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PROGRESS REPORTS
on the
PEEL-HARVEY ESTUARINE SYSTEM STUDY

E.P. HODGKIN

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DEPARTMENT OF CONSERVATION & ENVIRONMENT
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E.P. Hodgkin
Research Co-ordinator,
Estuarine Studies.

October, 1978

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PEEL-HARVEY ESTUARINE SYSTEM STUDY

Progress of the Study as reported to a meeting of EMAC held 11 May 1978.

I regret the long delay between the meeting and issue of this report. Clearly there has been considerable progress in many areas since then and some statements made in the report would be modified now. Nevertheless this is a useful record of progress in the principal areas of investigation as at the time of the May meeting.

Ernest Hodgkin

Ernest P. Hodgkin
RESEARCH CO-ORDINATOR

10 October, 1978

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SUPPLEMENTARY STUDIES

ESTUARINE AND MARINE ADVISORY COMMITTEE

Progress reports on the

PEEL-HARVEY ESTUARINE SYSTEM STUDY

Presented to a meeting on

11 May 1978

PRESENT:

Mr. B. Bowen, Chairman, EMAC
Dr. D. Hancock, EMAC
Dr. B. Logan, EMAC
Dr. W. Andrew, EMAC
Dr. E. Hodgkin, Research Co-ordinator, Estuarine Studies
Dr. R. Field, Secretary, EMAC
Mr. C. Murray, Department of Conservation and Environment
Dr. R. Chittleborough, Project Leader, Cockburn Sound Study
Dr. P. Birch, Department of Conservation and Environment
Dr. M. Mulcahy, Department of Conservation and Environment
Mr. V. Paparo, Department of Conservation and Environment
Mr. I. Parker, (In-Part), Department of Conservation and Environment
Prof. A. McComb, Botany Department, University of W.A.
Dr. D. Kidby, Soil Science and Plant Nutrition Department, University of W.A.
Mr. J. Gabrielson, Soil Science and Plant Nutrition Department, University of W.A.
Mr. R. Black, Physics Department, W.A.I.T.
Dr. R. Brown, Geology Department, University of W.A.
Prof. P. Young, Centre for Resource and Environmental Studies, Australian National University
Mr. R. Humphries, Centre for Resource and Environmental Studies, Australian National University
Mr. P. Sewell, CSIRO Division of Land Resource Management
Mr. D. Wallace, Public Works Department
Mr. R. Lenanton, Fisheries and Wildlife Department
Mr. J. Lane, Fisheries and Wildlife Department
Dr. A. Burbidge, Fisheries and Wildlife Department
Dr. H. Jones, Fisheries and Wildlife Department
Mr. H. Agnew, Associated Surveys
Miss T. Schwinghammer, Peel Inlet Management Authority

The Chairman, Mr. B.K. Bowen, opened the meeting and asked research workers involved in the Peel-Harvey Estuarine System Study to report on the progress of their studies.

Ray Brown Reported on the inventory of organic detritus and sediments of Peel Inlet undertaken in the Geological Department of the University of W.A.

The objective was to establish the nature of the sediments and their organic content at different levels in the sediments of Peel Inlet and make some comparison with Harvey Estuary.

Methods used were scanning electron microscopy and chemical analysis to quantify the carbon, nitrogen and phosphorous content of a number of cores (Fig. 1). N was determined as Kjeldahl N, and P photometrically as the phospho-molybdate complex.

The main Holocene sedimentological units studied in Peel Inlet were a central Basin Unit surrounded by a Marginal Sand Unit beneath both of which there is a basement of Pleistocene soil and dune rock. The thin upper member of the Basin Unit is predominantly silty, and the thicker lower member is a skeletal mud. The similar units in Harvey are elongate. The analytical work was based mainly on analyses from a few cores representative of the Basin Unit, Marginal Sands, the main Cladophora growth area, with a few in Harvey Estuary and Harvey channel. There is only a limited quantity of r·cognisable siliceous skeletal material, but this increases towards the upper levels. A detailed examination of this formed no part of the present survey and would require a special study in its own right.

The main thrust of the work related to C, N and P content of the cores and these were sampled at depth intervals dependent on the observed stratigraphy of the cores. The results are summarised in Tables 1-5.
Representative cores were illustrated showing in general slightly lower nutrient levels in the surface sediments of the Basin Unit (ignoring the top 1-2 cm) and fairly constant higher (but still low) levels through the rest of the Holocene sediments and generally dropping off abruptly at the bottom of them and in the Pleistocene soil where this was penetrated. Slightly higher levels were present in sediments of Point Grey sill, and Harvey Estuary, but Marginal Sand showed much lower nutrient levels. C/N ratios are similar in the Basin Units of both Peel and Harvey and increase in the lower members of these. N/P ratios do not vary significantly through the columns, but are higher in Harvey than in Peel.

In summary, organic content of Harvey sediments are rather higher than those of Peel, especially in the basin muds, they also have a rather higher N/P ratio. In Peel Inlet itself the organic content of the marginal sand is lower than that of the basin muds. In response to questions Brown said that, with the exception of surface sediments the top 2 cm of which were discarded all those examined could be prehistoric; also that there was no material available for reliable dating the upper sediment layers because of active mixing (bioturbation) by crabs etc. The whole Holocene sequence has an age of about 6400 years, since the Inlet was first flooded. The bulk of the sediments, apart from the flocculent decomposing algal mass, is characterised by being an inorganic detrital sediment with an organic admixture of 5-10%. There is no progressive decrease in organic content with depth and any degradation of organic matter must have taken place in the surface sediment layer or in the water mass.

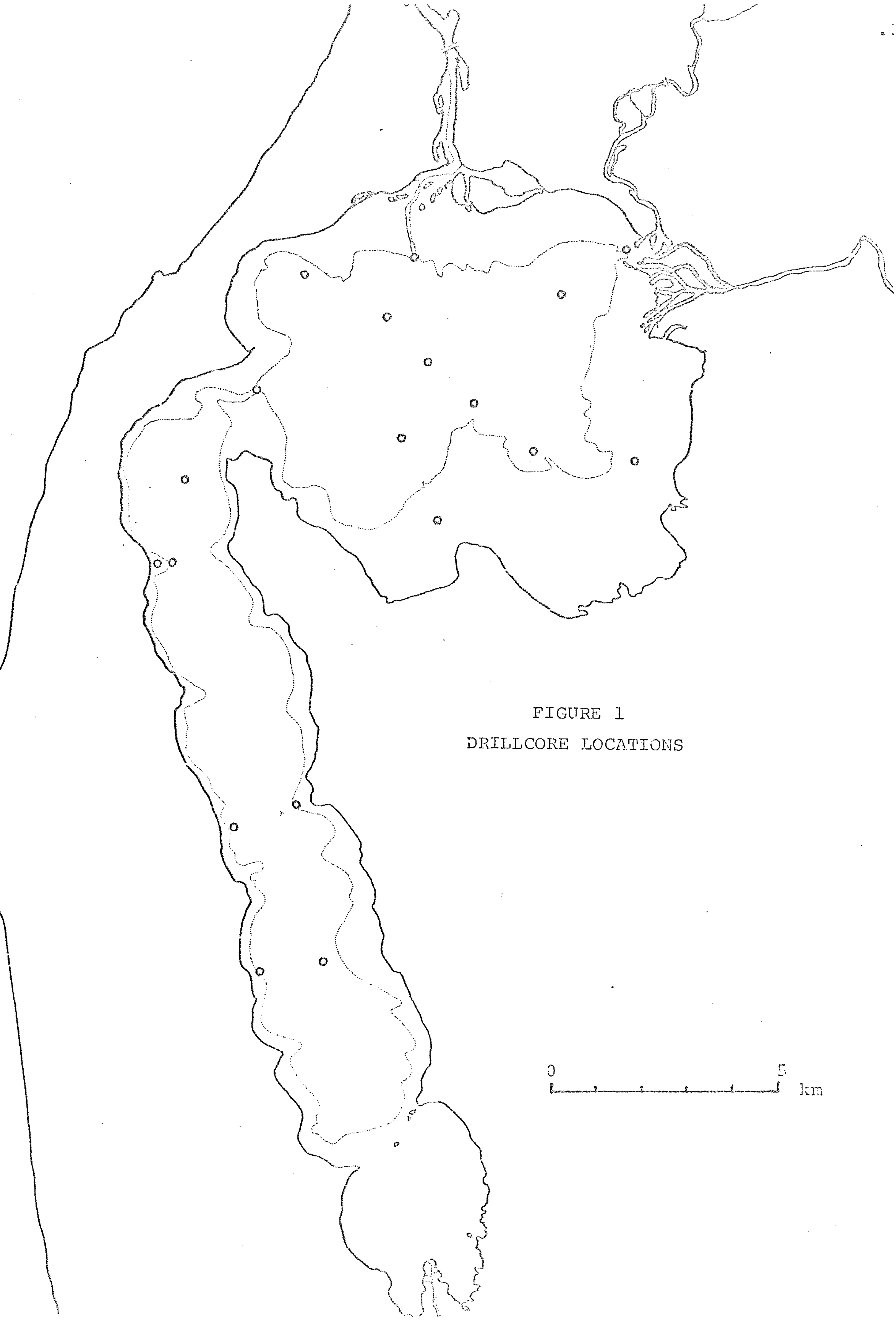


FIGURE 1
DRILLCORE LOCATIONS

TABLE 1 VERTICAL DISTRIBUTION OF ORGANIC CARBON IN PLATFORM AND BASIN SEDIMENTS

	n	C%	Std.Devn.
PEEL INLET			
Basin Sheet Upper Member			
Surface	15	1.05	0.34
Subsurface	7	0.97	0.33
Total	22	1.1	0.3
Basin Sheet Lower Member			
Top section	5	1.3	0.2
Mid section	17	1.9	0.2
Lower section	3	1.1	0.2
Marginal Sheet			
Surface	20	0.41	0.25
Subsurface	8	0.38	0.23
Total	28	0.4	0.2
POINT GREY SILL			
Top section	2	1.7	0.4
Mid section	9	2.3	0.1
Transition	3	1.7	0.1
Lower section	3	0.9	0.1
HARVEY ESTUARY			
Basin Sheet			
Top section	5	1.7	0.4
Mid section	5	2.6	0.4
Lower section	3	0.8	0.3

TABLE 2: COMPARISON OF ORGANIC CARBON CONTENT IN MAJOR UNITS AND REGIONS.

