AUSTRALIAN CENTRE FOR TROPICAL FRESHWATER RESEARCH

# Sleeper Log Creek Aquaculture Project

## Sea Water Supply Investigations - Stage 1 for Growth Industries Management Qld.

Report No. 89/02 April 1989

Prepared by: B. Otto and
R.E. Volker

RECOMMENDATIONS

The following recommendations are made:

(i) The bed level of Sleeper Log Creek (including local sand bars) between the farm channel intake structure and the sea should be lowered so that the crest height at the intake structure becomes the controlling factor for the discharge of water into the channel. The numerical investigation reported herein suggests that a "bed level" of -0.40 m A.H.D. would allow a minimum volume of approximately 540 ML to flow in daily. Dredging is expected to be necessary to retain the bed level at this value.

If dredging is not maintained, it is anticipated that, with the daily water volumes required, the velocity in the creek, especially over the sand bar at its mouth, will be increased so drastically compared with natural flow velocities ( 0.25 m/s) that sediment transport will occur towards the intake structure and that the sand bar will be eroded.

(ii) On the assumption of a 25 m wide intake, the crest level at the channel intake should be set at approximately of -0.40 m A.H.D. provided that the entire daily requirement of 540 ML can be stored below this level. If this should not be possible, additional investigations will be necessary.

(iii) Because at the highest tides, there will be large differences between maximum water levels and the suggested crest height, large velocities are expected to occur over the weir crest if the overfall is uncontrolled. The scour effect of high water velocities within the creek and within the intake structure should therefore be assessed.

(iv) The possible diversion of fresh water into the salt water supply channel under conditions of high local runoff should also be studied. An uncontrolled free overfall weir structure will draw mainly from the water surface. Combinations of relatively low tides, in the order of the crest level, and high fresh water influx into the lower reaches of Sleeper Log Creek, could lead to situations where mainly fresh water passes over the weir crest.

## 1. INTRODUCTION

The Australian Centre for Tropical Freshwater Research was commissioned by Growth Industries to perform modelling studies designed to assist in assessing water supply potential from Sleeper Log Creek for the adjacent partially constructed prawn farm. This report provides results from Stage I of the studies and it concentrates on the capacity of the existing channel in Sleeper Log Creek to convey water from the sea, under tidal action alone, to the inlet of the artificial channels in the prawn farm. The study included field measurements of water levels and velocities in the tidal reaches together with computer predictions of flow rates over natural and artificial controls on the discharge into the channels of the farm.

## 2. SCOPE OF INVESTIGATION

The aim of this investigation is to determine

(a) the tidal response of Sleeper Log Creek and Two Mile Creek under existing conditions;

(b) whether a daily water supply of 540 Megalitres (ML) can be economically drawn from the Sleeper Log Creek system.

(a) The response of the two creek systems under investigation to changing seawater levels at their mouth, is a complex problem for which a full investigation would need either extensive numerical modelling or long term insitu measurements. For the feasibility study reported herein, a simple method of water level measurements was chosen to assess the response of the two creek systems. A limited set of tidal conditions was selected for the boundary conditions for the two creek systems. Results of this investigation therefore give only an indication of the range of conditions which can be experienced.

(b) There was a requirement to determine whether a salt water quantity of 540 ML could be drawn daily from Sleeper Log Creek and, if so, under what conditions such a supply could be obtained.

# 3. TIDAL MEASUREMENTS

## 3.1 General Remarks

For this investigation two days in March 1989 were chosen for the field tests. On March 14 measurements were taken for a tidal difference of only 0.7 m and relatively low water levels whereas on March 16 the tidal difference was 2.4 m with much higher tides. Table 1 shows the measurement periods and information from the tide tables for Townsville and Lucinda for the respective days.

Table 1. Tide Tables

| Date | Measuring Period | Townsville | | Lucinda | |
|---|---|---|---|---|---|
| | | time [h] | height [m] | time [h] | height [m] |
| 14.3.89 | 1100 | 0453 | 2.65 | 0441 | 2.56 |
| | – | 1141 | 1.19 | 1151 | 1.25 |
| | 1730 | 1715 | 1.89 | 1706 | 1.77 |
| | | 2259 | 0.96 | 2249 | 1.02 |
| 16.3.89 | | 0001 | 0.76 | 0630 | 2.95 |
| | 0530 | 0631 | 3.07 | 1315 | 0.85 |
| | – | 1310 | 0.75 | 1842 | 2.16 |
| | 1330 | 1847 | 2.27 | | |

The above heights are taken from official tide tables and are given with respect to Port Datums. To relate the above water levels to A.H.D. (Australian Height Datum), amounts of 1.576 m and 1.574 m have to be subtracted from the tide levels to Port Datums at Townsville and Lucinda respectively.

## 3.2 Test Design

The investigation of the tidal response of Sleeper Log and Two Mile Creek was carried out by instrumenting the creeks with a total of 7 tide gauges as shown in Figure 1. Tide gauge 1 was situated in Sleeper Log Creek approximately 200 m upstream from the junction of Christmas and Sleeper Log Creeks and was the furthest gauge upstream from the mouth of the creek.

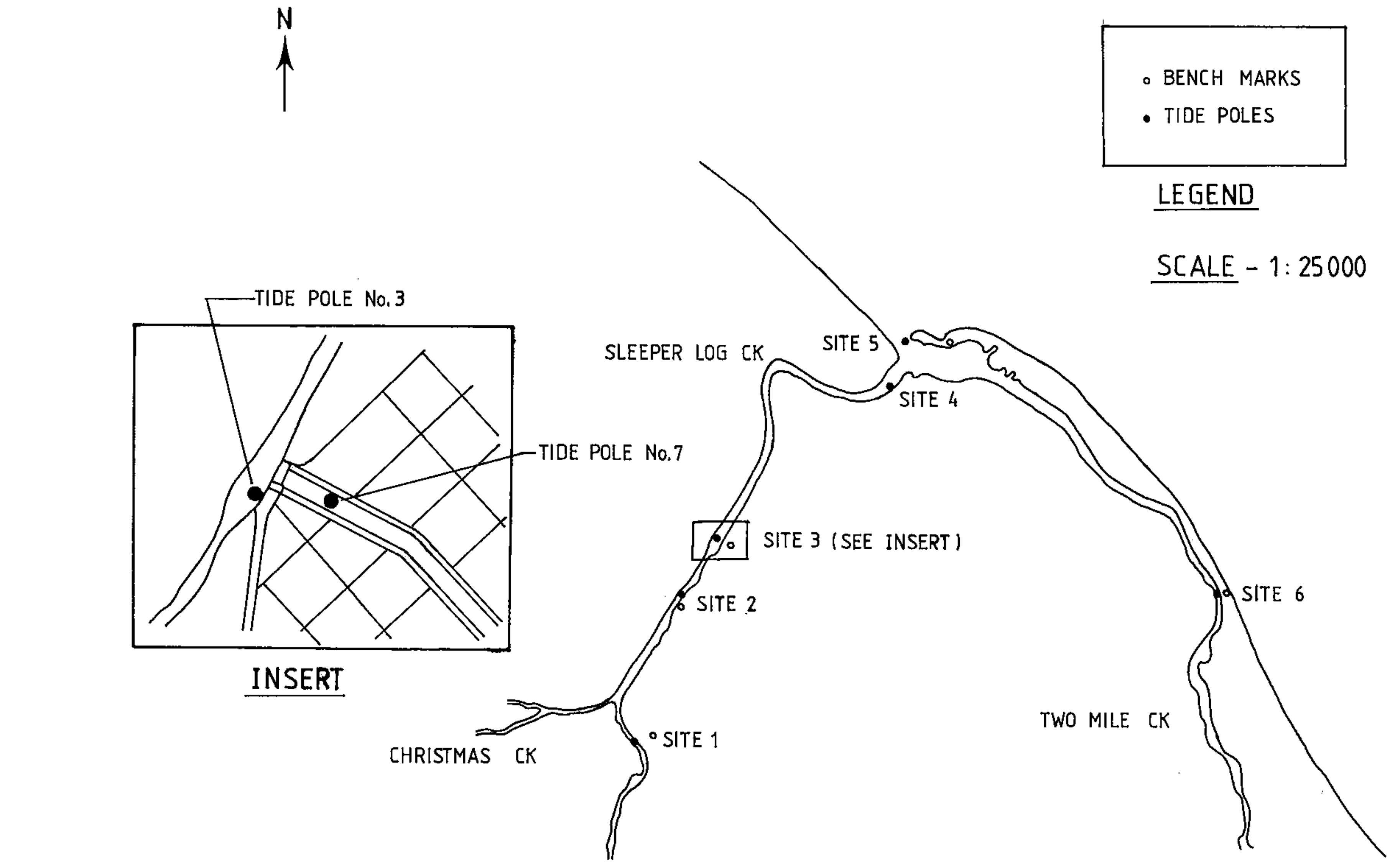

N
BENCH MARKS
TIDE POLES
LEGEND
SCALE - 1: 25000
TIDE POLE No.3
TIDE POLE No.7
INSERT
SLEEPER LOG CK
SITE 5
SITE 4
SITE 3 (SEE INSERT)
SITE 2
SITE 1
SITE 6
CHRISTMAS CK
TWO MILE CK

FIGURE 1

Tide gauge 2 was used only as a means of checking results and was not measured continuously.

Tide gauge 3, situated at the existing intake structure of the saltwater storage channel lies approximately 1.2 km upstream of the mouth of Sleeper Log Creek. At this location velocity distributions in a cross-section of the creek were also measured to determine the discharges passing through the cross section under natural conditions.

Tide gauge 4 was situated at the mouth of Sleeper Log Creek, immediately behind a sand bar at the creek entrance.

Tide gauge 5 at the tip of the sand spit was installed to measure the tidal movement of the sea.

Tide gauge 6 situated in Two Mile Creek approximately 1.8 km upstream of its mouth, was the only gauge installed in this creek and was positioned as far upstream as feasible with reasonable access.

Tide gauge 7 was located within the saltwater supply channel approximately 20 m from the intake structure. It was chosen to monitor the response of the existing channel and inlet system (including the partially eroded earth mound on the creek side of the intake structure). The water level was also measured at the entrance of the intake structure to monitor the head loss through the structure.

Tide gauges were read at variable intervals depending on the speed at which water levels were changing. The reading intervals ranged from 15 minutes to one hour. The accuracy to which levels could be read is estimated to be $\pm 10$ mm.

Water velocities in Sleeper Log Creek at site 3 were measured by means of a propeller meter (OTT METER) in 5 locations across the creek. At each of these locations the velocities were measured from the water surface to the creek bed. The number of measurements per location depended on the depth of water. For each velocity measurement the meter recorded its propeller revolutions per minute and this reading was then related to the average water velocity over that period.

## 3.3 Results

### 3.3.1 Tide gauge readings

Figures 2 and 3, representing results of measurements taken on 14 March 1989 and 16 March 1989 respectively, show the variation of water levels, measured relative to A.H.D., with time. Each measuring location is represented by a different symbol.

### 3.3.2 Velocity measurements

Figures 4 and 5 show a three-dimensional plot of the measured velocities within the cross section of the creek at site 3 obtained on the 14 March 1989 and 16 March 1989 respectively.

## 3.4 Discussion of Results

### 3.4.1 Water levels in Sleeper Log Creek

Referring to Figures 2 and 3 and gauge readings of tide gauges 1, 3, 4 and 5 results can be interpreted as follows:

(a) Tide gauge readings for the two observed high tides correlate very well between gauges 1, 3, 4 and 5 in a period of time close to the occurrence of the high tide. Hence there is no significant time lag between the occurrence of maximum water levels in the creek and the sea, nor is there an amplification of water levels in the creek. The section of Sleeper Log Creek investigated therefore reacts effectively to a rise in sea water level. This can be seen in Figure 2 for the time period between 16:00 and 17:30 hours, with a rising tide, and between 6:00 and 8:30 for an outrunning tide.

(b) At the two observed low tides the water levels within the creek, namely gauges 1, 3, and 4 show very similar readings, while tide gauge 5 shows significantly lower values. The water levels of the sea, taken from tide tables are still lower than the reading of gauge 5.

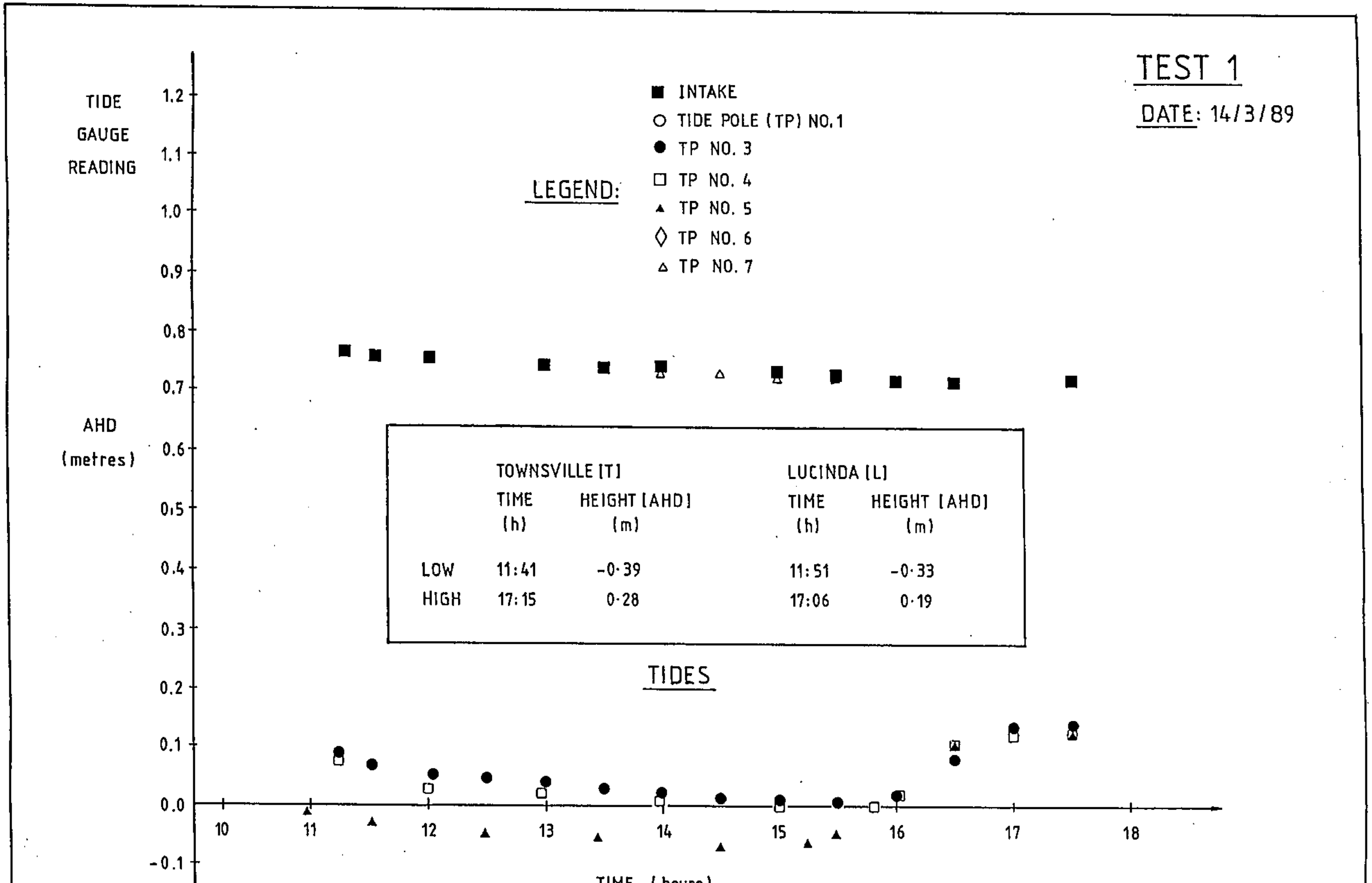

TEST 1
DATE: 14/3/89
TIDE GAUGE READING
AHD (metres)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
LEGEND:
INTAKE
TIDE POLE (TP) NO.1
TP NO. 3
TP NO. 4
TP NO. 5
TP NO. 6
TP NO. 7
TOWNSVILLE [T]
TIME (h)
HEIGHT [AHD] (m)
LUCINDA [L]
LOW 11:41 -0·39 11:51 -0·33
HIGH 17:15 0·28 17:06 0·19
TIDES
10
11
12
13
14
15
16
17
18
TIME (hours)

