is assumed that there is no chloride loss or gain as a result of rainfall or evaporation, therefore the cells where rainfall or evaporation occurred were modelled as closed boundaries in the salinity model.

3. HYDRODYNAMIC MODEL

3.1. Model Set-up and Operation

The hydrodynamic model was set-up for the Thurne Broads network using river flow as the boundary conditions at the upstream limit of each river. Drainage pump flows and rainfall and evaporation were input as lateral inflows. The tide provided the downstream water level boundary condition at Great Yarmouth.

A time step of 60 seconds was found necessary to run the hydrodynamic model for the Thurne Broads model in order to eliminate numerical instability. The model was run for the whole year of 1993 with 4 consecutive periods of 3 months due to the output file size (approximately 10 MB each). The end of the first run was used as a hot start for the second run.

The hydrodynamic results were recorded and stored hourly to ensure that the effect of each individual semi diurnal tide would be properly reproduced. The stored hydrodynamic data were used later to drive the salinity dispersion model.

A Manning roughness of n=0.035 throughout the Broadland rivers was adopted for the runs in the model based on the sensitivity tests carried out in Ref.[5].

3.2. Water Level Prediction

The predicted hourly water levels are compared with observed values in Fig.3.1 for a typical 10 day period in July 1993. The comparison indicates that the nature of the semi-diurnal tides has been reproduced correctly by the model. The phase of the tides have also been predicted successfully, but the predicted amplitude of the tide (~ 3.5 cm) is slightly smaller than the observation (~4.0 cm). It should be pointed out that because the model output was hourly, some of the water level peaks were not picked up and shown in the plot.

The predicted water levels at Wayford Bridge in January and February 1993 are plotted in Figure 3.2 and compared with the daily maximum and minimum water levels. The predicted water levels at Hickling Broad throughout 1993 are compared in Figure 3.3 with the maximum and minimum water level recorded each day. The results show generally good agreement between the predicted and recorded water levels.

3.3. Discussion

Flood Event

Figure 3.3 shows that the peak levels at Hickling Broad were satisfactorily reproduced during two fluvial floods. One was in October and the other was in November 1993. The two recorded maximum water levels (+0.83 and +0.75 m AOD) were associated with two floods in October and November 1993. Although the model reproduces the peak water levels in both floods accurately, Hickling Broad drains much more rapidly in the model between the two floods than was observed with predicted levels being up to 0.1m lower than observed. The reason for this is not known but suggests the model allows the whole of the Bure and Thurne wet fens to drain too rapidly.

Surge

The surge residuals at Lowestoft are plotted in Figure 3.4 for the whole of 1993. This shows the large surge that occurred on 21 February. The predicted water levels at Hickling Broad and

Wayford Bridge, Figures 3.2 and 3.3, both show the effect of the surge. Unfortunately there were no observations at Hickling Broad in this period. The observations at Wayford Bridge suggest peak water levels were about 0.12m lower than predicted, possibly because more of the surge went into storage than assumed in the model.

4. CHLORIDE MODEL

4.1. Model Set-up and Operation

The Mike 11 Transport-Dispersion model was set up to calculate the chloride concentration in the Thurne Broads system. The model assumes that the river system is well mixed, which means that the chloride is homogeneous vertically and laterally at each cross-section.

The stored hydrodynamic data were used to drive the chloride model which was run for the whole year of 1993 with 4 consecutive periods of 3 months each. The chloride at Great Yarmouth was taken as 20.6 g/l and the chloride concentration of the pumps are listed in Table 2.3.

A time step of 60 seconds was used for the Transport-Dispersion model in order to maintain stability. A dispersion coefficient of $D_x=25$ m^2/s was used for the Thurne Broads, and a value of $D_x=200$ m^2/s elsewhere in the Broads system as determined in the previous study, Ref. [4].

4.2. Chloride Prediction

The modelled chloride concentrations at Repps, Candle Dyke, Heigham Sound, Hickling Broad and Horsey Mere are compared with the recorded chloride concentrations as shown in Figures 4.1 - 4.5. The predicted chloride concentrations follow the pattern of the measurements, but are generally lower than the recorded values.

Figure 4.1 shows that the predicted chloride concentration at Repps are generally significantly lower than the recorded concentration. The concentration peak caused by saline intrusion associated with the large surge on 21 February 1993 is very marked in the model and evident in the hourly measurements.

Figure 4.2. indicates that the modelled chloride concentrations at Candle Dyke are approximately half of the observed values. The model result also suggests that Candle Dyke experienced a concentration peak during the surge event of 21 February 1993, but unfortunately the measurement failed to catch this peak because water samples at Candle Dyke were only taken fortnightly.

In Heigham Sound, Figure 4.3 shows that the simulated concentrations are roughly half of the measured ones, and the model results suggest that the surge induced peak concentration reached Heigham Sound. The field measurements did not pick up this event since samples were only collected monthly.

The modelled chloride concentrations at Hickling Broad in Figure 4.4 are much lower than the recorded concentrations, particularly between February and September 1993 when the model concentrations are only 20% of the measurements.

The predicted chloride concentration in Horsey Mere is compared with the measured values in Figure 4.5. This shows that a reasonable fit between model results and observations has been obtained except for the two particularly high measured concentrations in June and July 1993.

4.3. Discussion

The lower predicted chloride concentration in the model suggests that either there is a lack of salt entering the Thurne Broads system or there is too much salt leaving the system. This problem of too little chloride in the Thurne Broads system caused by the following reasons:

(a) the salt brought into the Thurne Broads by the large surge may not have been correctly modelled. This problem could be caused by the fact that Mike 11 model is based on the assumption that the river flow is fully-mixed, but in reality, the water in the river system, during a major surge, is likely to be stratified. This means that the saline intrusion would travel much further upstream than the model predicts in the lower part of the river channel. This effect is incorporated to some extent into the model by the use of a very high dispersion coefficient in the River Bure. Although the amount of chloride entering Hickling Broad during the February surge may have been underestimated in the model, this is unlikely to have been sufficient to change the salinity of Hickling Broad for the next seven months;

(b) an unidentified shortcoming in the model may have led to an underestimate of the salt exchange between Horsey Mere and Hickling Broads by the model;

(c) there is an unidentified source of salt somewhere in the Broad system although there is no direct evidence to support this suggestion at present. However, the recorded chloride concentration at Repps may indirectly support this suggestion. The chloride concentrations at Repps were in the range of 1.0 - 5.0 g/l, but the measurements of chloride concentrations at Hickling Broad, Heigham Sound and Candle Dyke were all around 1.0 - 2.5 g/l. The available information suggests there is no other source of salt between Candle Dyke and Repps. This raises the question why the salinity at Repps is higher than Candle Dyke since the tide induced saline intrusion does not normally reach as far upstream as Repps.

(d) A closer examination of the recorded chloride at Repps in Fig 4.6 suggests that the chloride at this site may follow a fortnightly cycle, which is likely to be associated with the tides. The chloride concentration at Repps in this period is in the range 1.5 to 4.0 g/l of chloride, with the highest concentrations occurring as the water levels in Hickling Broad rose, when the net water flow past Repps would have been upstream from the River Bure. This suggests the high chloride content is associated with a downstream source of salt, possibly the sea at Great Yarmouth.

The occurrence of such high chloride concentrations on normal tides at Repps indicates the possibility of stratified flow with water containing high chloride concentrations travelling in the lower layer of the Rivers Bure and Thurne having little mixing with the surface layer. The chloride measurements at Repps seem to be indicative of conditions in a more saline lower layer. However for a short period starting on 8 July Figure 4.6 shows a rapid drop in chloride concentrations followed by a gradual rise. This could be indicative of a change in the level of the interface between saline and fresh water or the mixing of the two layers due to disturbance which later separates as the disturbance passes.

(e) The mass balance has been checked by calculating the mass injected into Horsey Mere from Eastfield, Brograve and Horsey Mill pumps. The resulting average chloride concentration from the pumps is compared with the recorded and model predicted chloride concentration at Horsey Mere as shown in Fig.4.7. There is too little chloride in Horsey Mere in the model. This is because the model includes the mixing of Horsey Mere water with the remainder of the Thurne Broads as tides rise and fall each fortnight. This dilutes the chloride in Horsey Mere. However, the observed concentrations suggest there is either very little mixing of Horsey Mere with the remainder of the system or that the water that returns to Horsey Mere as the tides rise each fortnight from neaps to springs contains more chloride than the model assumes. One source of this chloride could be chloride moving upstream in a lower stratified layer as postulated at Repps.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The model has successfully reproduced the water levels at Hickling Broad and Wayford Bridge in 1993. The peak flood events in October and November 1993 were also correctly modelled.

The characteristics of the semi-diurnal tides have been simulated correctly by the model. The phase of the tides has also been predicted successfully, but the modelled amplitude of the tides is slightly smaller than the observed one.

The chloride modelling results are less satisfactory than the water level model results.

The model results are not sensitive to the way Heigham Sound is represented in the model. The previous study, Ref.[4] adopted a side channel at Heigham Sound which could allow chloride to penetrate upstream further. In this study the side channel has been removed and the volume has been connected to the main channel which encourages greater mixing throughout Heigham Sound. This modification did not affect the model results significantly.

The predicted chloride concentrations at Repps, Candle Dyke, Heigham Sound, Hickling Broad and Horsey Mere generally follow the pattern of the measurements. The surge-induced saline intrusion in February 1993 has been modelled quite well, but the model concentrations are systematically lower than the observations. This suggests that there is insufficient chloride entering the model of the Thurne Broads system.

The failure of the model to reproduce the chloride concentrations in Hickling Broad could arise from one of two reasons:

- an unidentified source of salt; or
- a feature of the Thurne Broads system that is not represented correctly by the model such as salinity stratification.

5.2 Recommendations

The Thurne Broads model can be used with confidence for hydrodynamic studies, but should be treated with caution for water quality studies until the reason for the low model concentrations throughout the Thurne Broads are understood.

Continuous salinity recorders should be installed for periods of at least one month at different sites within the Thurne Broads area to help locate any unidentified sources of salt. These records should measure near surface and near bottom salinity to check for the presence of salinity stratification.

These recorders should record for at least one month at each site to pick up any effect the fortnightly variation in water level has on salinity. The Thurne Broads model could be used to help interpret the results of these field tests.

6. REFERENCES

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TABLES AND FIGURES

Tables

Figures

Appendix A

SPECIFICATION OF SERVICE

NATIONAL RIVERS AUTHORITY

SPECIFICATION FOR SERVICE

THURNE MODEL PHASE 2

General objectives of work to be undertaken

To develop the existing MIKE 11 model of the Thurne Broads to obtain a better fit between observed and predicted salinity data by running the model for 1993 and making pragmatic changes to critical parameters identified by the project team.

To hand the model over to the NRA and to provide documentation and training to NRA staff.

Specific work to be undertaken

1 Prepare data files for the 1993 calender year.

NRA to provide
- daily rainfall for Hickling.
- MOREC potential evaporation for grid square 121
- Fluvial flow River Bure, Horstead Mill.
- Electricity readings for land drainage pumps (existing conversion factors to be checked by NRA & IDB).
- Chloride concentrations for Horsey Mere, Hickling Broad, Heigham Sound,R Thurne d/s Candle Dyke.
- Chloride concentrations from land drainage pumps.
- Salinity data from continuous monitor on R Thurne at Repps.
- Water level records for Wayford Bridge

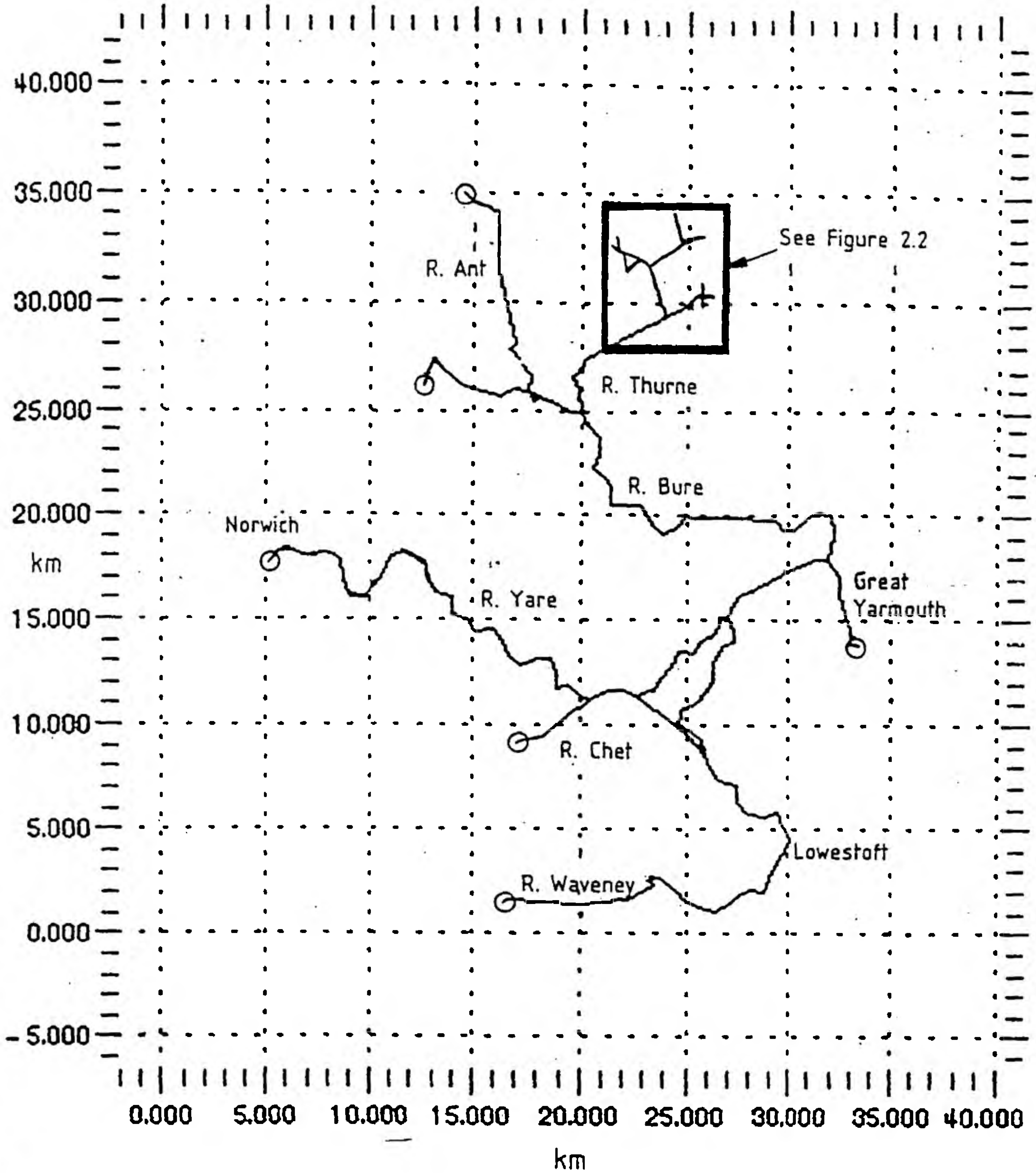
Binnies to provide
- tidal data

2 Undertake initial model runs using 1993 data and existing model parameters. Model to be run over 3 month periods

3 Compare model output with data from Repps and with routine spot monitoring data for Hickling Broad, Horsey Mere, Heigham Sound and R Thurne d/s Candle Dyke.