	PLATFORM (SANDS)	BASIN (MUDS)
Tidal Delta	1.0%	0.8%
Peel Inlet	0.4%	1.0% 1.7%
Point Grey Sill	0.3%	1.8%
Harvey Estuary	0.3%	2.2%

TABLE 3: COMPARATIVE VERTICAL DISTRIBUTION OF N AND P IN PEEL-HARVEY BASIN SHEET SEDIMENTS

	N					P				
	n	°/oo	Std.	C/N	Std.D	n	°/oo	Std.D	N/P	Std.D
PEEL INLET										
Upper Member	6	1.3	0.3	7.9	0.9	3	0.11	0.03	12.5	5.4
Lower Member										
Top section	8	1.3	0.2	10.5	1.5	1	0.13	-	10.7	-
Mid section	19	1.7	0.2	10.9	0.7	8	0.15	0.05	13.3	4.9
Lower section	3	0.5	0.1	15.8	-	-	-	-	-	-
POINT GREY SILL										
Lower Member										
Top section	2	1.8		9.3	0.1	2	0.13		14.0	
Mid section	9	2.1	0.1	10.9	0.4	2	0.16		13.5	
Transition	2	1.5		10.9	0.9	1	0.13		11.8	
Lower section	4	0.8	0.2	12.1	2.6	1	0.07		8.2	
HARVEY ESTUARY										
Top section	6	2.2	0.6	7.6	0.9	6	0.13	0.51	18.9	5.8
Mid section	7	2.1	0.6	11.3	2.3	4	0.12	0.01	20.3	5.9
Lower section	4	0.8	0.3	9.5	1.8	2	0.07		13.7	

TABLE 4: COMPARATIVE DISTRIBUTION OF N AND P IN MAIN PEEL-HARVEY SEDIMENT UNITS

	n	N °/oo	Std.D	C/N	Std.D	n	P °/oo	Std.D	N/P	Std.D
PEEL INLET										
Marginal Sheet	7	0.5	0.4	6.4	0.8	4	0.08	0.10	14.0	7.6
Basin Sheet Upper member	6	1.3	0.3	7.9	0.9	3	0.11	0.03	12.5	5.4
Basin Sheet Lower Member	23	1.6	0.3	11.1	1.4	9	0.15	0.05	13.0	4.0
Basin Sheet Whole Unit	29	1.5	0.3	9.9	3.4	12	0.14	0.04	12.9	4.6
HARVEY ESTUARY										
Marginal Sheet	10	0.1	0.1	7.1	0.6	2	0.01		17.0	4.2
Basin Sheet Upper	6	2.2	0.6	7.6	0.9	6	0.34	0.51	18.9	5.8
Basin Sheet Lower	11	1.6	0.8	10.7	2.3	6	0.10	0.03	18.1	5.9
Basin Sheet Whole Unit	17	1.8	0.8	9.5	2.4	12	0.12	0.05	18.5	5.6

TABLE 5: REGIONAL COMPARISON OF C, N & P IN MAJOR SEDIMENT UNITS

	n	C/N	Std.D	n	N/P	Std.D
MARGINAL SANDS						
Tidal Delta	5	7.0	0.5	3	9.8	2.1
Peel Inlet	7	6.4	0.8	4	14.0	7.6
Harvey Estuary	6	7.1	0.6	2	17.0	4.2
BASIN MUDS						
Tidal Delta	7	9.9	1.5	2	9.8	2.1
Peel Inlet	26	9.9	3.4	12	12.9	4.6
Pt. Grey Sill	17	11.0	1.4	6	12.5	2.5
Harvey Estuary	17	9.4	2.4	12	18.5	5.6

E.P.H. The following figures have been culled from the literature on Australian estuaries:

Rochford (1951) Surface samples	Organic C %	Total N $^o/oo$	Total P $^o/oo$
Georges River (NSW) average of 2 stations	4.5	3.5	0.6
Macleay River (NSW)	2	1.7	0.3
Swan River, average of 12 stations	2.6	2.9	0.53

Congdon (1977) records phosphate levels in surface sediments at various sites in the estuary of the Blackwood River which range from 57 - 865 µg/g dry weight (August) and 753 - 4953 µg/g d.w. (March). His figures for nutrients in core samples are shown overleaf (page 8).

Ron Black The hydrological and climatological picture of the estuarine system.
This study involved monitoring inputs to the system from rivers and drains and any groundwater input, also measurement of evaporative loss, in order to try to determine a water balance for the system. It did not, initially, involve study of the tidal flux.
A weather recording station has been operated at Robert Bay, a second self-recording rain gauge was installed near the south end of Harvey Estuary, and a third at Mandurah. Rainfall in 1976 and 1977 was of course well below average (Harvey gauge 545 mm in 1977, average 800-900 mm; Mandurah only about half the normal).

The data presented (Figs. 2-7) refer to 1976 because river flow data for 1977 is not yet available, however flows in the drains showed a remarkably similar pattern in the two years. From local information it seems probable that the Mayfield's drain, the largest, flows at not more than a mean of 0.2 m^3/sec throughout a normal winter. There was no measurable flow after November in 1976 or 1977 and this pattern continues through the summer and autumn until at least late May.

Flow in Harvey River shows a different pattern because it drains an irrigated area. It continued with a mean flow of up to about 0.5 m^3/sec through summer, unlike the Murray River which ceased to flow. In these very dry years flow in the Harvey River has been almost one third that of the Murray River, despite its much smaller catchment. Because the Harvey catchment is severely truncated by the Harvey weir, maximum flows in the River may last only a few hours. Sampling on a weekly basis may therefore result in a somewhat misleading graph. A continuously recording water level gauge has recently been installed and will give a more reliable picture.

Water samples have been taken regularly from the drains and rivers for analysis for N and P (in the Botany Department) - when there has been a gaugeable flow. Despite the high nutrient levels in the Harvey River, and in the drains, this is of course a much smaller total contribution than that from the Murray River, especially in an average or wet winter.

Chemical analyses of sediments - from Congdon 1977

Table 2.12: Chemical analysis of sediments with depth
(South of Molloy Isd - May 1975)

	Depth (cm)		
	0-30	30-60	60-90
Interstitial P	92[1]	83	61
Adsorbed P	41	91	191
Total P	565	356	697
Organic N	262	268	122
Loss on ignition	2.2%	2.2%	2.4%

Table 2.13: Chemical analysis of sediments with depth
(South of Molloy Isd - July 1975)

	Depth (cm)				
	0-9	9-17	17-25	25-33	33-42
Interstitial P	24.5[1]	14.6	3.9	3.5	13.0
Adsorbed P	29.6	110.0	101.1	36.8	87.3
Total P	1841	1610	1654	1648	1579
Organic N	1000	620	1590	600	960
Loss on ignition	27.0%	27.6%	31.1%	22.3%	26.2%

Table 2.14 Chemical analysis of sediments with depth
(Swan Lake - September 1975)

	Depth (cm)				
	0-15	15-30	30-45	45-60	60-75
Interstitial P	16.1[1]	14.2	21.3	13.9	17.3
Adsorbed P	59.2	132.5	169.6	108.1	125.2
Total P	905	2160	3356	2338	3085
Organic N	267	1088	1217	898	710
Loss on ignition	2.5%	11.0%	11.6%	10.5%	9.6%

[1] Values are the means for four separate cores: all nutrient data are expressed as µg/g dry weight.

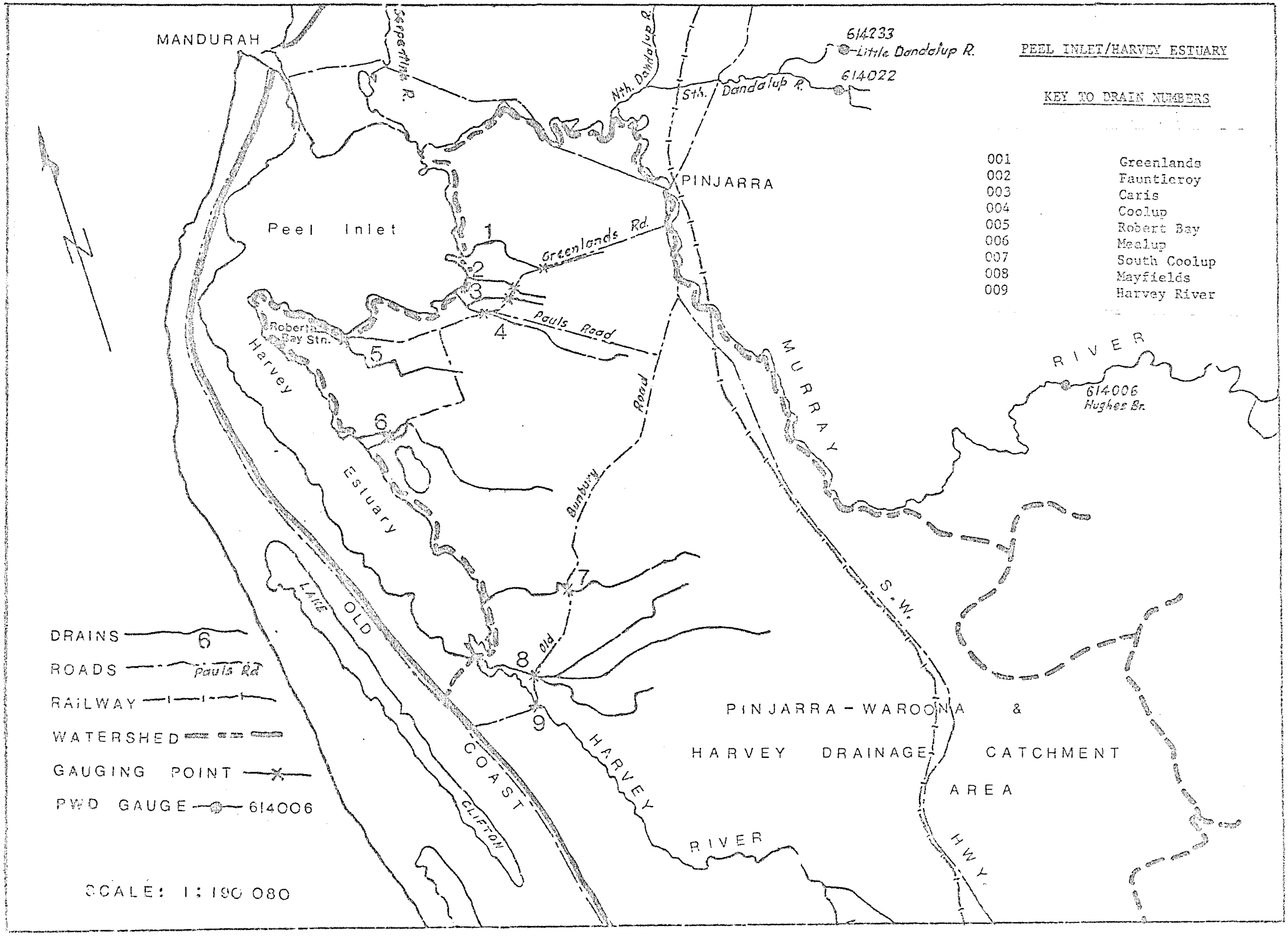
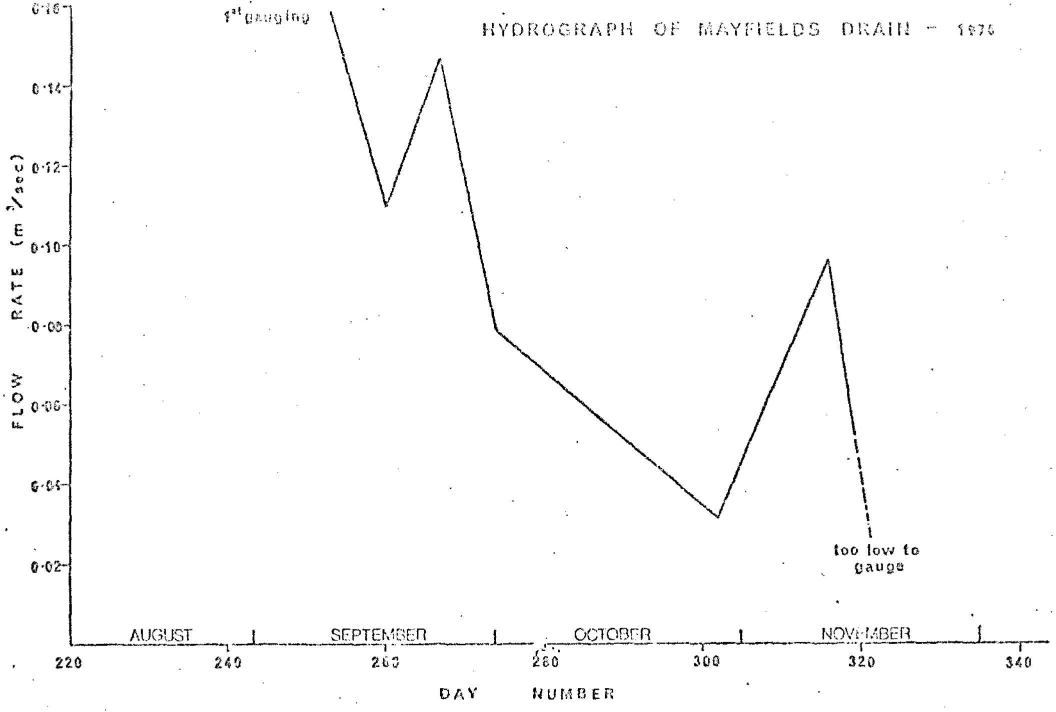
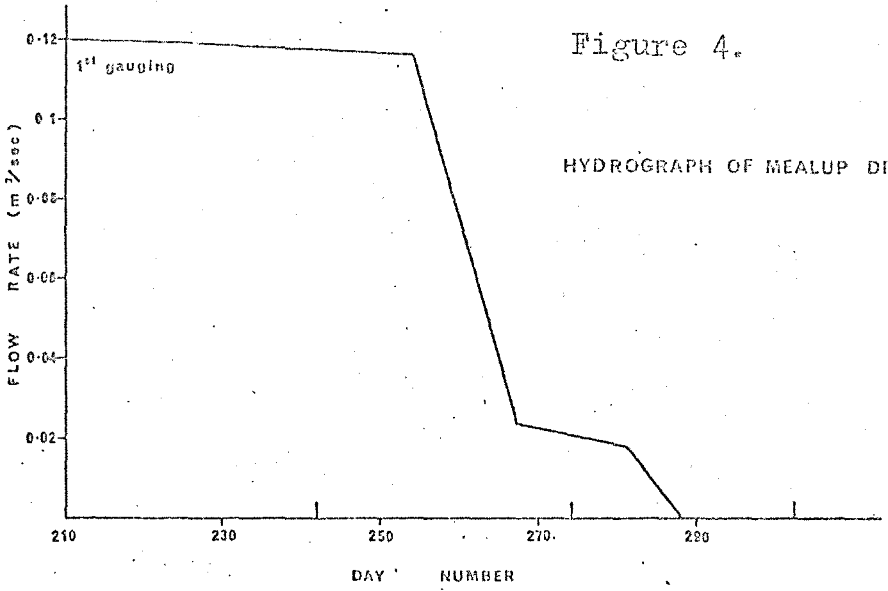