FIGURE 2

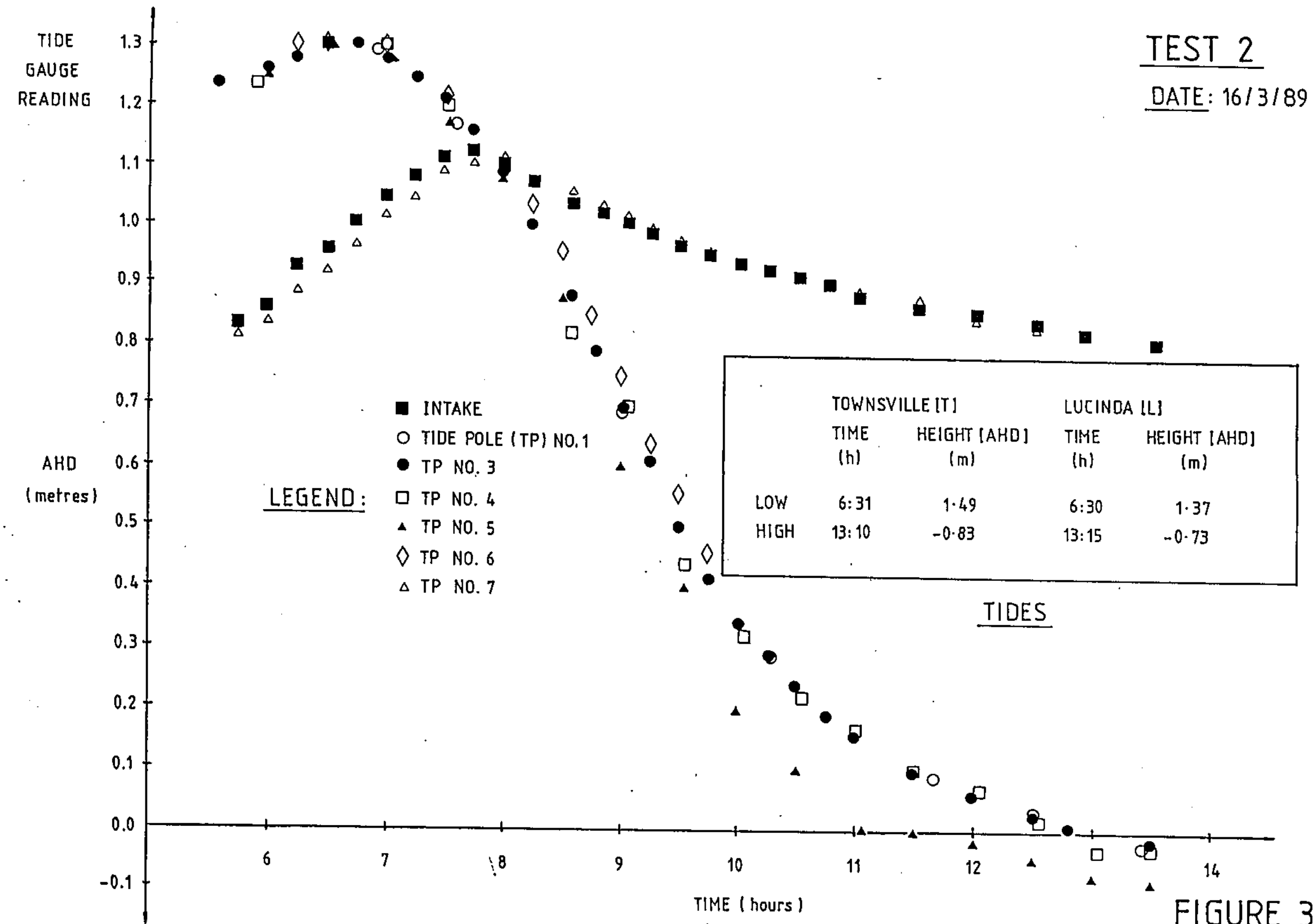

TEST 2
DATE: 16/3/89
TIDE GAUGE READING
AHD (metres)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
6
7
8
9
10
11
12
14
TIME ( hours )
LEGEND:
INTAKE
TIDE POLE (TP) NO.1
TP NO. 3
TP NO. 4
TP NO. 5
TP NO. 6
TP NO. 7
TIDES
TOWNSVILLE [T]
LUCINDA [L]
TIME (h)
HEIGHT [AHD] (m)
TIME (h)
HEIGHT [AHD] (m)
LOW 6:31 1·49 6:30 1·37
HIGH 13:10 -0·83 13:15 -0·73

FIGURE 3

VELOCITIES

Date: 14/3/89
SITE 3

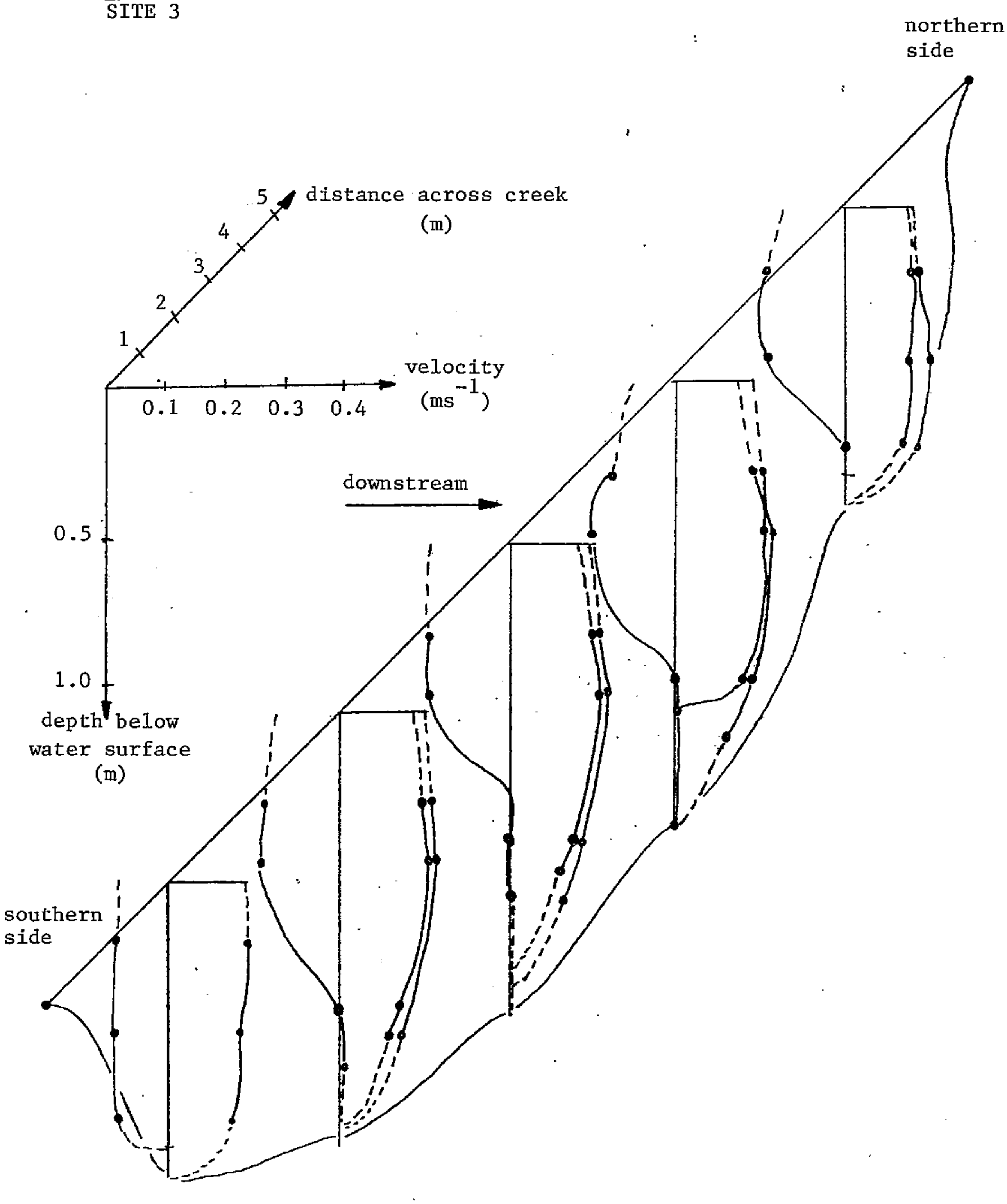
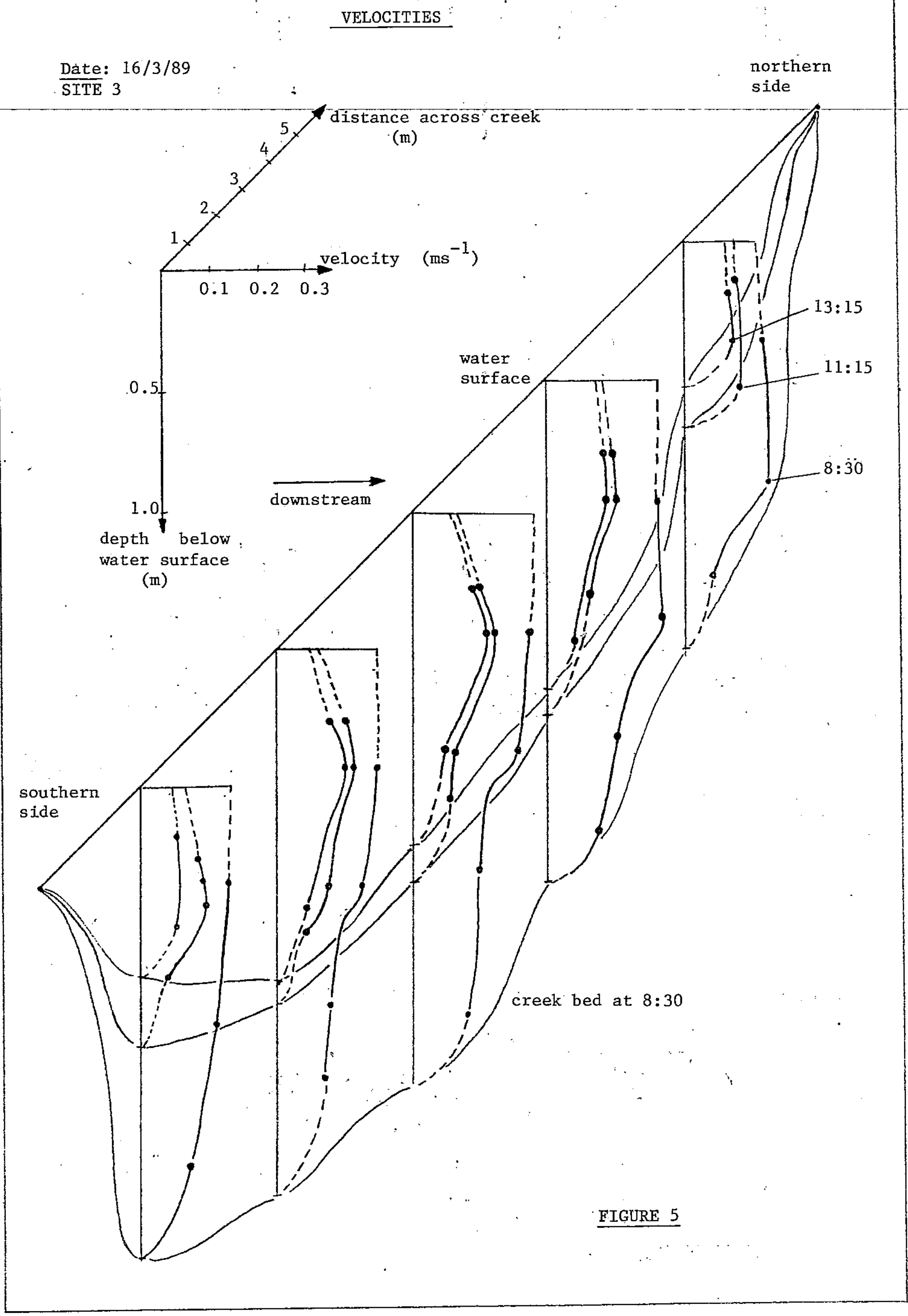



FIGURE 4



VELOCITIES
Date: 16/3/89
SITE 3
distance across creek (m)
1
2
3
4
5
velocity (ms-1)
0.1 0.2 0.3
0.5
1.0
depth below water surface (m)
downstream
northern side
southern side
water surface
13:15
11:15
8:30
creek bed at 8:30


FIGURE 5

(c) Tide gauge readings within the creek and at gauge 5 which represents the water level in the lagoon behind the sand spit begin to diverge approximately 4 hours before low tide. Both water levels (creek and lagoon) asymptotically reach a constant level well after the occurrence of the low tide (Figure 2). This suggests that the Sleeper Log Creek system and the lagoon behave like basins separated from the sea. Because the sea level drops faster than the basins can empty, a difference in water level becomes evident.

This situation is schematically shown in Figure 6.