4 Investigate the observation that modelled salinity fluctuations extend too far upstream and ways of improving model fit.

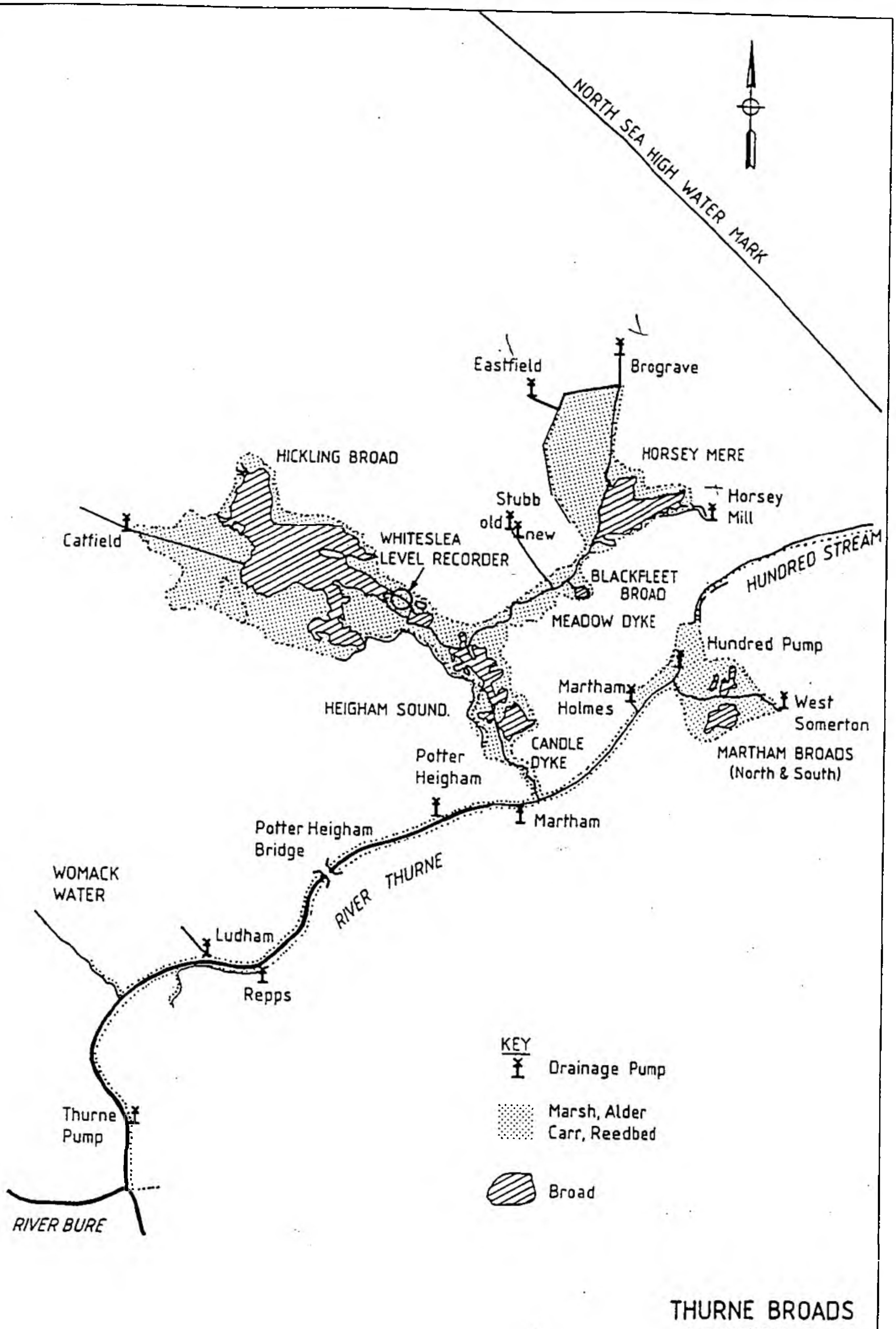
5 Explore effects of changing model to allow Heigham Sound to act as a lake rather than a wide channel.



BROADLAND MODEL LAYOUT

Boundary Condition Locations :- O

OVERALL LAYOUT OF
THURNE BROADS MODEL
Figure 2.1



THURNE BROADS
LOCATION PLAN
Figure 2.2

Oct 92 – Dec 93 10920 hours total

FREQ	%	Level (m)
0	0.00	−2.5
0	0.00	−1.6
0	0.00	−1.5
0	0.00	−1.4
1	0.01	−1.3
2	0.02	−1.2
4	0.04	−1.1
16	0.15	−1
15	0.14	−0.9
36	0.33	−0.8
69	0.63	−0.7
77	0.71	−0.6
92	0.84	−0.5
210	1.92	−0.4
436	3.99	−0.3
1006	9.21	−0.2
1853	16.97	−0.1
2262	20.71	0
1946	17.82	0.1
1077	9.86	0.2
687	6.29	0.3
389	3.56	0.4
264	2.42	0.5
144	1.32	0.6
94	0.86	0.7
63	0.58	0.8
48	0.44	0.9
32	0.29	1
26	0.24	1.1
15	0.14	1.2
17	0.16	1.3
13	0.12	1.4
6	0.05	1.5
2	0.02	1.6
18	0.16	2.5

HOURLY RESIDUAL LEVELS

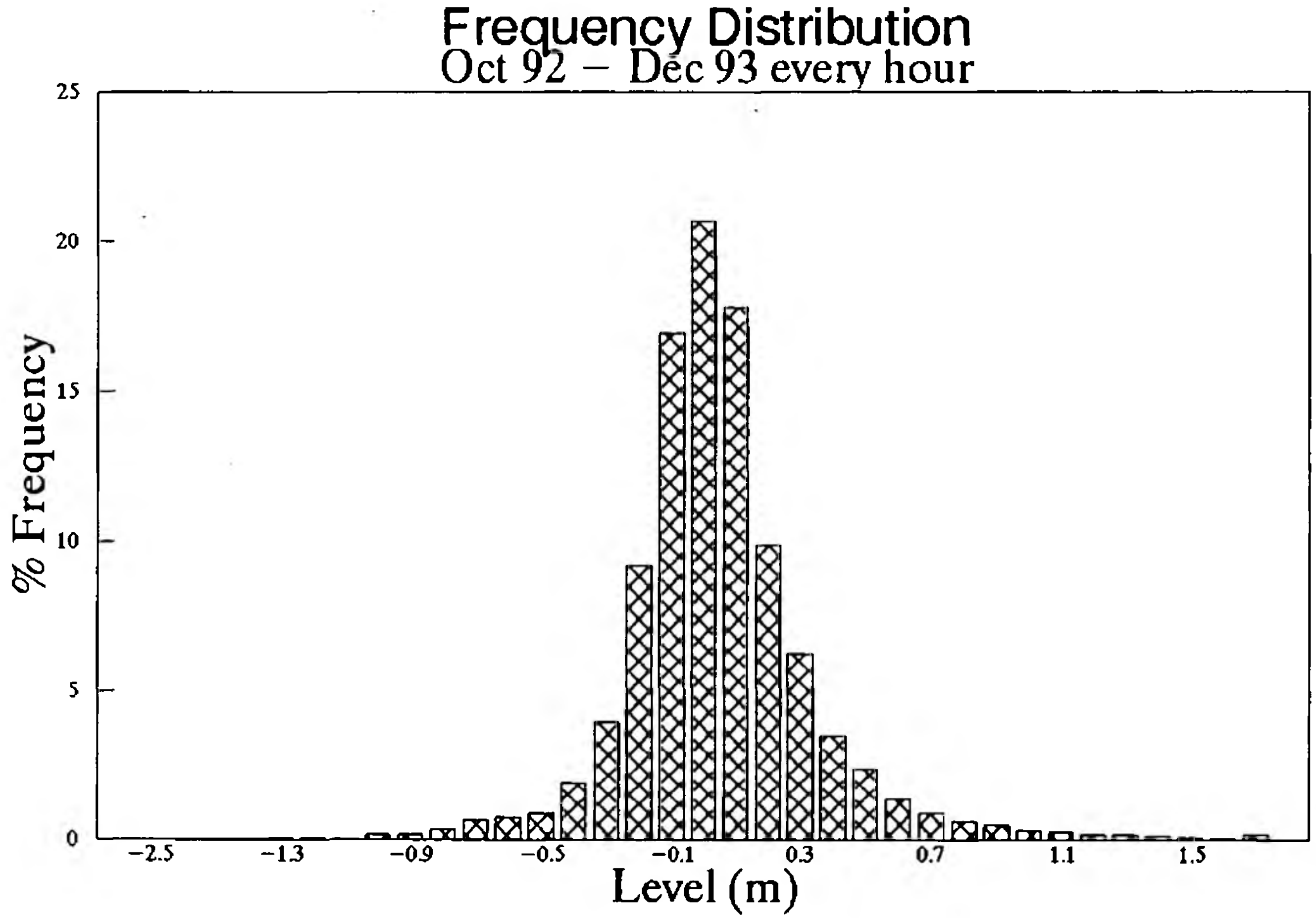


Figure 2.3 Surge levels Occurrence Frequency Analysis

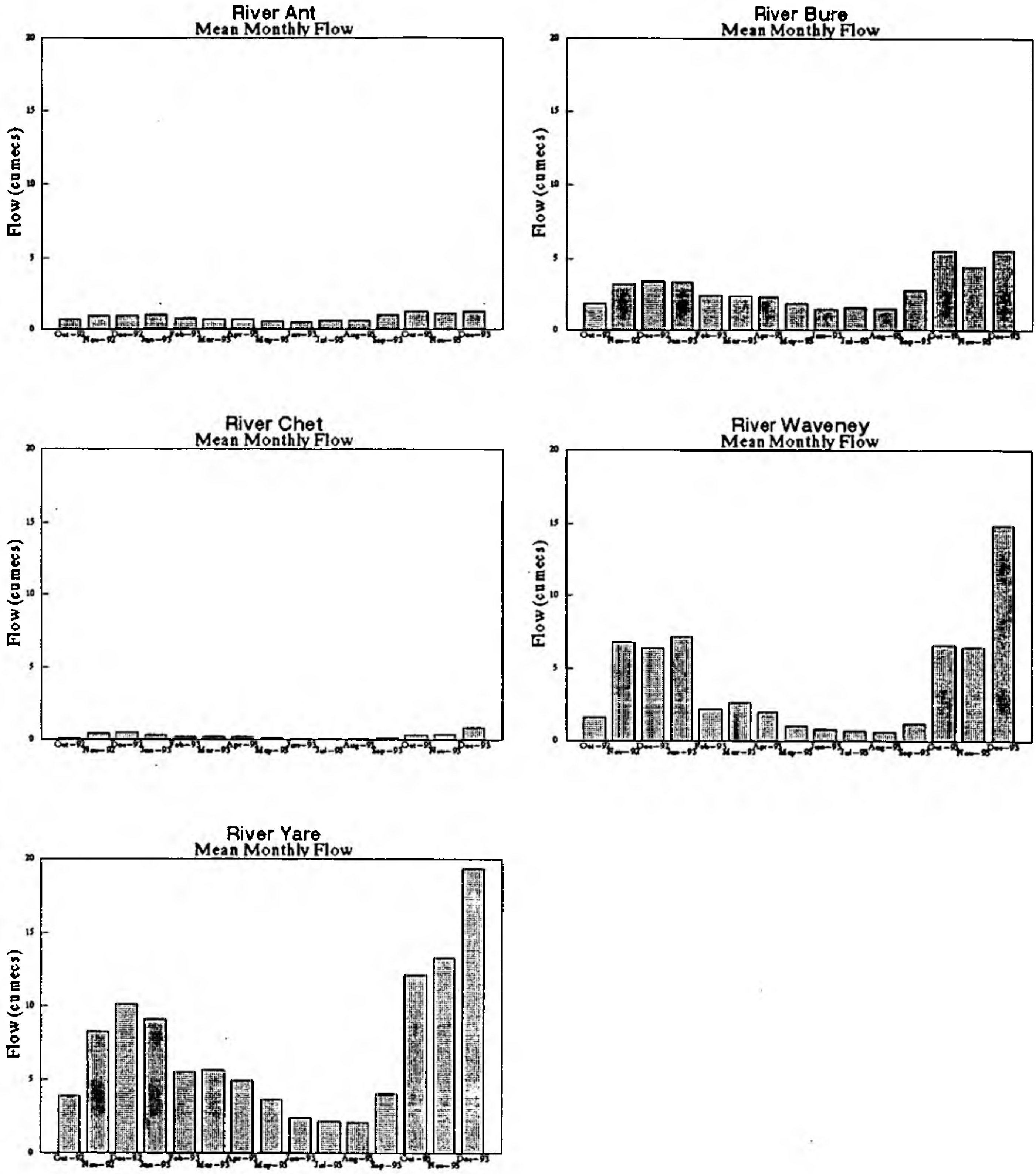


Figure 2.4 Mean Monthly River Flows at Model Boundaries

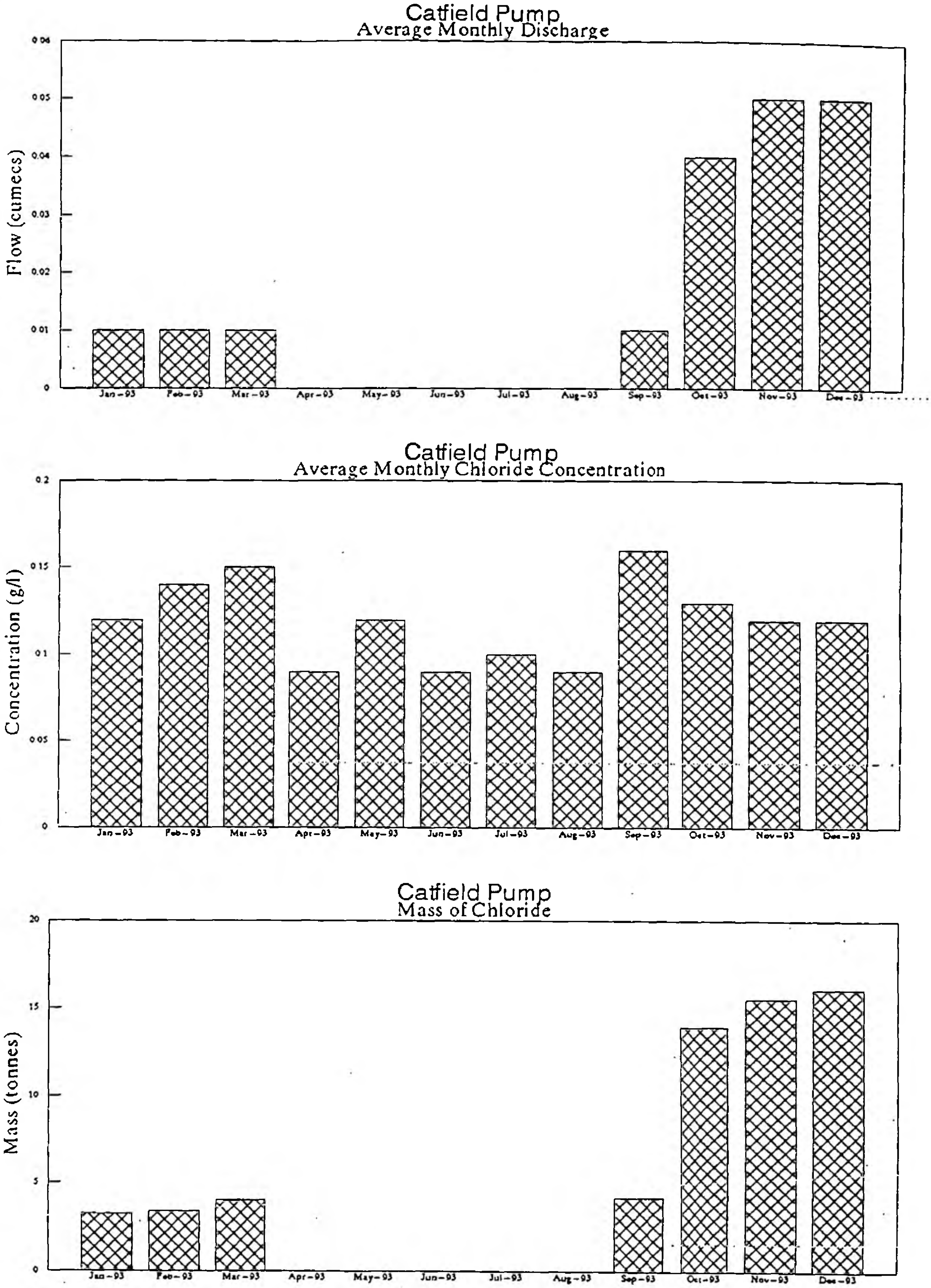


Figure 2.5 (a) Mean Monthly Flow, Chloride Concentration and Mass at Catfield Pump

