HYDRODYNAMIC MODEL STUDY OF THE KEURBOOMS-BITOU ESTUARY

by
P Huizinga and T R M G Gaillard

KEYWORDS:
Estuaries
Mathematical models
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THE NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY

WILL CEASE TO EXIST AS SUCH ON 31 MARCH 1988, AND

WILL BECOME PART OF THE NEWLY FORMED CSIR

DIVISION OF EARTH, MARINE AND ATMOSPHERIC SCIENCES

AND TECHNOLOGY ON 1 APRIL 1988

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SYNOPSIS

An application of the NRIO's one-dimensional hydrodynamic estuary model to the lower part of the Keurbooms-Bitou estuary is described. Proper model calibration was not possible owing to lack of information. The model was used to determine flow rates through a number of cross-sections where biological and chemical measurements were taken to determine the fluxes of certain materials through these cross-sections. Finally, the requirements for an improved model application are discussed.

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Figure 1 Map of the Keurbooms-Bitou estuary

2 Model schematization

3a-h Recorded water levels and computed flow rates in the Keurbooms-Bitou estuary at the positions indicated

LIST OF SYMBOLS

A = cross-sectional area (m^2)

b = width (m)

C = Chezy coefficient ($m^1/_2/s$)

g = gravitational constant (m/s^2)

h = water level (m)

Q = flow (m^3/s)

R = hydraulic radius (m)

t = time (s)

x = distance (m)

1. INTRODUCTION

In March 1987 the Marine Biology Division of the NRIO undertook extensive research into the nutrient flux in the Keurbooms-Bitou estuary. As part of this research, biological and chemical samples were taken at several cross-sections in the estuary during certain periods. At the same time water-level recordings were taken to be used as input information for the NRIO one-dimensional model. Although there were not enough data available for a proper model calibration, some model simulations were done to give an estimate of flow rates through these cross-sections. On the basis of the results thus obtained, combined with the data from the samples, an estimate can be made of the total quantities of biological material transported through these cross-sections.

Survey data collected by the Sediment Dynamics Division of the NRIO were used for modelling of bathymetry (see Figure 1). Because relatively little data were available interpolations were made.

Because the water-level recordings from three positions were used as open boundary conditions for the model it meant, unfortunately that the model could not be calibrated. Consequently the accuracy of the model results could not be determined and recommendations are made in Chapter 5 of this report for more comprehensive field measurements for further improved model design and calibrations.

The model results are presented graphically in a number of figures and also in a more condensed form in a table of hourly flow rates.

2. COMPUTATION METHODS

The model techniques are based on explicit finite-difference methods to solve the differential equations for one-dimensional flow.

Momentum equation:

$$\frac{\partial h}{\partial x} = - \frac{1}{gA} \frac{\partial Q}{\partial t} - \frac{1}{C^2 A^2 R} |Q|Q + \frac{2b}{gA^2} Q \frac{\partial h}{\partial t} \qquad ...(1)$$

Continuity equation:

$$\frac{\partial Q}{\partial x} = - b \frac{\partial h}{\partial t} \qquad ...(2)$$

A description of the methods is available (CSIR, 1987a) and more extensive information can be found in the literature (Dronkers, 1964). Some relevant aspects, are explained very briefly in this report.

The schematization of the Keurbooms-Bitou model is given in Figure 2. Water levels (h) are computed at the positions indicated, while the flow rates (Q) in cubic metres per second are determined in the estuary sections connecting these positions.

The computations are done in time-steps which, for stability reasons, are 30 s. The main driving forces in the model are the open boundary conditions. For example, in the Keurbooms-Bitou model the sea tide at position 1 and the water levels in the vlei at positions 27 and 36 could be used. With the Keurbooms-Bitou model, simulations were done with water-level recordings at position 3 instead of position 1 as open boundary condition, cutting out the mouth itself.

Other driving forces which could be used are:

i) Flow rates (Q) instead of water levels (h) as open boundary conditions.

ii) Wind stresses.

iii) Evaporation rates.

Later in Section 3.2.1 the ways in which the bathymetric data are implemented in the model are described. After this has been done accurately the major unknown is the effect of bottom shear stresses on the flow rates. These are determined with a variation of the Chezy formula:

$$C = 18 \log 6R/a \qquad \ldots(3)$$

In this formula the Chezy coefficient (C) is a function of the hydraulic radius (R) and the obstruction (or ripple) height (a). On the basis of knowledge of the river bed an estimation of "a" can be made. If more comprehensive field data were available "a" would be adapted in the calibration process until the model results agreed satisfactorily with these data.

3. MODEL DESIGN

3.1 Description of the Hydrodynamically Important Aspects of the Keurbooms-Bitou Estuary

The estuary consists of two tributaries, the Keurbooms and the Bitou, which meet about 2 km from the mouth (see Figure 1). The Blind river to the south-west of the mouth is a dead end of the estuary without any fresh water inflow. Between the mouth and the confluence of the rivers the depths decrease gradually. Upstream of the confluence the Bitou river becomes very shallow and beyond the N2 bridge it has become a strongly meandering shallow tidal river in wide marshy flood-plains. The tidal action can be noticed as far upstream as the secondary road bridge at Wittedrif, 10 km from the mouth. Halfway between these two bridges is a causeway which is flooded at high water, damming up the water at low-tide. The Keurbooms is also becoming very shallow between the confluence and the N2 bridge, in particular in both channels around Stanley Island. However, upstream of the N2 bridge the Keurbooms has a completely different character. Here the river banks form a narrow

gorge with heavy vegetation and the tidal channel becomes very deep in places (more than 20 m below MSL). A stretch of about 6 km upstream of the N2 bridge is under tidal influence (WNNR, 1975).

3.2 Field Data for Model Design and Calibration

3.2.1 Field data requirements

Ideally the model should cover the whole estuary (all waters under tidal influence) and the bathymetry should be covered in fine enough detail to model the essential features properly. At the downstream end the open sea tide or a water-level recording close to the mouth should be used as open boundary condition and at the upstream ends the river inflows should be the open boundary conditions. Normally water-level recordings from 2 or 3 positions inside the estuary are then used for model calibration.

3.2.2 Field data available for the Keurbooms-Bitou model

The data available can be listed as follows:

1) Profiles of cross-sections measured by the Sediment Dynamics Division of the NRIO (see Figure 1) in March 1986 were used to prepare the model topography in the standard way as described in other reports (Gaillard and Huizinga, 1986; Huizinga, 1987a). The area covered by the model is the part of the estuary between the mouth and the N2 bridges.

2) Water-level recordings were taken at three positions (see Figure 1):

(a) a vertical Ott recorder was installed at the jetty just opposite the estuary mouth.

(b) a light-weight Van Essen pressure transducer recorder was installed at the Yachtclub just downstream of the N2 bridge in the Keurbooms river.

(c) another Van Essen recorder was installed in the Bitou river at the jetty at Bitou House.

The data obtained from these recorders are shown in Figures 3a-3h and were used for open boundary conditions in the model simulations.

3.2.3 Discussion: insufficient field data

Comparing available and required field data it is clear that the following additional requirements exist for adequate calibration data:

i) Additional surveyed cross-sections, particularly between the mouth and the N2 bridges. Additional cross-sections would also be required upstream of the N2 bridges to cover the entire area of tidal influence.

ii) River inflow data on both Bitou and Keurbooms rivers.

Refinements could also be made by obtaining more accurate water-level recordings (for example, using the NRIO's new MC systems water-level recorders) and by performing flow measurements during calibration data collection exercises at specific sections (N2 bridges, etc.). When proper model calibration data are available then the bottom roughness can be adjusted to achieve calibration. In this case, however, a bottom roughness was estimated by choosing a ripple height "a", based on experience, for equation 3.

To collect these additionally required data is expensive in time and cost, particularly because of the steep, thickly vegetated, inaccessible terrain in the upstream stretch of the

Keurbooms. This additional time and funding was not available in the case of the present Keurbooms River studies. However, it was considered worthwhile continuing with the modelling exercise despite the shortcomings in the calibration data, because a first estimate of mouth flow rates would be very useful for the corresponding biological work that was done during the calibration period. This could be refined at a later stage.

4. MODEL SIMULATIONS TO DETERMINE FLOW RATES

4.1 General

Model simulations were done for the period 15 March 1987, 10h20, two days before spring-tide, until neap-tide on 23 March 1987, 10h20. The results are presented graphically in Figures 3a-3h and at hourly flow rates in Tables Ia-Ii for the sections corresponding with positions where biological sampling took place. At the top of each figure the recorded water levels which were used as open boundary conditions are displayed, while on the other graphs the computed flow rates are shown for the positions indicated. In the graphs underneath the water-level recordings the flow rates in and out of the Blind River (section 3) are shown. Below that are the flow rates computed in the Keurbooms at sections 8 (near the mouth), 15 (just before the confluence), 16 (in the Keurbooms just upstream of the confluence) and 26 (in the Keurbooms at the N2 bridge). At the bottom of the figures the flow rates determined for sections 8 and 15 are shown again, together with those in the Bitou just upstream of the confluence (section 34) and in section 36, near Bitou House. The hourly flow rates in Tables Ia-Ii are given for the same sections as those displayed in the figures.

4.2 Discussion of the Results

4.2.1 Influence of starting conditions (see Figure 3a)

At the start of the computation all the water levels were assumed to be zero (=MSL) and gradually over the first 3 hours a transition to the recorded water levels for the open boundary conditions was made. Consequently the model results for the first six hours of the computation are highly artificial and should not be used for any computation of fluxes of materials.

4.2.2 Influence of unreliable water level recordings

At neap-tide, towards the end of the simulation period, the water-level recordings had become unreliable because of technical problems. For this reason, too, the simulation results of 22 and 23 March 1987 should not be used for any computation of fluxes of material.