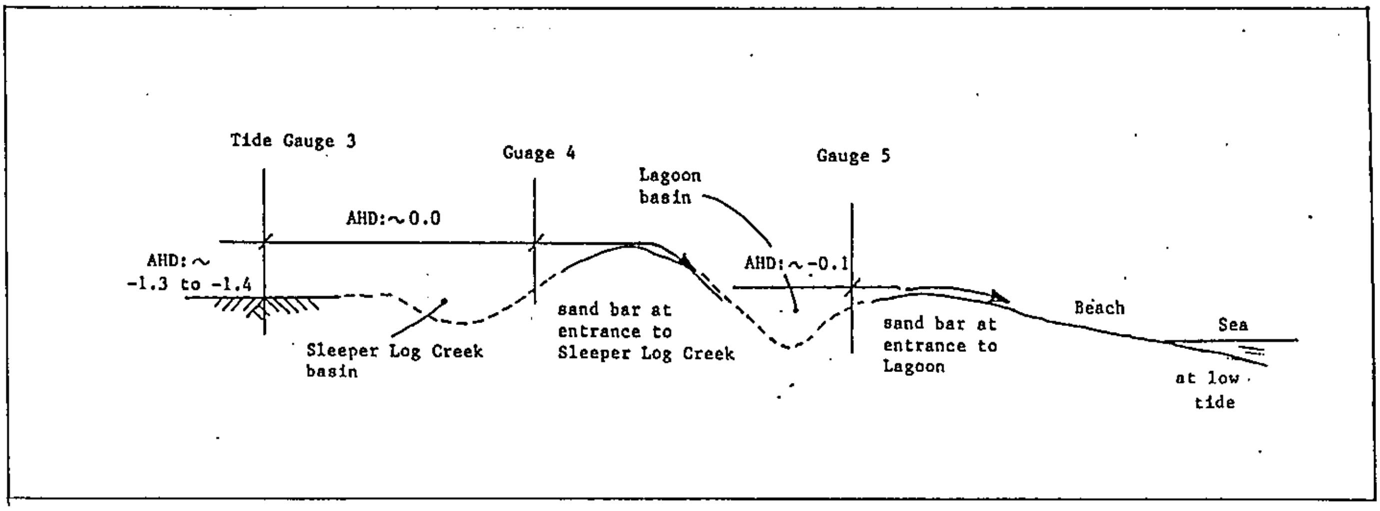



Figure 6. Schematic elevation through Sleeper Log Creek and Lagoon

From (a), (b) and (c) it can be concluded that the Sleeper Log Creek system displays almost no lag in reacting to a rising tide once the tide rises above the level of the sand bar at its mouth (see Figure 2 at 16:00). The bar at the mouth has an inlet level of approximately A.H.D. = 0.0. This means that only tides which exceed this height will have an effect on the water level in the creek; in other words, tides in Townsville have to rise above approximately 1.6 m Townsville Port Datum (Port Datum = 1.576 m A.H.D.) in order to raise water levels in the creek. Once the water level of the sea rises above this level, creek and sea behave like one body of water and tide gauges 1, 3, 4 and 5 show essentially the same readings.

3.4.2 Water levels in Two Mile Creek

Records of water levels in Two Mile Creek at tide gauge 6, taken on 16 March 1989, are shown in Figure 3. Comparing these with the readings from gauge 5 it can be seen that at high tide both gauges show almost identical values. As time progresses and the tide retreats gauge 6 shows consistently higher water levels than gauge 5. This could be accounted for by the fact that Two Mile Creek has such a high resistance towards the outflowing water that water at the mouth drains more rapidly than at site 6, or that a pond and sand bar situation as outlined in the previous section occurs somewhere upstream of gauge 6 in Two Mile Creek.

From the steepness of the curve, identifying the behaviour of Two Mile Creek at site 6 at 9:30, and comparing it with the respective reading in Sleeper Log Creek, it is unlikely that there exists in Two Mile Creek a sand bar which is significantly higher than the one in Sleeper Log Creek. Visual inspection of Two Mile Creek between site 5 and 6 supports that assumption. It is therefore believed that Two Mile Creek drains to the level of the sand bar at site 5 corresponding to a value of -0.1 m A.H.D.

### 3.4.3 Water levels in salt water supply channel

From Figure 2 it can be seen that the measured water levels in Sleeper Log Creek and at site 5 always lie below the water level measured in the supply channel for the entire duration of the test. The high tide at 17:15 hours therefore did not affect the water level at gauge 7. Water levels in the channel asymptotically reached the value of A.H.D. = 0.716. This level corresponds to the height of a rock bar at the entrance to the intake structure which prevents the water level in the channel from falling below it. This rock bar and the eroded opening in the earth mound, separating creek and supply channel, control the flow into the channel system rather than the configuration of the intake structure, because the width of the intake structure is considerably greater than the eroded opening and the invert level of the intake structure (A.H.D. of -0.75 m) lies below the crest of the rock bar.

On 16 March 1989 the tide rose above the height of the rock bar and resulted in inflow into the channel. Because of the restriction at the opening in the earth mound water levels rose much more slowly in the channel than in the creek, which led to considerable differences in water levels. At 6:00 am, for example, a head difference of 0.40 m was recorded, and was accompanied by considerable water velocities through the passage in the mound. Due to these high velocities there was also a minor head loss of approximately 5 mm recorded across the actual intake structure. Due to these flow restrictions the maximum water level at gauge 7 showed a time lag of 1:25 hours behind the water level in the creek, and its peak was well below that of the creek.

3.4.4 Water velocities in Sleeper Log Creek at site 3

Figures 4 and 5 show velocity profiles through a cross section of the creek at site 3, at various times during the tidal cycle. The velocity profiles taken in a period of time near low tide (Figure 4, 11:50 am; Figure 5, 13:15 pm) show good agreement between the two tests. The maximum measured velocities were approximately 0.15 $ms^{-1}$ in the centre section of the creek at 0.5 m below the surface. Towards the free surface and the creek bed as well as towards the banks of the creek, velocities decreased. An average velocity of approximately 0.125 $ms^{-1}$ over the cross section results in a discharge of about 5 $m^3s^{-1}$.

The highest velocities were measured at 8:30 am on 16 March 1989 when the rate of change in measured water levels in Sleeper Log Creek was at a maximum. Water velocities of up to 0.25 $ms^{-1}$ were measured near the surface in the centre of the creek. The integration of the velocities over the creek cross section resulted in a calculated discharge of approximately 10 $m^3s^{-1}$.

Since the tide on 16.3.89 was a reasonably high tide of 3.07 m (Port Datum Townsville) it is believed that under natural conditions water velocities will not drastically exceed 0.25 $ms^{-1}$ at site 3. Consequently the natural peak discharges at site 3 are likely to be of the order of 10 $m^3s^{-1}$.

3.5 Conclusions from Tidal Measurements

From tide gauge readings and velocity measurements, the following conclusions can be drawn:

(i) Sleeper Log Creek is completely cut off from the sea at tides which do not reach a level of 1.6 m Townsville Port Datum (or A.H.D. = 0.0 m), due to a sand bar at the entrance to the creek. This sand bar acts like a barrier keeping a pond of water in the creek during low tides. In the absence of this bar the creek could possibly run dry at tides which, at the seaward side of the sand bar, fall below the bed level of the creek.

(ii) The lagoon behind the sand spit and therefore also Two Mile Creek, are cut off from the sea when sea water levels fall below A.H.D. of -0.10 m for any significant period of time.

(iii) When tides rise above A.H.D. = 0.0 m, Sleeper Log Creek is interconnected with the sea. Water levels during slowly rising tides (Figure 2) indicate that the creek almost instantaneously responds to the change in tide level. For rapidly falling tides as encountered on 16/3/89 the creek's water level decreases at a somewhat slower rate than the sea water level because of the resistance across the sand bar.

(iv) In both sets of measurements it was observed that the maxima of water levels in the entire creek systems of Sleeper Log Creek and Two Mile Creek coincide with the maximum water level measured for the tidal cycle. Therefore, under natural conditions the two creeks are freely connected to the sea if the tide rises above A.H.D. = 0.0 m and the sand bars do not pose a significant hindrance for the entering sea water in this condition.

(v) Water flow into the existing supply channel is mainly restricted by the width of the eroded opening in the earth mound and the height of the rock bar forming the base of this opening.

(vi) The measured water velocities in Sleeper Log Creek at site 3 were integrated over the creek cross section. This resulted in a maximum discharge of 10 $m^3s^{-1}$. Under natural conditions it is believed that the maximum discharges are also in the order of 10 $m^3s^{-1}$.

## 4. ASSESSMENT OF AVAILABILITY OF REQUIRED WATER VOLUME OF 540 ML PER DAY

### 4.1 Introduction

The section of Sleeper Log Creek which is influenced by tidal movements can be idealised (in a first approach) as a basin which has a free overfall weir at the sand bar at its mouth. The same idealisation can be made for the salt water supply channel. In order to fill either basins the tide has to rise above the respective levels of the bars. Assuming that the water levels in both basins are kept below their respective crest level by consuming water during filling or by keeping the entire stored volumes below this level, the daily volumes of water flowing into the basins can be easily calculated using the formula for free overfall flow over broad crested weirs.

For such a calculation it is necessary to establish the variation of tidal heights at the overfall, the height of the weir crest and the width of the weir. In this investigation the width of the weir was assumed constant and equal to 25 m, both for the bar at the mouth of Sleeper Log Creek and for the intake structure. The tidal variation at the sea was based on half hourly records of tidal movement predicted for Townsville in the years 1980 until 1999. This time span is sufficient to encounter every possible tidal movement in this area. The investigation was aimed at finding the influence of the weir height on the daily water volumes discharged into each basin, and in particular at finding whether lengthy periods occur when the required daily water volume of 540 ML is not discharged into the basins.

4.2 Numerical Procedure

Figure 7 illustrates the parameters involved,

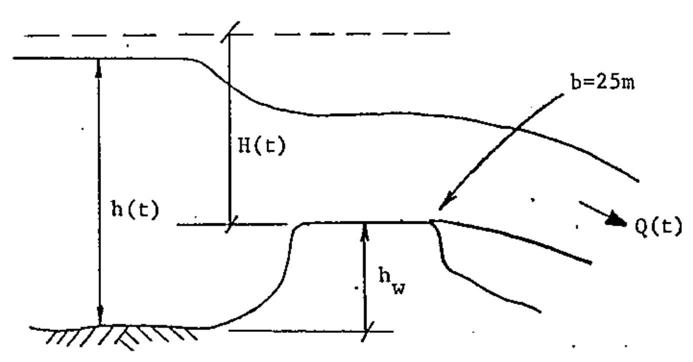



Figure 7. Definition sketch for flow over broad crested weir

$h(t)$ tide level relative to Townsville Port Datum [m]
$H(t)$ difference between energy line and crest level [m]
$h_w$ crest level (Townsville Port Datum) [m]
$b$ width of crest
$Q$ discharge over weir $m^3s^{-1}$

Tidal records were calculated by the Marine Modelling Unit within the Department of Civil and Systems Engineering at James Cook University, for half hourly intervals for the time span between 1.1.1980 to 31.12.1999.

For one particular crest height ($h_w$) the daily water volumes were calculated as follows:

(i) for each time step, dt = 0.5 hours:
The free overfall formula of Belanger for broad crested weirs gives

$$Q(t) = \frac{2}{3} \cdot \frac{1}{\sqrt{3}} \cdot b \cdot \sqrt{2g} \cdot (H(t)-h_w)^{3/2} \qquad H(t)=h(t)$$

and the volume of water discharged during this time step is

$$V_{dt} = Q(t) \cdot dt$$

(ii) daily water volumes were calculated by summing up the individual values of $V_{dt}$ during that day.

(iii) if the daily water volume was less than the required volume of 540 ML, it was graphed for the particular day.

Steps (i) to (iii) were repeated for the following crest heights (heights relative to Townsville Port Datum).

$h_w$ = 1.6 m, crest level of sand bar
$h_w$ = 1.4 m
$h_w$ = 1.2 m
$h_w$ = 1.0 m
$h_w$ = 0.8 m, current invert level of intake structure.

4.3 Results

Figures A1 to A20 of Appendix A illustrate for each calendar year, between 1980 and 1999, the daily water volumes entering the basins and not exceeding 540 ML. Different symbols are used for different crest levels.

4.4 Discussion of Results

It is evident from Figures A1 to A20 of Appendix A that the height of the crest has a marked influence on the daily water volumes passing over the weir crest; the higher the crest level, the longer are the periods which show daily volumes below 540 ML and the more often these periods occur. The crest level also influences the minimum water volumes passing over the crest.

The graphs show that crest levels which are lower than 1.2 m (A.H.D. = -0.38 m) result in daily water volumes which, with very few exceptions, exceed 540 ML. These exceptions are:

| Month year [-] | $h_w$ [m] | Number of days not exceeding 540 ML/day [-] | Minimum daily water volume [ML] |
|---|---|---|---|
| April 1981 | 1.2 | 2 | 540 |
| May 1995 | 1.2 | 2 | 500 |
| May 1996 | 1.2 | 1 | 540 |
| May 1999 | 1.2 | 2 | 500 |

For a crest level of 1.4 m (A.H.D. = -0.18 m), the longest period for which the requirements on daily volumes are not met, is 5 to 7 days while minimum daily volumes drop as low as 200 ML/day.

An increase in crest level to 1.6 m (A.H.D. = +0.02 m), which corresponds to the height of the existing sand bar at the creek mouth, results in longer periods of low daily water volumes passing over the crest and a more frequent occurrence of them. Over the 20 years investigated, in almost every month, daily volumes are not met for some period of time. Generally, the results show that the longest such period during a year is of the order of 10 days, with one exception of approximately 20 days in May 1989 while the daily water intake volumes can reduce to 30 ML.

### 4.5 Conclusions on Crest Heights of Intake Structure

It is concluded that under the assumption made for this investigation, a crest height of 1.2 m (A.H.D. = -0.38 m) would be optimal at the intake structure. It is also evident from this investigation that if the sand bar at the mouth of the creek were to remain at its current level of approximately 1.6 m (A.H.D. = +0.02 m), it would become the controlling factor for the discharge of water into the salt water supply channel within the farm. Without the removal of sand between the intake structure and the sea to a level below A.H.D. of approximately -0.40 m, frequent and lengthy periods can be expected during which it will not be possible to draw 540 ML/day into the salt water supply channel.

## 5. RECOMMENDATIONS

The following recommendations are made:

(i) The bed level of Sleeper Log Creek (including local sand bars) between the farm channel intake structure and the sea should be lowered so that the crest height at the intake structure becomes the controlling factor for the discharge of water into the channel. The numerical investigation reported herein suggests that a "bed level" of -0.40 m A.H.D. would allow a minimum volume of approximately 540 ML to flow in daily. Dredging is expected to be necessary to retain the bed level at this value.

If dredging is not maintained, it is anticipated that, with the daily water volumes required, the velocity in the creek, especially over the sand bar at its mouth, will be increased so drastically compared with natural flow velocities ( 0.25 m/s) that sediment transport will occur towards the intake structure and that the sand bar will be eroded.

(ii) On the assumption of a 25 m wide intake, the crest level at the channel intake should be set at approximately -0.40 m A.H.D., provided that the entire daily requirement of 540 ML can be stored below this level. If this should not be possible, additional investigations will be necessary.

(iii) Because at the highest tides, there will be large differences between maximum water levels and the suggested crest height, large velocities are expected to occur over the weir crest if the overfall is uncontrolled. The scour effect of high water velocities within the creek and within the intake structure should therefore be assessed.

(iv) The possible diversion of fresh water into the salt water supply channel under conditions of high local runoff should also be studied. An uncontrolled free overfall weir structure will draw mainly from the water surface. Combinations of relatively low tides, in the order of the crest level, and high fresh water influx into the lower reaches of Sleeper Log Creek, could lead to situations where mainly fresh water passes over the weir crest.