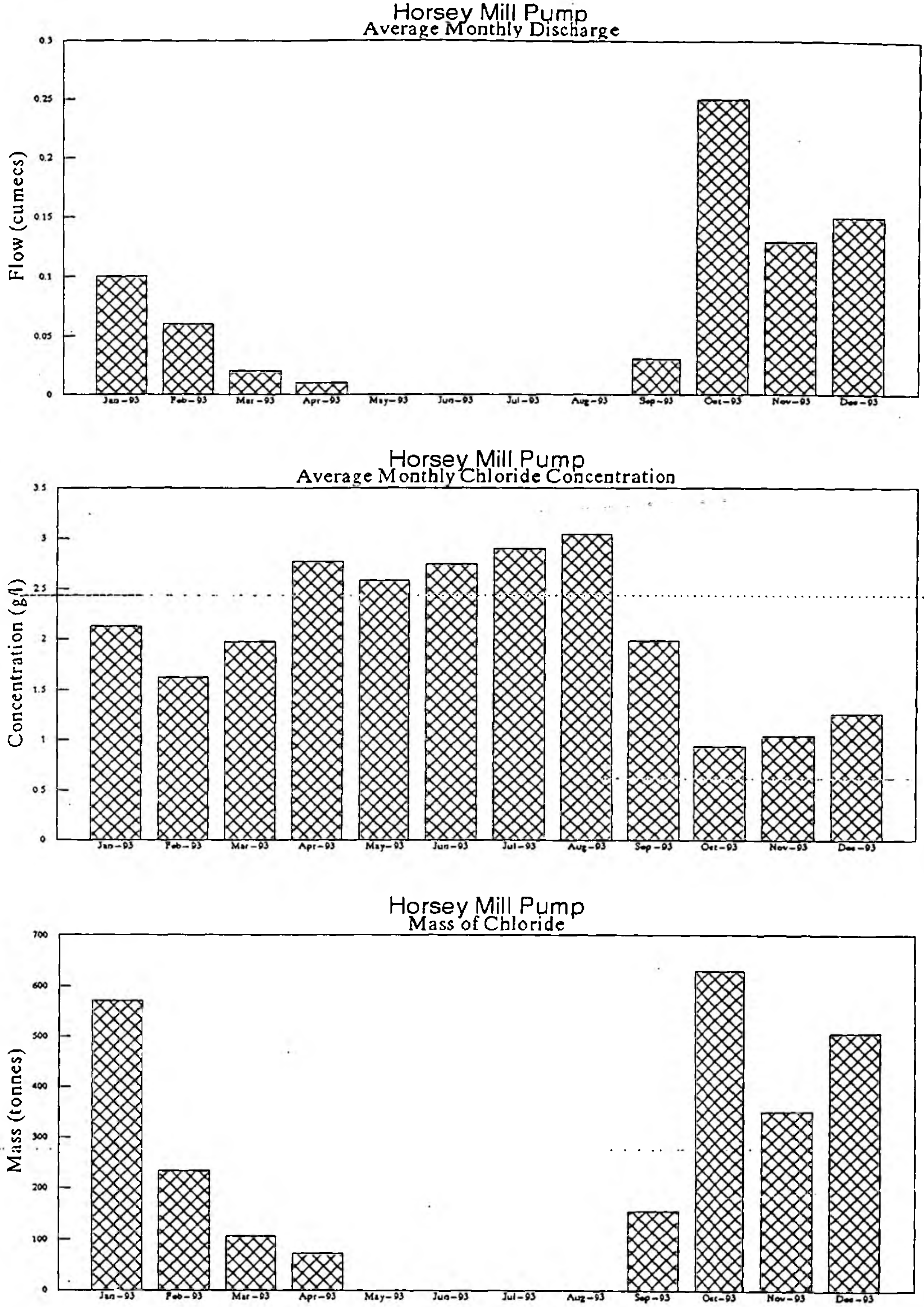


Figure 2.5 (b) Mean Monthly Flow, Chloride Concentration and Mass at Horsey Mill Pump

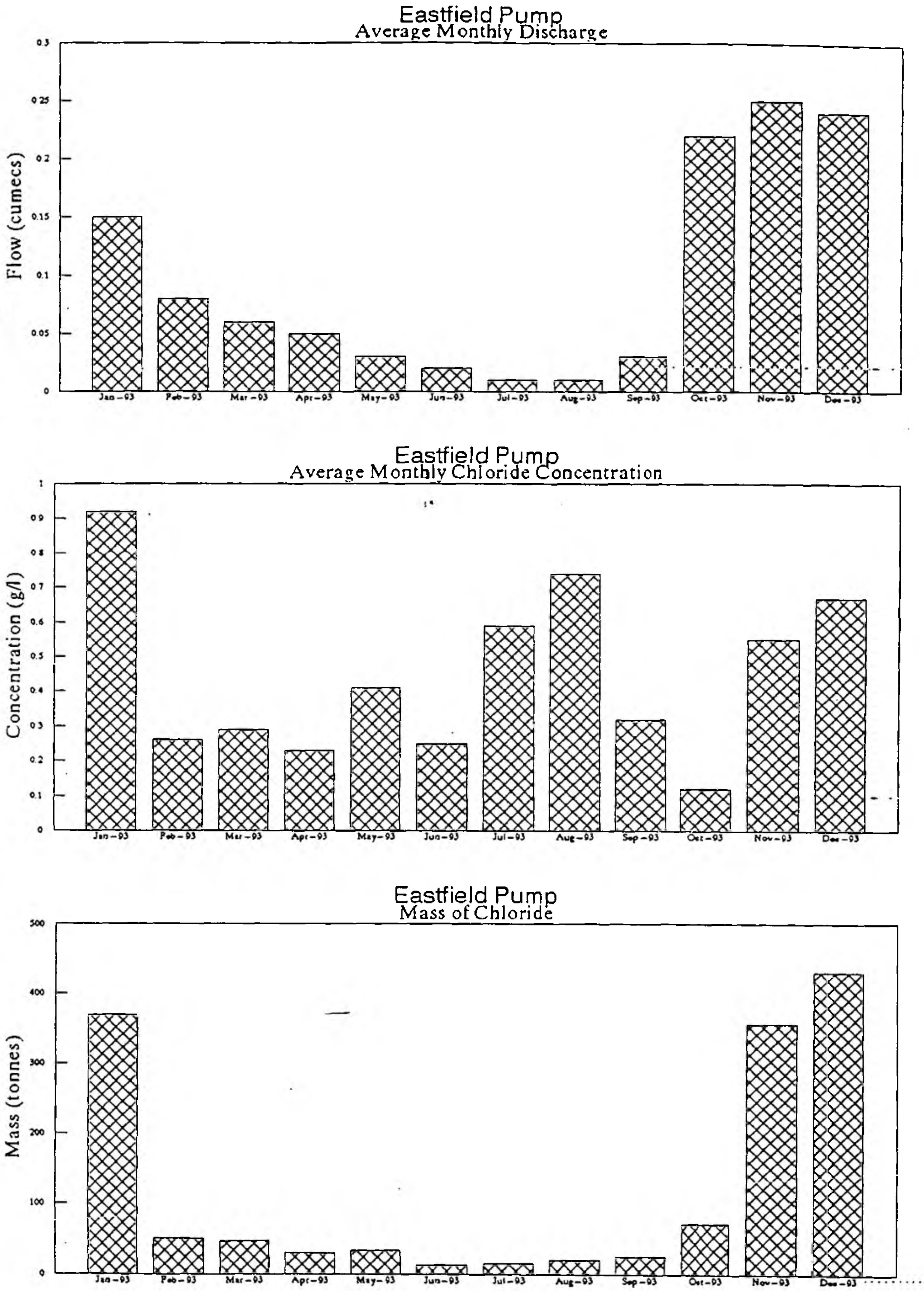


Figure 2.5 (c) Mean Monthly Flow, Chloride Concentration and Mass at Eastfield Pump

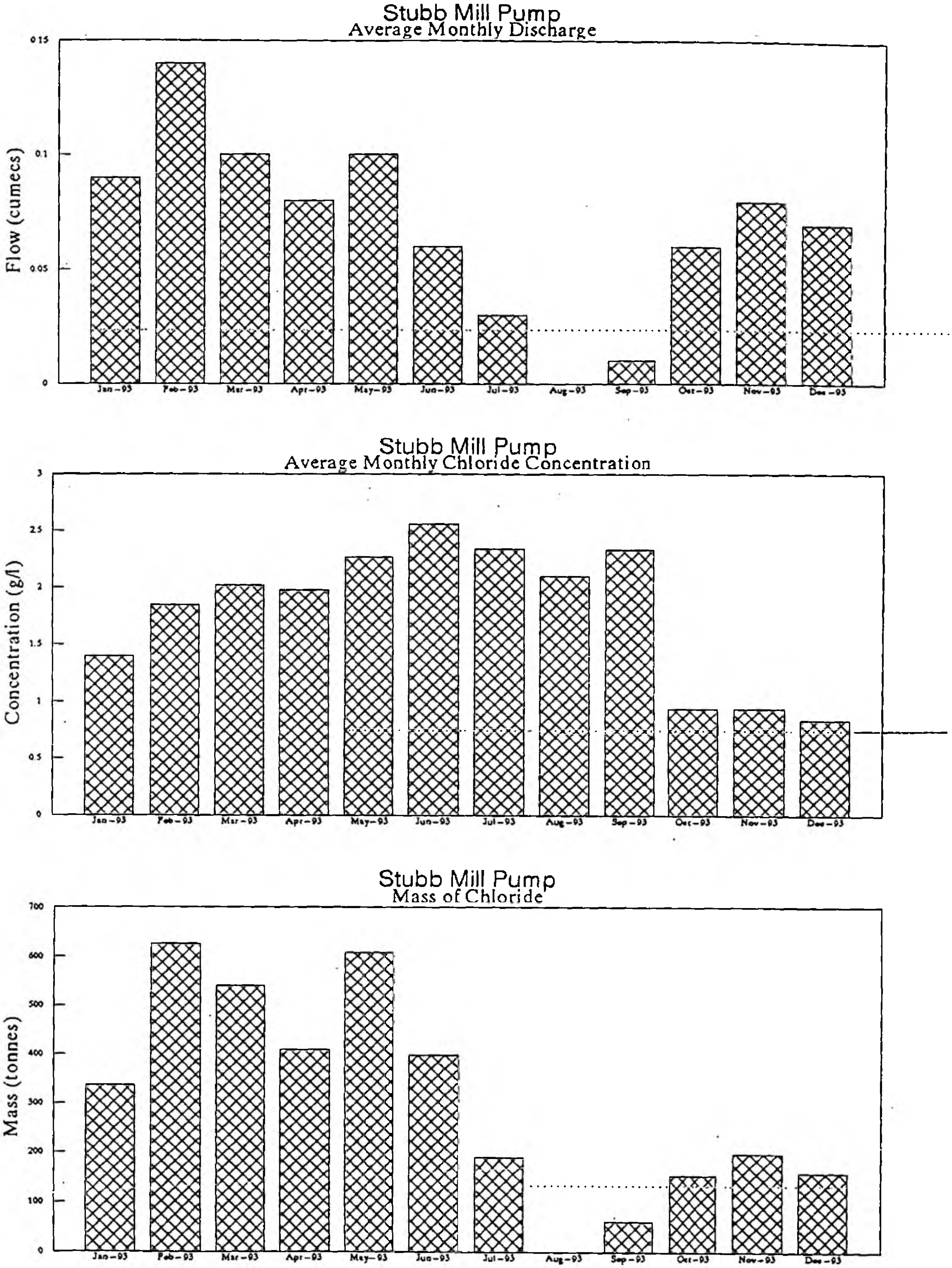


Figure 2.5 (d) Mean Monthly Flow, Chloride Concentration and Mass at Stubb Mill Pump