PEEL INLET/HARVEY ESTUARY
KEY TO DRAIN NUMBERS
001 Greenlands
002 Fauntleroy
003 Caris
004 Coolup
005 Robert Bay
006 Mealup
007 South Coolup
008 Mayfields
009 Harvey River
MANDURAH
Serpentine R.
Nth. Dandalup R.
Sth. Dandalup R.
614233
Little Dandalup R.
614022
PINJARRA
Peel Inlet
Greenlands Rd.
Pauls Road
Roberts Bay Stn.
Harvey Estuary
1
2
3
4
5
6
7
8
9
Road
Bunbury
Old
MURRAY RIVER
614006
Hughes Br.
S.W. HWY.
PINJARRA - WAROONA & HARVEY DRAINAGE CATCHMENT AREA
HARVEY RIVER
LAKE CLIFTON
OLD COAST
N
DRAINS 6
ROADS Pauls Rd
RAILWAY
WATERSHED
GAUGING POINT
PWD GAUGE 614006
SCALE: 1:190 080

FIGURE 2



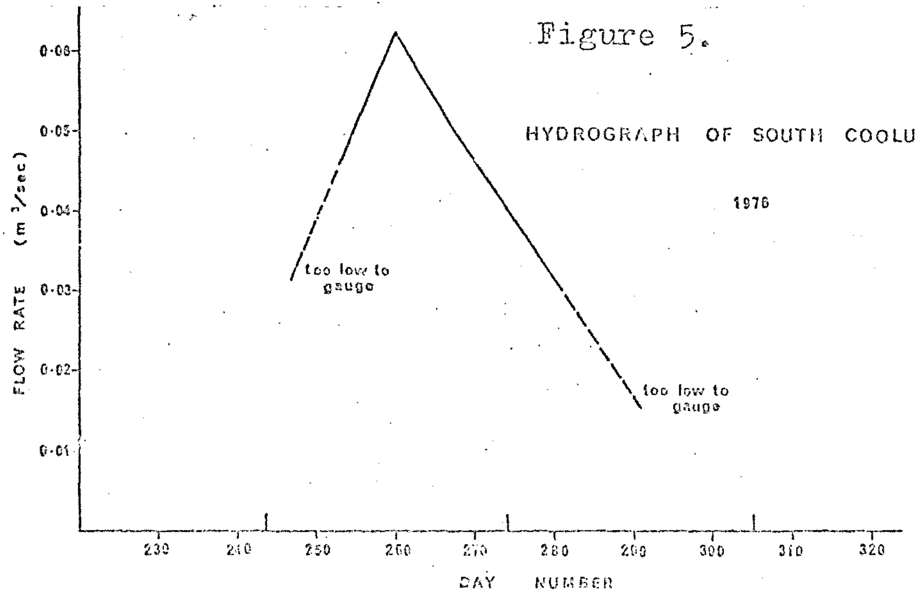
HYDROGRAPH OF MAYFIELDS DRAIN - 1976

Figure 4.



HYDROGRAPH OF MEALUP DRAIN - 1976

Figure 5.



HYDROGRAPH OF SOUTH COOLUP DRAIN

1976

Figure 6.

HYDROGRAPH OF HARVEY RIVER -- 1976

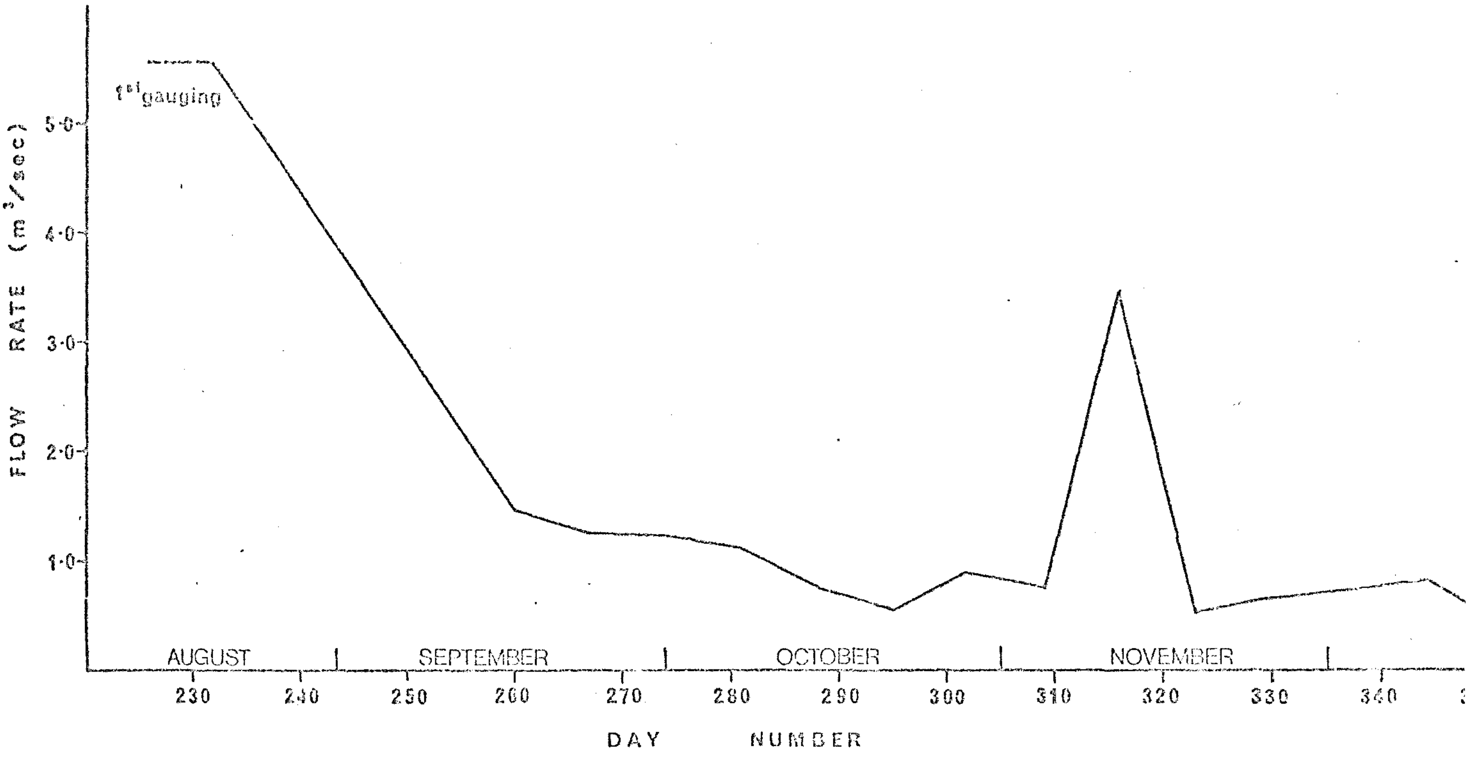
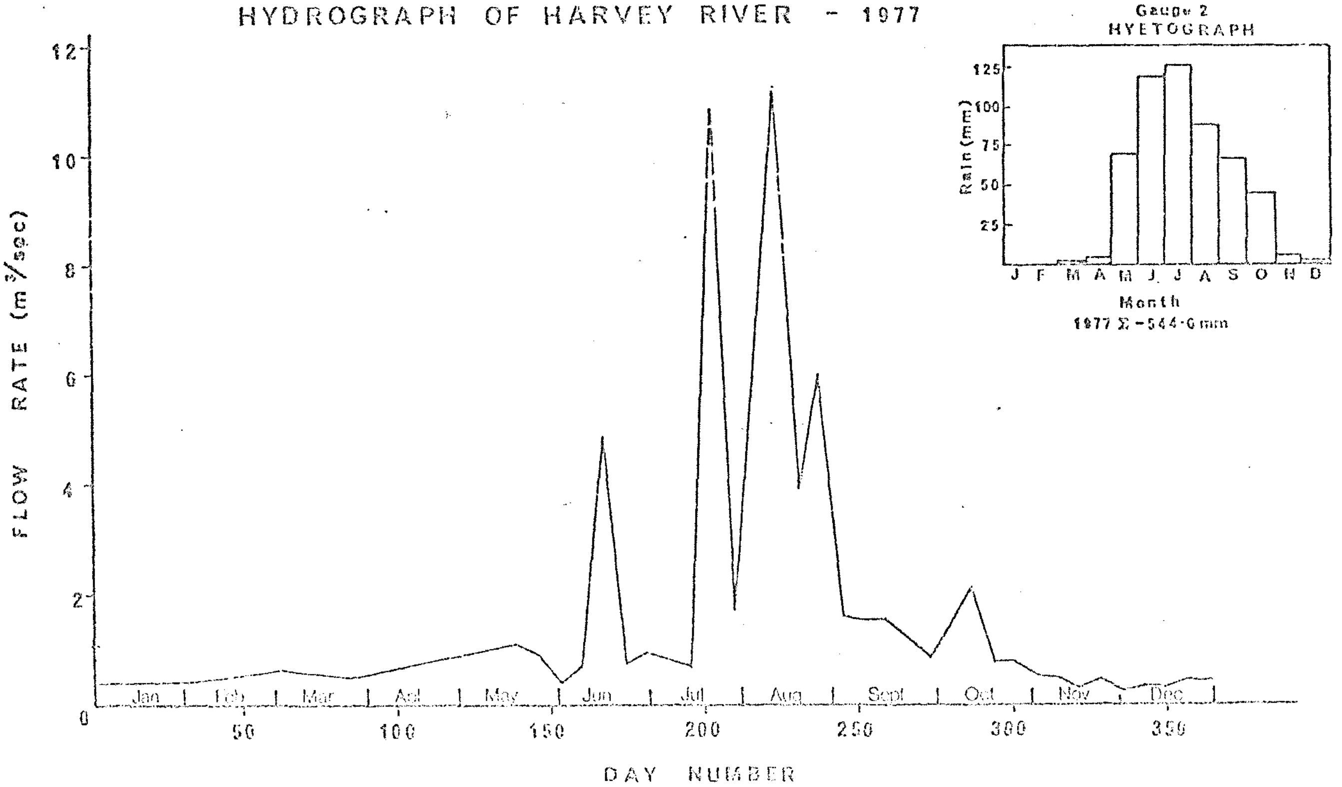


Figure 7.