# APPENDIX A

Effect of intake crest level on
daily inflow volumes

LEGEND FOR FIGURES A1 TO A20

Crest Levels relative to Townsville Port Datum

| | | |
|---|---|---|
| * | $h_w$ = 1.6m | , crest level of sand bar |
| o | $h_w$ = 1.4m | |
| + | $h_w$ = 1.2m | |
| - | $h_w$ = 1.0m | |
| = | $h_w$ = 0.8m | , current invert of intake structure |

Each month is shown separately

x-axis : day of month

y-axis : daily inflow in Mega-Litres (ML)

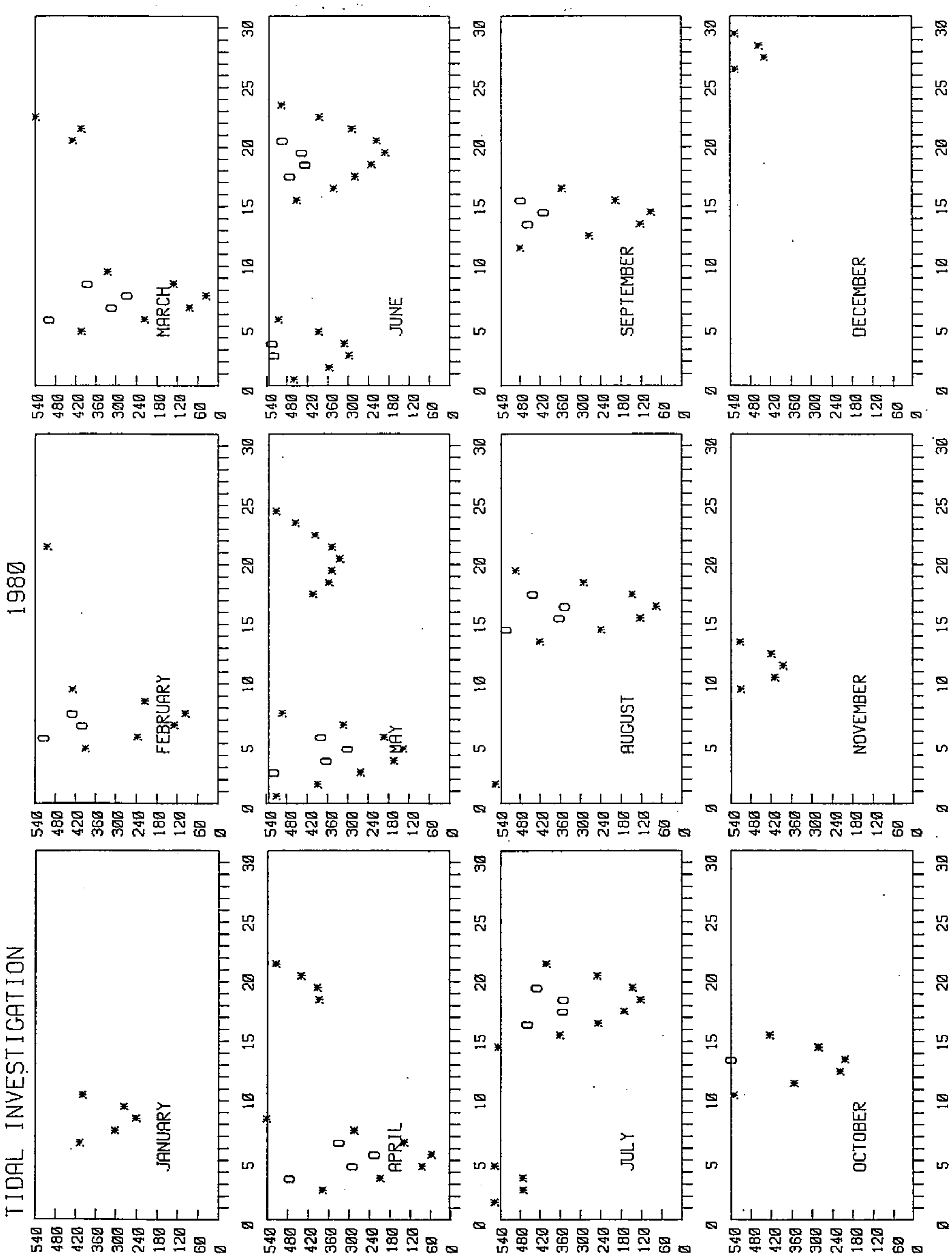

TIDAL INVESTIGATION
1980
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

FIGURE A1

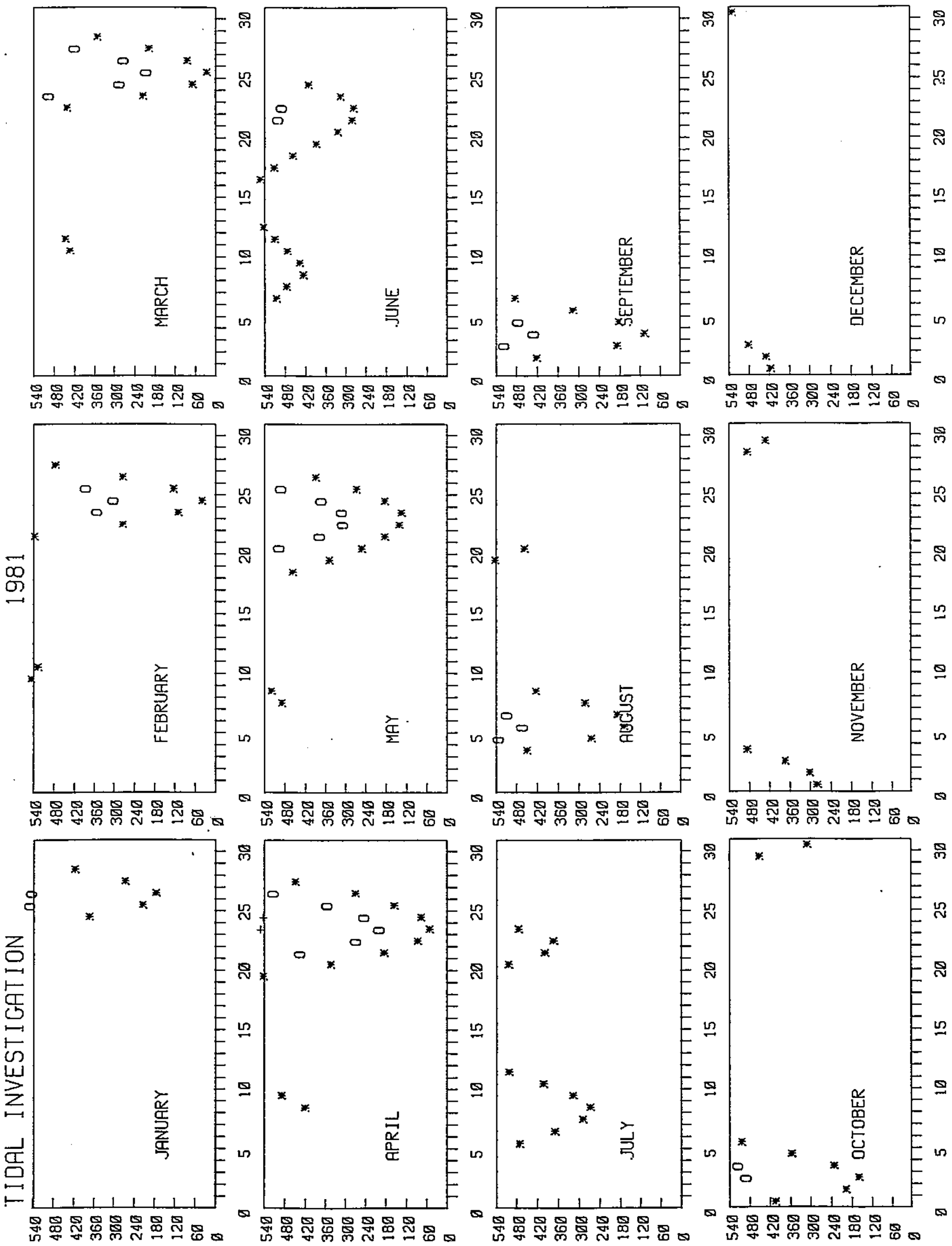

TIDAL INVESTIGATION
1981
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

FIGURE A2

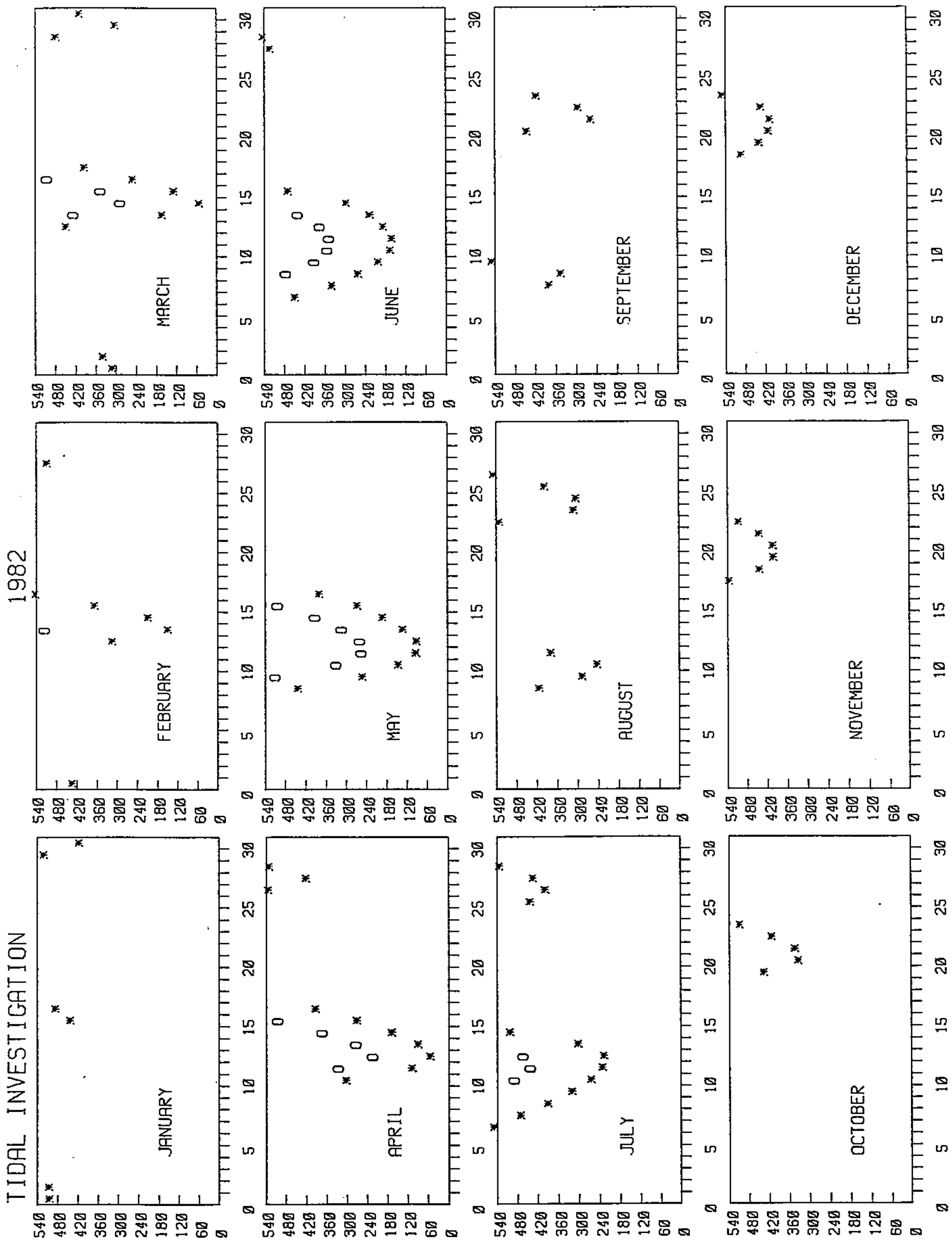

TIDAL INVESTIGATION
1982
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
540 480 420 360 300 240 180 120 60 0
0 5 10 15 20 25 30