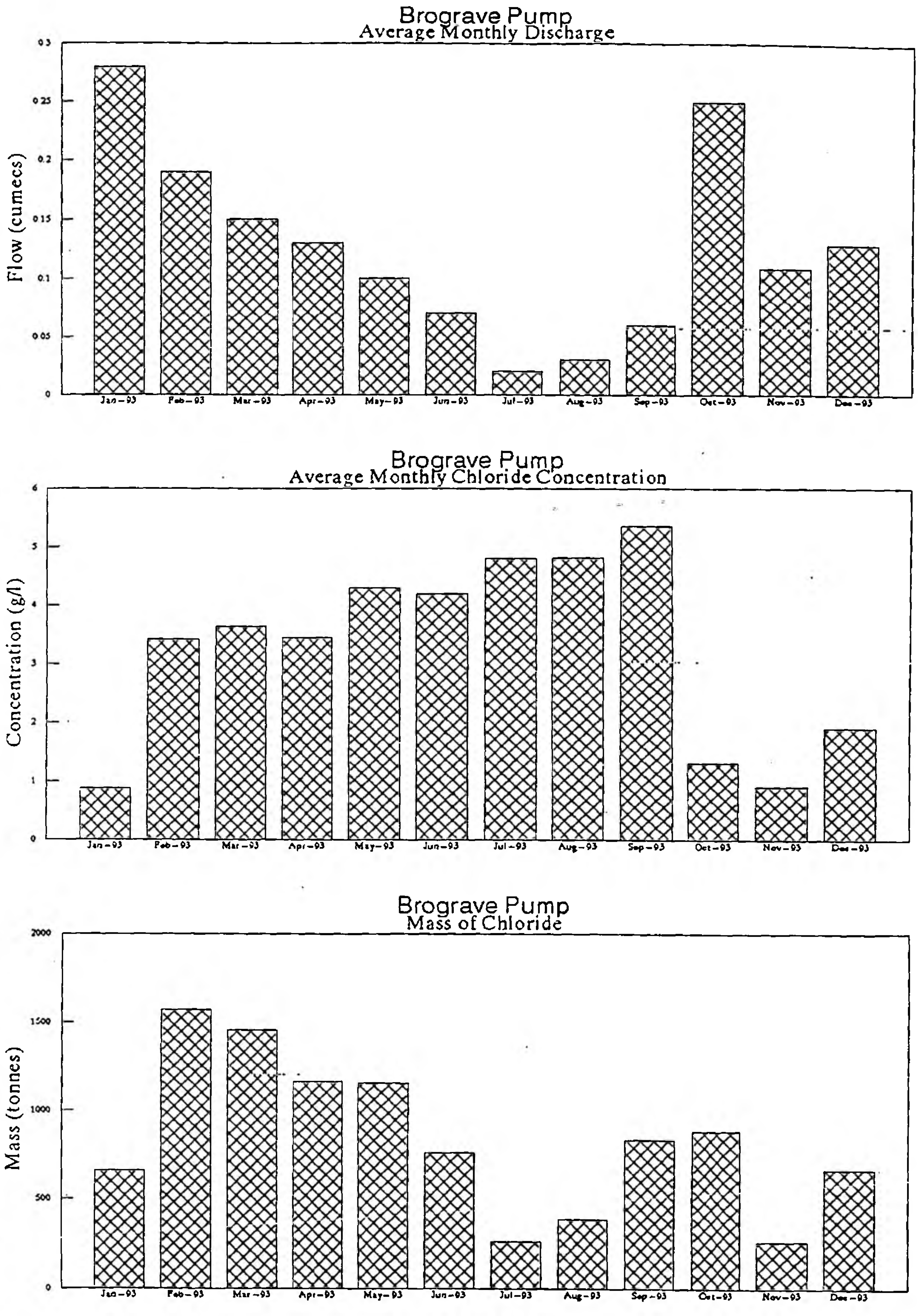
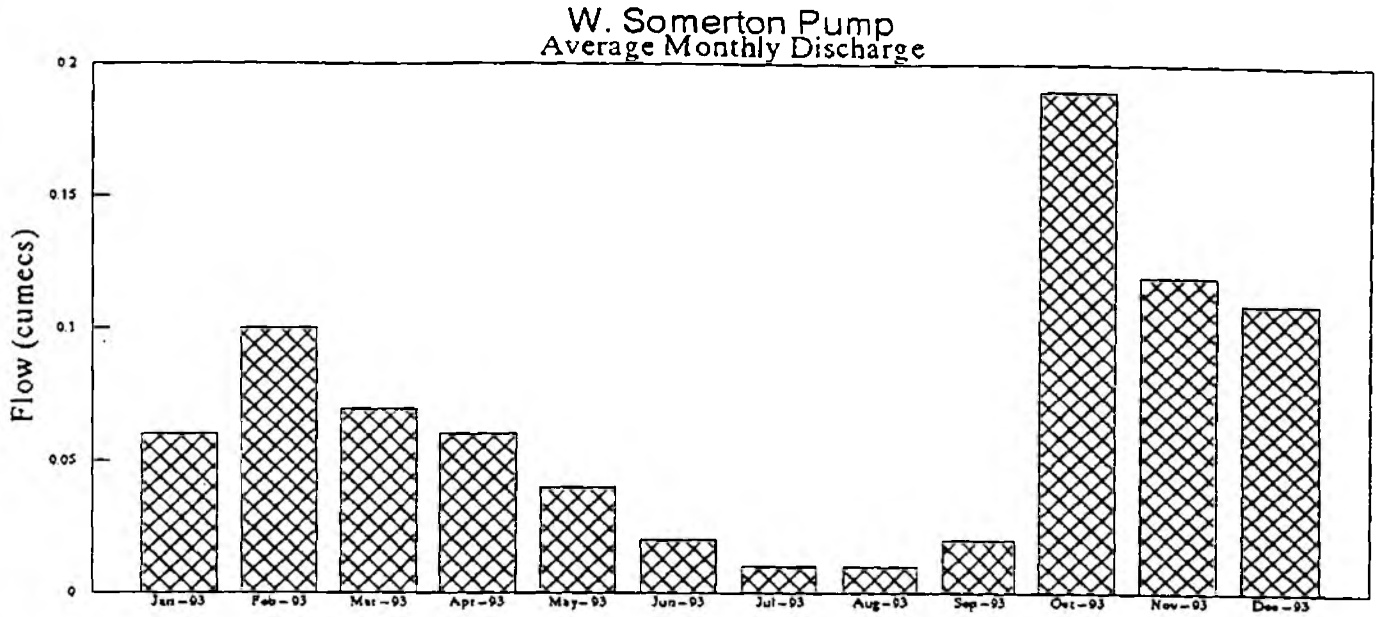
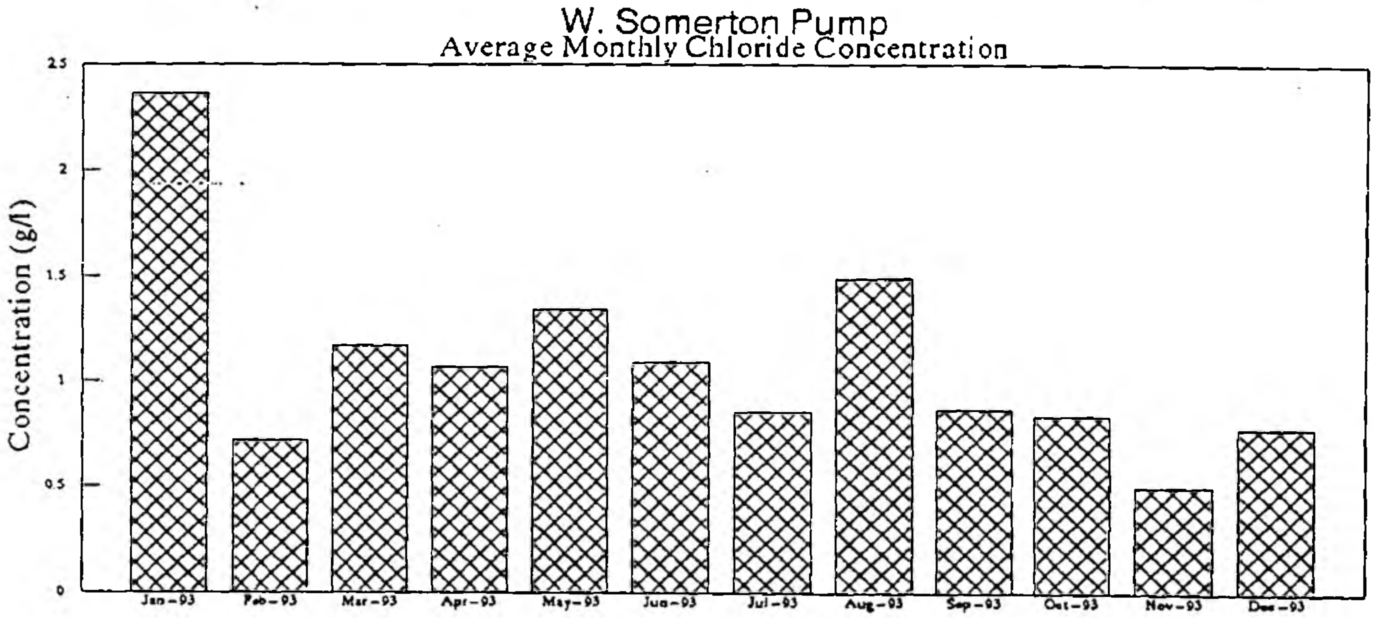


Figure 2.5 (e) Mean Monthly Flow, Chloride Concentration and Mass at Brograve Pump





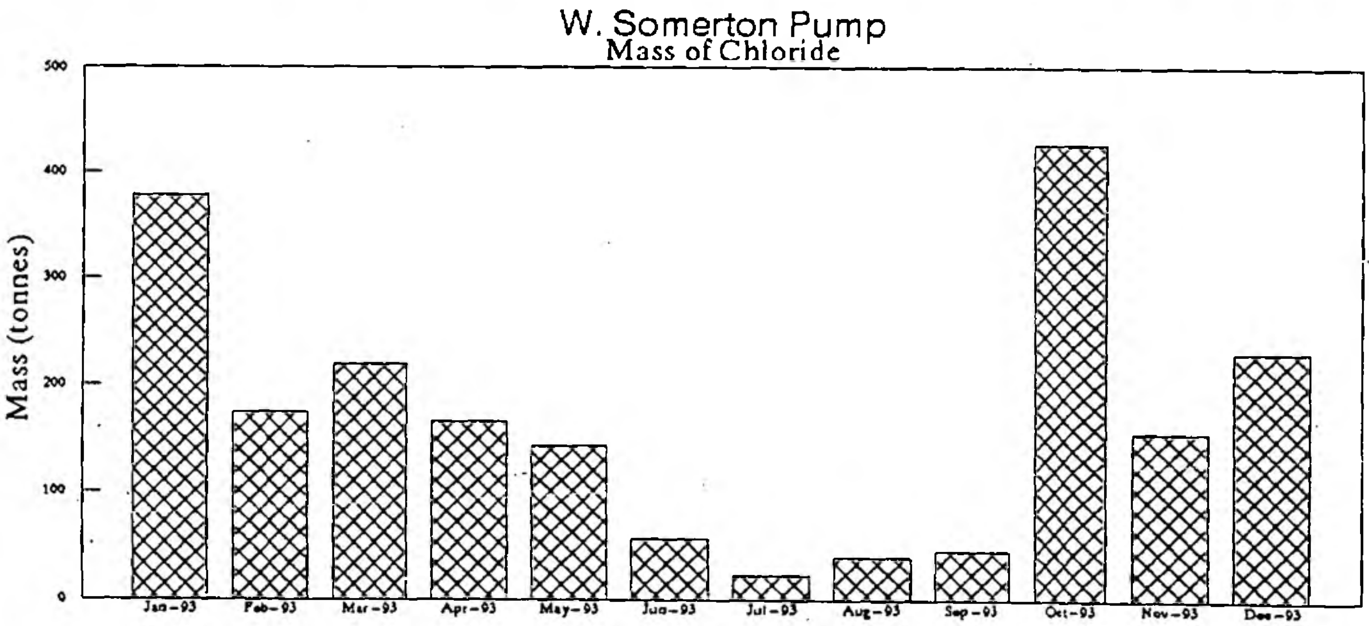
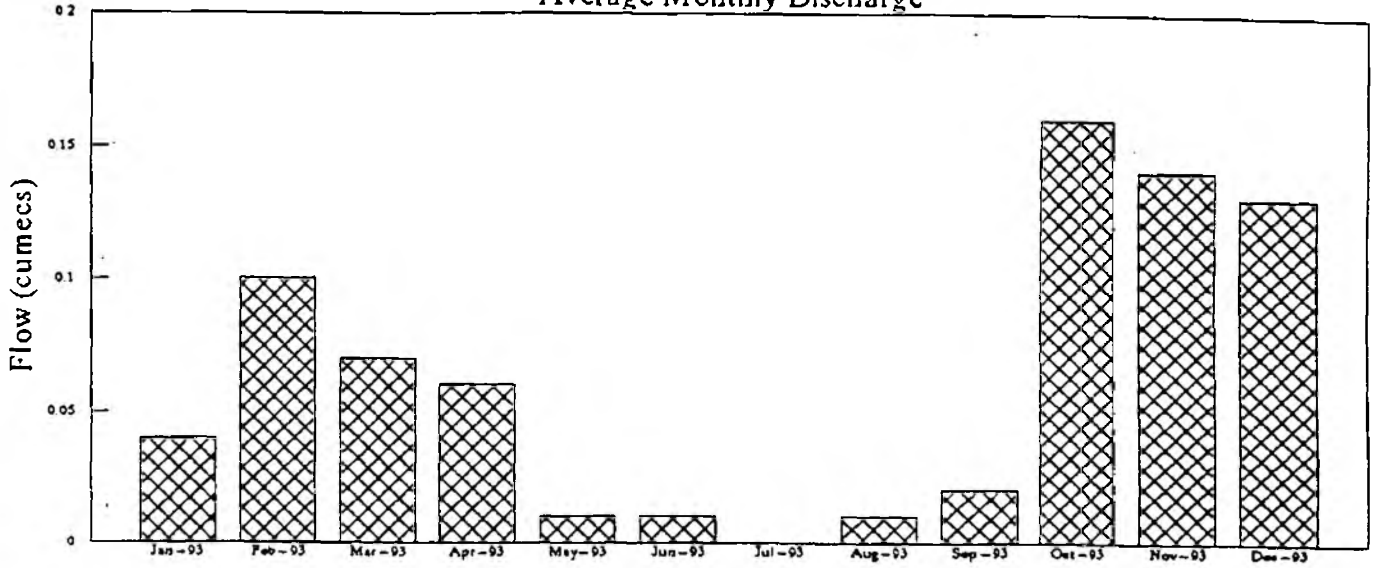
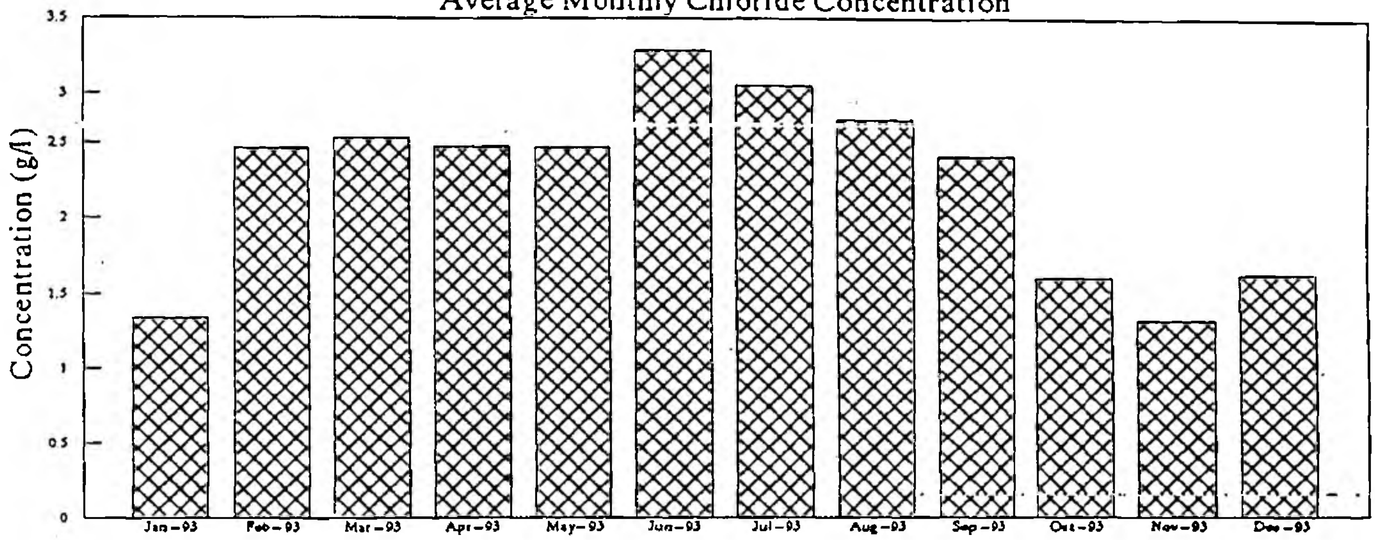