HYDROGRAPH OF HARVEY RIVER - 1977



An important part of the programme has been estimation of groundwater flow. In January 1977, about 130 wells and bores on the coastal plain east of Peel and Harvey Inlets were accurately levelled to Australian height datum. Water levels in them were then taken over a very short period of time. On two east-west transects this was done over a period of an hour or so, in January and July 1977. The observed hydraulic gradient was about 1 in 1000. In order to estimate flow it was also necessary to know the hydraulic conductivity of the sediments and the depth of the Quaternary sediments and figures for these were obtained in consultation with Mr. Tony Allen of the Geological Survey.

With this data, groundwater flow was estimated by the D'Arcy Equation:

$$Q = KAS$$

Where Q = Flow (m^3/sec)

K = Hydraulic conductivity (m^3/day/m^2)

A = Area (m^2)

S = Hydraulic gradient

Data

(i) S. From January 1977 survey of bore holes and wells,

$$\text{Average } S = 1 \text{ in } 1000$$
$$= 0.001$$

(ii) A. Depth of Quaternary sediments $\approx$ 10 m (GSWA logs)

(iii) K. $K \approx 5\ m^3/\text{day}/m^2$.

From Which

$$Q \approx 2000\ m^3/\text{day} \text{ (from North East/East shore)}$$

This is a very small percentage of flow to the estuary, probably never more than 1% of the total.

Evaporation cannot be measured directly from such a large water surface and evaporation, as measured from a standard pan, has to be related to this by means of a "pan factor". There is no universal agreement as to the magnitude of this pan factor which varies from about 0.65 to 0.85 depending on location. An appropriate pan factor for Peel Inlet was estimated by making an energy balance study in which net radiation over the Inlet was measured in summer and winter and used to compute evaporation, which was compared with the actual pan evaporation. With this data monthly evaporation can be estimated reasonably accurately, but not usefully for shorter time periods. In order to attempt to verify the evaporation estimates it is necessary to use the continuous records of rainfall, temperature and humidity and apply these to a range of empirical formulae. (Figs. 8-10). It will be noted that there are considerable differences between the three rainfall records, with Mandurah being much the lowest.

Figure 8.

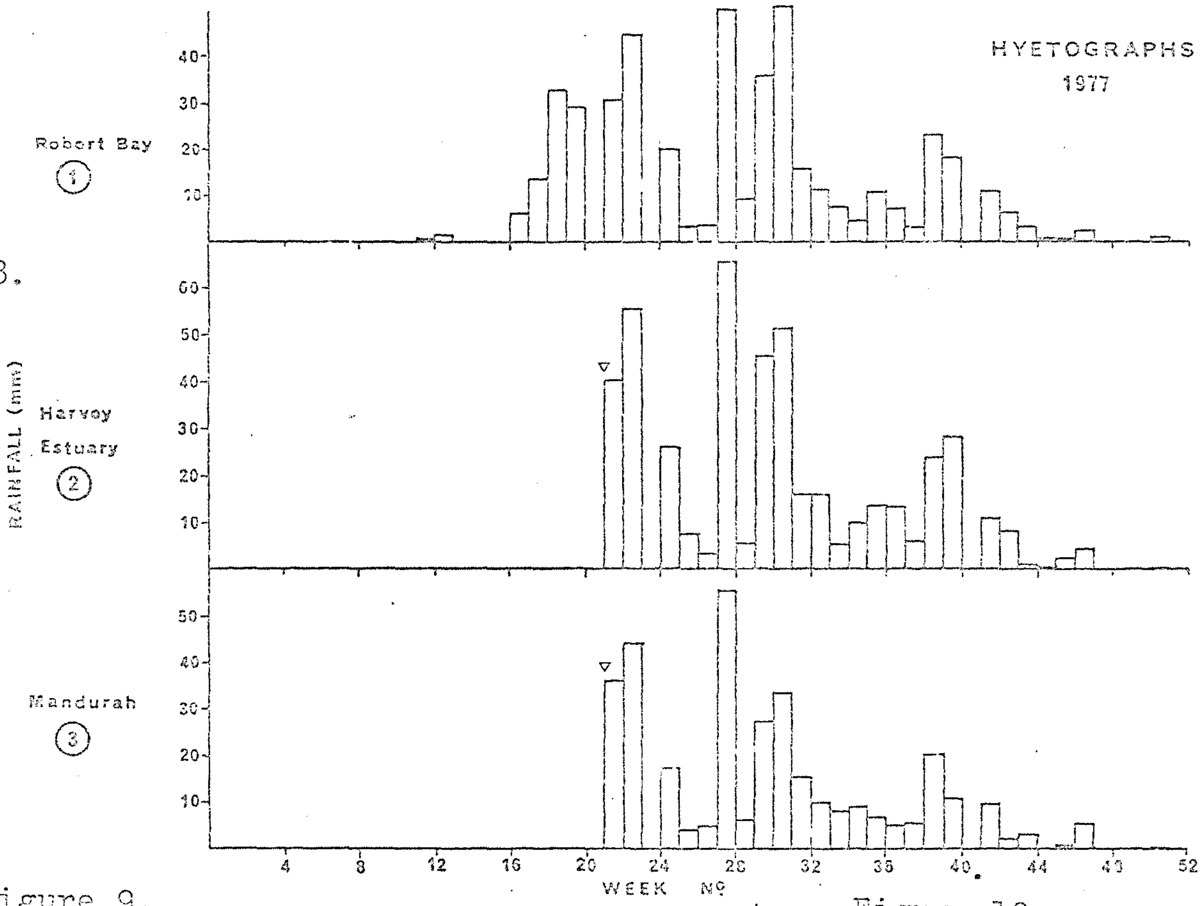


Figure 9.

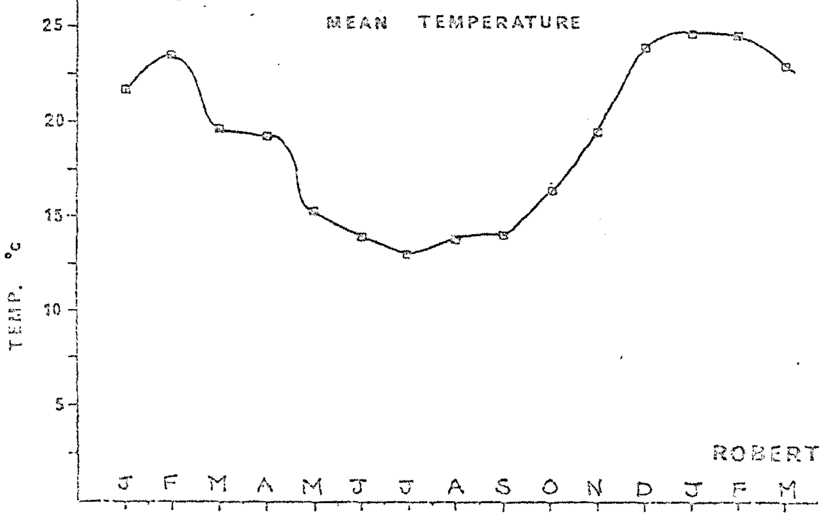
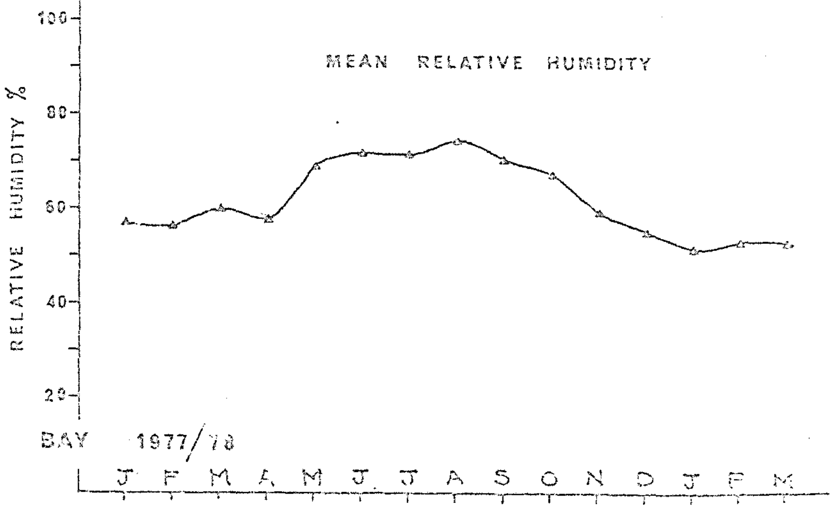


Figure 10.



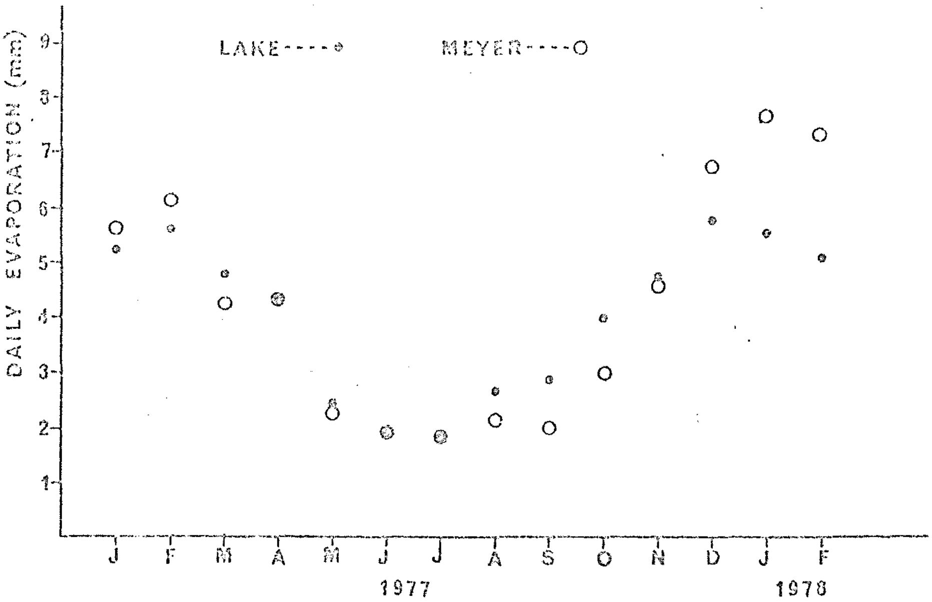
The continuously high temperatures of January-March (and April) 1978 should be noted. These sort of events have a dramatic effect on any method used to estimating evaporation. A great variety of methods have been used for such estimations and one, Meyer's vapour flow method, has been used for comparison with the results obtained using evaporation pan data and the pan factor of 0.8 which has been adopted - Figure 11.

Figure 11: Mean daily evaporation Robert Bay.

Total 1977:

Lake 1410 mm,

Meyer 1358 mm.



The greatest divergence between the two comes during the three hot months December 1977 - February 1978, when there may have been a great difference between the air temperatures used for the computation, and the water temperature.