FIGURE A3

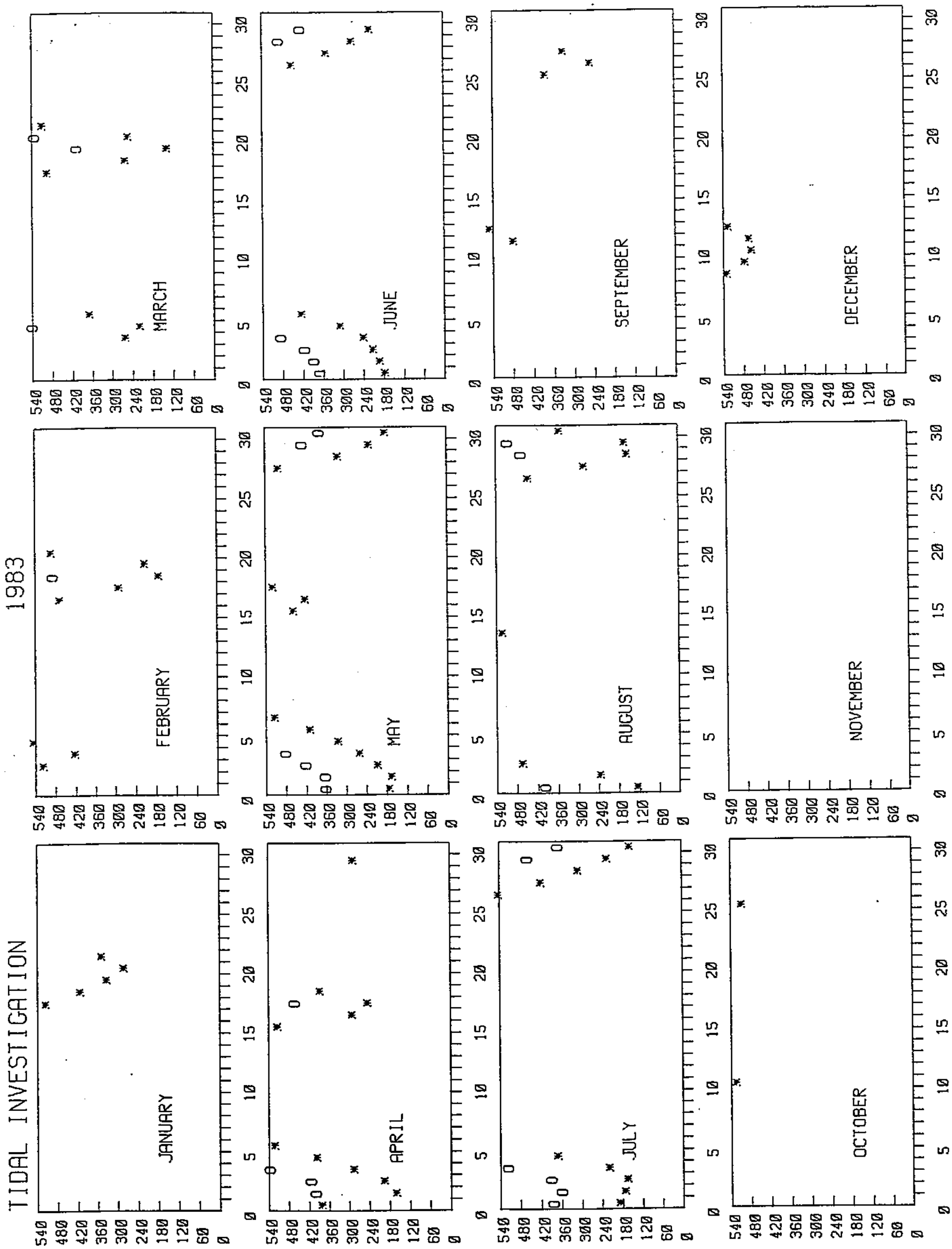

TIDAL INVESTIGATION
1983
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

FIGURE A4

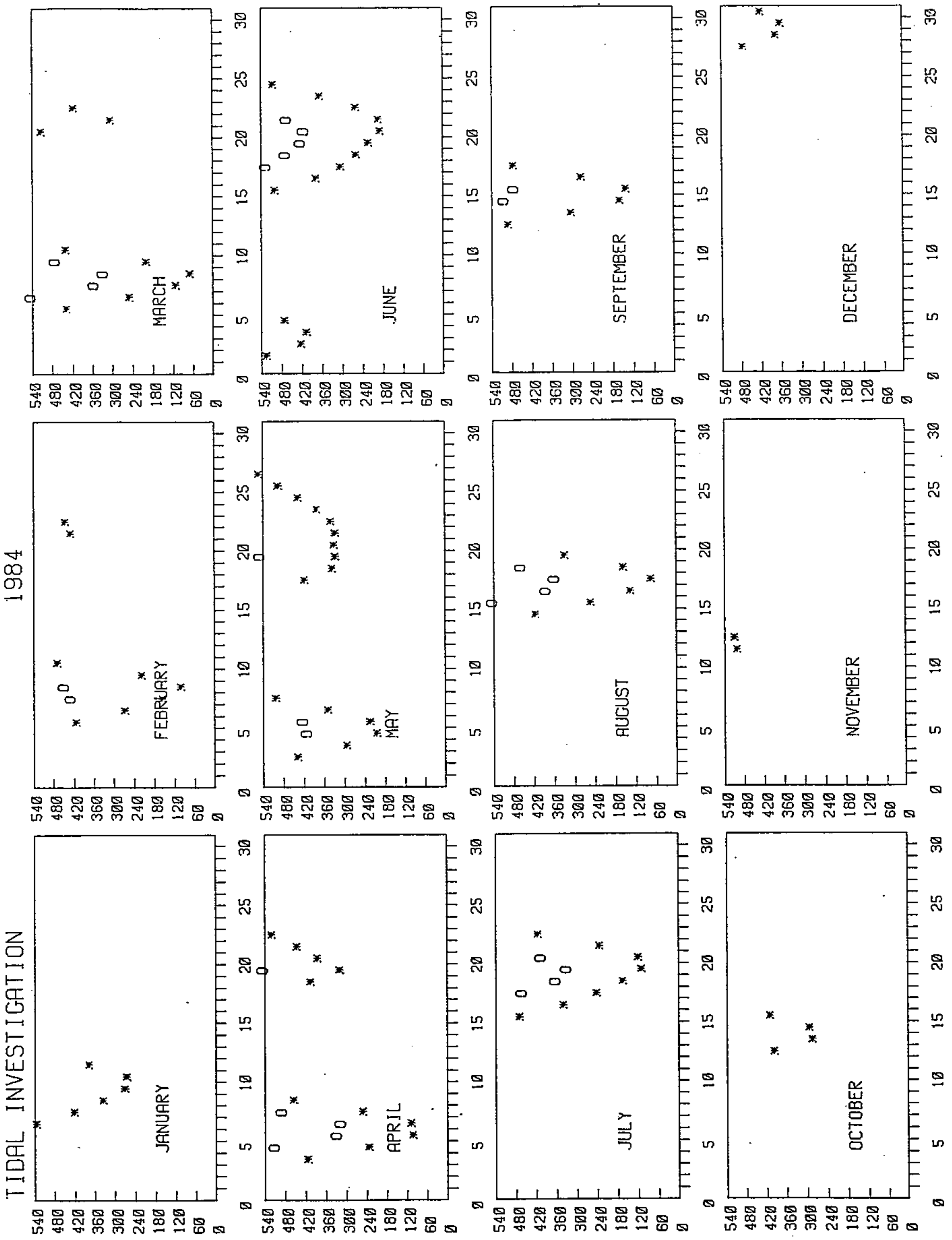

TIDAL INVESTIGATION
1984
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

FIGURE A5

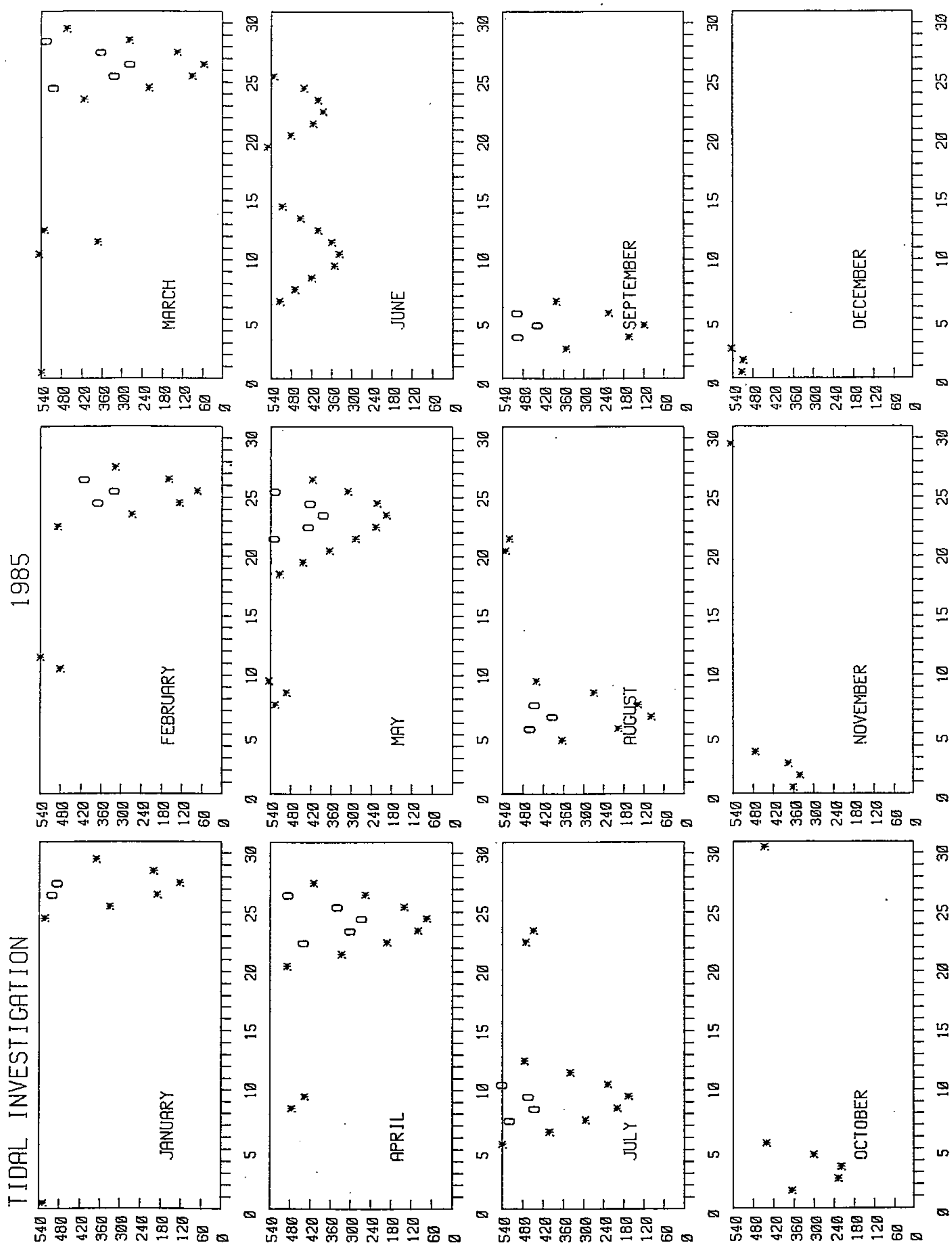
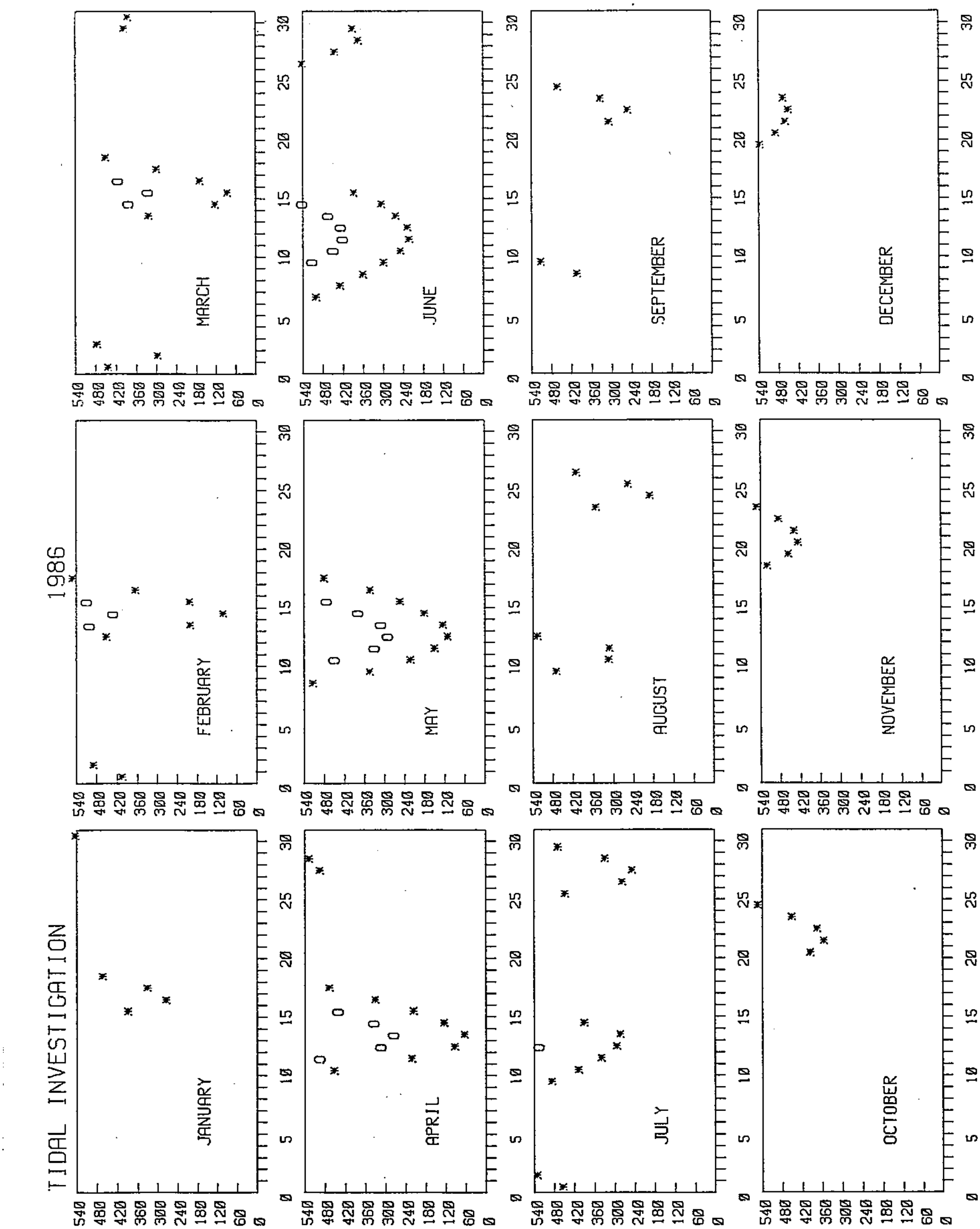