4.2.3 Recorded water levels and tidal delays

It can be seen from the recordings that the values for high water inland are slightly lower than those at the mouth, which are very similar to the sea tide recorded at Mossel Bay (see Figure 3c). The low water at the inland water-level recorders can be up to 0,40 m higher than at the mouth, which in turn can be up to 0,50 m higher than the sea tide.

In the table below the tidal delays between the sea tide as recorded at Mossel Bay and the recorder positions as obtained from these recordings are given for spring-tide on 17 March 1987 (see also Figure 3c).

Tidal delays in hours between the sea tide and the indicated positions:

	Mouth (position 3)	Keurbooms N2 bridge (position 27)	Bitou house (position 36)
High water	0,1-0,3	1	0,7
Low water	1	3	2,5

The longer tidal delays at low water are caused by the very shallow river beds which retard the ebb flow.

4.2.4 Computed flow rates

The results speak very much for themselves. The inflow at flood tide always lasted about 4,5 hours and reached about 25 per cent higher flow rates than the ebb-tide which always lasted about 8 hours. The short-period higher harmonic which is particularly visible in the flows into the Blind river is artificial and is due to the truncating of the water-level recordings to the nearest centimetre before using them as open boundary conditions in the model.

Flow rates could not be determined at Bitou bridge, which was a sampling position but an estimate could be based on the reduction of about 20 per cent in flow rates between sections 34 and 36, which are 500 m apart. The distance between section 36 and the Bitou N2 bridge is about 1 100 m and, assuming a linear reduction with distance, this reduction could be about 44 per cent. However, it is more likely that this reduction is slightly less than linear and could probably be in the order of 35 per cent. It is, therefore, recommended that flow rates assumed at Bitou bridge should be 65 per cent of those obtained from the model at section 36.

The hourly flow rates given in Tables Ia-Ii can be used directly to determine fluxes of materials through the indicated cross-sections. From these results the tidal volumes too can be easily determined. During spring tide (17 March 1987) the

tidal prism is about 5 million m^3 of which between 10 and 15 per cent flows into the Blind river. At neap-tide the model results are very unreliable and, therefore, the tidal prism for neap-tide cannot be determined.

Because of the lack of prototype information and the resulting difficulty of achieving a proper model calibration the computed flow rates cannot be considered very accurate. Based on experience from previous model applications the accuracy of the results could be out by up to about 25 per cent.

5. CONCLUSIONS

1) Valuable experience has been gained by this model application which covered only a part of the estuary. However, this approach is not recommended because such a model cannot be calibrated properly.

2) Possible improvements can be made in several ways:

i) by application of the model to the whole estuary under tidal influence;

ii) by surveying additional cross-sections between the mouth and the N2 bridges for more accurate bathymetric data for the model input;

iii) by using measured river inflow as the upstream open boundary conditions;

iv) by obtaining more accurate water-level recordings, for example by using the NRIO's new MC systems water-level recorders;

v) by doing flow measurements at certain cross-sections, such as at the N2 bridges, for improved model calibration.

3) The results obtained with the model can be significantly improved upon but can nevertheless be used as a basis for other research in the estuary.

Provided more field data become available, the model could also be further developed for:

(a) river flood studies (see also Huizinga, 1987b);

(b) water quality studies (see Huizinga, 1986).

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TABLE Ia

HOURLY FLOW RATES IN THE KEURBOOMS-BITOU ESTUARY

15/03/87

Position:	3		8		15	
	BLINDE RIVIER		ESTUARY MOUTH		ESTUARY SPLITTING	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
1020-1120	24607	3766	797	93569		129186
1120-1220	95465		177950		50410	25352
1220-1320	138423		480369		332056	
1320-1420	175543		853801		632375	
1420-1520	88829		1010266		842214	
1520-1620	9217	28429	710524		661288	
1620-1720		111755	50924	363382	63890	275978
1720-1820		143636		854530		674689
1820-1920		109499		780655		625687
1920-2020		73502		656052		533429
2020-2120		51615		538472		441872
2120-2220	72	26884		457272		381571
2220-2320	12025	1546		335718		305003
2320- 20	85328		62698	91886	8024	152532

Position	16		26		34		36	
	KEURBOOMS SPLITTING		KEURBOOMS BRIDGE		BITOU SPLITTING		BITOU FARM	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
1020-1120		37367		95864		96517		106269
1120-1220	25057	5403	5418	86995	22099	42654	16194	75136
1220-1320	155670		58593		152011		111792	
1320-1420	339022		109911		253372		184862	
1420-1520	525574		223618		278782		211219	
1520-1620	408205		198536		234766		201055	
1620-1720	34585	149890	26642	70770	30142	112021	30985	88787
1720-1820		334826		123591		306539		251074
1820-1920		288563		112938		307205		255857
1920-2020		253130		103903		255410		213136
2020-2120		205617		84518		217097		185251
2120-2220		166435		72437		200351		175466
2220-2320		134379		74089		161701		145068
2320- 20	1219	72520		59864	2232	90325		107642

TABLE Ib

HOURLY FLOW RATES IN THE KEURBOOMS-BITOU ESTUARY

16/03/87

Position:	3		8		15	
	BLINDE RIVIER		ESTUARY MOUTH		ESTUARY SPLITTING	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120	156019		472645		307917	
120- 220	192954		929050		699625	
220- 320	114794		1184475		980993	
320- 420	17432	13995	922756		813847	
420- 520		93328	63170	484211	65032	437588
520- 620		143114		976690		781619
620- 720		138677		894720		709398
720- 820		89129		760040		622139
820- 920		55852		617776		511433
920-1020		42792		522231		431441
1020-1120	14158	4587		401655		362950
1120-1220	73789		16193	148117		217147
1220-1320	140210		380711		222482	134
1320-1420	163265		759038		561114	
1420-1520	127527		1025409		833093	
1520-1620	38580	13075	950934		850132	
1620-1720		94013	221791	126292	236676	83603
1720-1820		140478		804736		643616
1820-1920		134044		824249		653042
1920-2020		92571		730864		588953
2020-2120		60699		600706		494686
2120-2220		32733		512971		424987
2220-2320	8138	5110		397451		350027
2320- 20	72176		6822	149108		227895

Position:	16		26		34		34	
	KEURBOOMS SPLITTING		KEURBOOMS BRIDGE		BITOU SPLITTING		BITOU FARM	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120	115628		50358	6039	168513		134594	264
120- 220	308236		96899		351591		285532	
220- 320	525094		187833		409897		323963	
320- 420	540492		197100		239491		176552	
420- 520	80547	159980	40526	139569	2901	292651	102	285376
520- 620		397115		148476		346413		281972
620- 720		322977		112850		351525		293027
720- 820		287226		128374		307535		260297
820- 920		230356		95180		259211		222548
920-1020		190396		79920		223763		195184
1020-1120		153178		80928		199314		180521
1120-1220		96417		65005		129223		135949
1220-1320	88965	924	41853	12805	110615	863	76914	6771
1320-1420	287159		121603		238305		177942	
1420-1520	487139		222563		306882		236926	
1520-1620	595975		312580		226075		174383	
1620-1720	248933	31526	156206	18330	11302	71813	5233	59854
1720-1820		339672		137126		274515		226172
1820-1920		280583		99352		340897		287789
1920-2020		257489		95451		303462		255823
2020-2120		219384		101392		254634		220192
2120-2220		181267		63378		226738		198587
2220-2320		143039		73055		195803		176303
2320- 20		93770		67189		142186		148447

TABLE Ic

KEURBOOMS-BITOU ESTUARY

17/03/87

Position:	3		8		15	
	BLINDE RIVIER		ESTUARY MOUTH		ESTUARY SPLITTING	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120	132175		291171		145210	7696
120- 220	189912		772316		558431	
220- 320	144177		1115096		899757	
320- 420	62771	2049	1140074		1006492	
420- 520		93971	501181	32641	502769	13764
520- 620		144316		759388		603581
620- 720		110905		896947		732362
720- 820		107646		733499		583491
820- 920		81581		647905		522388
920-1020		56540		555166		447545
1020-1120	2410	11502		445815		381938
1120-1220	33163			295330		297670
1220-1320	90127		86473	37314	19784	105952
1320-1420	153983		491015		327733	
1420-1520	143637		826457		633871	
1520-1620	73378		916481		775712	
1620-1720	2645	40148	639910		610752	
1720-1820		107956	19143	427276	34223	338452
1820-1920		138679		785530		617313
1920-2020		97057		723519		582374
2020-2120		72973		622823		508009
2120-2220		38277		531867		437292
2220-2320		11011		422770		362531
2320- 20	24196	1807		310887		299734

Position:	16		26		34		36	
	KEURBOOMS SPLITTING		KEURBOOMS BRIDGE		BITOU SPLITTING		BITOU FARM	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120	47286	4688	27775	25218	82312	9432	60677	20699
120- 220	254043		109677		268023		208155	
220- 320	483069		210735		373304		295337	
320- 420	647942		324179		325405		265173	
420- 520	302037	35980	106048	43817	215267		200549	
520- 620		542407		362626	25919	59454	50255	39403
620- 720		407013		194372		292825		235641
720- 820		311713		134907		243147		195023
820- 920		260852		118255		236978		196180
920-1020		214569		99705		212980		180206
1020-1120		176369		96801		192188		169272
1120-1220		135842		71951		156957		147073
1220-1320	2359	55369		61808	11832	64498	5443	83818
1320-1420	130370		53611	2315	172224		132019	
1420-1520	319546		132060		277981		214547	
1520-1620	482082		233403		261658		203900	
1620-1720	447606		225371		148039		119765	4
1720-1820	48391	202728	28126	140200	118	133620		106027
1820-1920		362619		172424		224357		174315
1920-2020		300384		137270		254560		208780
2020-2120		239965		102731		246002		210054
2120-2220		192087		82456		227223		197441
2220-2320		156141		82929		194018		172765
2320- 20		122830		63937		171000		160658