Reverting to estimation of flow to the estuary, Black noted that the long term median annual flow in the Murray River is $327 \times 10^6 m^3$, from a catchment of 7000 km^2, however this represents only 7.3% of the rain falling on the catchment - the rest is absorbed into the ground. In 1976 rainfall was about half the average and river flow in the Murray only one quarter of the median flow ($87 \times 10^6 m^3$). In this situation rain falling directly on the basins ($500 mm \times 135 km^2 = 67 \times 10^6 m^3$) forms a large proportion of the freshwater input to the system.

Estimation of the Murray River flow to the estuary still needs further refinement, from the point of view of nutrient input. The river is gauged at Hughes Bridge and although gauged flow in the N and S Dandalup Rivers and Marrinup Brook are added, the gauging points are still a long way from the estuary. In particular the data does not show adequately what happens under high flow conditions. It is therefore planned to add dye to the river upstream of Pinjarra on three occasions (low, medium and high flow conditions) and monitor flow of the dye over the weir; together with the water level. It should then be possible to make a comparison between flow at Hughes Bridge and at Pinjarra thus giving a much better estimate of actual flow to the estuary.

ESTIMATED
WATER BALANCE OF THE PEEL INLET/HARVEY ESTUARY 1976

ON THE ASSUMPTION THAT OVER A 12 MONTH PERIOD, THE NET TIDAL EXCHANGE WILL BE ZERO (WHICH MAY NOT BE EXACTLY SO), THE FOLLOWING ARE THE SYSTEM INPUTS/OUTPUTS:*

INPUT			OUTPUT	
RIVER FLOW	(MURRAY	3.2	EVAPORATION (NET LAKE) (BASED ON ANNUAL PAN FACTOR OF 0.8 - NEEDS SEVERAL YEARS' DATA FOR VERIFICATION)	6.3
	(SERPENTINE	0.2		
	(HARVEY**	1.0		
DRAIN FLOW	(MAYFIELDS	0.03		
	(MEALUP	0.03		
	(SOUTH COOLUP	0.01		
	(ALL OTHER	0.01		
PRECIPITATION ON INLET		2.0		
GROUNDWATER (EASTERN SHORELINE UNCONFINED)		0.02		
		Σ = 6.5		Σ = 6.3

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* UNITS ARE RELATIVE DERIVED AS MEAN VALUES FROM MONTHLY YIELDS.

** ESTIMATED FROM WEEKLY GAUGINGS AND THUS LIKELY TO OVER ESTIMATE SHORT TERM PEAK FLOWS.

NOTES:

1. POSSIBLE OMISSIONS
   - (I) OTHER GROUNDWATER (NORTHERN AND WESTERN)
   - (II) SEEPAGE LOSSES
2. CALCULATIONS ARE BASED UPON COMPOSITE 1976 AND TRANSPOSED 1977 DATA. MURRAY, SERPENTINE, ETC. FLOWS NOT YET AVAILABLE FROM PWD FOR ALL OF 1977.
3. THIS SUMMARY SHOULD THEREFORE ONLY BE CONSIDERED AS A STATEMENT OF THE RELATIVE CONTRIBUTIONS OF VARIOUS COMPONENTS AT THIS STAGE.

The Serpentine River presents a more difficult problem because the gauge is at the falls and because the river also responds to releases from the dam. PWD now has monthly gaugings on the river below the dam and recently made a study of flow in tributaries on the coastal plain. The last unknown is of course exchange with the sea and this is considered later.
In discussion it was pointed out that direct nutrient input with rainwater is not being estimated.
However, it is only in a dry year that rain forms a large part of the freshwater and nutrient input and while the volume of flow in Harvey River in a wet winter is only twice that in a dry (a 2:1 ratio) the ratio in the Murray River is 50:3 for the period of record to date.

Hugh Agnew The fluid mechanics of Peel Inlet.

The aim of this, as of other physical studies of the system is to provide an understanding of physical aspects of the estuary which are important in quantifying the nutrient balance. Also, as in the Blackwood study we wish to have a general understanding of the mechanics of the water body.

In particular we need to understand:

1. What are the physical forcing inputs to the water body : rainfall, river run-off, water level variations?

2. What are the time and length scales of these?

3. What are the transport and exchange efficiences of the dominant mechanisms which are forcing the water body of the Peel Inlet?

4. How do these vary throughout the year and what are the extremes from year to year?

5. On the basis of the available synoptic data, can we then hindcast what the condition of the estuary would have been in previous years? In particular, we need to know to what extent is it flushed in winter under the different rainfall conditions which have been experienced. Hopefully this should show us how the physical factors mesh in with biological aspects of the estuarine environment, for example dynamics of the crab populations.

In the Peel Inlet Study the methods being used to answer these questions are by means of: (a) the intensive investigations of October, February, and a forthcoming winter one; followed in each case by careful analysis of the results, and (b) continuing monitoring programmes, with periodical re-evaluation of the nature of the data being collected. The dominant time scale is the season and investigations, continued over one or at most two seasons should provide 90% of the information required.

The aims of the summer (February) dye-release experiment were to determine:

a) What are the physical forcing inputs to the water body?

b) What are the times and length scales of these?

c) What is the transport and exchange efficiency of the dominant mechanisms during the summer period?

d) For what period of the year do the observed conditions characterize the dynamics of the system?

If we can split the year into distinguishable seasons, depending on what the various mechanisms are, we can make our sampling more efficient by doing it in the characteristic seasons and not duplicating unnecessarily.

During the week 12-18 February inputs to the Inlet were measured by - (a) flow in the Mandurah channel (Ron Black's current metering) and, (b) changes in water level (Don Wallace's tide recorders), together with atmospheric inputs (Ron Black's weather records). Water velocity and dispersion was measured by dye (fluorescein) releases at points in Peel Inlet, tracked throughout daylight over 5 days. Salinity and temperature data also gave some feel for what was happening at night.

Preliminary conclusions as to the dynamics of the estuary under summer conditions are as follows.

1. Mechanisms

a) Water velocity and exchange in the Inlet is dominated by water level variation and associated conservation conditions.

b) Wind: on the scale of the normal easterly - sea breeze cycle, this has little effect on water movement, but it does supply energy for vertical mixing and some horizontal dispersion (to a maximum of 1 km).

c) Salinity is determined by the balance between exchange and evaporation.

2. Scales

a) Water level variations, which are the dominant input to the water body, are associated with two time scales:

Diurnal, astronomical tides of small amplitude;
7-10 days, induced by variations in barometric pressure.

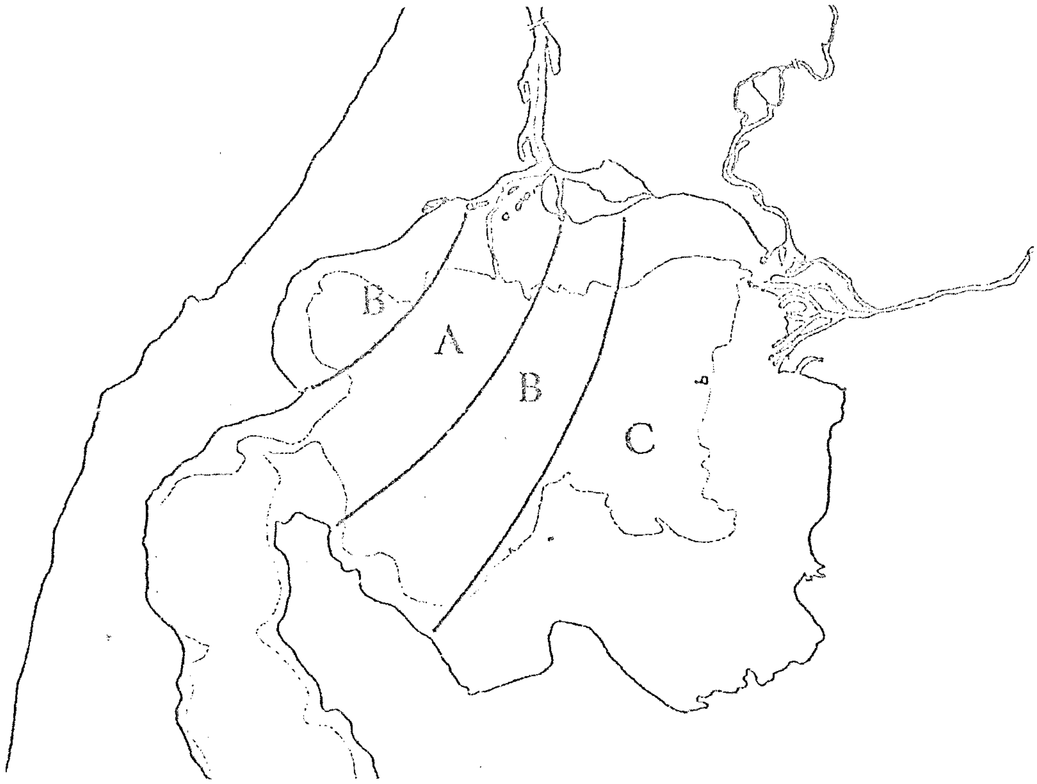
b) The shorter scale may be important for induced water velocities, but the longer period variation dominates the exchange. The horizontal length scales associated with these changes depend on the size of the variations but are typically 5 km.

c) Wind induced dispersion is limited to horizontal scales of the order of 1 km and is on a diurnal time scale.

3. Exchange, in Peel Inlet

In general terms three regions can be recognised (Fig. 12)

Figure 12: Estimated exchange times in Peel Inlet (Agnew)



Region A, the direct exchange region, contains the volume of water which is directly involved in exchanges that result from variation in water level. The residence time of this water is of the order of one week; the water being exchanged either with the sea or with Harvey Estuary on this time scale. This conclusion is well supported both by the dye tracking and the salinity profiles.

Region B in the immediate proximity of region A is mixed both by currents induced in that region and by wind dispersion. The residence time here would be greater than a week, but not more than a month.

Region C is remote from the direct exchange region and water is moved around slowly by the water level variations and stirred by wind stress. The residence time of the water here is estimated at between one month and 6 weeks; based mainly on observed salinities and evaporation rate, at the time of the experiment (max. S in Austin Bay 48 $^{0}/oo$)

Characterising the summer condition then this regime will persist while freshwater run-off is much less than either volume fluxes induced by water level variation or evaporation (or direct rainfall).

In conclusion, Agnew discussed recommendations for future studies. Similar short term studies need to be undertaken, certainly in winter and possibly under intermediate conditions.

He did not think the winter experiment should be done at a time of maximum run-off, rather under more typical winter run-off conditions. On the basis of experience in the Blackwood Estuary Study more is likely to be learnt then. During August 1974 river run-off completely flushes the Blackwood estuary, making it fresh throughout.

The available salinity data indicate that even in the wettest winter Peel Inlet is not completely flushed (though Harvey Estuary is). Under maximum river flow conditions the volume of flow may of course be great enough to prevent ingress of sea water for a short time. What prospect have we of seeing this in 1978?

We need to know the relationship between volume of river flow and the other forcing factors - evaporation, astronomical tide, and barometric water level variation - under all river run-off conditions.

Continuing studies, which are being undertaken and are essential to the investigation should be:

a) Development of a water level (volume) - barometric pressure model. This should make it possible to determine the volume of exchange with the sea from the barometric record.

b) A run-off - rainfall model, rainfall being the easier to measure.

c) Investigation of the relationship between salinity and water level variations through the established summer periods only to verify the proposition that exchange is dominated by longer period water level variations.

This last point has been emphasised by the observed decrease in salinity in Peel Inlet since the February exercise, during which period the greater variations in barometric pressure (not only Cyclone Alby) have probably exchanged a volume comparable with the whole volume of the estuary with the sea. Agnew emphasised that this was still a time when the mechanics of the summer condition operated.