Figure 2.5 (f) Mean Monthly Flow, Chloride Concentration and Mass at W. Somerton Pump

New Somerton Pump
Average Monthly Discharge



New Somerton Pump
Average Monthly Chloride Concentration



New Somerton Pump
Mass of Chloride

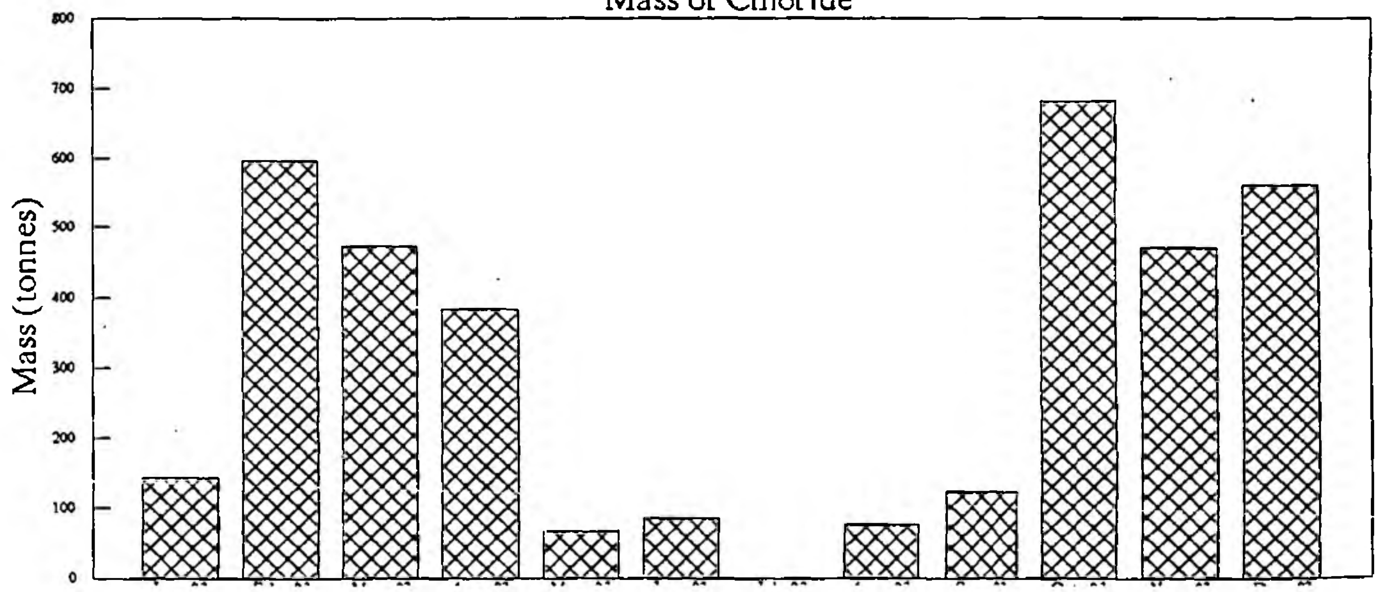


Figure 2.5 (g) Mean Monthly Flow, Chloride Concentration and Mass at N. Somerton Pump

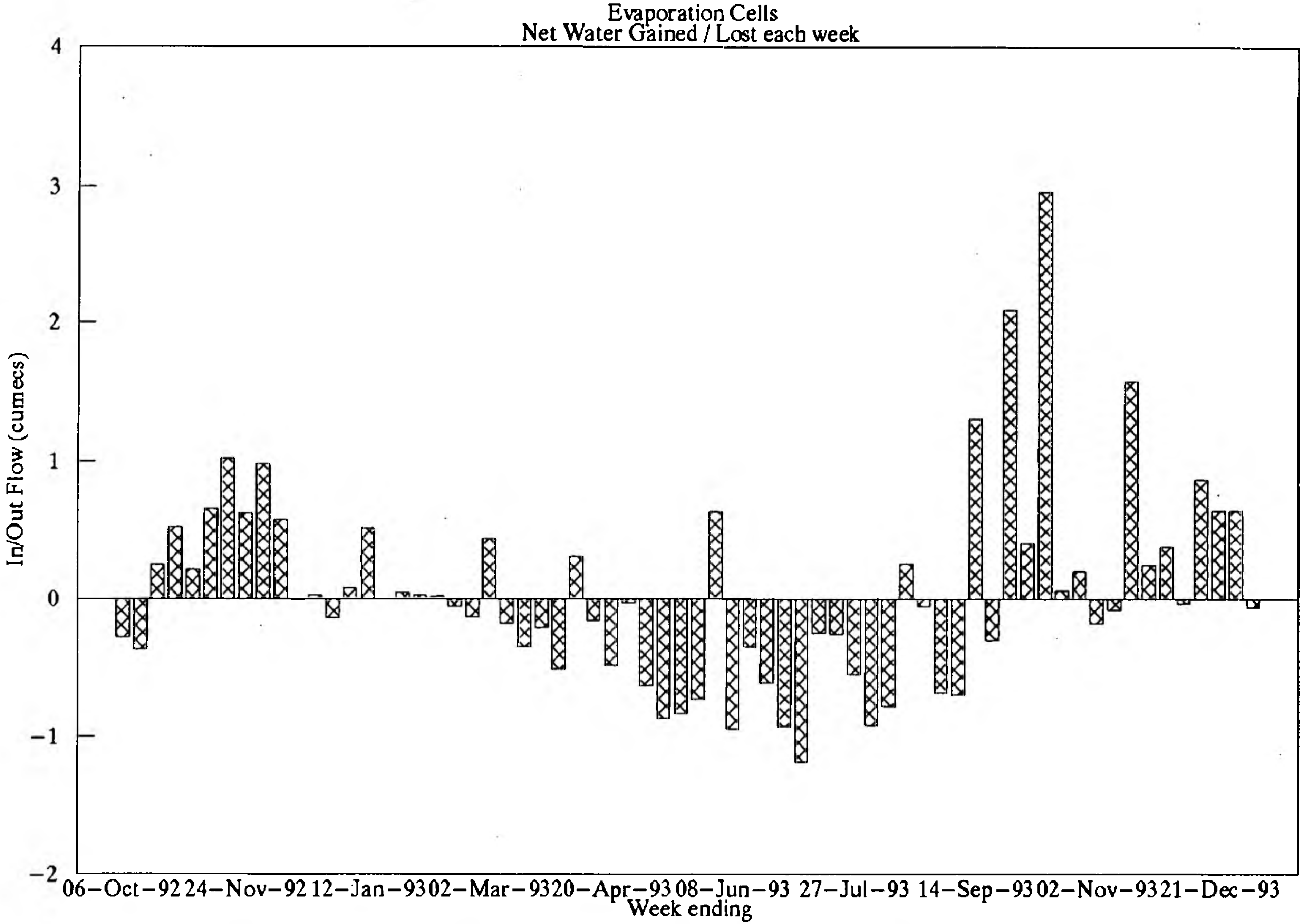


Figure 2.6 Net Water Gained or Loss from Rainfall and Evaporation

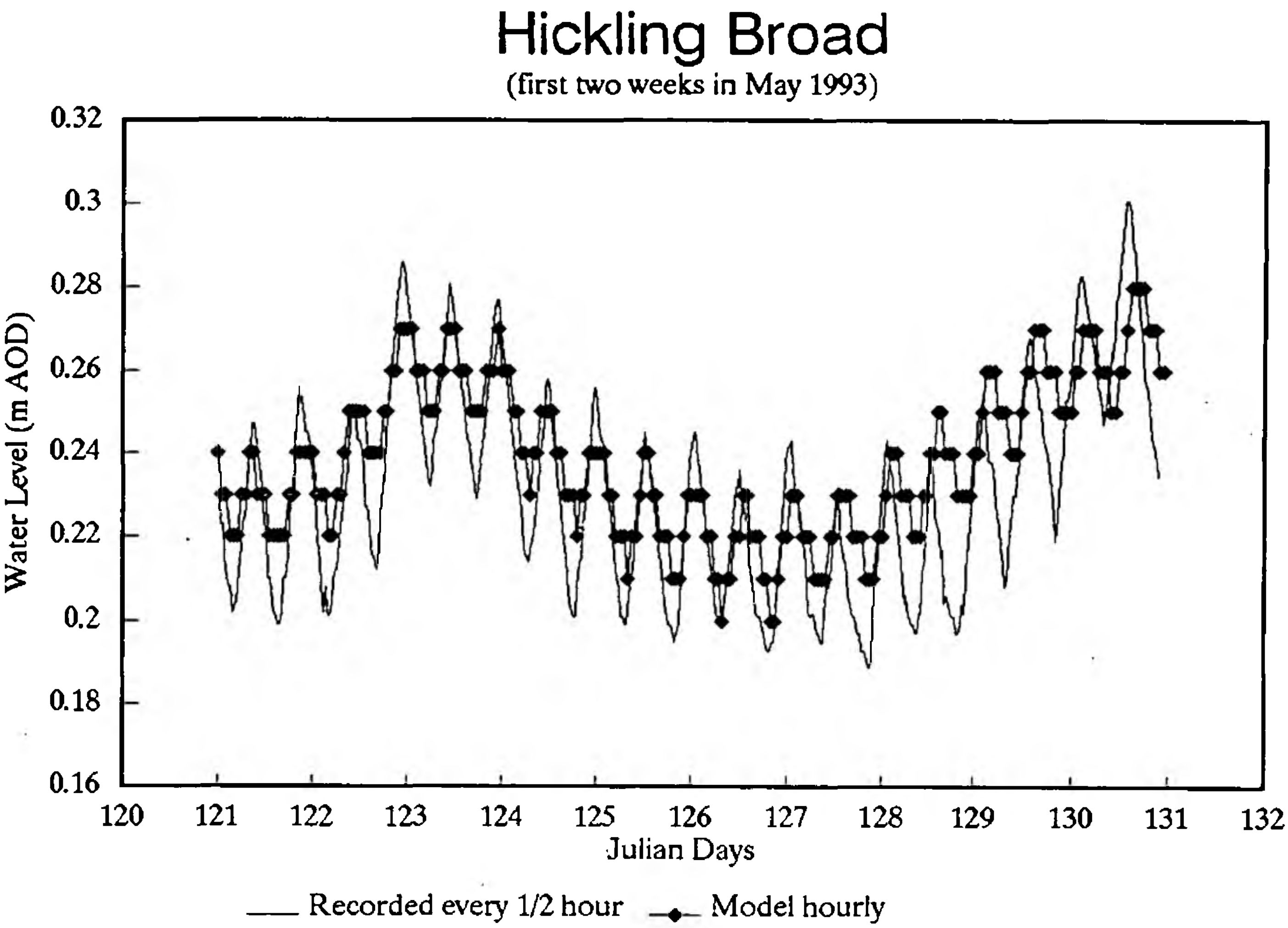


Figure 3.1 Comparison of Hourly Predicted and Recorded Water Level

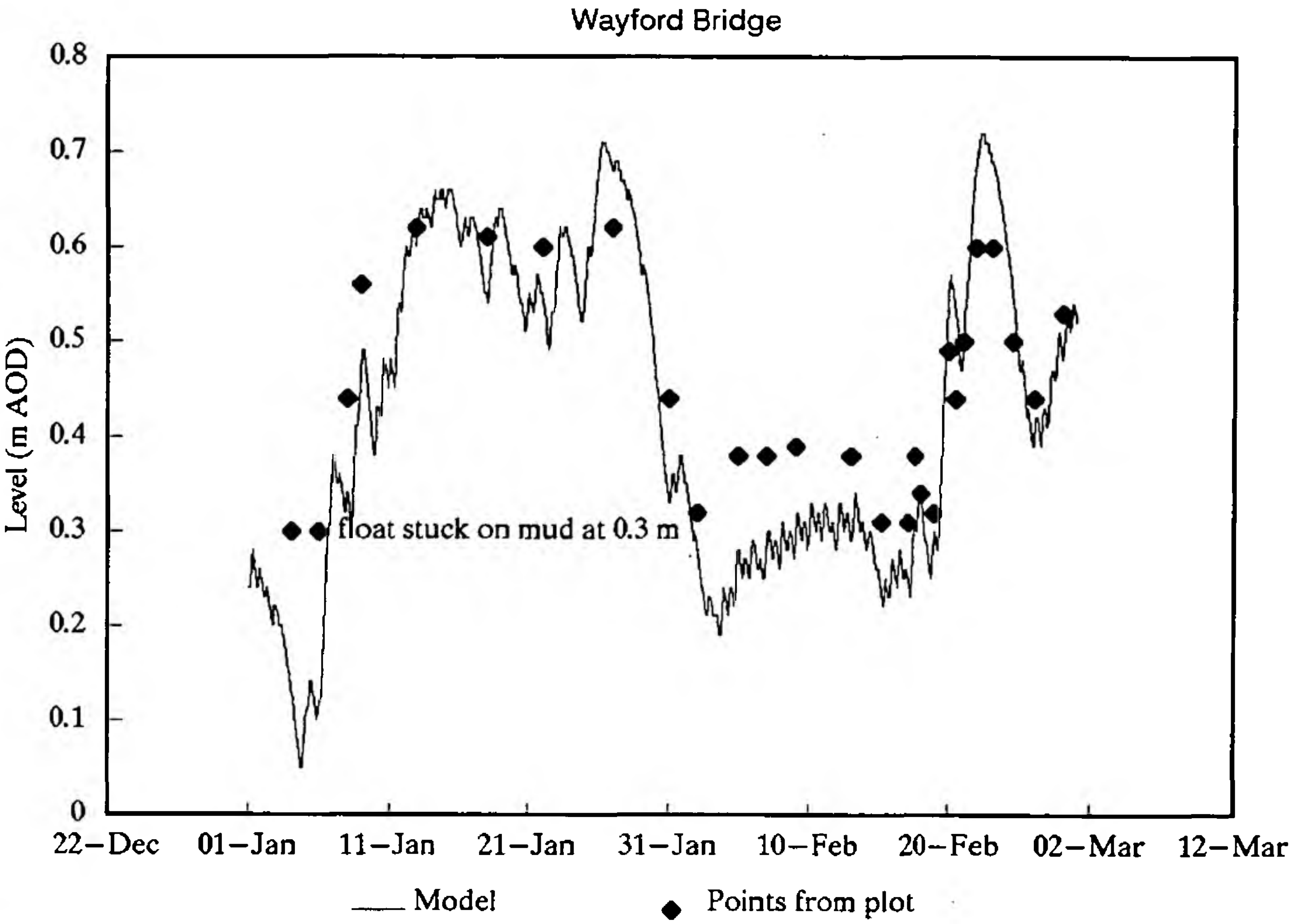
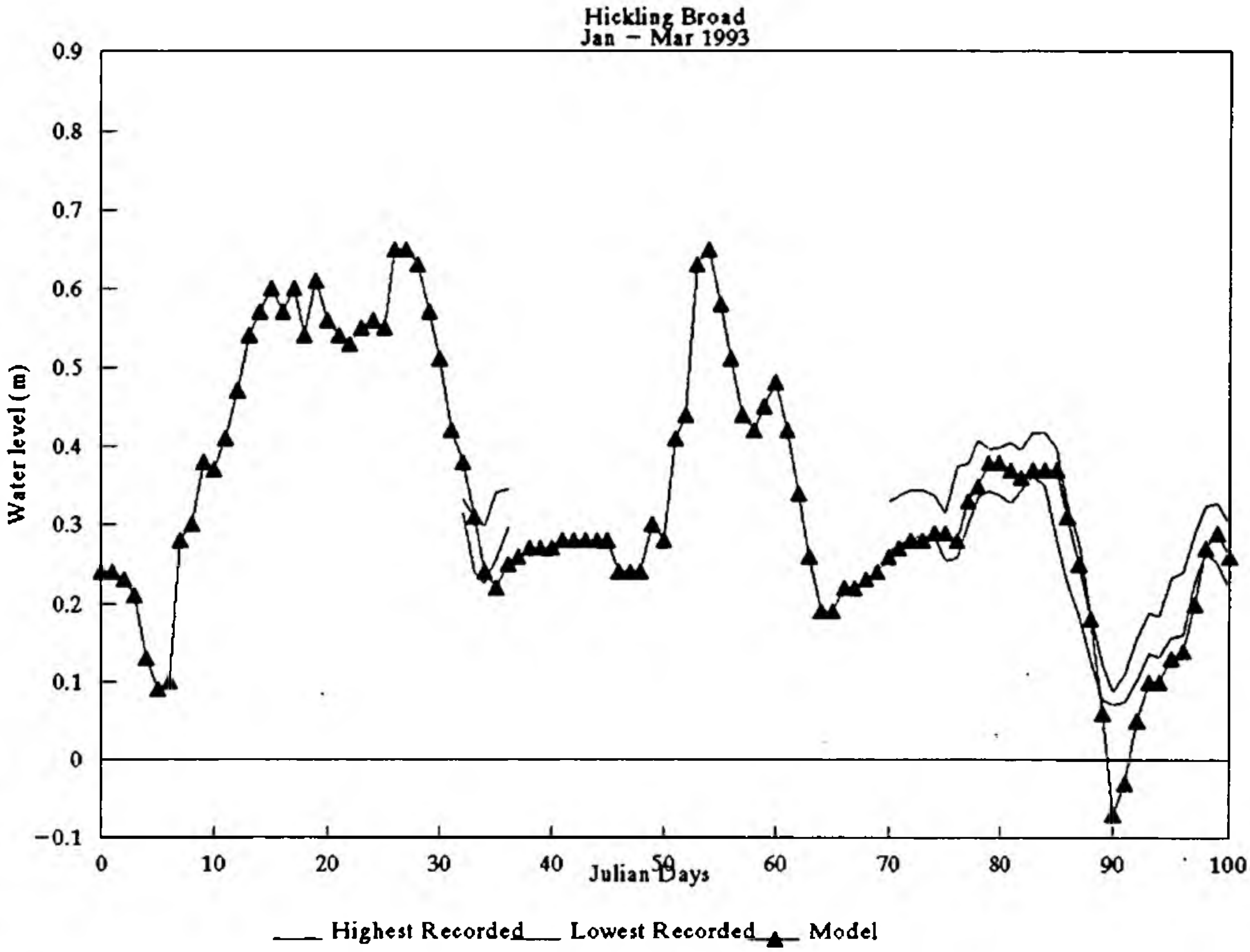