TABLE Id

KEURBOOMS-BITOU ESTUARY

18/03/87

Position:	3		8		15	
	BLINDE RIVIER		ESTUARY MOUTH		ESTUARY SPLITTING	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120	85747		61959	71902	5453	146100
120- 220	144446		420195		258984	
220- 320	190538		852817		622927	
320- 420	105996	49	1051147		858041	
420- 520	10291	34277	764953		710750	
520- 620		102421	93817	305675	113330	239592
620- 720		127046		829703		668754
720- 820		114182		770705		612608
820- 920		90247		680681		553092
920-1020		55761		576773		465014
1020-1120	263	27709		476856		395280
1120-1220	7124	2975		362061		320544
1220-1320	41483			207159		245438
1320-1420	104584		172043	7799	64931	53233
1420-1520	149713		550564		385187	
1520-1620	124196		813393		638432	
1620-1720	29508	1729	805522		709650	
1720-1820		47554	383218		389710	
1820-1920		113838		426235	2983	302431
1920-2020		128673		679083		519960
2020-2120		84580		628031		499702
2120-2220		58417		537294		432752
2220-2320		20845		443827		366449
2320- 20	8681	1802		329832		295818

Position:	16		26		34		36	
	KEURBOOMS SPLITTING		KEURBOOMS BRIDGE		BITOU SPLITTING		BITOU FARM	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120	2937	57873		51114		103404		125926
120- 220	117329		61302	6044	118236		86206	3821
220- 320	309518		105710		271919		201562	
320- 420	541824		251503		273122		194705	
420- 520	594409		314989		99476	2864	68818	7792
520- 620	130765	117779	72606	74169		128166		110307
620- 720		366297		156957		272721		223807
720- 820		276169		95625		306159		255266
820- 920		245150		102064		283756		243756
920-1020		214090		94959		228588		190177
1020-1120		179715		88463		200006		173666
1120-1220		145465		79833		164963		147675
1220-1320		109336		76871		137729		137298
1320-1420	18747	28899	765	44649	34697	36081	21164	55789
1420-1520	166716		61942		190979		146071	
1520-1620	324015		110254		280852		223158	
1620-1720	419487		192055		265121		217784	
1720-1820	262482		131938		121597		111110	
1820-1920	160	214733	4510	97047	12780	76061	23273	50847
1920-2020		278352		116814		212555		164935
2020-2120		251466		100652		223229		181626
2120-2220		204150		89263		209195		176984
2220-2320		167105		75768		184181		158722
2320- 20		132423		74375		154612		139821

TABLE Ie

KEURBOOMS-BITOU ESTUARY

19/03/87

Position:	3		8		15	
	BLINDE RIVIER		ESTUARY MOUTH		ESTUARY SPLITTING	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120	50738		1788	152859		211615
120- 220	97171		220856		99312	14002
220- 320	171014		596798		412682	
320- 420	149867		963285		753541	
420- 520	74857	7575	1071228		927915	
520- 620	5935	46410	688449		665612	
620- 720		121575	26909	299980	47440	178004
720- 820		121182		670549		523443
820- 920		104545		643980		498937
920-1020		83520		583434		458513
1020-1120		52798		508040		404497
1120-1220	3079	7615		396450		342720
1220-1320	20792			266214		265057
1320-1420	76268		69108	50333	12844	111076
1420-1520	115821		391090		261088	
1520-1620	157454		724140		534464	
1620-1720	90981		905761		749153	
1720-1820	2450	28280	690246		654736	
1820-1920		78128	117211	149768	136580	104755
1920-2020		111169		646051		506106
2020-2120		95441		622559		485828
2120-2220		65028		534647		428505
2220-2320		43047		446898		363384
2320- 20	1041	20588		370497		310531

Position:	16		26		34		36	
	KEURBOOMS SPLITTING		KEURBOOMS BRIDGE		BITOU SPLITTING		BITOU FARM	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120		94167		61914		122101		124983
120- 220	24001	10357	10718	30880	62992	12090	47882	27546
220- 320	175008		65447		208464		162460	
320- 420	368544		139167		345187		275317	
420- 520	542613		248454		350623		287112	
520- 620	365682	40	135077	3848	285749		262756	
620- 720		370227		227466	265567		304511	
720- 820		309461		103603	1247	188420	3796	146155
820- 920		220734		52404		250732		204530
920-1020		201634		72218		232785		192144
1020-1120		177396		66997		207868		176300
1120-1220		147698		74601		183142		162620
1220-1320		115110		70022		146243		138597
1320-1420	3944	50035		52215	3851	72868	437	91987
1420-1520	107667		46011	2253	133978		102921	
1520-1620	262333		94775		237924		180391	
1620-1720	431754		197958		284001		224517	
1720-1820	434384		229096		205391		176667	
1820-1920	130446	30397	98338	10247	20148	80722	18655	67927
1920-2020		243103		73846		237152		193572
2020-2120		220771		66353		238514		193363
2120-2220		192740		48922		214326		178419
2220-2320		155759		55187		191092		163236
2320- 20		132896		53132		165471		144747

TABLE If

KEURBOOMS-BITOU ESTUARY

20/03/87

Position:	3		8		15	
	BLINDE RIVIER		ESTUARY MOUTH		ESTUARY SPLITTING	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120	12052	295		249797		237903
120- 220	80846		103765	42061	35157	85874
220- 320	134326		472061		326853	
320- 420	146242		765302		579270	
420- 520	99735		968923		798364	
520- 620	34130	13167	837024		749293	
620- 720		68700	219495	52839	241527	17613
720- 820		102882		388156		252515
820- 920		126512		628209		486208
920-1020		86047		630477		503280
1020-1120		54580		530926		434712
1120-1220	113	36656		435419		354960
1220-1320	4645	10583		328515		287983
1320-1420	34718			162382		195247
1420-1520	86322		205244	853	112405	17516
1520-1620	121982		510823		369720	
1620-1720	71405		639530		524246	
1720-1820	33766	2729	621893		538746	
1820-1920		57908	211762	41844	227405	29119
1920-2020		87561		540804		444135
2020-2120		77130		582620		470890
2120-2220		69701		534428		428257
2220-2320		42911		450114		365959
2320- 20		26506		378971		315159

Position:	16		26		34		36	
	KEURBOOMS SPLITTING		KEURBOOMS BRIDGE		BITOU SPLITTING		BITOU FARM	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120		98334		50087		134654		125107
120- 220	14063	36224	644	38528	13917	58416	8272	73215
220- 320	142763		74196		161519		124362	
320- 420	300016		114872		245147		186774	
420- 520	479450		210546		282347		215851	
520- 620	505847		210971		218905		176875	
620- 720	69992	151257	22305	106508	312644		324991	
720- 820		365628		195129	138823		179769	
820- 920		252825		82095	47	209076	565	169692
920-1020		192971		32256		285332		243649
1020-1120		174182		59308		240621		205415
1120-1220		158411		55993		180262		152490
1220-1320		124923		59105		153693		137117
1320-1420		86442		57874		110931		111591
1420-1520	47116	9627	31226	17809	52942	12693	35958	22378
1520-1620	189700		80981		155310		114884	
1620-1720	299124		142034		201367		158477	
1720-1820	377142		192759		141304		105250	
1820-1920	241777		134036		29679	73673	23109	71156
1920-2020	691	186876	3065	99788		241357		212440
2020-2120		223536		78020		225651		189504
2120-2220		187967		55826		219289		183919
2220-2320		155580		48276		193528		165205
2320- 20		132312		64126		170724		150207

TABLE Iq

KEURBOOMS-BITOU ESTUARY

21/03/87

Position: 3 8 15

	BLINDE RIVIER		ESTUARY MOUTH		ESTUARY SPLITTING	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120	928	9538		311866		274441
120- 220	25517	3		202050		223874
220- 320	62810		69361	37832	19509	86167
320- 420	81473		326507		234514	
420- 520	89510		508836		385182	
520- 620	60693		544126		432065	
620- 720	13472	10641	322609		268679	
720- 820		43868	430	314605	1226	273959
820- 920		81071		531592		423075
920-1020		83505		531362		415770
1020-1120		56013		475389		383647
1120-1220		35780		409044		339747
1220-1320	301	16336		352466		300948
1320-1420	11589	298		258608		254950
1420-1520	40979			120374		178590
1520-1620	50066		97158		36824	17137
1620-1720	71277		283936		192357	
1720-1820	60449		363139		275132	
1820-1920	17146	2722	333562		291136	
1920-2020	328	21109	129800	809	146277	
2020-2120		40890		107452	1634	50793
2120-2220		65105		262790		179182
2220-2320		59860		336539		252408
2320- 20		35640		313983		245737

Position: 16 26 34 36

	KEURBOOMS SPLITTING		KEURBOOMS BRIDGE		BITOU SPLITTING		BITOU FARM	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120		111107		56121		155848		144118
120- 220		80340		51523		144298		143632
220- 320	20979	23613	2133	27831	784	80094		99896
320- 420	110792		51717		109948		87500	
420- 520	200106		52913		160624		117860	
520- 620	289214		100394		118102		73773	
620- 720	277336		96401		12583	37095	2577	54913
720- 820	24454	117389	13447	102307		173594		162796
820- 920		253018		127547		149610		115292
920-1020		221497		82949		172037		135404
1020-1120		187832		80870		177692		147346
1120-1220		158221		77999		168424		146692
1220-1320		138445		76033		152317		135400
1320-1420		114945		86416		137249		131762
1420-1520		78701		65662		107270		116940
1520-1620	24472	6596	10614	31866	8236	20125	293	34525
1620-1720	127799		51760		47886		19853	174
1720-1820	199488		83055		57980		28212	
1820-1920	217304		111166		63003		44389	
1920-2020	128226		91232		20191	43	23720	
2020-2120	1483	58232	22901	16226	18814		37568	
2120-2220		134526		44627	2692	31853	11917	15045
2220-2320		141395		52578		95311		69886
2320- 20		131195		55101		101644		79841