Arthur McComb. The biology of the estuary and especially of *Cladophora*.

In opening, McComb noted that much of the effort of the Botany group involved nutrient analyses on samples collected by Birch and Black, the results of which are supplied to CRES for the modelling programme. Most of the analyses are up to date, and, with new equipment and casual assistance, the backlog of analyses for total N and total P is being overtaken. There has not been time yet to assess the CRES plots and their correlation matrices and a meaningfull interpretation must wait until the winter data is available.

The biology of *Cladophora* is being studied by David Gordon, and an Honours student is now studying the phytoplankton (Rod Lukatelich) and another the rooted benthic plants (Steven Carstairs).

The biology of *Cladophora* is intractable.

a) because the plants do not stay in one place,

b) because the alga does not go through a complete life cycle each year - the population is not lost and replaced,

c) its distribution in space and time is not obviously related to any particular environmental parameter.

Two species are present in the estuary and these have been provisionally identified as *Cladophora* aff. *nitidula* and *Cladophora* aff. *battersii*. *C.* aff. *nitidula* is an uncommon, large, diffuse, light green, branching, attached species found in the shallows, and also in the Swan estuary. *Cladophora* aff. *battersii* is the dominant species in Peel Inlet (it is not identical with *glomerata* of Europe or *prolifera* of Bermuda, both of which are "nuisance" species similar in general behaviour to the *Cladophora* of Peel Inlet).

The classical life history of *Cladophora* involves motile spore stages which settle and develop as germlings on the substratum, to which they are attached by rhizoids. The plants may subsequently become detached and float around, growing vegetatively. So far attached stages appear rare and not of importance in the estuary. Motile algal spores are common, but so far none has been definitively associated with *Cladophora*, nor have specialised sporangia which produce the spores been observed.

In the literature, Hoek (1963) refers to *C.battersii* as a species for which no life cycle has been described and he speculates that multiplication is most probably by thallus fragmentation. In Peel Inlet *Cladophora* grows as a perennial species and recrutiment to the population does not seem to be dependent on spore formation. Plant fragments can readily be grown in sterile culture; they grow actively and form algal masses similar to those present in the estuary.

After the February dye study an extensive sampling programme was undertaken at 36 sites in the estuary (both Peel and Harvey) for various parameters: chlorophyll, salinity, dissolved and particulate yellow material, turbidity, NH_4-N, PO_4-P, NO_3-N for both ooze and sediment; *Cladophora* biomass, bare sand (% cover), *Halophila ovalis*, *Ruppia maritima*, *Chaetomorpha*, Rhodophyta. Not all the data have yet been processed. Certain correlations can be seen, but at this stage it is not possible to say which are causally related. Examples are shown in Table 6, but samples have not yet been processed for total N and total P.

Considerably higher levels of both phytoplankton (chlorophyll a) and of particulate matter (other than phytoplankton) were observed in Harvey than in Peel.

Observations on *Cladophora* biomass and percentage cover (bare sand) showed concentrations of the alga in NE and SE parts of Peel Inlet and smaller quantities in Falcon Bay. *Cladophora* was only found in quantity at the extreme northern end of Harvey Estuary. The rooted plant *Halophila* was widespread, but was only abundant at sampling stations in shallows at the northern end of Harvey Estuary, and *Ruppia* was only common at two shallow water stations in Peel Inlet. The filamentous green alga *Chaetomorpha* was less abundant than anticipated. Maps illustrating the distributions were displayed and will be available when analysis of the results has been completed.

The data on plant distribution will be used for correlations with nutrient and other concentrations (as above), for mapping with the aid of air photographs, and comparison and amalgamation with observations on percentage cover obtained by Humphries in the February exercise.

Changes taking place at individual sites have been observed regularly since mid 1976. At beacon 46 there was a massive build up of algal populations in late 1976, which is believed to be attributable to growth (Fig. 13). This was reflected in an increase in both P and N in the algal mass. Total P and N were at very low levels in the water, but as much higher levels of N and P were found in the sediments it had been suggested that these may be an important source of nutrients for algal growth (Atkins et al, 1977). The massive spring increase in algal growth has not been repeated, and biomass has remained at a high level.

Of the correlations observed (Table 7) it will be noted that there is a significant negative correlation between algal biomass and NH_4-N (possibly because the alga mops up the ammonia as it is released from the sediment), a positive correlation with temperature (largely attributable to the dramatic increase in alga in 1976), and a negative correlation with PO_4-P. No significant correlation has yet been found with wind speed and direction, despite the drop in algal biomass early in 1977 at a time when there was a considerable increase in alga accumulating on the beach (weed clearing data).

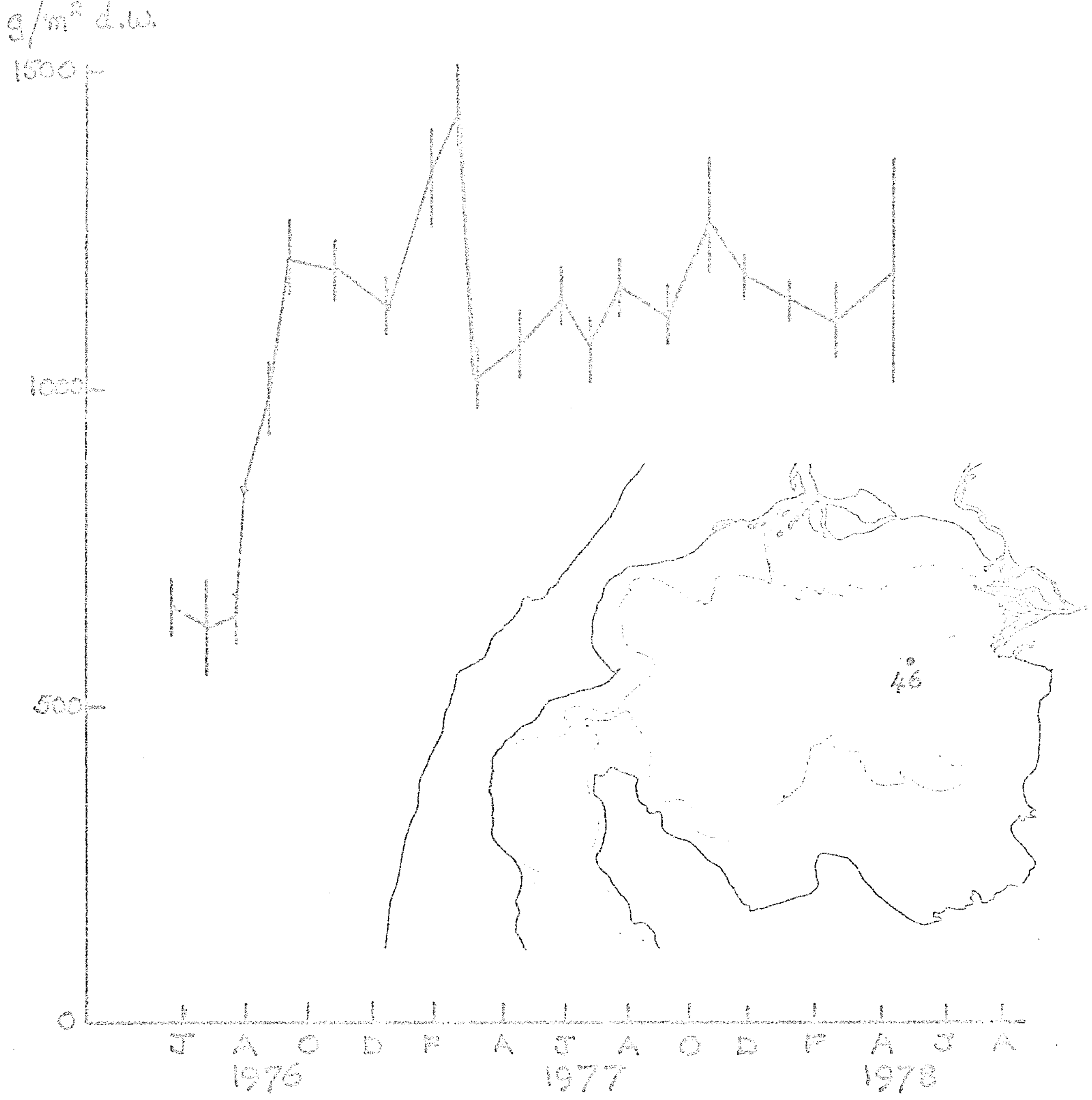


FIGURE 13 *Cladophora* biomass at post 46.

TABLE 6

Correlations, between percentage cover and various parameters during the February survey.

	R	P
Ooze		
Loss on Ignition	.359	.094
NH_4N	.308	.165
PO_4P	.232	.203
NO_3N	.056	.421
Sediment		
Loss on Ignition	.432	.037
NH_4N	.361	.078
PO_4P	.287	.132
NO_3N	.148	.280
Turbidity	.350	.158
Depth	.207	.205

TABLE 7

Correlations between *Cladophora* biomass and various parameters at beacon 46. Data were obtained monthly over the period June 1976-May 1978.

	R	P
NH_4N	-.528	.012
Temp	.479	.019
PO_4P	-.435	.036
Salinity	.376	.056
Wind 7^d	.371	.087
NO_3N	-.292	.113
Wind 28^d	.265	.170
Wind 7^d max	.201	.236
Wind 1^d max	.191	.248
Tot N	-.167	.254
Tot P	-.089	.363
Org P	-.066	.398

In situ algal growth has been measured from the increase in weight of *Cladophora* held in perforated perspex flasks. The average growth in flasks placed on the surface of the algal mass has been 30-40%, up to 50%, over 4 week periods. In contrast, the algal biomass sampled nearby remained static over the same period. The discrepancy between these observations therefore needs to be explained.

There are several possible explanations.

1. Transport by wind - generated waves seems unlikely because observations show only an oscilatory movement of the algal biomass, except under such extreme conditions as those of cyclone Alby when turbulence was observed.

2. Oxygen bubbles produced during photosynthetic activity can cause algal balls to float to the surface and this has been observed in both field and laboratory. Wind moves these floating balls across the water surface and they can accumulate in the shallows, as happened with floating oranges used by Peter Birch and drifters used in the February experiments.

3. Grazing, by amphipods or crabs may also be an important factor.

4. Decomposition on the spot.

Whatever the mechanism there remains the implication that the available nutrients are being continuously depleted, from the sediments beneath *Cladophora* beds. One possible source of replenishment which has not so far been investigated could be the input of particulate material from the water column. This question needs to be followed up during the period of winter river flow.

Water analyses for 4 months summer period (Dec. - April 77-78) at beacon 46 are shown in Table 8A.

Nutrient levels in filtered water from within the algal mass, "interalgal water", for the same 4-month period are shown in Table 8B.

Nutrient levels, especially of phosphate, in interalgal water are thus considerably higher than in the overlying water, as shown by the ratios in Table 8C.

This data emphasises the importance of decomposition processes in the production of nutrients from the 'sediments' (and especially the black ooze which overlies the sediments proper, as studied in the geological analyses of sediments.)

Laboratory experiments have also been made in which algal populations were spiked with known levels of P and N and a mixture of vitamins, trace elements, etc. Growth may have been light limited and the experiments are now being repeated.