Figure 3.2 Comparison of Predicted and Recorded Water Level at Wayford Bridge



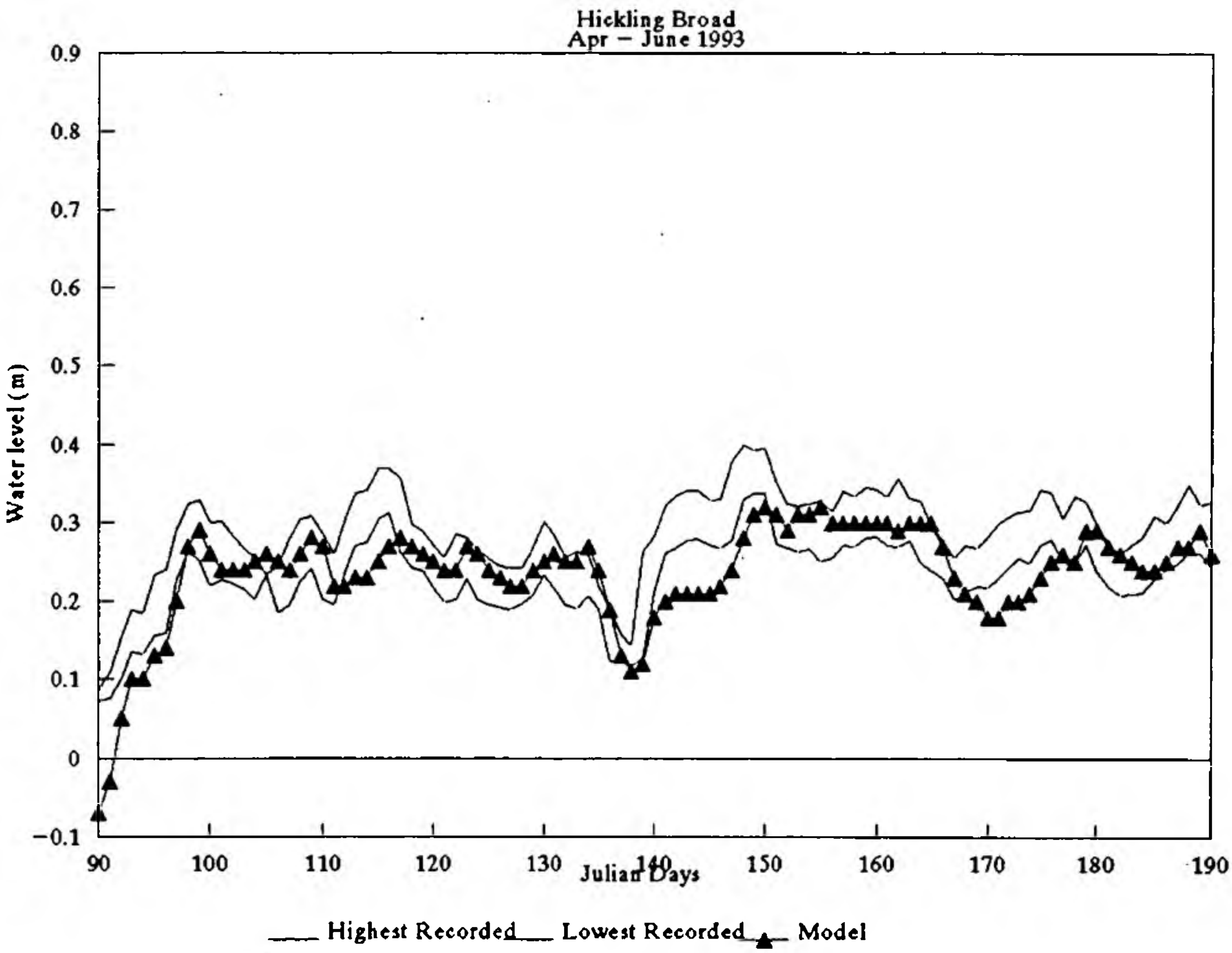
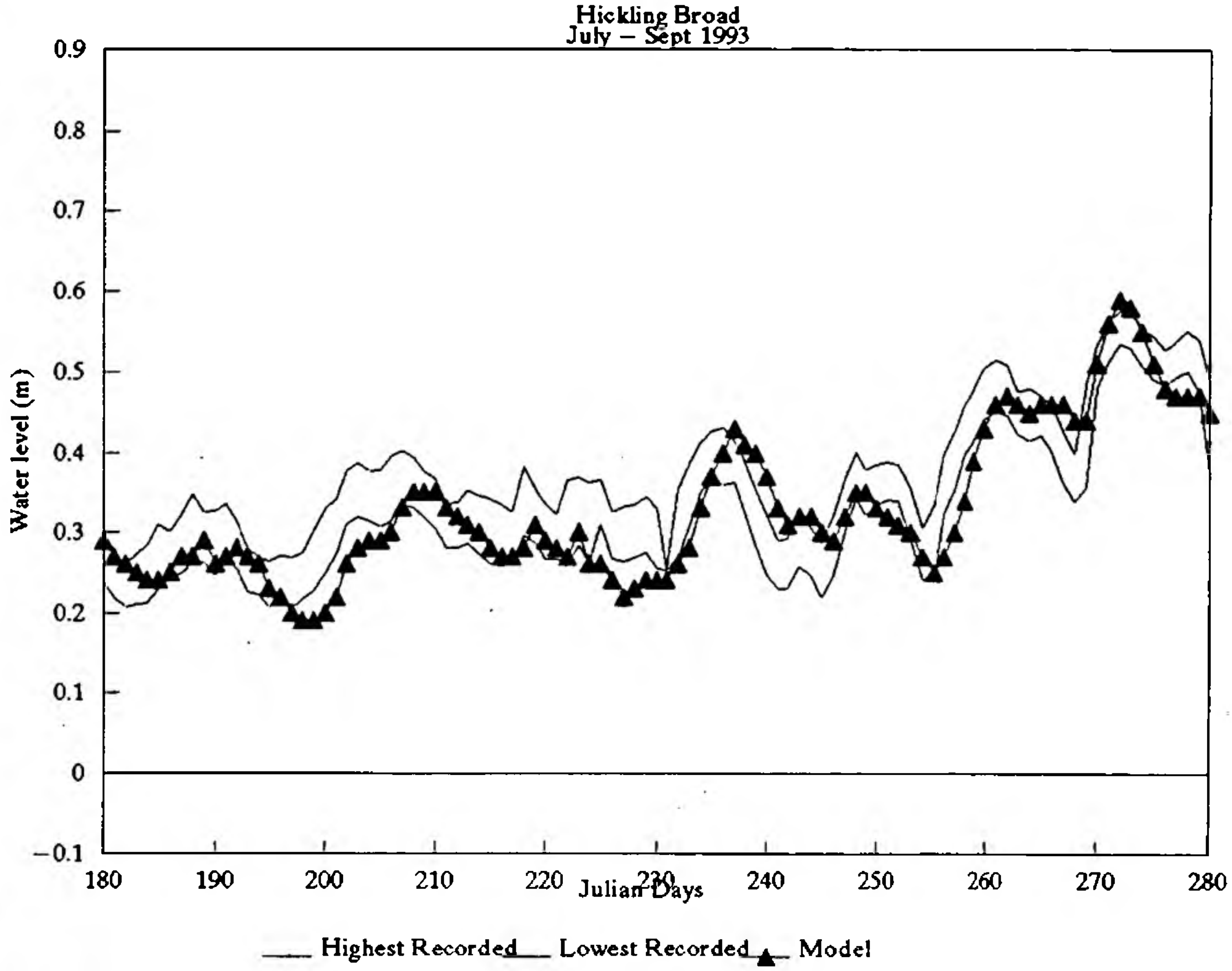
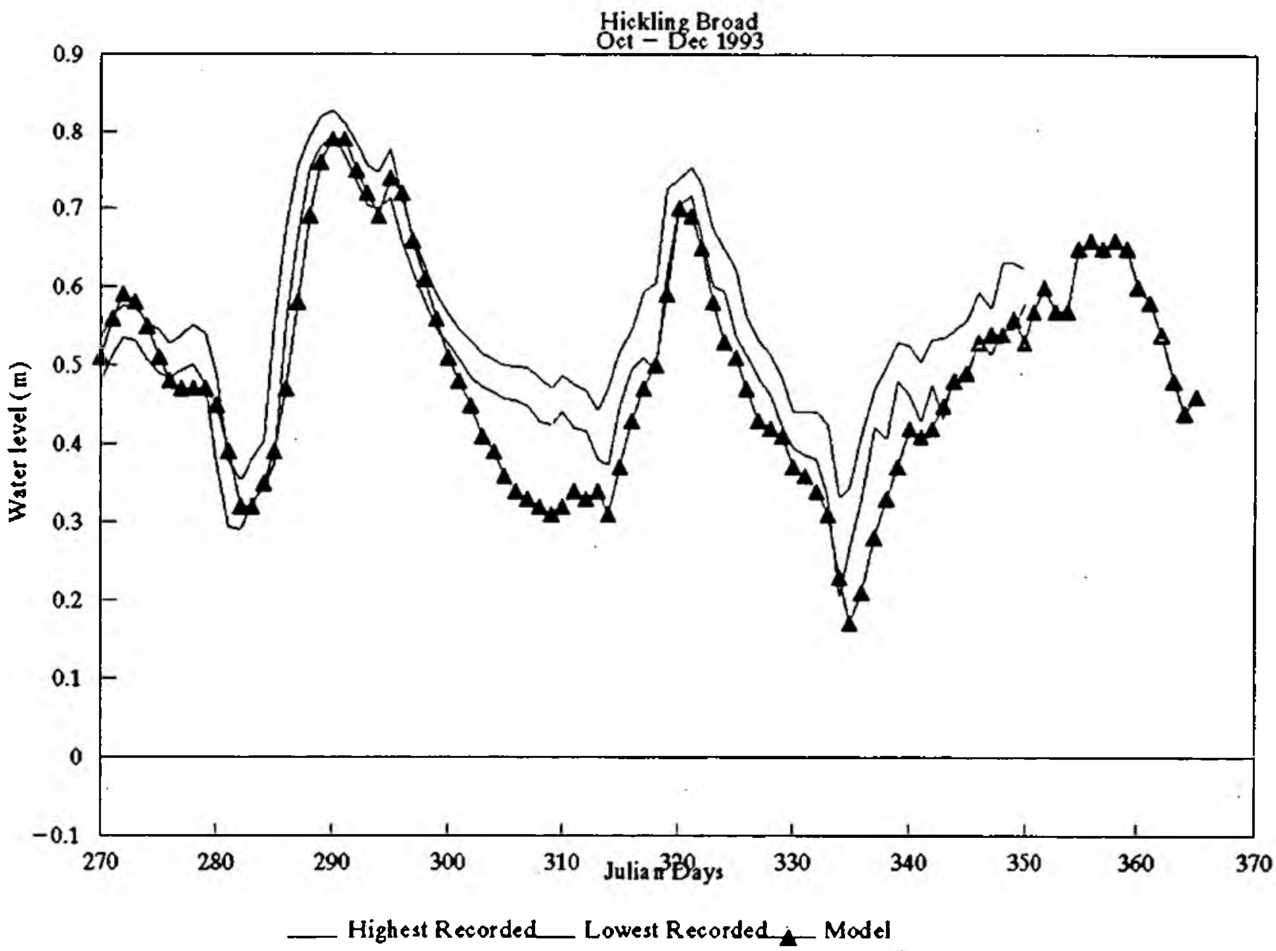


Figure 3.3 Comparison of Predicted and Recorded Water Level at Hickling Broads


Hickling Broad
July – Sept 1993
Water level (m)
Julian Days
Highest Recorded
Lowest Recorded
Model


Hickling Broad
Oct – Dec 1993
Water level (m)
Julian Days
Highest Recorded
Lowest Recorded
Model