TABLE Ih

KEURBOOMS-BITOU ESTUARY

22/03/87

Position:	3		8		15	
	BLINDE RIVIER		ESTUARY MOUTH		ESTUARY SPLITTING	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120		14836		262025		219309
120- 220	2397	1416		200366		190327
220- 320	23247			120028		154457
320- 420	50641		90916	7359	35746	33969
420- 520	51676		241171		171886	
520- 620	65161		339604		249844	
620- 720	29285	243	336054		276095	
720- 820	16429	6497	248558		222042	
820- 920		37493	56276	26048	81596	2961
920-1020		61883		221260		143396
1020-1120		47360		298439		226000
1120-1220		42300		273658		205268
1220-1320		31494		263331		204837
1320-1420	6556	7032		215741		197309
1420-1520	12223			130434		146115
1520-1620	30350		30425	30431	5986	56388
1620-1720	36424		150685		96770	
1720-1820	43928		238706		178402	
1820-1920	26907		242628		188799	
1920-2020	6214	3185	94732		81661	
2020-2120	5842	8239	74	39220	62	37912
2120-2220		24076		147685		114164
2220-2320		42632		226244		167712
2320- 20		29959		220940		173752

Position:	16		26		34		36	
	KEURBOOMS SPLITTING		KEURBOOMS BRIDGE		BITOU SPLITTING		BITOU FARM	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120		112792		54325		98215		84843
120- 220		86778		57790		100980		97187
220- 320		58178		45580		100701		106772
320- 420	44704	6146	16566	6484	362	51178		72384
420- 520	118860		61383		41159		20672	352
520- 620	182017		80040		49913		19962	
620- 720	219703		98244		43894	930	23496	4165
720- 820	200834		101637		16659	1975	11447	7832
820- 920	53985	22008	53675	965	55194		70146	
920-1020		132932		40237	22924	19031	35377	7863
1020-1120		130943		35926		80425		55665
1120-1220		100916	3247	4271		91556		71057
1220-1320		82892		27927		111504		94684
1320-1420		73642		35436		119089		111496
1420-1520		43033		29261		104892		107005
1520-1620	26156	6379	7136	5151		78572		90862
1620-1720	94319		52954		8039	14888	3024	25578
1720-1820	127031		66611		40052		20995	
1820-1920	164544		79815		15135	3057	5309	14527
1920-2020	158237		100886			80202		87709
2020-2120	119664		99572			157421		158110
2120-2220	68349		102449			176125		165465
2220-2320	18901	5644	82463			169517		150114
2320- 20		21199	33778			143843		128254

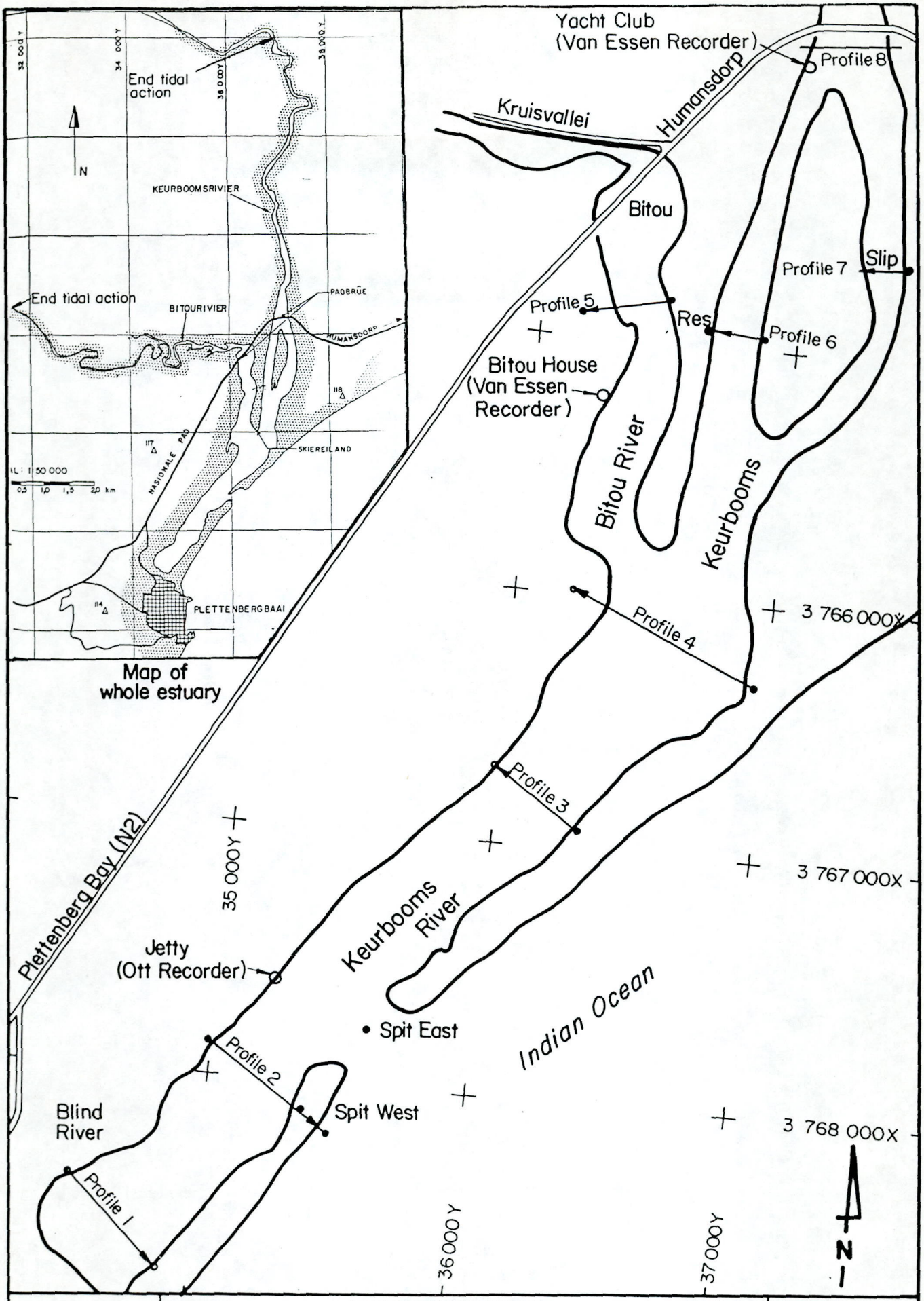
TABLE 11

KEURBOOMS-BITOU ESTUARY

23/03/87

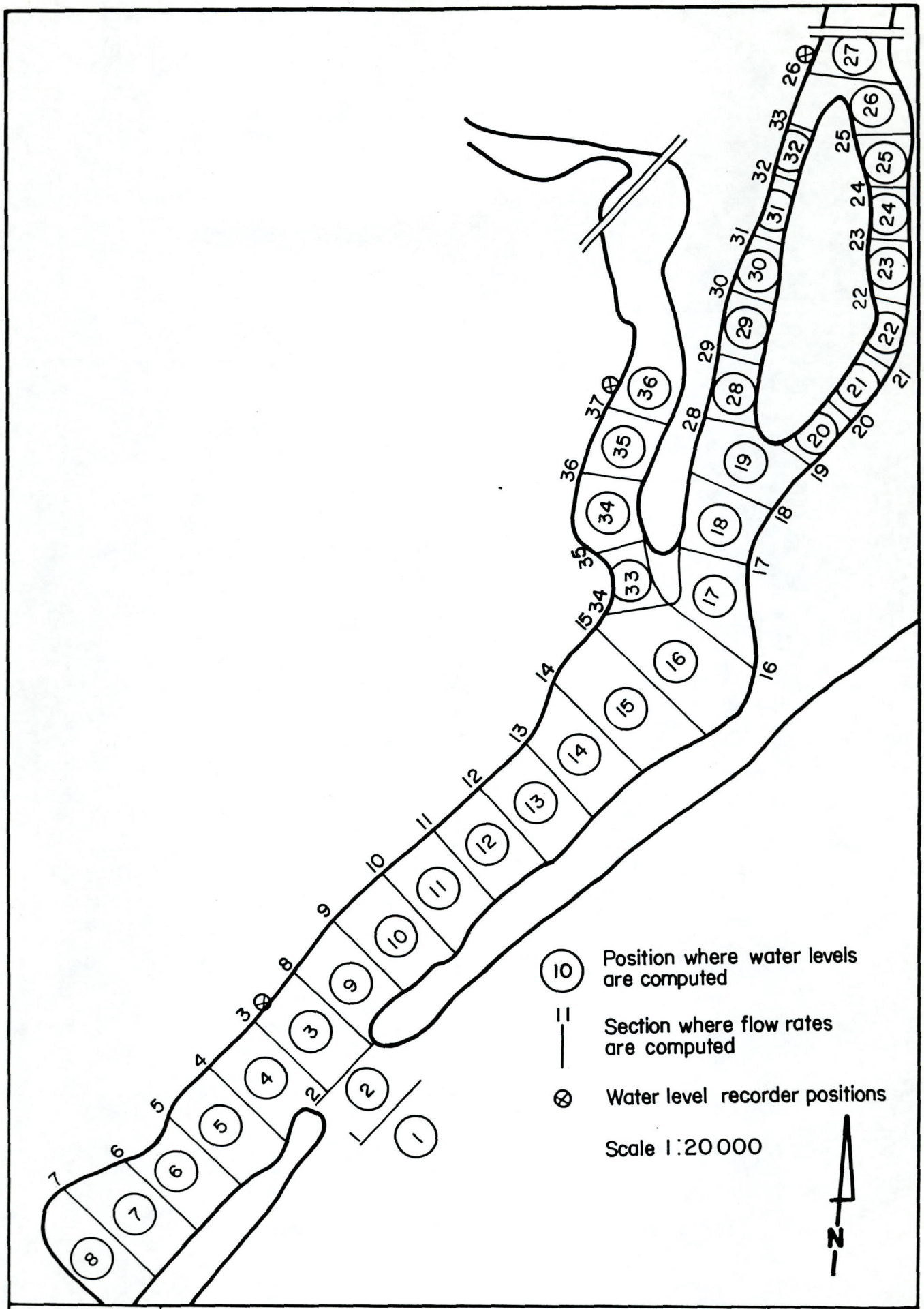
Position:	3		8		15	
	BLINDE RIVIER		ESTUARY MOUTH		ESTUARY SPLITTING	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120	2575	28463		237302		190604
120- 220	1743	14905		207827		178829
220- 320	1524	3072		161562		153284
320- 420	17816	831	732	85323		107570
420- 520	15153	84	17006	5205	1986	15734
520- 620	33512	34	101339		46368	
620- 720	45328		178760		111020	
720- 820	37893		197698		141929	
820- 920	8528	7145	109766	4791	89242	1538
920-1020	1041	9884		91784		72444