TABLE [illegible]. Plant nutrients at Beacon 40, Reef Inlet

A. In the water body

	PO_4-P	Other Phosphorous	
		Soluble	particulate
µg l^{-1}	5.5	26.2	26.4
%	9	45	45

	NH_4-N	NO_3-N	Organic Nitrogen	
			Soluble	particulate
µg l^{-1}	31.6	2.4	1212	309
%	2	0.002	78	20

B. In interalgal water

	Phosphorous		Nitrogen		
	PO_4-P	Other P	NH_4-N	NO_3-N	organic N
µg l^{-1}	101	44	149	7	1992
%	70	30	7	0.3	92.7

C. Interalgal : overlying water ratios

	Interalgal water µg l^{-1}	Overlying water µg l^{-1}	Ratio
PO_4-P	101	5	20:1
Other P	44	53	0.8:1
Total P	145	58	2.5:1
NH_4-N	149	32	4.7:1
NO_3-N	7	3	2.3:1
Organic N	1992	1521	1.3:1
Total N	2148	1556	1.4:1

Recent experiments on productivity at different light intensities have shown that even at the surface of an algal bed in about 2 m water light is only just adequate for maintenance of the alga; it is light limited. Within an algal mass, photosynthesis was found to equal respiration (the compensation point) at a depth of about 2 cm. Below that level there can be no net growth and therefore in a bed of living alga of say 10 cm thickness biomass may well remain static. It is suggested that this stage may have been reached at the beacon 46 site. If the excess algal is scoured away, leaving a layer where there is net production, the biomass may build up again.

In summary: there appears to be a layer of about 2 cm of alga in which there is net growth, beneath this another 10 cm of living alga may accumulate but not grow, and below this again the alga has exhausted its carbon reserves and can no longer survive. This decomposes to the black ooze which builds up as the upper layers increase. In this situation the algal bed is not nutrient limited. Algae will float off and drift away to other areas of the estuary where (in the absence of algae and ooze) nutrient levels are low. Nutrient depletion has been observed in such algae (Atkins et al 1977).

Peter Birch presented a revised table of estimates of N and P loadings to Peel Inlet (Table 9) following criticism of his earlier estimates by Peter Sewell. These are from the Murray River, because this river supplies the main input from surface runoff. Flow data are not yet available for 1977, and therefore the extensive nutrient data obtained during the present study could not be used. Albuminoid - N + NH_4 - N is somewhat less than the total N now being measured. Also the data are only from quarterly sampling.

From the table it will be noted that variation in river flow (greatest to least) was nearly 10:1 and in nutrient concentration about 5:2. The higher concentrations, particularly of phosphorous, were in years of greatest flow so that nutrient loads to the estuary varied by more than an order of magnitude. In wet years, 1974 especially, the nutrient input was high potentially supplying a large part of the nutrient requirements of the macrophytes, particuarly *Cladophora*.

Commenting on the data Dr. Mulcahy said he had always thought that there would not be much phosphate lost from the catchment upstream of the escarpment and suggested that the phosphate found must be adsorbed onto particulate matter in the water.

Dennis Kidby Research objective: to establish the importance of nutrient cycling between sediment and the overlying water and algal populations. Direct involvement of the Soil Science Department only began with the appointment of Ann Huber in October 1977, followed by the arrival of John Gabrielson in January 1978 to take up the Research Fellowship funded by EMAC.

Table 9: Very Approximate N and P Loadings to Peel Inlet from the Murray River
(water samples taken at Ravenswood Bridge)
quarterly

Year	River Flow ($\times 10^{-6} m^3$)	Nitrogen (Albuminoid - N plus NH_4)			Phosphorous (Total P)		
		Conc.	Loading		Conc.	Loading	
		(µg/litre)	Kg/yr	g/m².yr	(µg/litre)	Kg/yr	g/m².yr
1972	140	300	40,000	0.6	40	5,000	0.08
1973	360	500	200,000	3	50	20,000	0.3
1974	707	400	300,000	5	70	50,000	0.8
1975	216	200	48,000	0.7	30	6,000	0.09
1976	88	400	30,000	0.5	40	3,000	0.04
Mean	302	400	100,000	2	50	20,000	0.3
1939-75							
Mean	525						

Data Sources : PWD monthly Streamflow records (Hughes Bridge)
Peel Management Authority, analyses by Govt. Chem. Labs.

Specific objectives of the study are:

1. To compartment nutrient levels (much of this has of course already been done).
2. To determine rates of exchange between the compartments.
3. To investigate mineralisation of the nutrients from the alga.
4. To determine exchange rates using undisturbed core samples.
5. To perform in situ experiments to confirm or replace laboratory measurements.
6. To survey and characterise phosphatase activity in the water. (The function of phosphatase enzymes is to break down the organic phosphate of living matter into inorganic phosphate, which is the only form in which it can be used by plants).
7. Survey of nitrogen fixing blue-green bacteria and conditions influencing fixation.

While 1-5 are in logical sequence, 6 has been undertaken first, by Ann Huber, whose experiments have just finished. Her work has involved sampling weekly and over diurnal periods, from surface to near bottom, at different locations in the system, and in relation to different water parameters in order to determine what the phosphatase levels may mean in relation to the recycling of phosphate.

Characterisation of the phosphatase (the nature and origins of the enzymes) is important in order to reflect real phosphatase activity, which some earlier studies in similar situations appear not to have done. In particular it is important to relate activity to pH, from whatever source the enzymes come. Considerable progress has been made in methods used in this research. The results are being analysed and will be presented at a future workshop.

Ann Huber is now starting on a survey of nitrogen fixing blue-green bacteria. What needs to be understood is when and under what conditions these organisms are contributing to the nitrogen input to the system.

Commenting on the availability of phosphorous from the sediments Kidby said that any organic phosphate present would be made available as inorganic phosphate by phosphatases in the water. However if the inorganic fraction is already fixed in the sediments, it is likely to remain in fixed form and therefore not be available to the plants. In answer to questions, Kidby said that all organisms produce phosphatases, some extracellularly, all intracellularly. Cladophora can store phosphate in response to high levels in the water. He thought that at this stage the most important thing to be done was to assess the extent to which phosphate is available from the sediments.

Humphries hoped that interalgal phosphate levels would be measured regularly so as to get a long term picture of accretion to or depletion of phosphate from the sediment. CRES feels it is important to develop a time series on the partitioning of phosphate within the system.

Also in answer to a question Kidby said that it will not be possible to make a quantitative study of the movement of phosphate between the compartments until experiments have been set up to measure labelled phosphorous. This will be done, probably not within the next three months, but hopefully before the end of 1978.

Peter Young. In introducing the CRES group's participation in the study Young noted the contribution made by visitors Bob Spear and George Hornberger.

He defined the CRES contribution as:

1. Expertise in systems area, introduction of relevant models.

2. Assist by helping to integrate study. Objective analysis of data, together with co-operative work with other groups to assist with familiarisation with co-workers and with the system.

Figure 14 shows the CRES study organisation and relationships between CRES and other groups.

One side of chart: hydrological and salinity modelling studies relevant to Cladophora problem, therefore scope of these studies is limited.

Expansion of physical data analysis includes contributions from Wallace and Black. Biological data analysis and modelling will be discussed later by Humphires and Young.

NOTE: A fuller account of the CRES group's contribution, with details of the equations, is available in DCE; also copies of two papers.

Spear and Hornberger: Eutrophication in Peel Inlet: An analysis of behaviour and sensitivity of a poorly-defined system.

Hornberger and Humphries: Introductory discussion of the speculative analysis of *Cladophora* nitrogen mass balance in Peel Inlet.

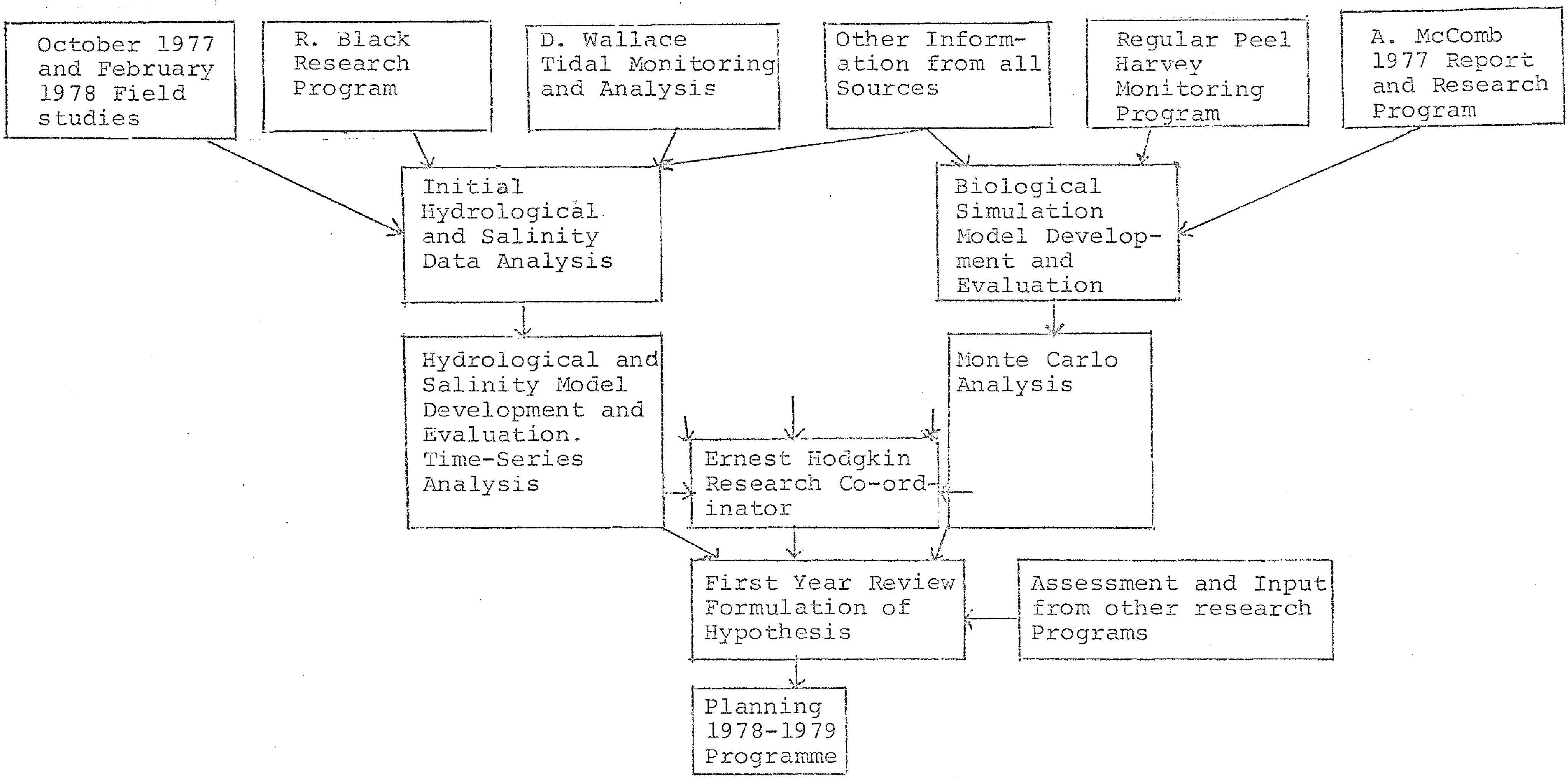


Figure 14: CRES study organisation and relationships between CRES and other groups.

Don Wallace. Water level variations in the estuary.

1. Recording Stations

Tide recording gauges were installed in early October 1977 at the locations shown in Figures 15.1 and 15.2

For the first month recording was at 5 minute intervals and thereafter at 15 minutes.

The resolution of the tide recordings is one centimetre with a stability better than one centimetre.

2. Analysis of Records

Initially the recorders were set to individual arbitary datums. This was done because of the lack of precise vertical height surveys in the immediate vicinity of the recorders. To provide precise survey levelling to each recorder would have entailed expenditure of time and funds which were not available.

In order to assign a common vertical datum to each recorder, the water level and wind records for October/ November 1977 were analysed.