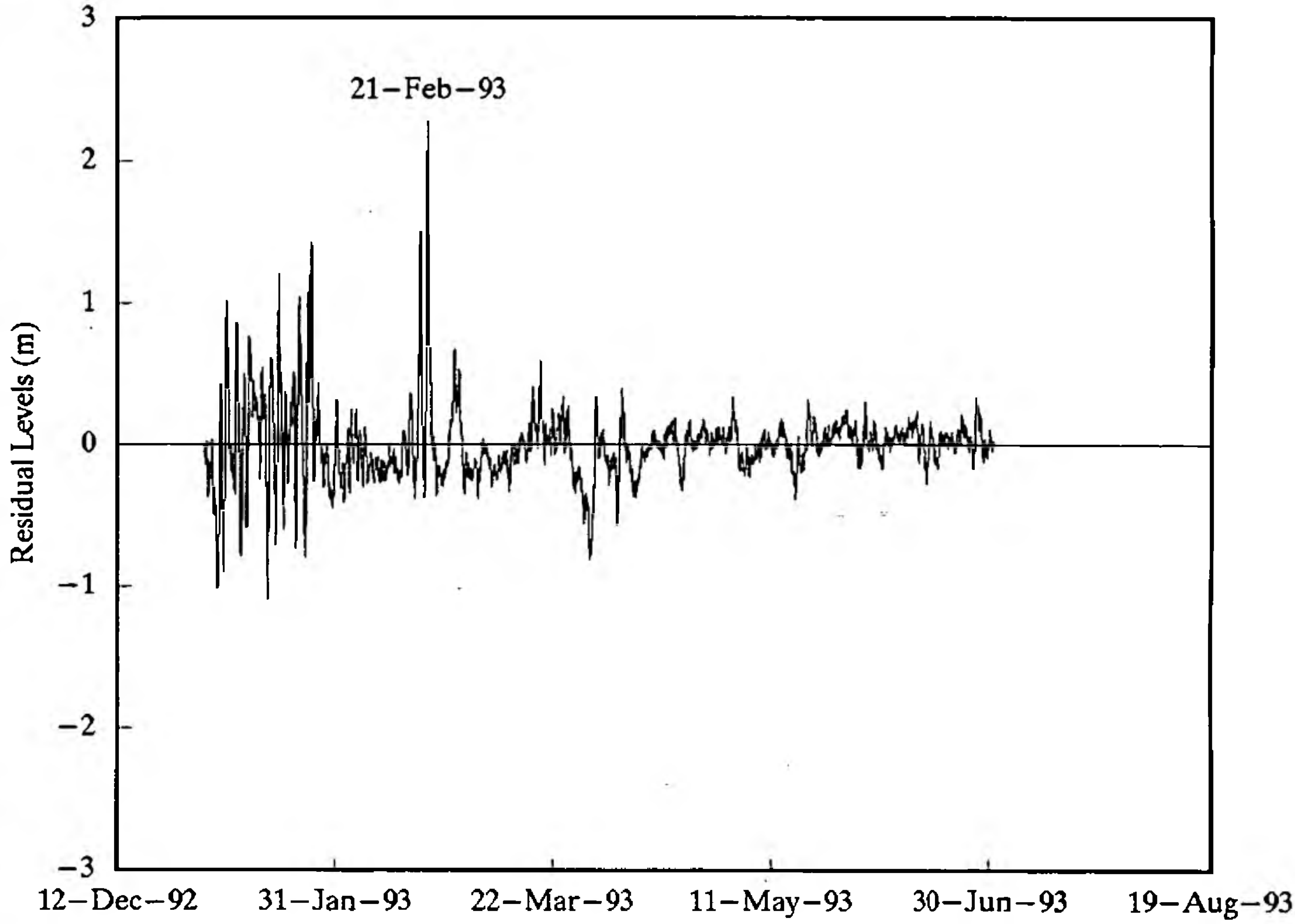


Figure 3.4 Surge Level at Lowerstoft during the Period of Jan. - Dec. 1993

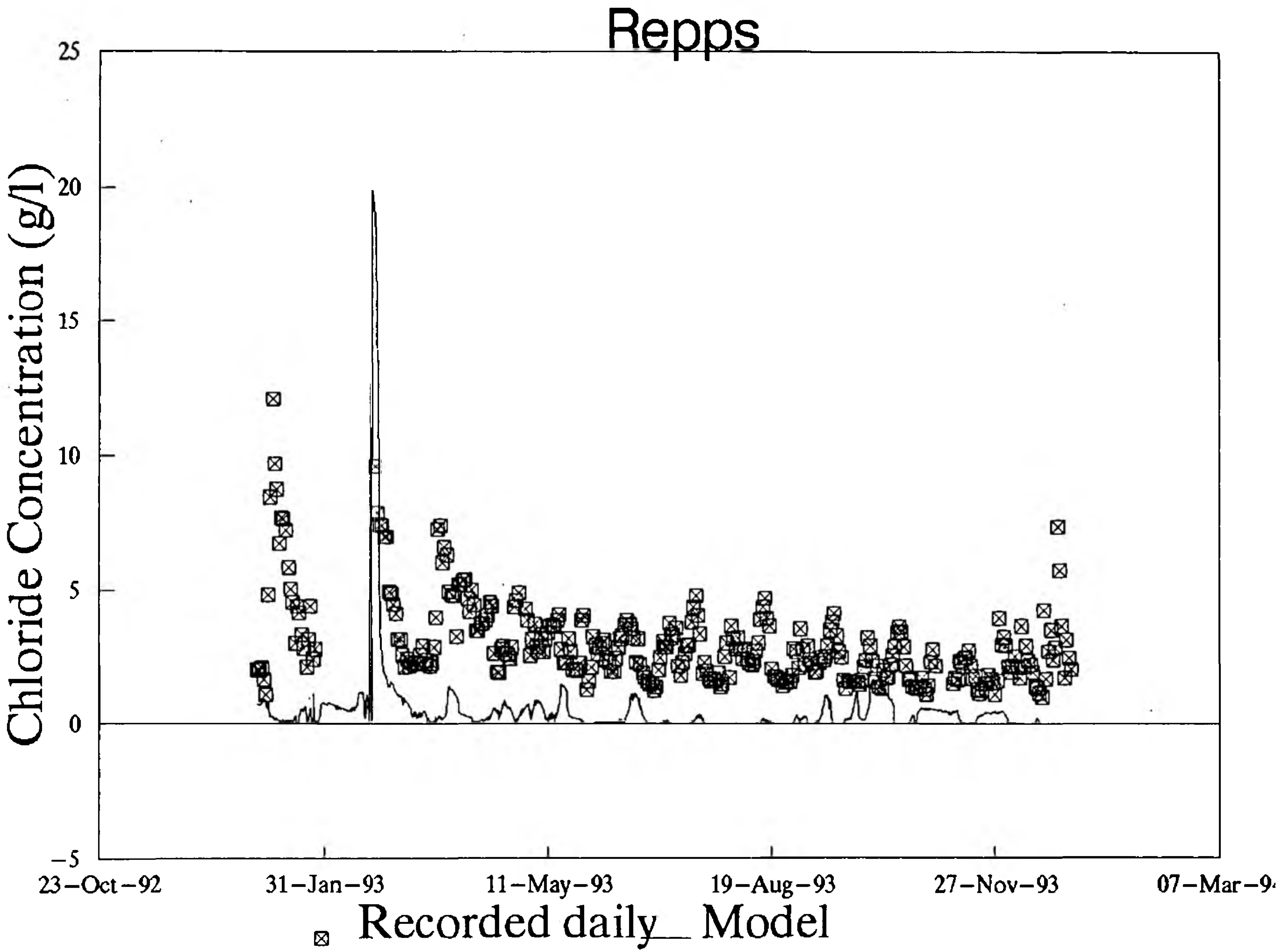


Figure 4.1 Comparison of Predicted and Recorded Chloridity at Repps

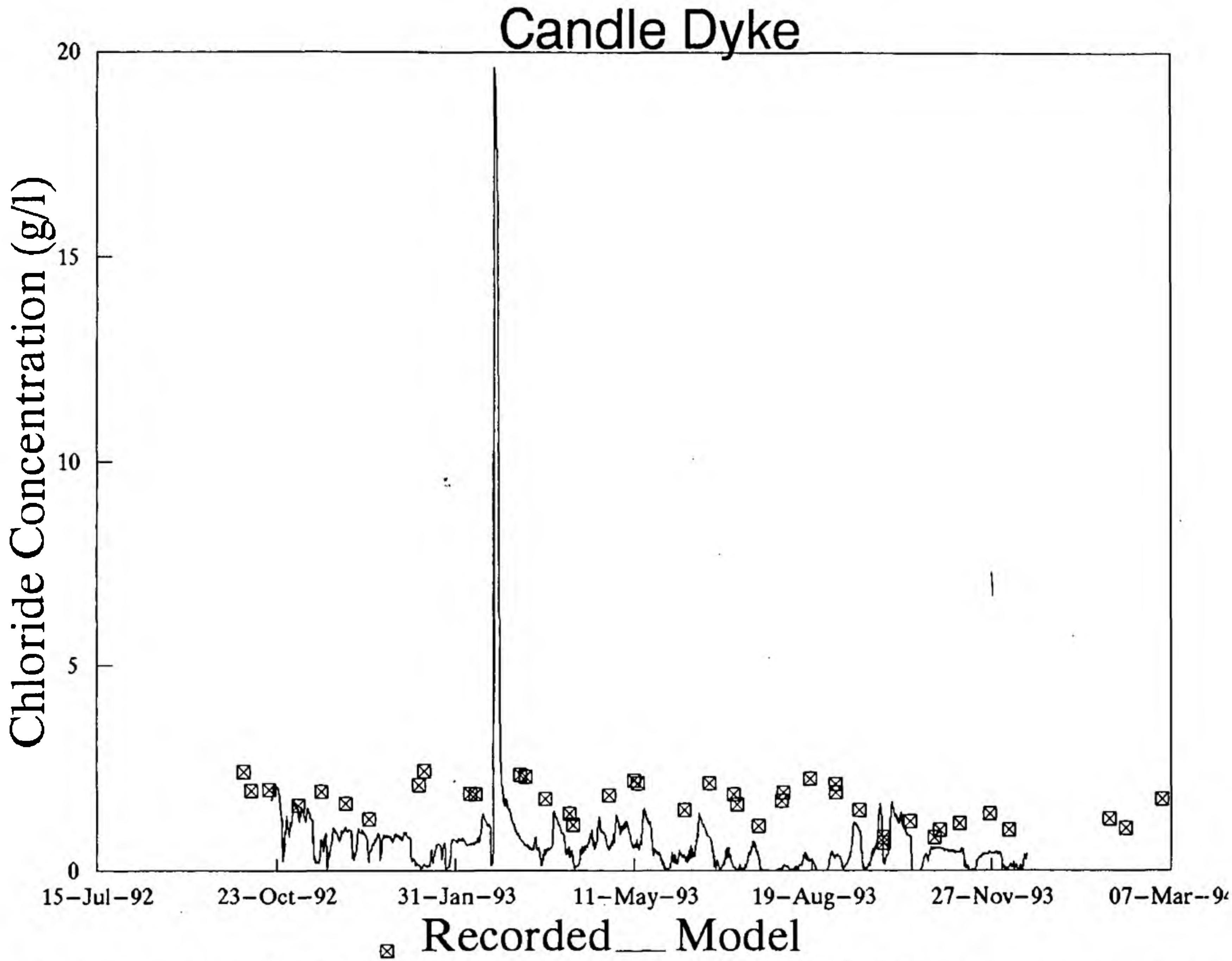


Figure 4.2 Comparison of Predicted and Recorded Chloridity at Candle Dyke

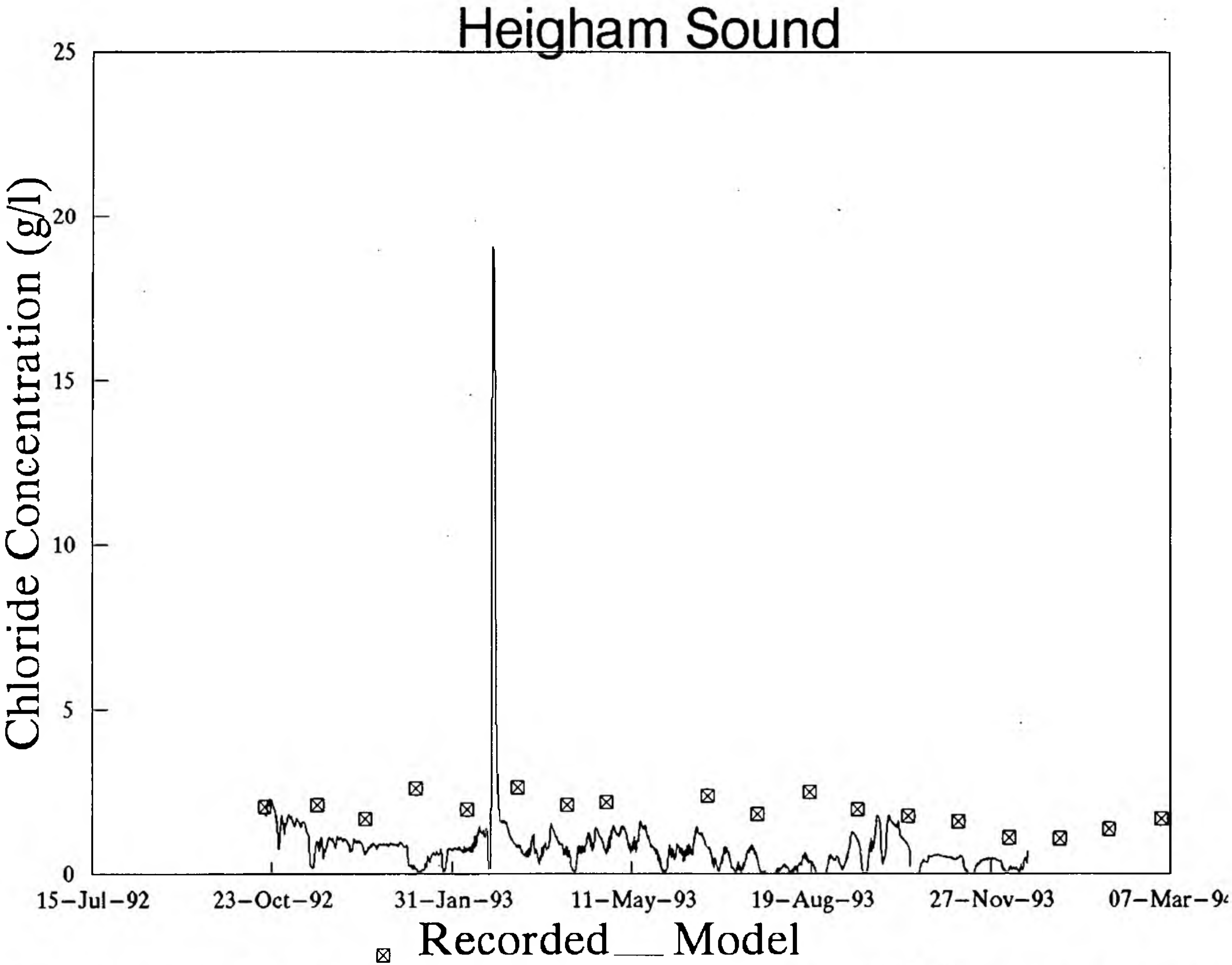


Figure 4.3 Comparison of Predicted and Recorded Chloridity at Heigham Sound