TIDAL INVESTIGATION
1985
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

FIGURE A6



TIDAL INVESTIGATION
1986
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER


FIGURE A7

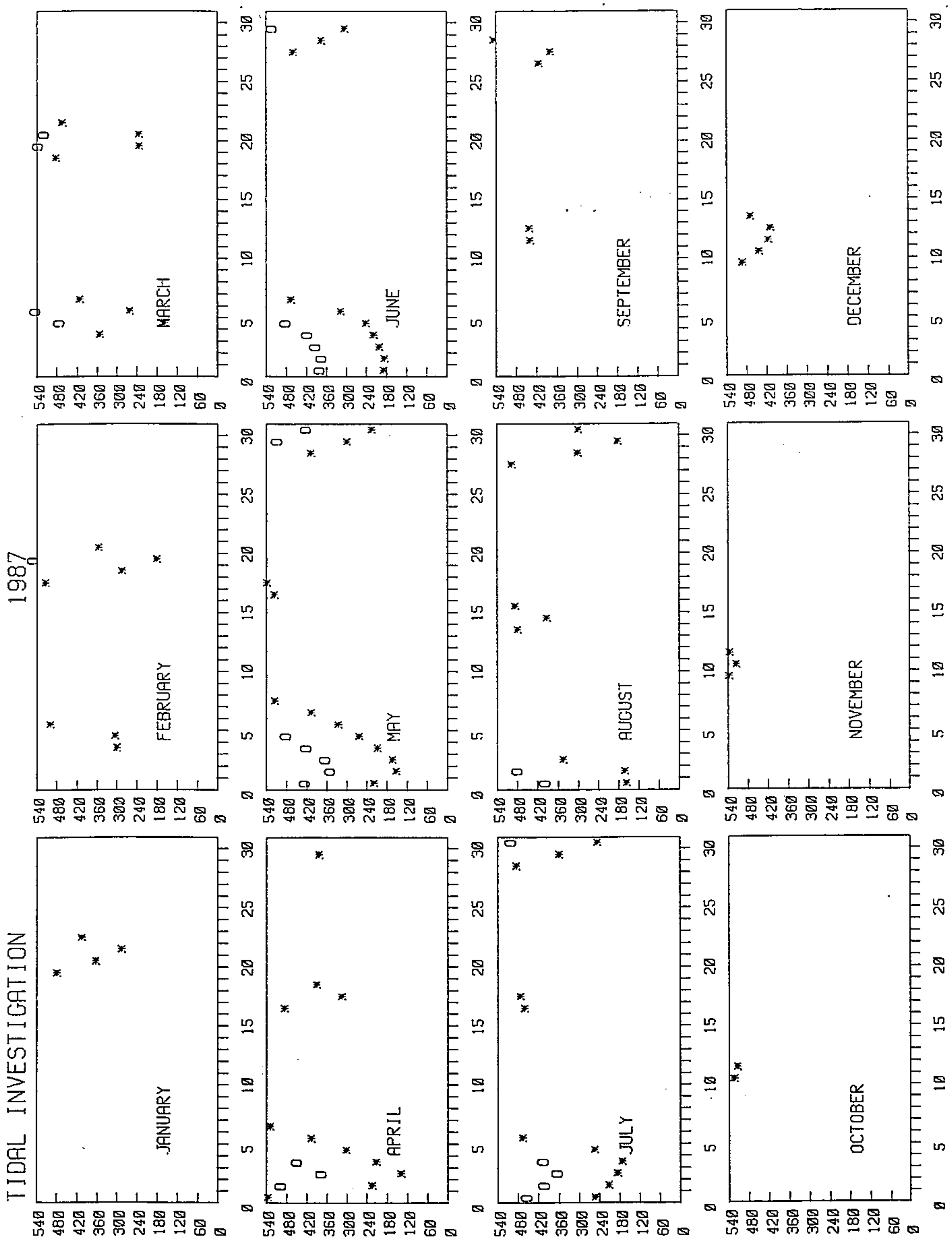

TIDAL INVESTIGATION
1987
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

FIGURE A8

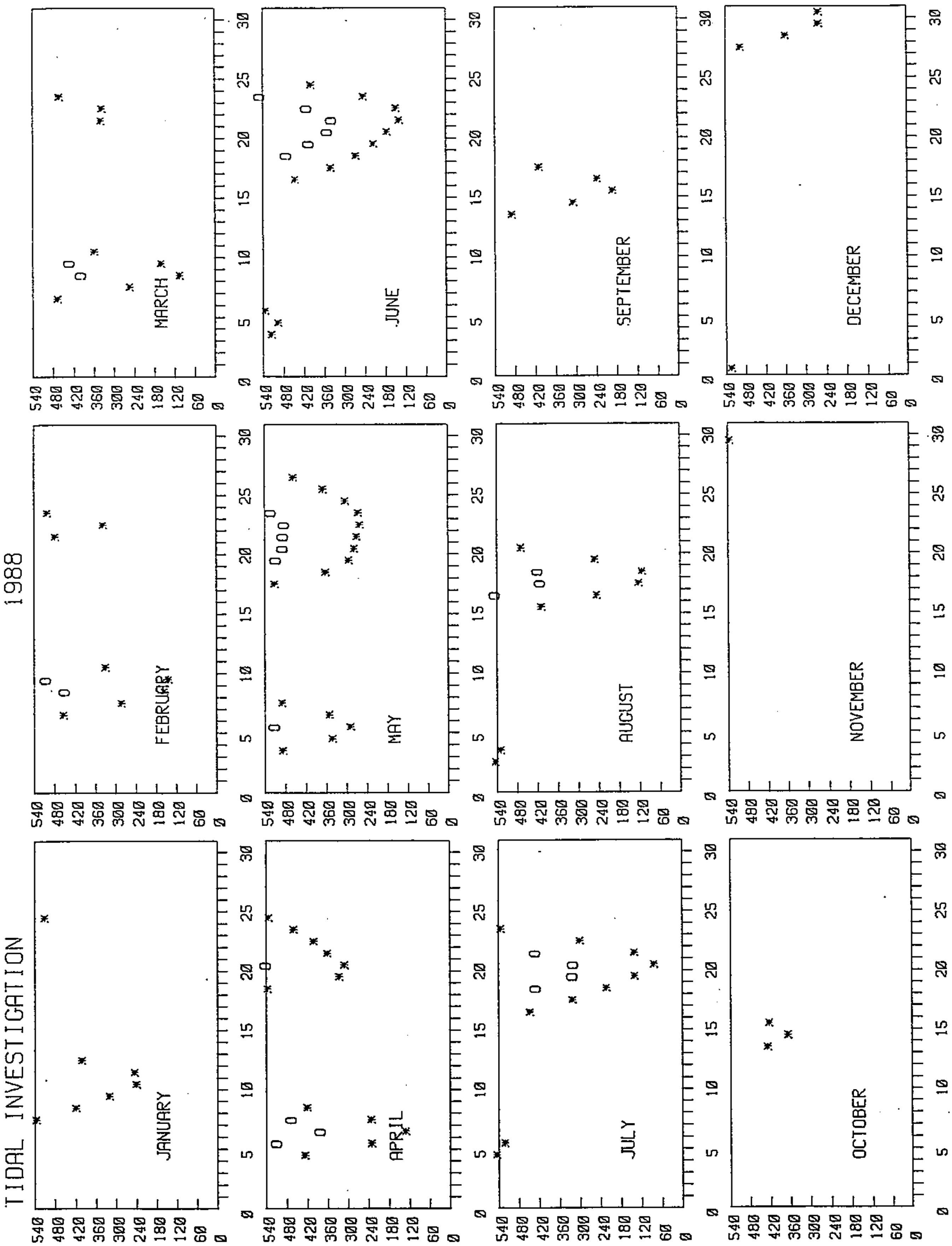
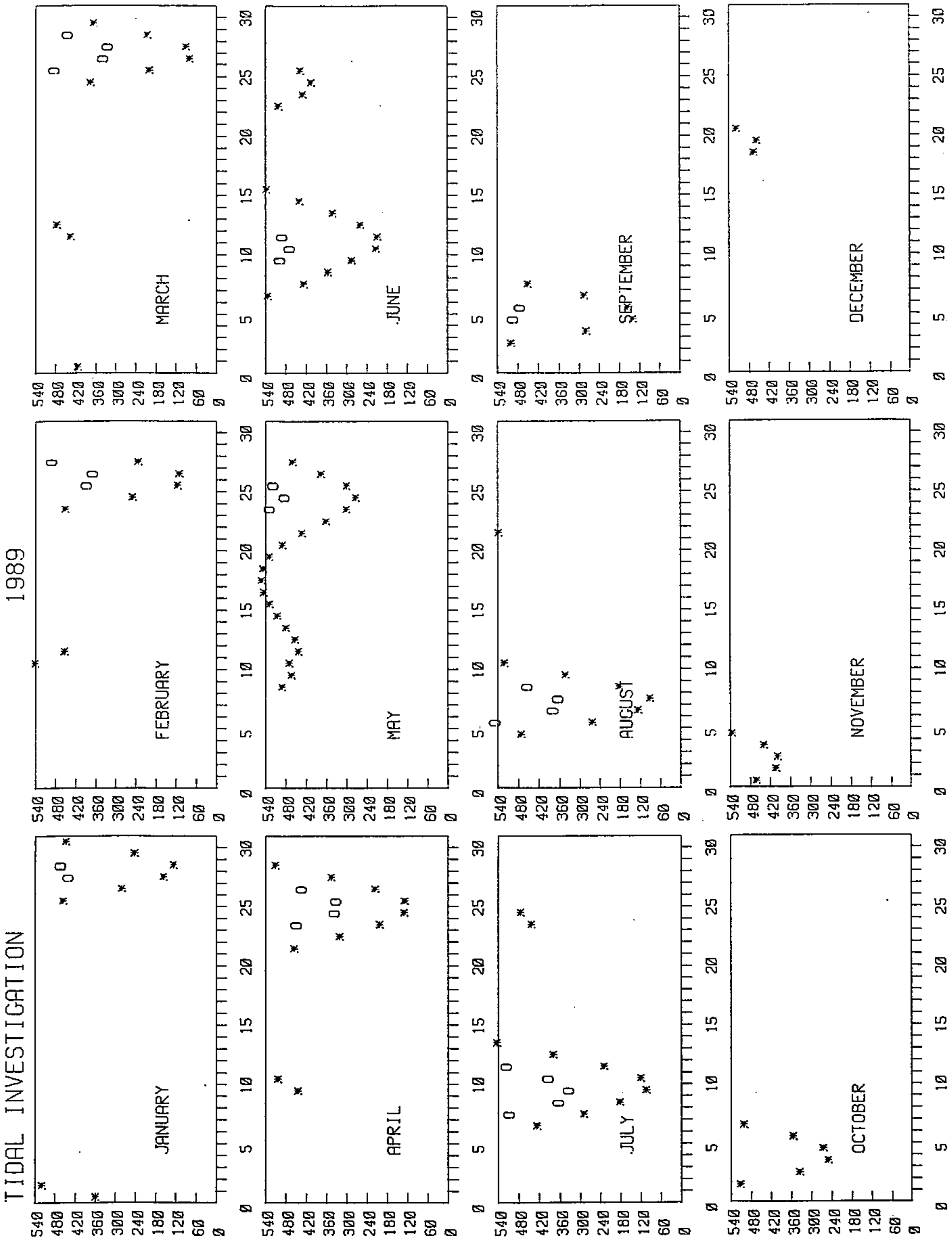

TIDAL INVESTIGATION
1988
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

FIGURE A9



TIDAL INVESTIGATION
1989
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
540
480
420
360
300
240
180
120
60
0
5
10
15
20
25
30


FIGURE A10

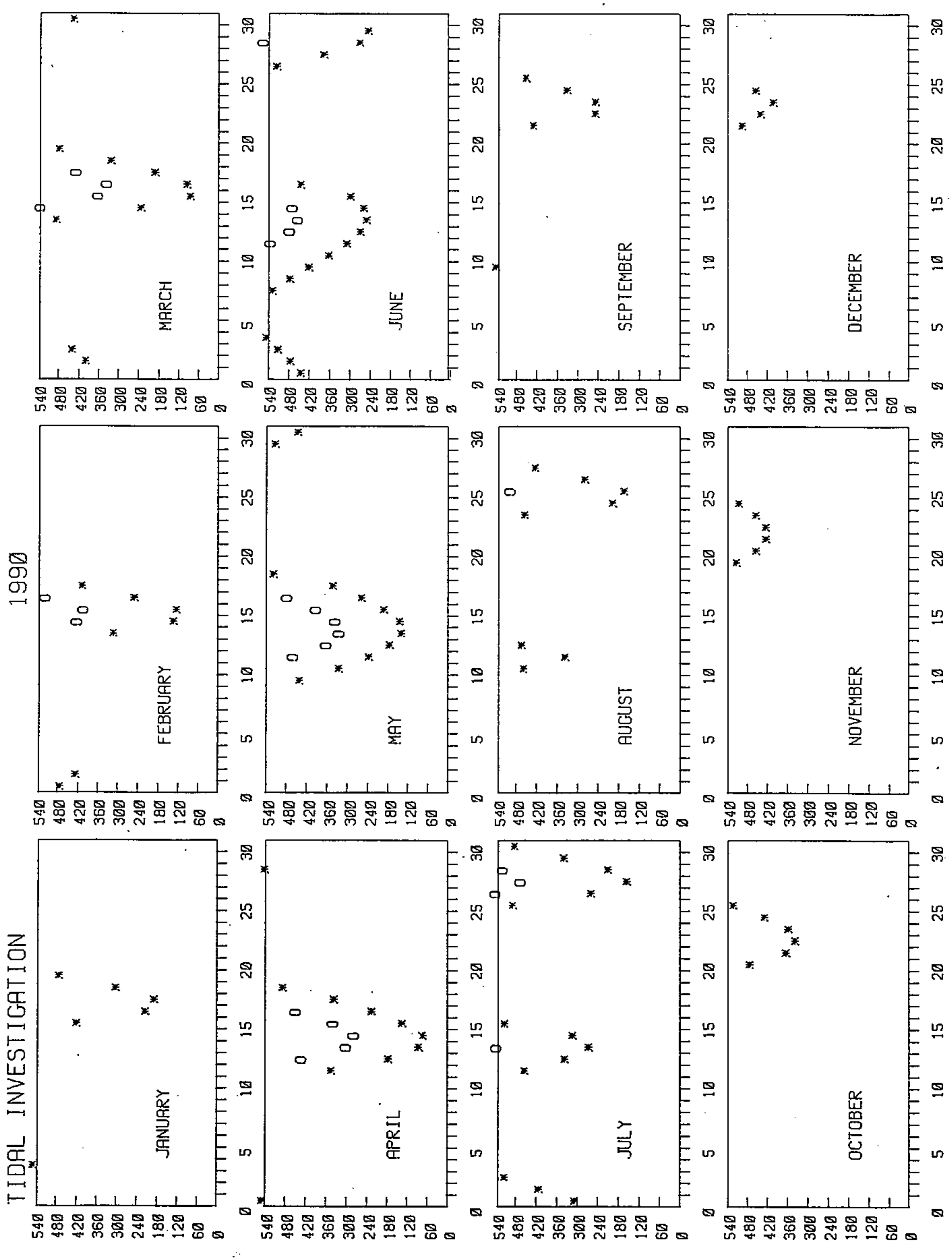
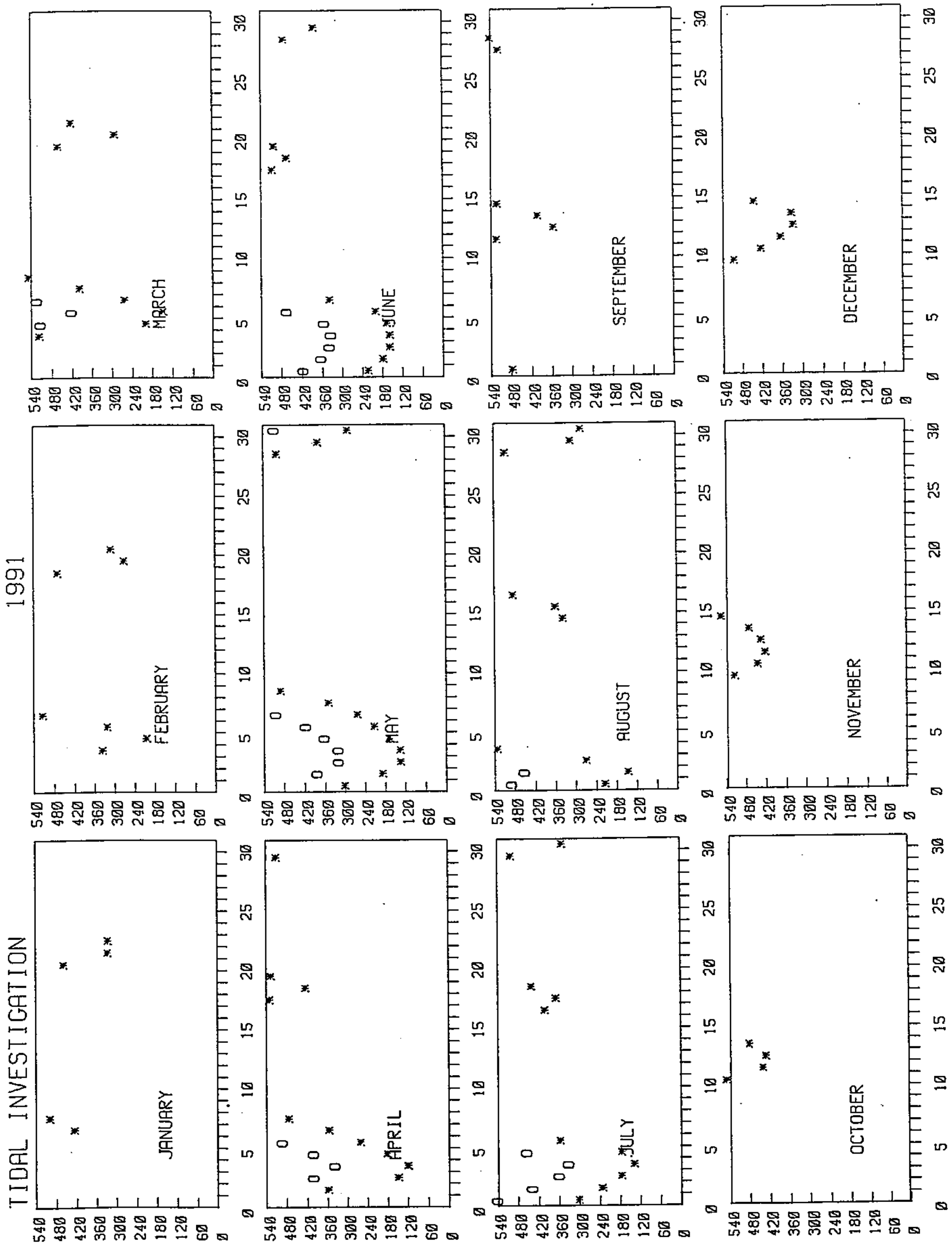