Position:	16		26		34		36	
	KEURBOOMS SPLITTING		KEURBOOMS BRIDGE		BITOU SPLITTING		BITOU FARM	
	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW	INFLOW.	OUTFLOW
20- 120		58797	822	10477		122980		107751
120- 220		60322		19437		112836		104110
220- 320		33472		8859		117832		114581
320- 420	9939	6935	10436	718		113596		117228
420- 520	62350		45527			80452		87496
520- 620	97965		50883			62046		78927
620- 720	137026		53740			39314		61710
720- 820	161726		65893			31192		50837
820- 920	155304		99504			72573		83551
920-1020	81223		73556			148823		137739



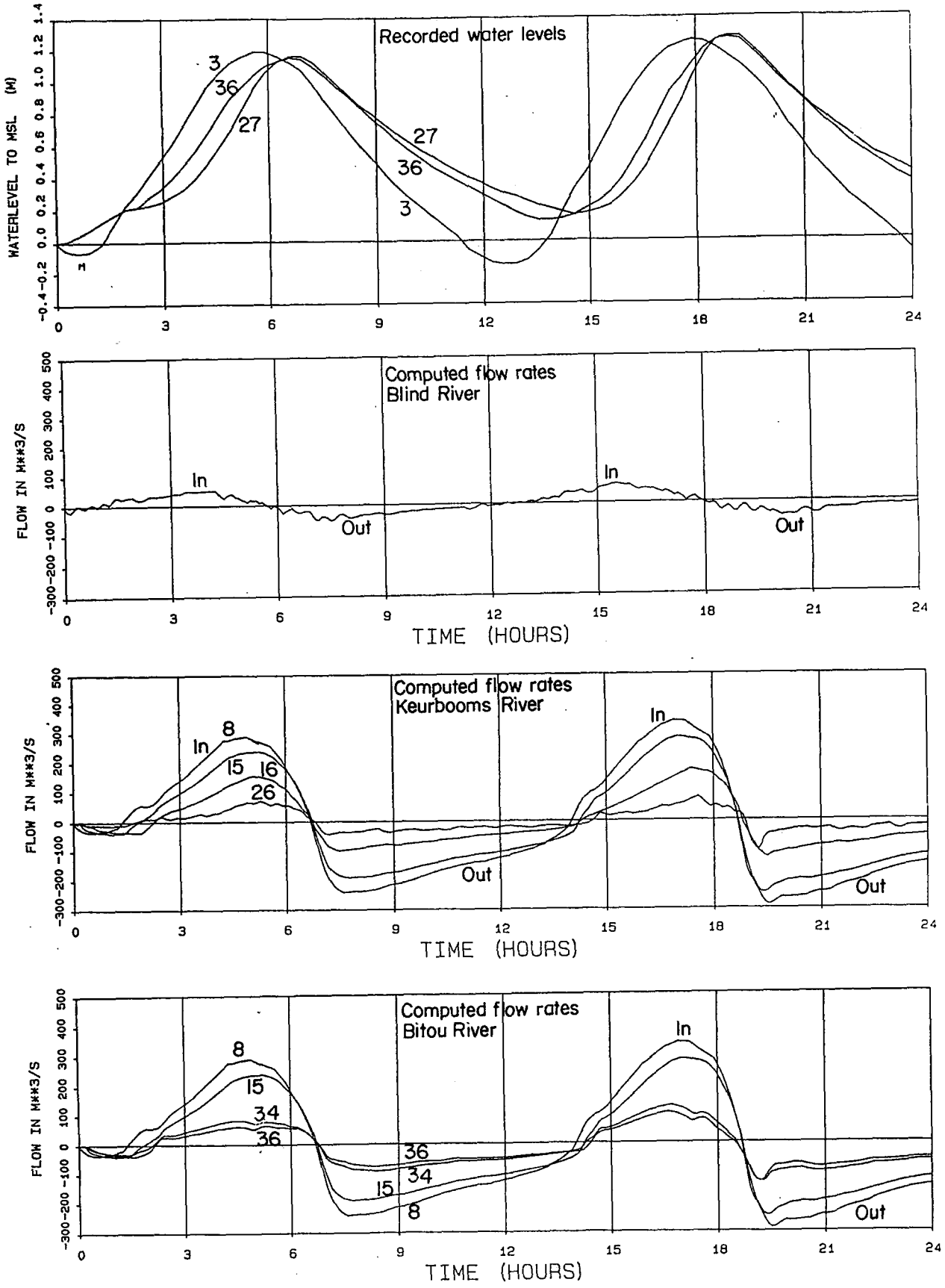
TRACED:	1- DIMENSIONAL MODEL	FIGURE
CHECKED:		
DATE:	MAP OF THE KEURBOOMS – BITOU ESTUARY	1
REF.:		

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



TRACED: CHECKED: DATE: REF.:	1-DIMENSIONAL MODEL MODEL SCHEMATIZATION	FIGURE 2

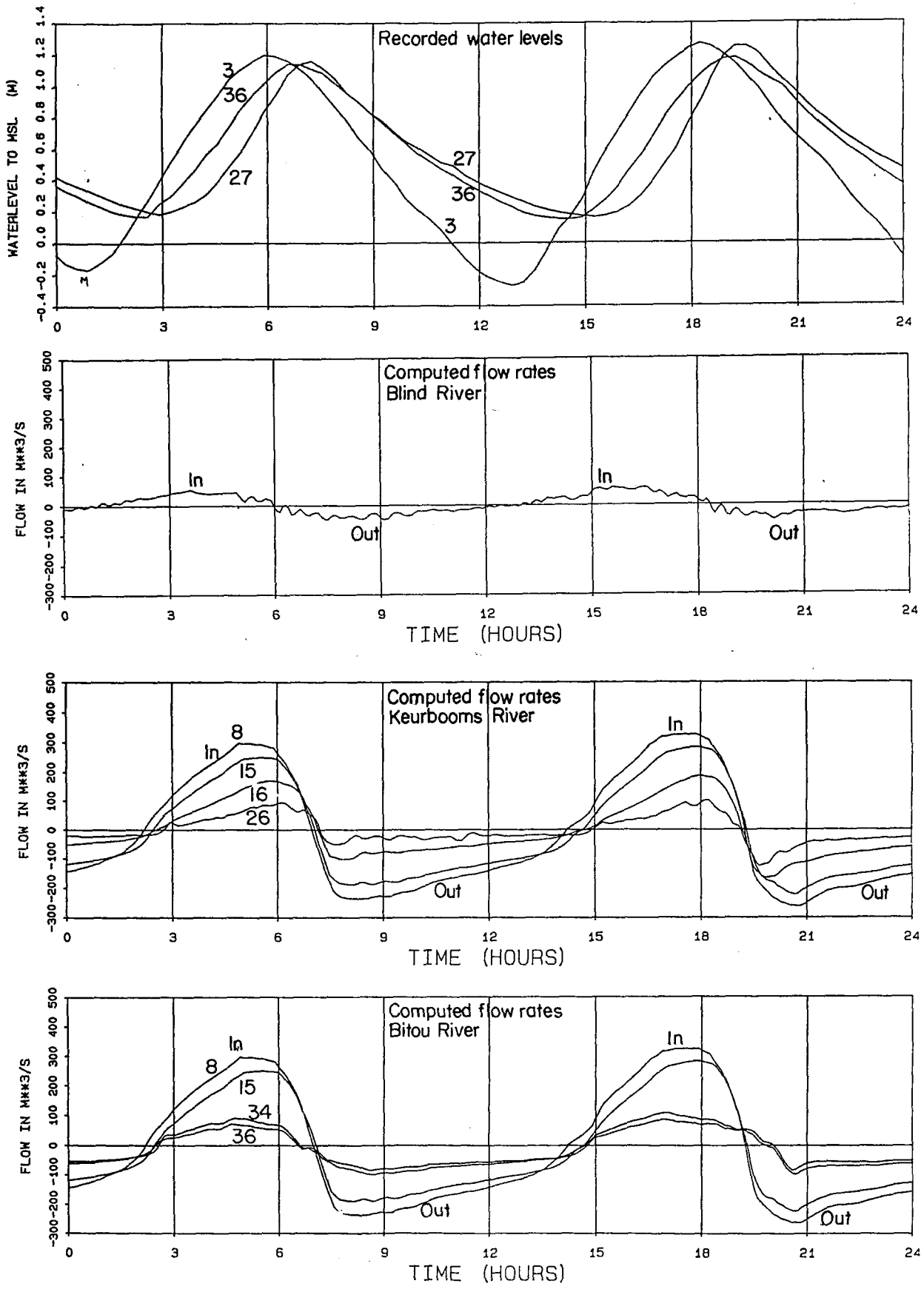
NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