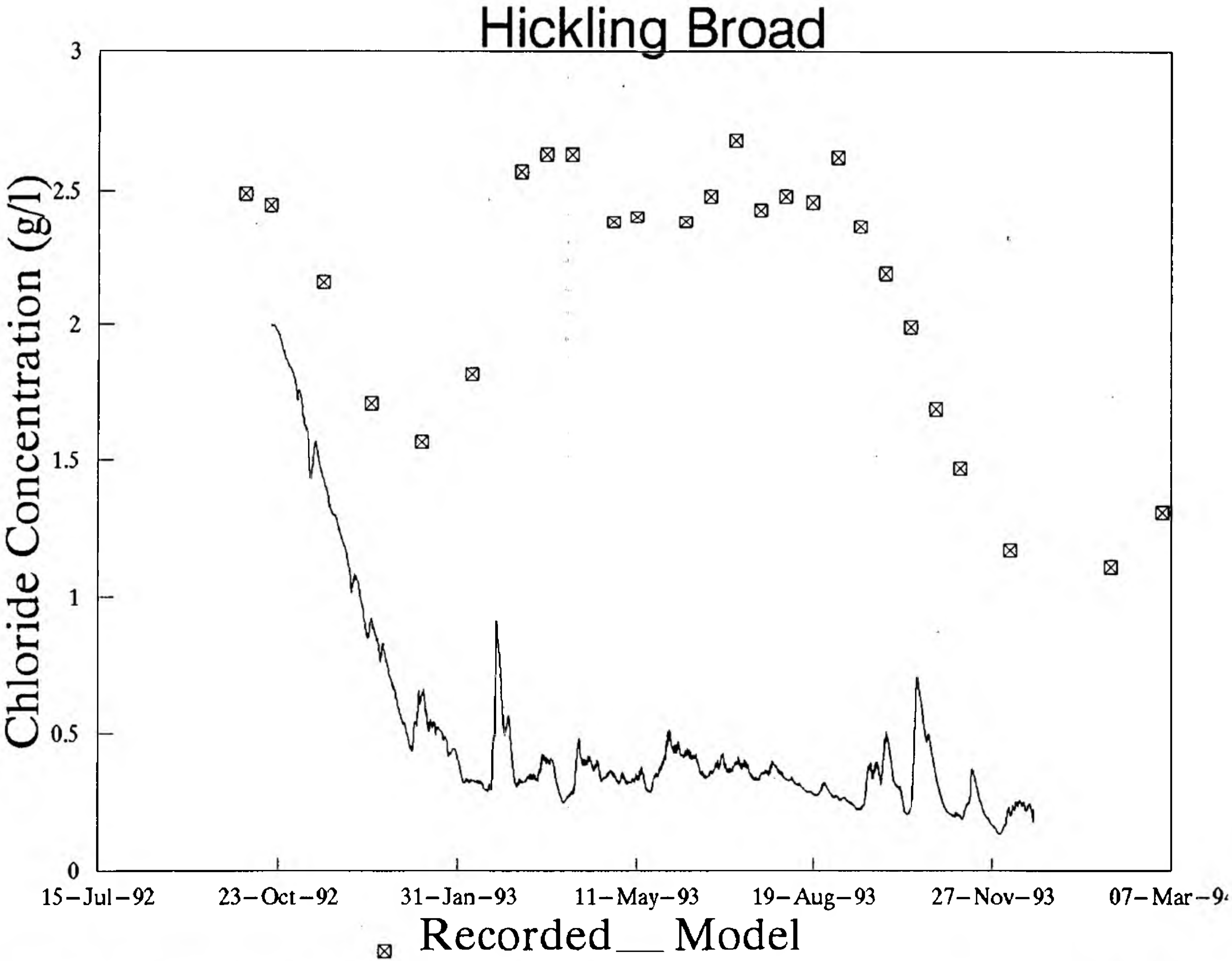


Figure 4.4 Comparison of Predicted and Recorded Chloridity at Hickling Broad

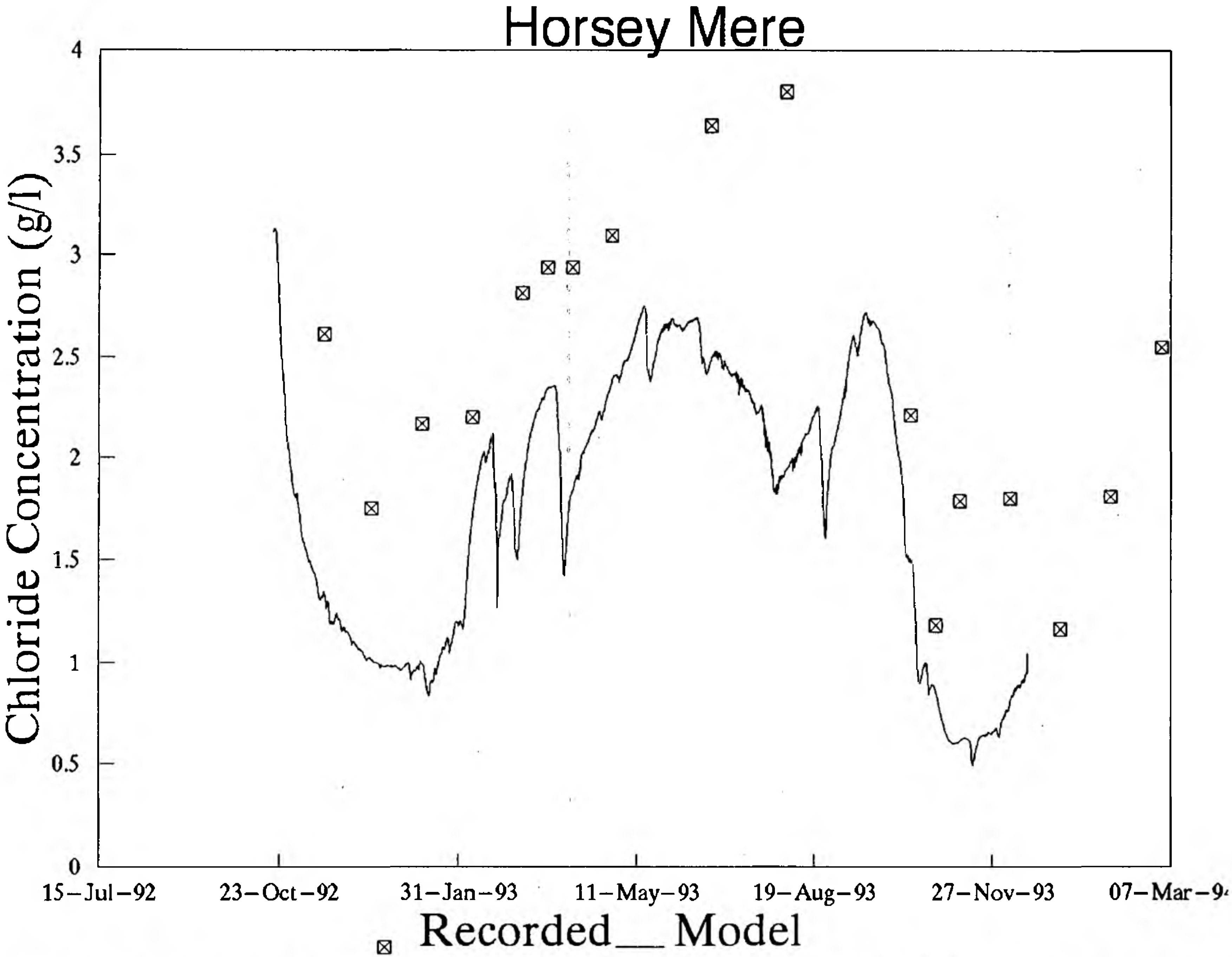


Figure 4.5 Comparison of Predicted and Recorded Chloridity at Horsey Mere

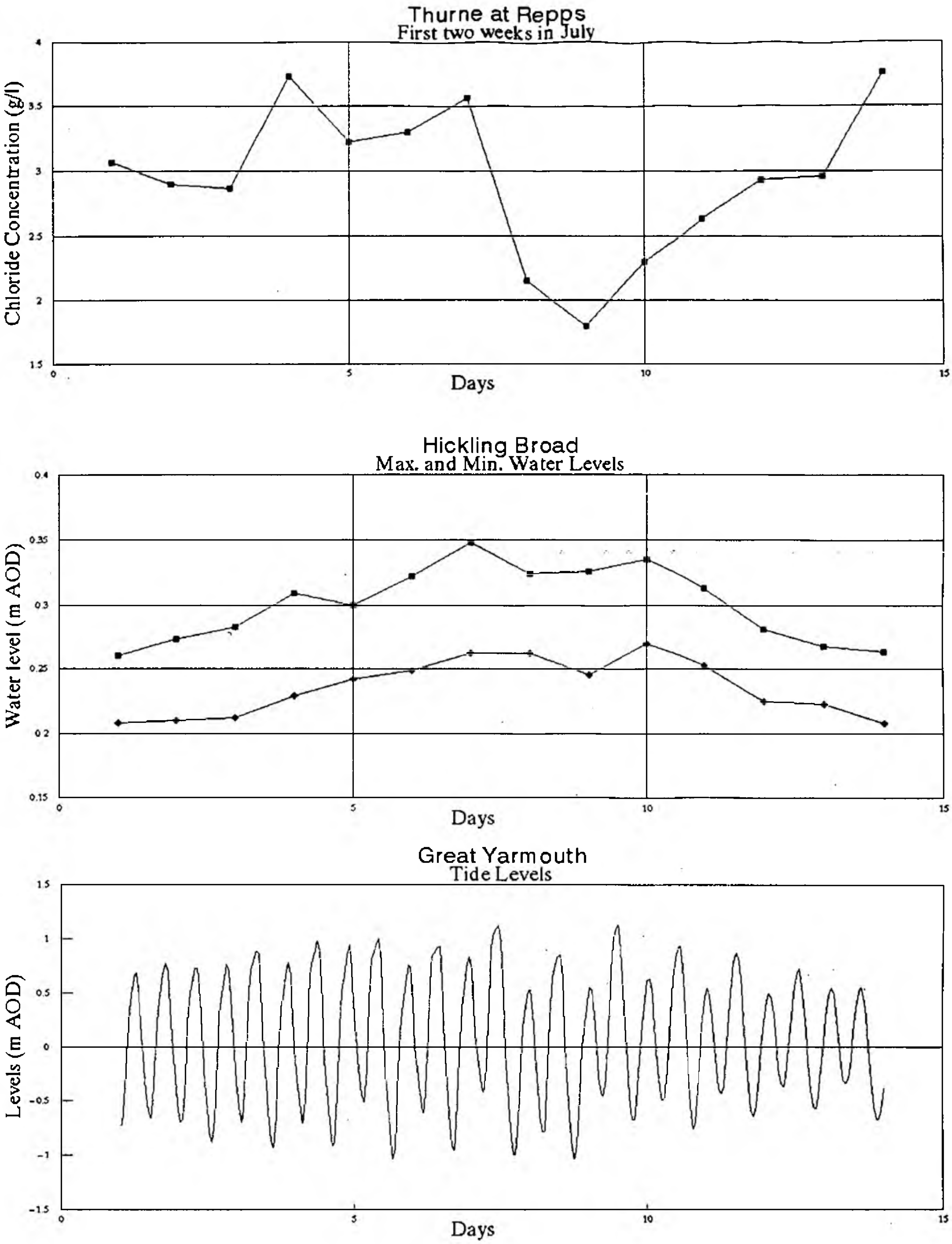


Figure 4.6 Recorded Chloride Variation at Repps

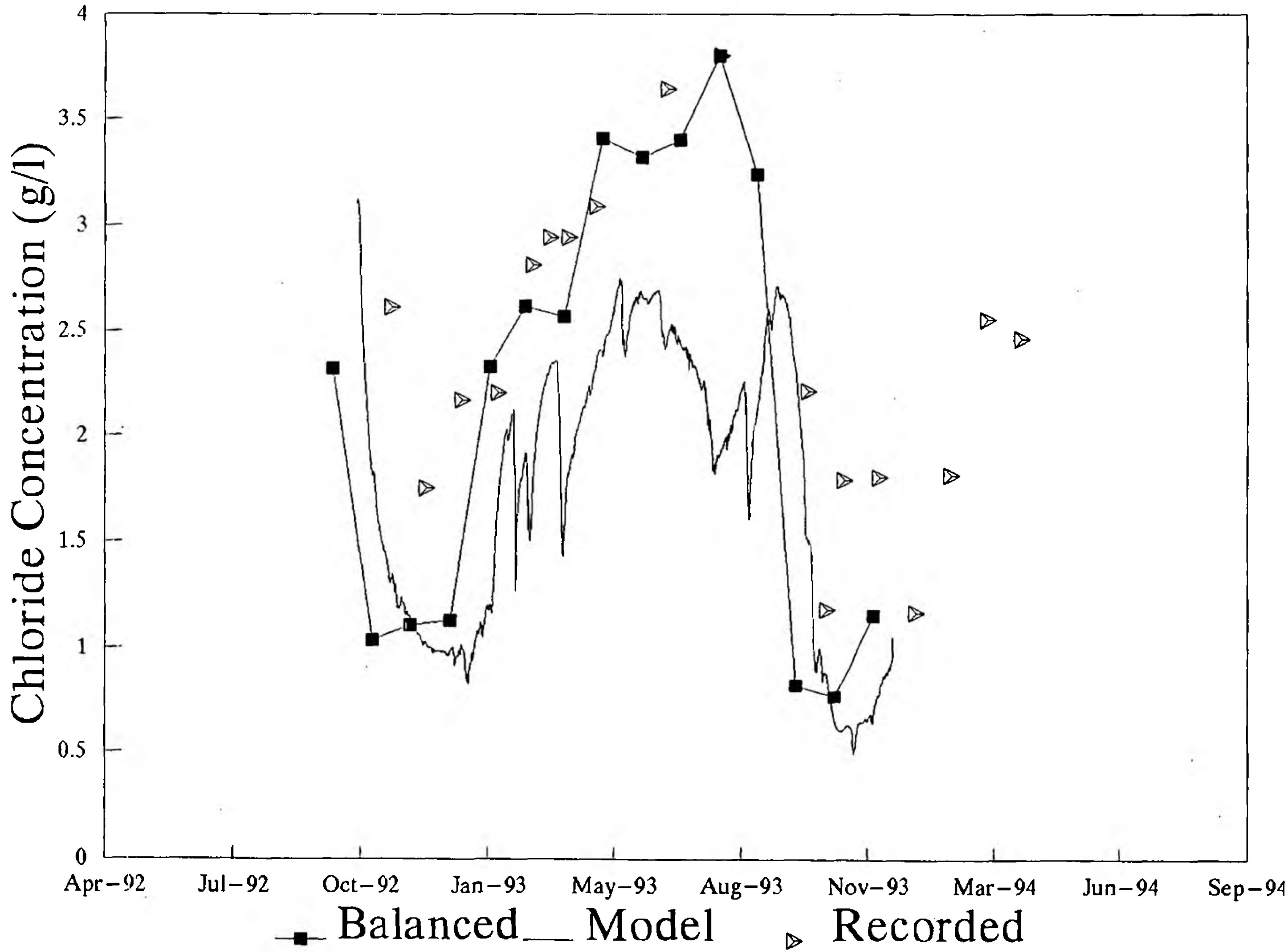


Figure 4.7 Chloride Mass Balance Calculation at Horsey Mere