TIDAL INVESTIGATION
1990
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

FIGURE A11



TIDAL INVESTIGATION
1991
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER


FIGURE A12

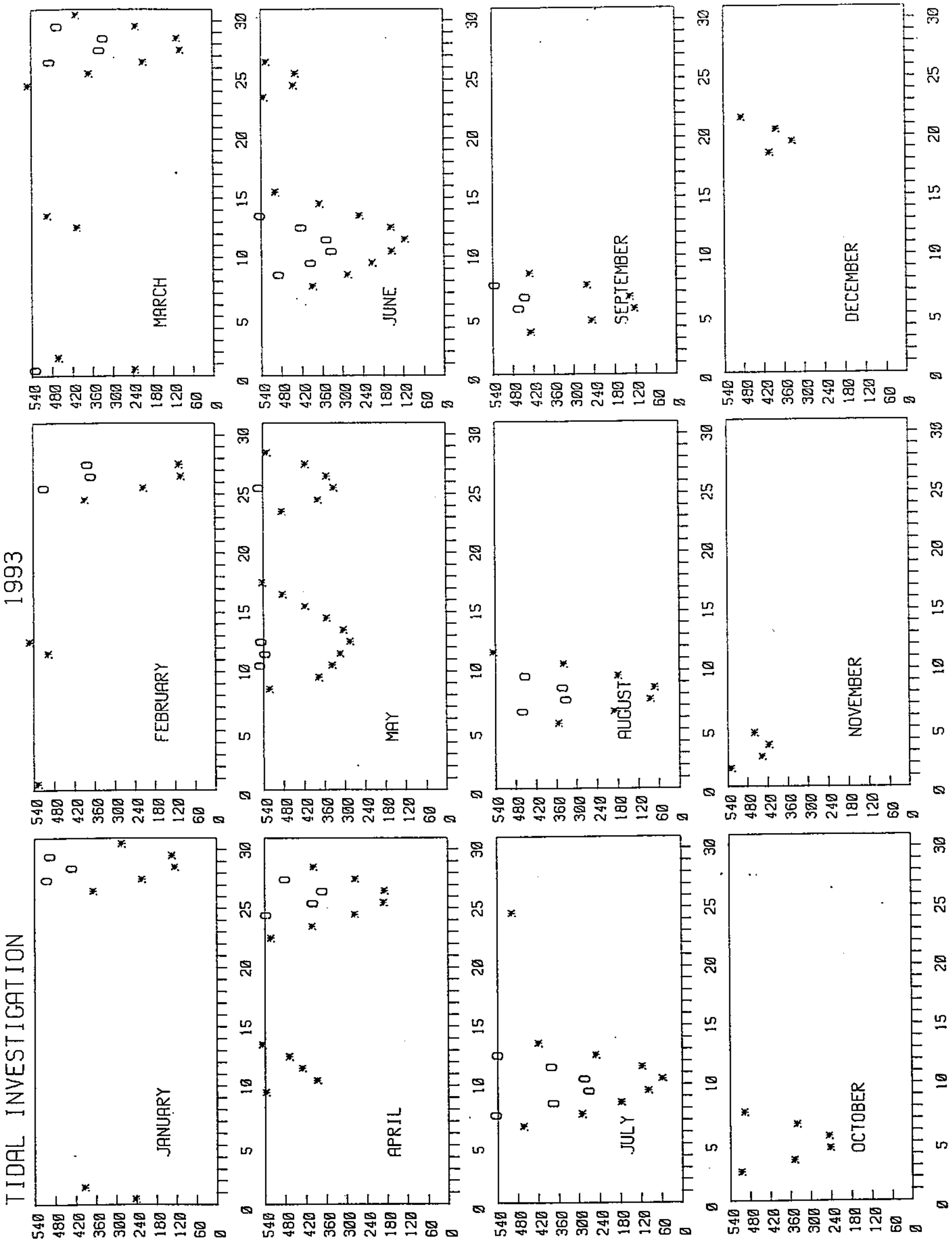

TIDAL INVESTIGATION
1993
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

FIGURE A13

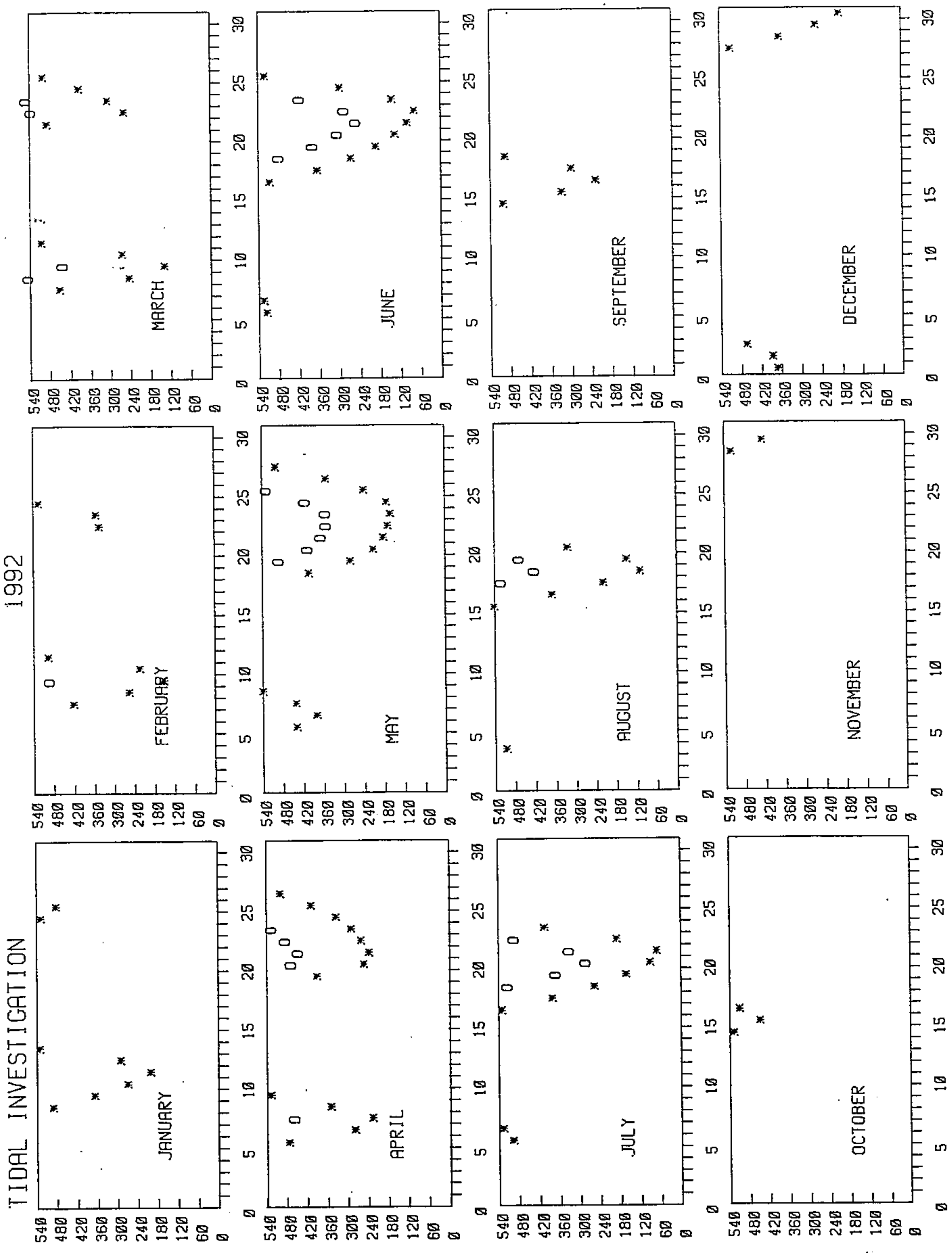

TIDAL INVESTIGATION
1992
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

FIGURE A14

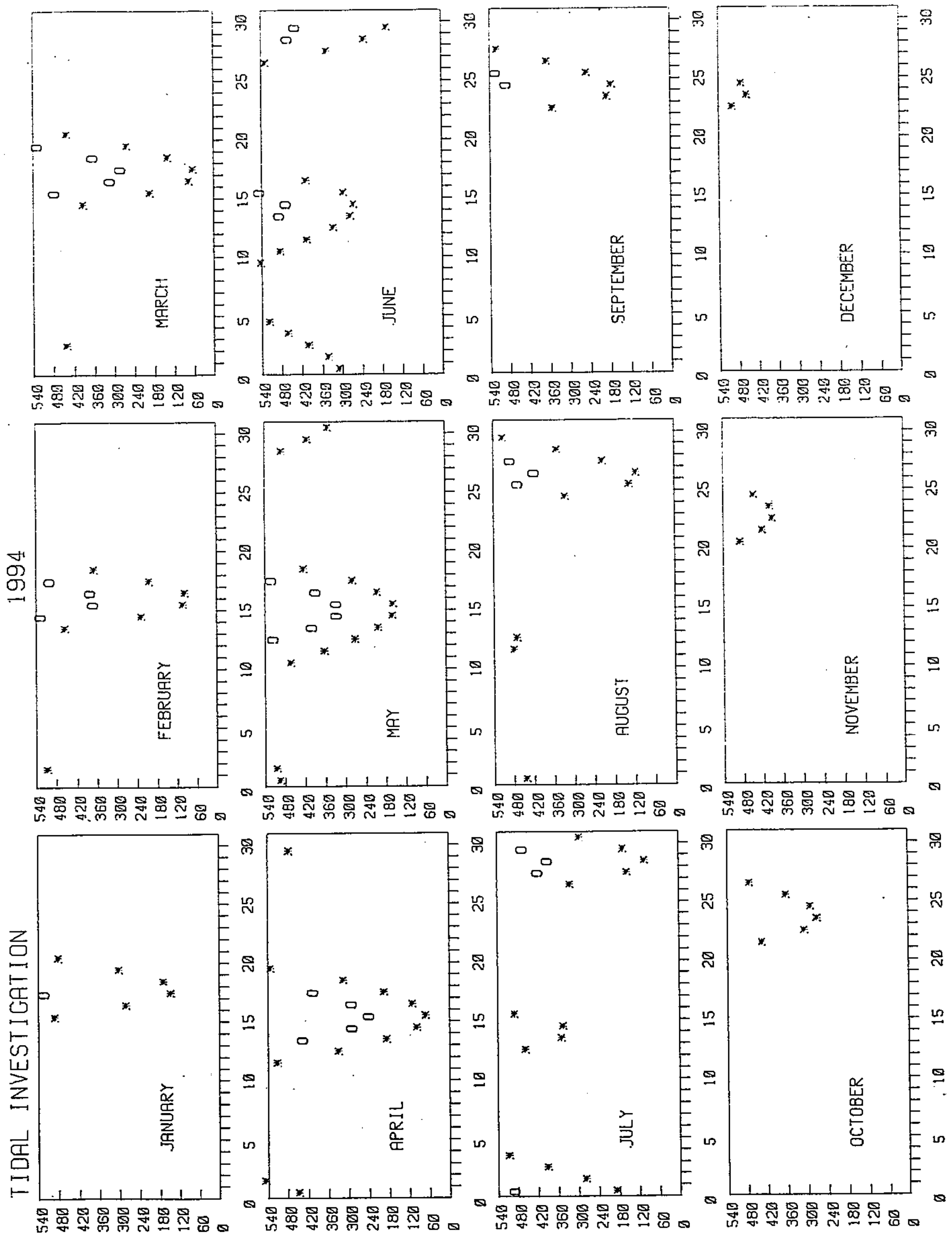

TIDAL INVESTIGATION
1994
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

FIGURE A15

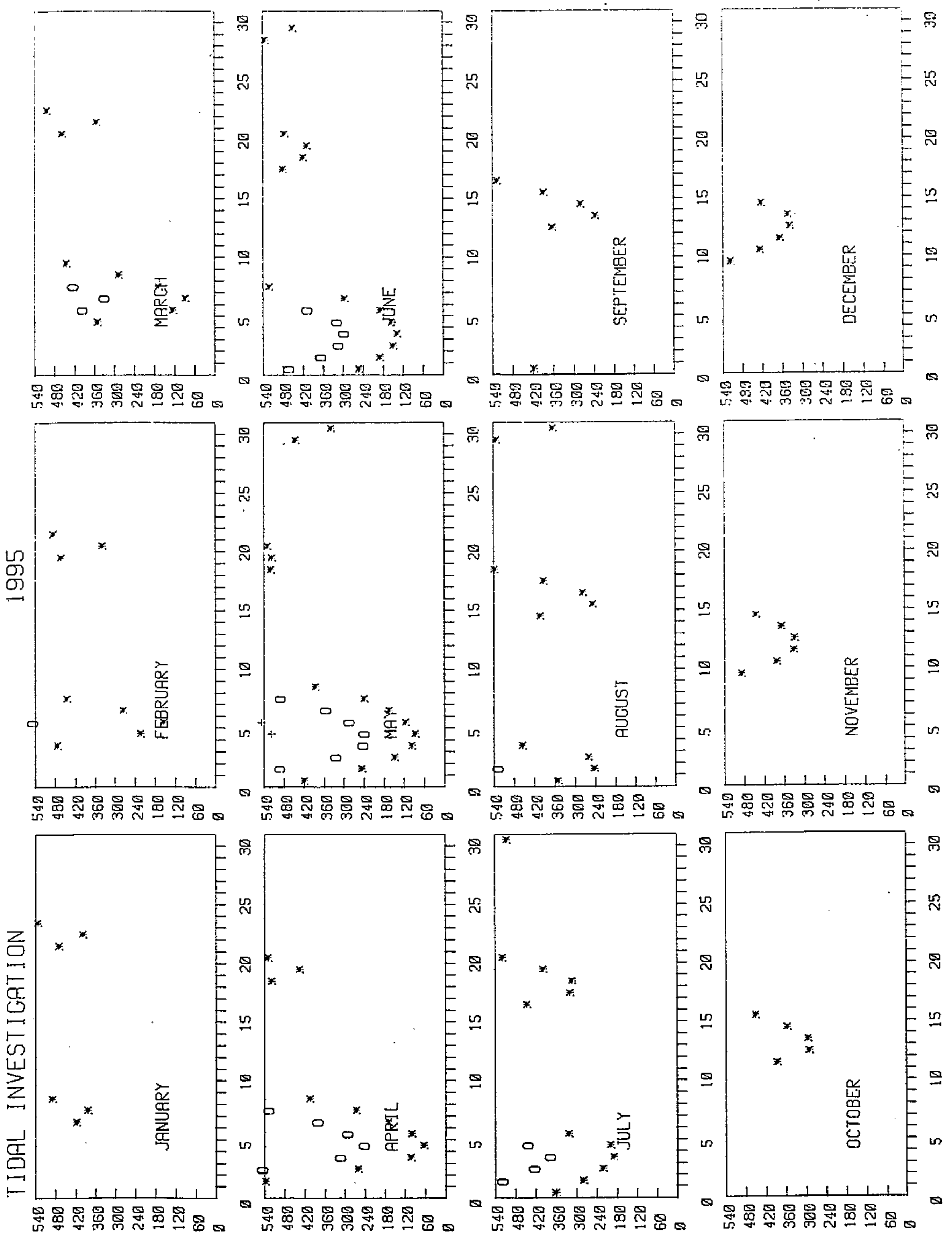

TIDAL INVESTIGATION
1995
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
540 480 420 360 300 240 180 120 60 0
0 5 10 15 20 25 30