(Numbers on graphs indicate positions shown in figure 2)

TRACED CHECKED DATE REF	1-DIMENSIONAL MODEL RECORDED WATER LEVELS AND COMPUTED FLOW RATES IN THE KEURBOOM-BITOU ESTUARY AT THE INDICATED POSITIONS FOR THE PERIOD 15/3/87 10H20 - 16/3/87 10H20	FIGURE 3a

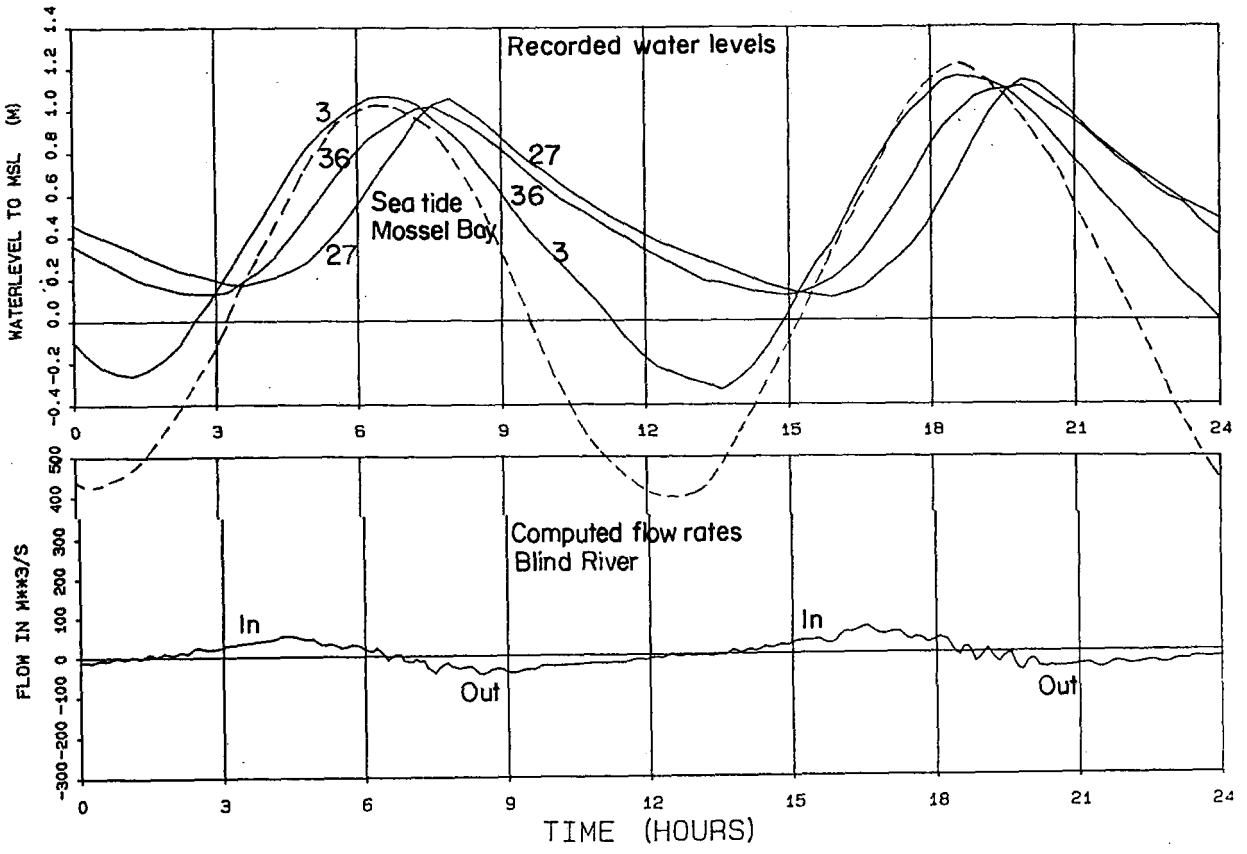
NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY

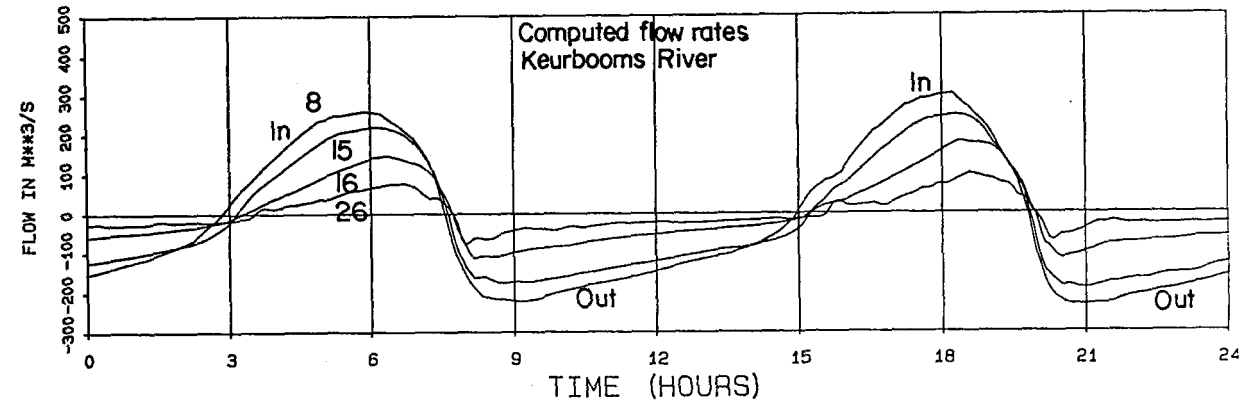


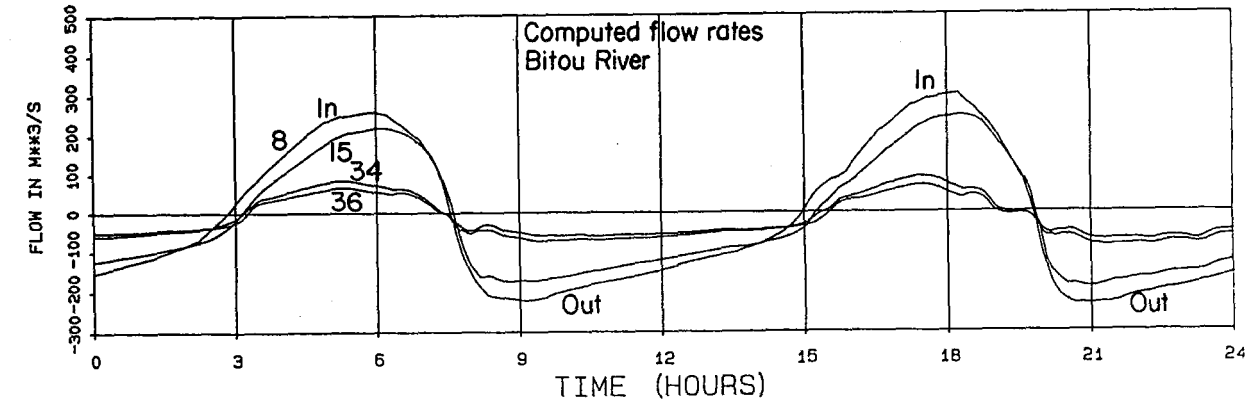
(Numbers on graphs indicate positions shown in figure 2)

TRACED: CHECKED. DATE: REF.	1-DIMENSIONAL MODEL RECORDED WATER LEVELS AND COMPUTED FLOW RATES IN THE KEURBOOM-BITOU ESTUARY AT THE INDICATED POSITIONS FOR THE PERIOD 16/3/87 10H20-17/3/87 10H20	FIGURE 3b

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



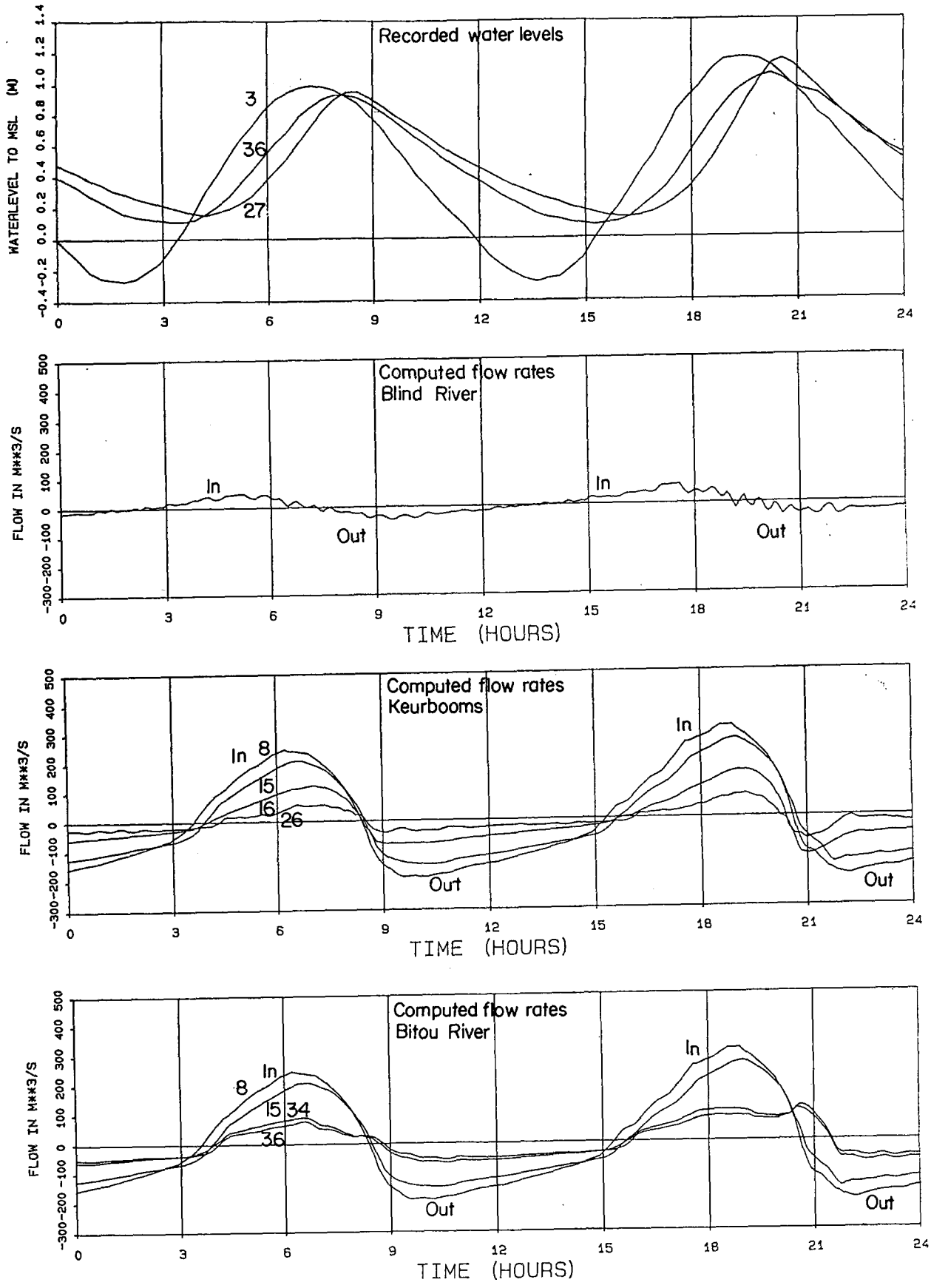




(Numbers on graphs indicate positions shown in figure 2)

TRACED: CHECKED: DATE: REF:	1-DIMENSIONAL MODEL RECORDED WATER LEVELS AND COMPUTED FLOW RATES IN THE KEURBOOM-BITOU ESTUARY AT THE INDICATED POSITIONS FOR THE PERIOD 17/3/87 10H20 – 18/3/87 10H20	FIGURE 3c

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



(Numbers shown on graphs indicate positions shown in figure 2)

TRACED CHECKED DATE REF	1-DIMENSIONAL MODEL RECORDED WATER LEVELS AND COMPUTED FLOW RATES IN THE KEURBOOM-BITOU ESTUARY AT THE INDICATED POSITIONS FOR THE PERIOD 18/3/87 10H20-19/3/87 10H20	FIGURE 3d

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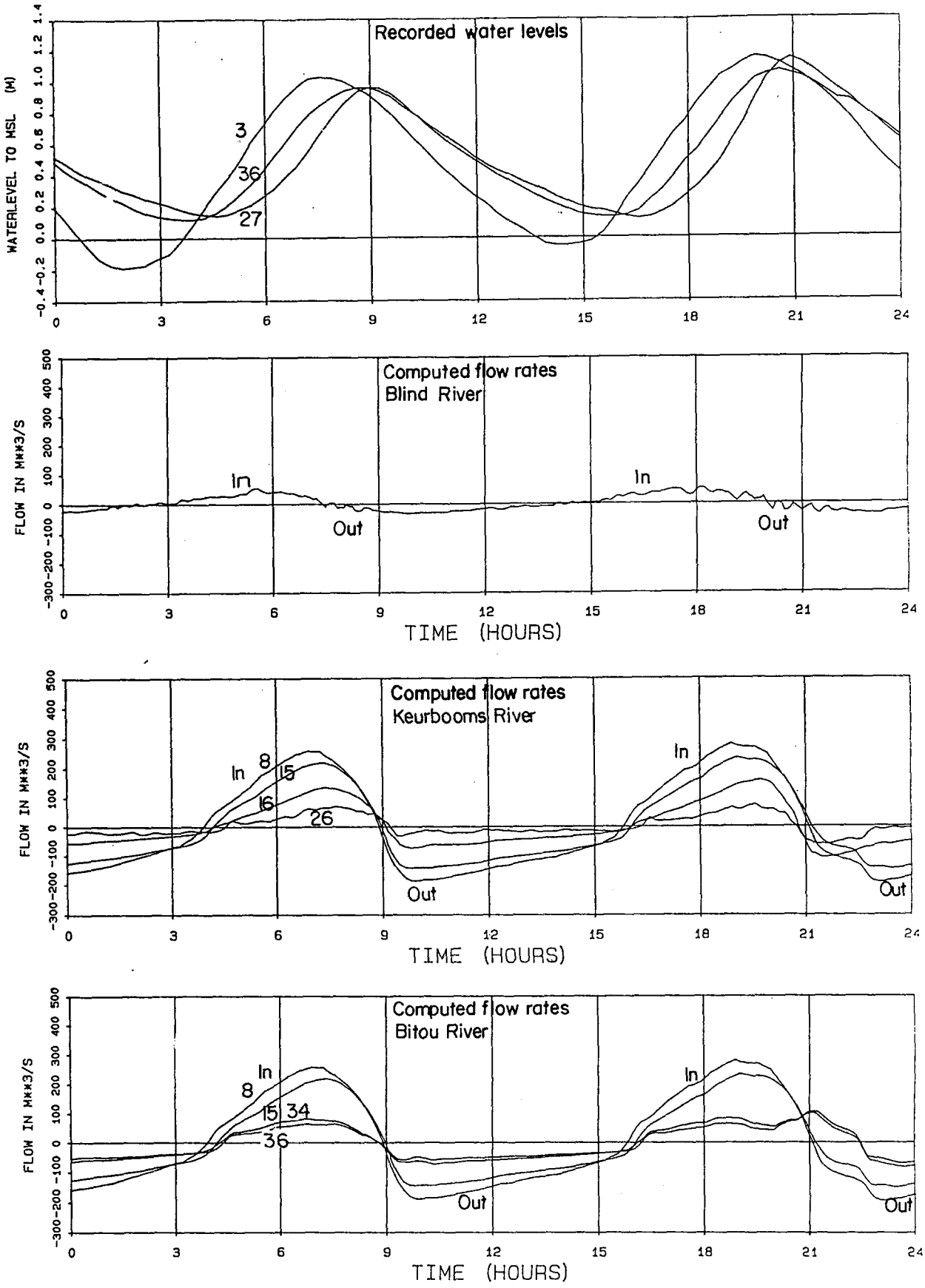
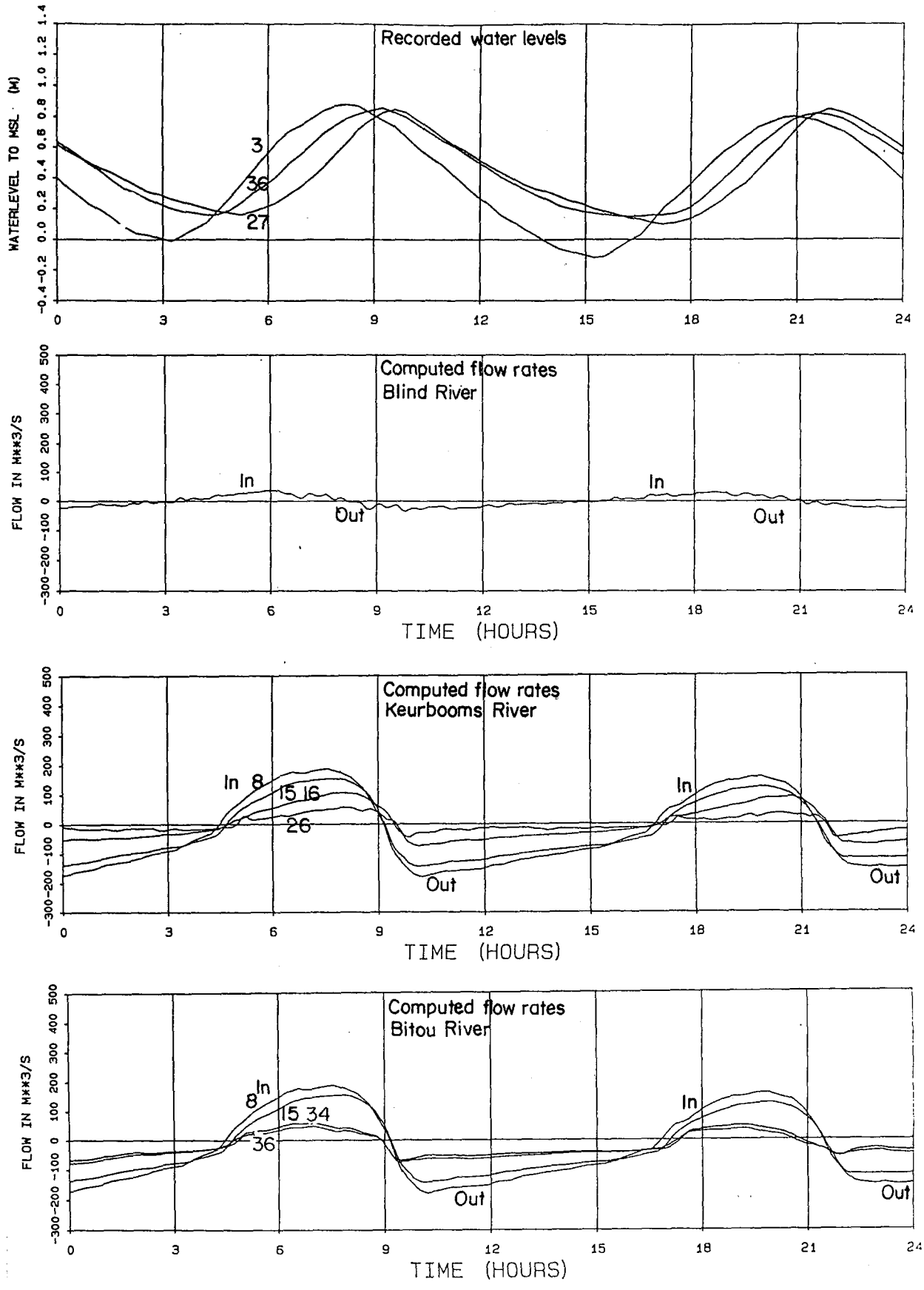