FIGURE A16

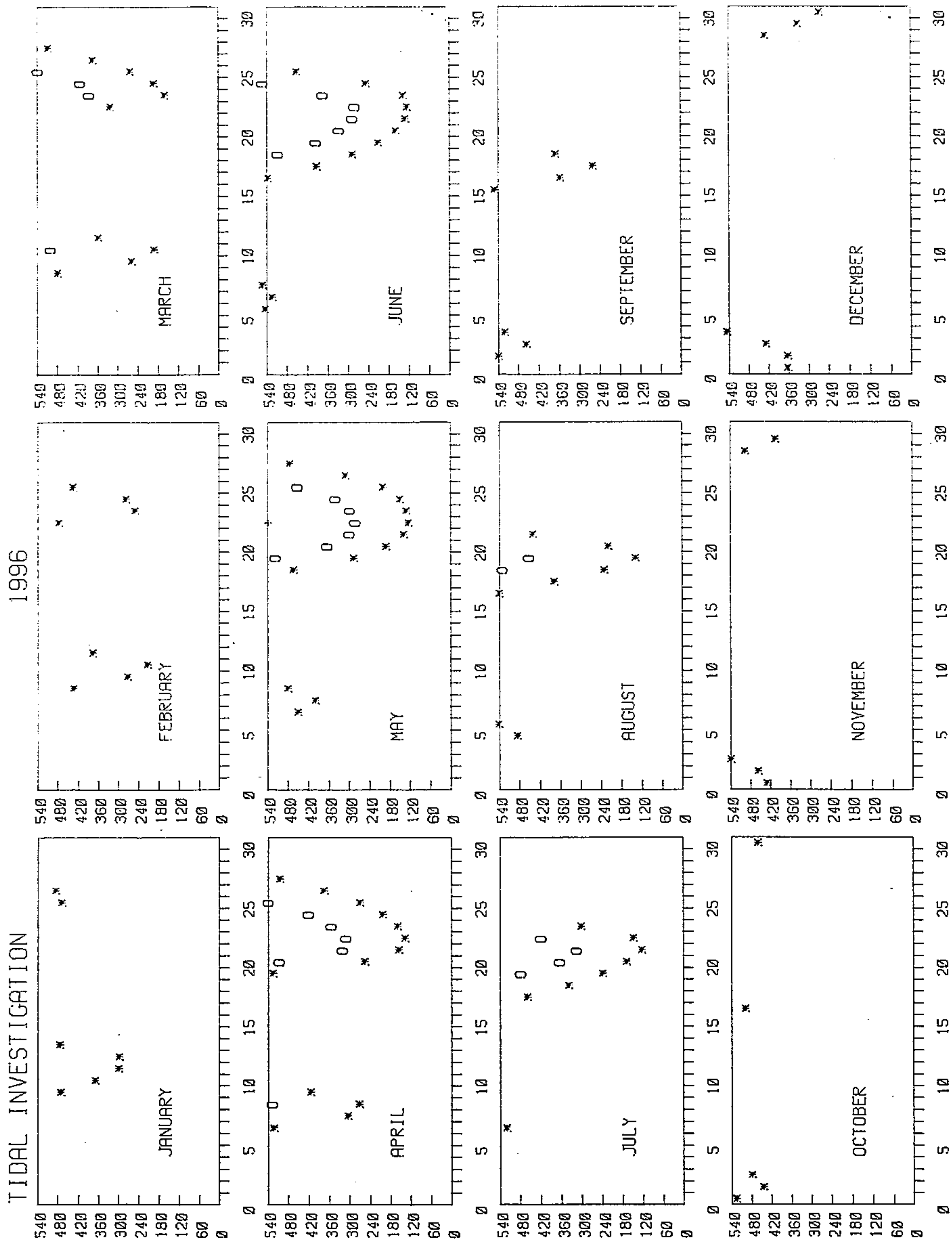

TIDAL INVESTIGATION
1996
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

FIGURE A17

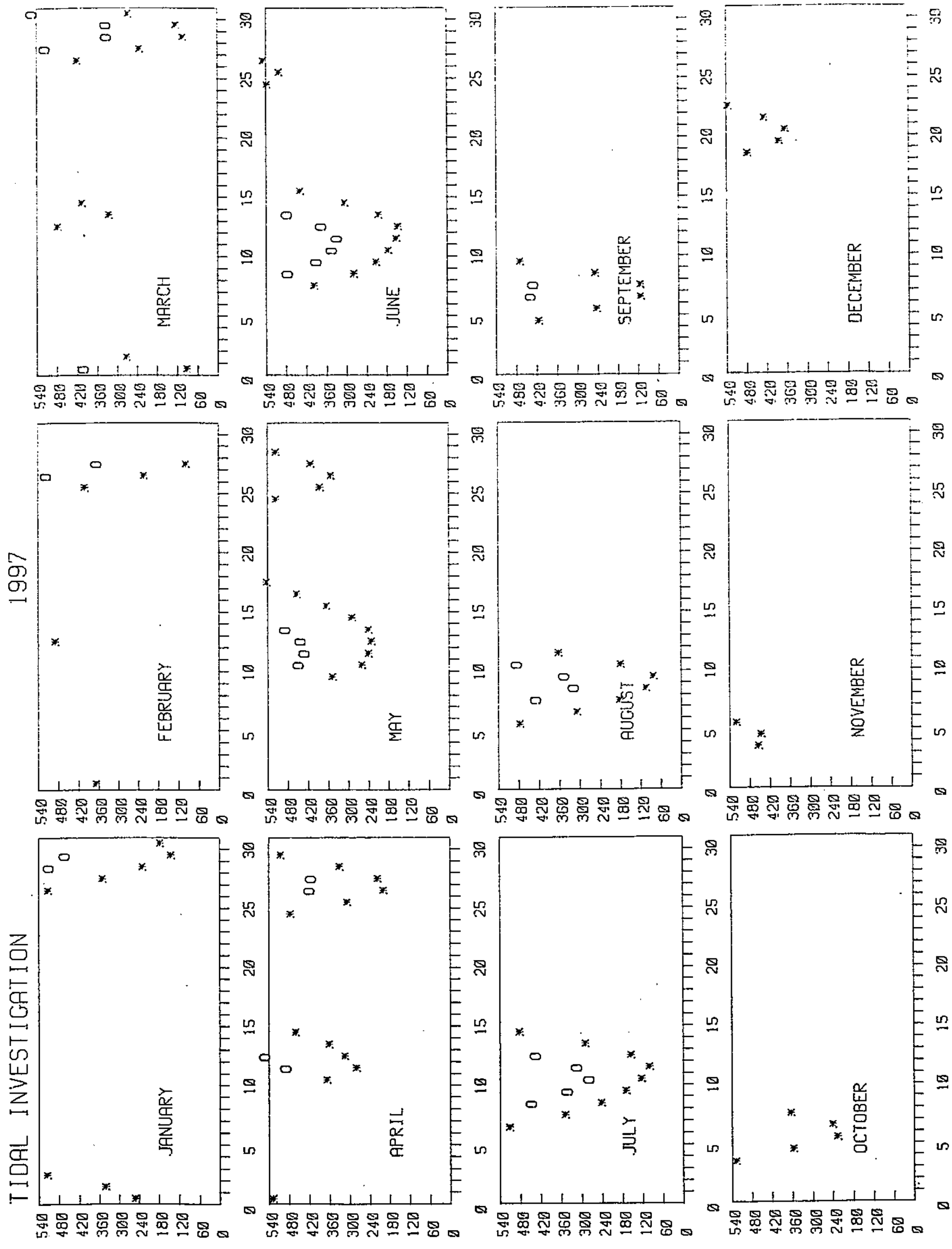

TIDAL INVESTIGATION
1997
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
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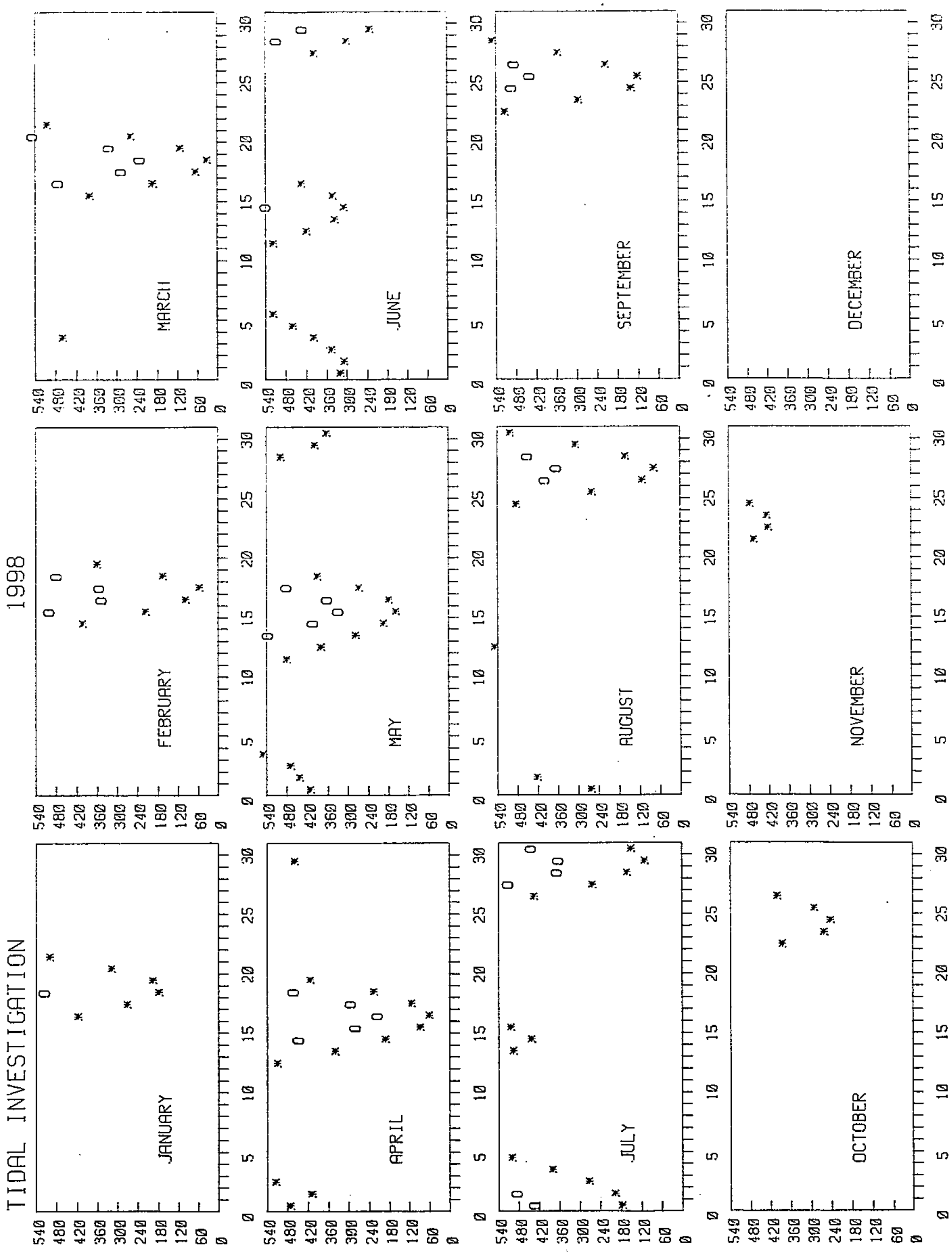
FIGURE A18



TIDAL INVESTIGATION
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JANUARY
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APRIL
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AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
540 480 420 360 300 240 180 120 60 0
0 5 10 15 20 25 30


FIGURE A19

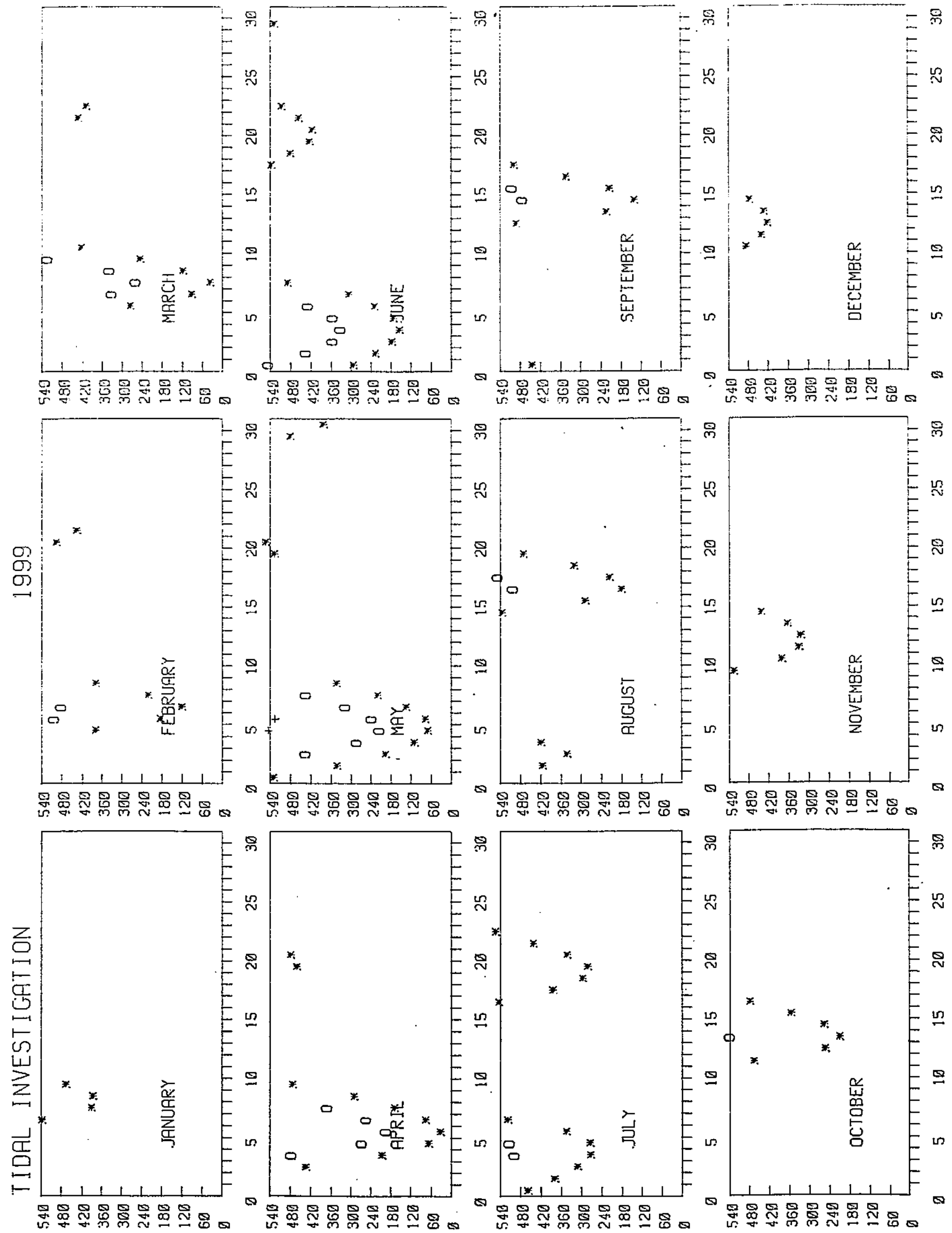
TIDAL INVESTIGATION
1999
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

**FIGURE A20**