(Numbers on graphs indicate positions shown in figure 2)

TRACED: CHECKED: DATE: REF:	1-DIMENSIONAL MODEL RECORDED WATER LEVELS AND COMPUTED FLOW RATES IN THE KEURBOOM-BITOU ESTUARY AT THE INDICATED POSITIONS FOR THE PERIOD 19/3/87 10H20-20/3/87 10H20	FIGURE 3e

NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY



(Numbers on graphs indicate positions shown in figure 2)

TRACED: CHECKED: DATE: REF.	1-DIMENSIONAL MODEL RECORDED WATER LEVELS AND COMPUTED FLOW RATES IN THE KEURBOOM-BITOU ESTUARY AT THE INDICATED POSITIONS FOR THE PERIOD 20/3/87 – 21/3/87 10H20	FIGURE 3f

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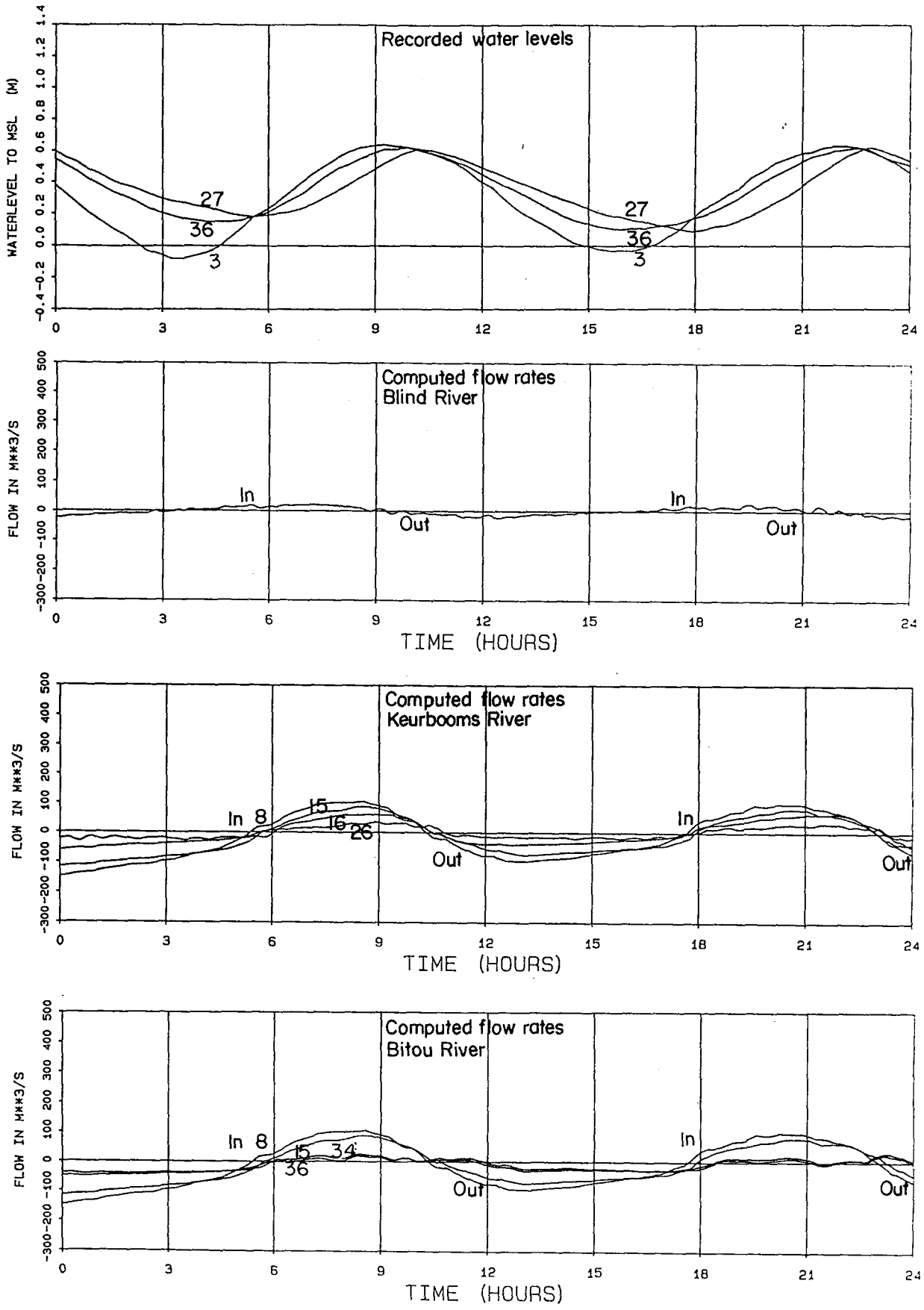

(Numbers on graphs indicate positions shown in figure 2)

TRACED: CHECKED: DATE: REF.	1-DIMENSIONAL MODEL RECORDED WATER LEVELS AND COMPUTED FLOW RATES IN THE KEURBOOM-BITOU ESTUARY AT THE INDICATED POSITIONS FOR THE PERIOD 21/3/87 — 22/3/87 10H20	FIGURE 3g

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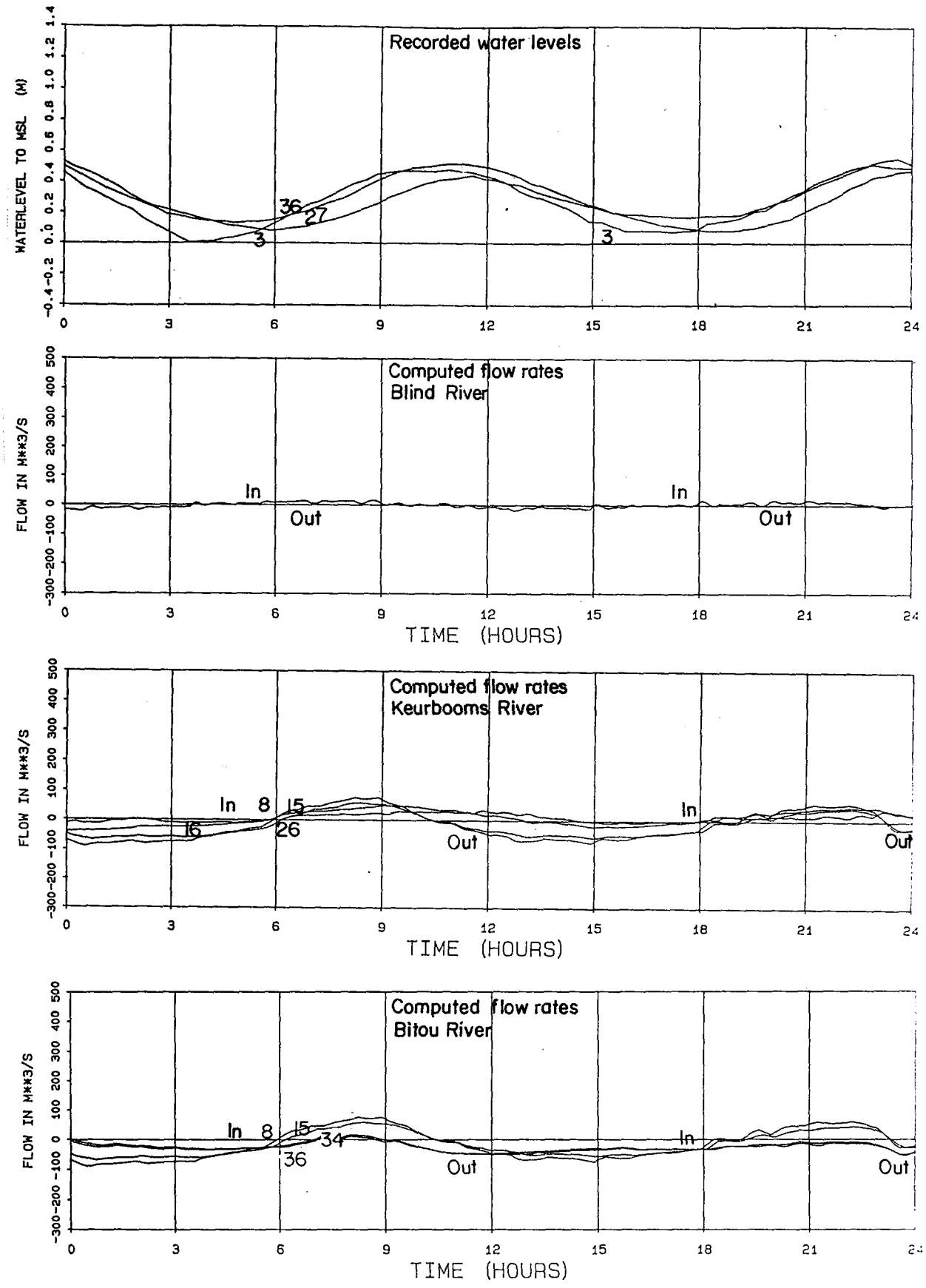

(Numbers on graphs indicate positions on figure 2)

TRACED: CHECKED: DATE: REF:	1-DIMENSIONAL MODEL RECORDED WATER LEVELS AND COMPUTED FLOW RATES IN THE KEURBOOM-BITOU ESTUARY AT THE INDICATED POSITIONS FOR THE PERIOD 22/3/87 – 23/3/87 10H20	FIGURE 3h

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