Correlation of the heights during periods of sustained calm and low tide range provided datum corrections which have been adopted up to the present time. This inferred datum is 0.759 metres below Australian Height Datum (A.H.D.).

Harmonic Tidal Analysis has been carried out on the data for the period October 1977 to February 1978.

Table 10 shows the collective results of this analysis.

Table 10: Range and Time Lag of Tides

Location	Range of Astronomic Tide	Time Lag From Mandurah Jetty
Mandurah Jetty	0.60 Metres	0.0 Hours
Chimneys	0.39 "	0.9 "
Coodanup	0.15 "	3.5 "
Falcon	0.15 "	5.3 "
Robert Bay	0.12 "	5.7 "
Dawesville	0.09 "	7.1 "
Ford (Island Point)	0.10 "	12.4 "

The Range of Astronomic tide in the table includes the principal semi-diurnal and diurnal tidal constituents M_2, S_2, N_2, K_1, P_1 and O_1. Upstream of the Chimneys recorder, the semi-diurnal constituents become negligible.

FIGURE 15.1

PEEL – HARVEY ESTUARINE STUDY
LOCATION OF WATER LEVEL RECORDERS

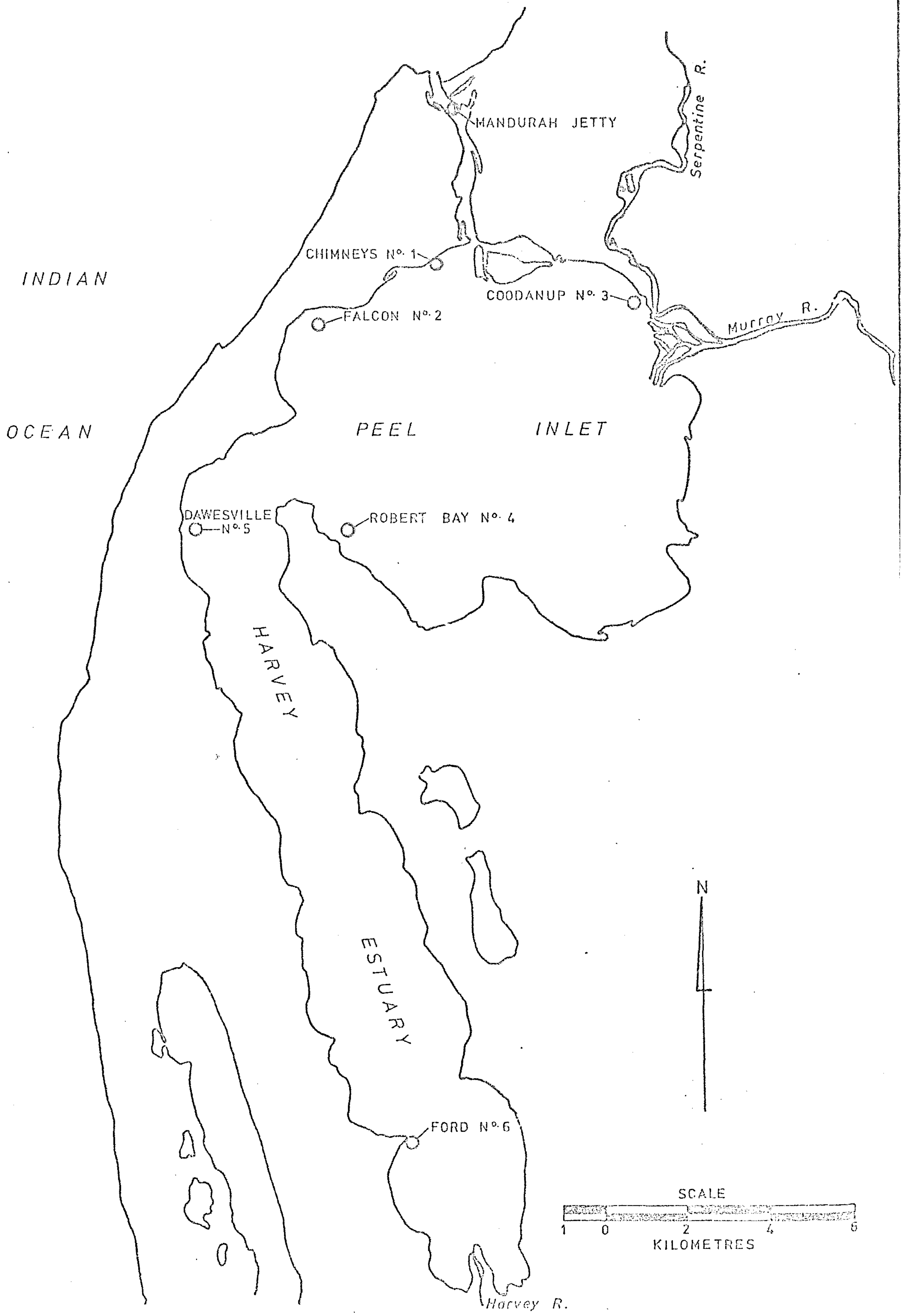
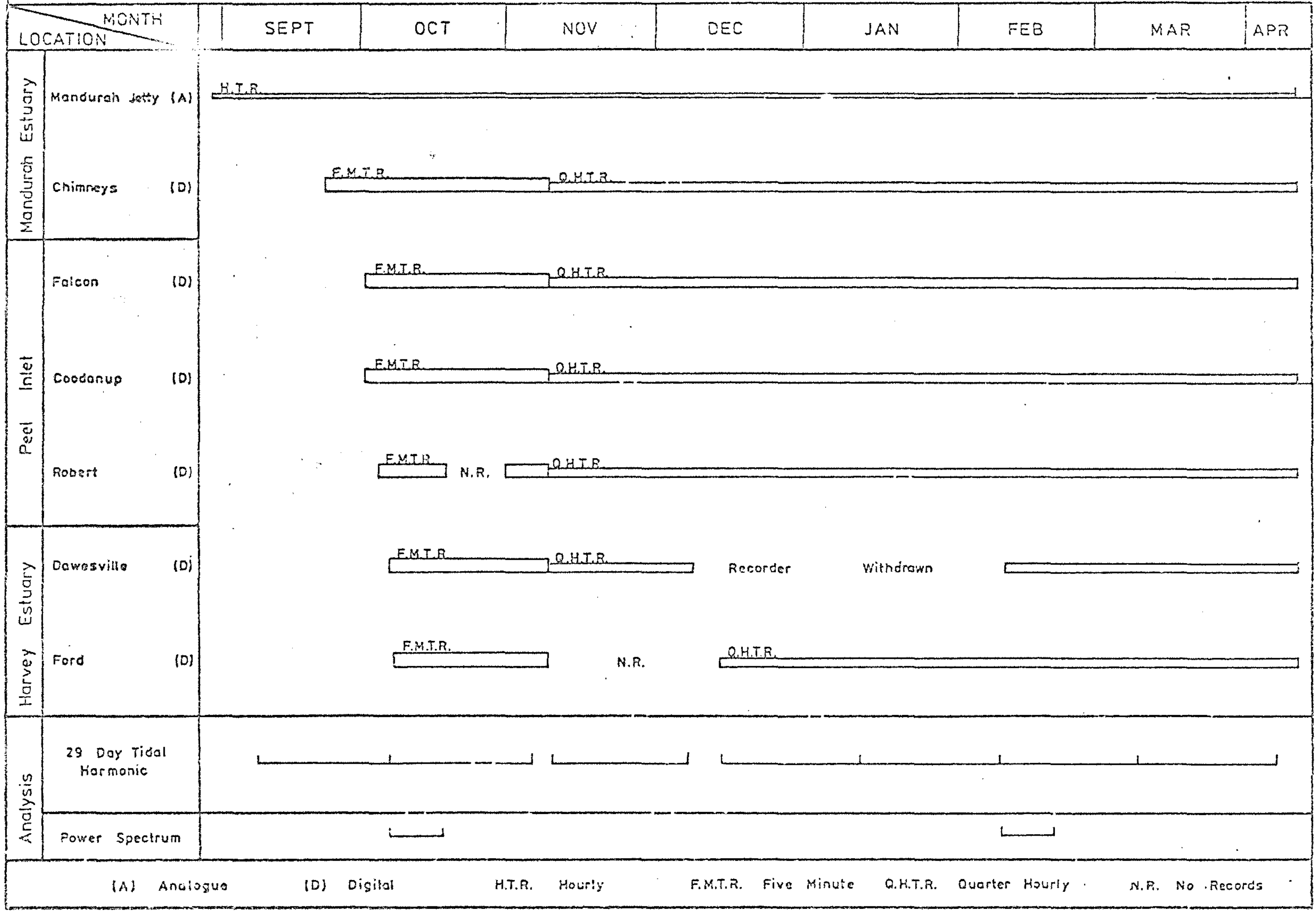


FIGURE 15.2

PEEL – HARVEY ESTUARINE STUDY
Water Level Time Series 1977/78



It will be noted that water level at Ford is at almost exactly opposite phase with the input at Mandurah Jetty. This will be an important factor in restricting tidal exchange between Harvey estuary and the sea.

Harmonic Analysis of the water levels also provides the 29 day mean level unaffected by the astronomic tide (Table 11). Examination of this data indicates an apparent change in datum between October 1977 and February 1978, particularly if the Mandurah Jetty and Ford records are compared. Up to 6 centimetre difference is indicated.

This anomally appears to be due to an increased salinity upstream causing a surface gradient related to the density variation.

Residual wind effects upon the mean levels have not been investigated.

It has been suggested that the inclusion of ocean tide data would provide an improved input to the tide system, however due to the instability of the sand bar at the ocean entrance the relationship between the ocean and Mandurah Jetty varies. This has been observed in the analysis of the Mandurah Jetty records.

Upstream of Mandurah Jetty the underwater topography is stable and the relationship between recorders remains constant.

3. Records of Cyclone Alby (See Figure 15.3)

An extreme event occurred on April 4, 1978 when Cyclone "Alby" passed southwards off the coast. The maximum height of 1.64 m was reached at Mandurah Jetty at 2000 hours. This level was due to the ocean storm surge induced by the barometric pressure and wind effects.

In Harvey Estuary the northerly wind stress raised the water level at Ford and lowered it at Dawesville. The maximum effect occurred at 1915 hours with a water level difference of 1.18 m. A similar situation existed between Falcon and Coodanup with a westerly wind causing a 0.91 m difference at 2045 hours. Under normal weather conditions these height differences would only have amounted to a few centimetres.

The passage of cyclone "Alby" produced a net gain of water level in Peel Inlet and Harvey Estuary of 0.20 m in 14.5 hours.

TABLE 11: SUMMARY OF 29 DAY MEAN WATER LEVELS OF QUARTER HOURLY DATA

INFERRED DATUM adopted relative to 0.759 m below A.H.D. at Mandurah Jetty

REGION	MANDURAH ESTUARY		PEEL INLET			HARVEY ESTUARY	
STATION LOCATION	MANDURAH JETTY	CHIMNEYS	FALCON	COODANUP	ROBERT	DAWESVILLE	FORD
Station Number	051	052	053	054	055	056	057
Time Origin	Metres	Metres	Metres	Metres	Metres	Metres	Metres
8.10.77	0.637	0.640	0.608	0.617	N.R.	0.619	0.652
9.11.77	0.617	0.612	0.570	0.578	0.573	0.573	N.R.
15.11.77	0.658	0.652	0.603	0.613	0.610	N.R.	N.R.
14.12.77	0.699	0.703	0.656	0.651	0.663	N.R.	0.682
12. 1.78	0.681	0.677	0.641	0.636	0.630	N.R.	0.621
23. 1.78	0.657	0.644	0.617	0.608	0.608	N.R.	0.604

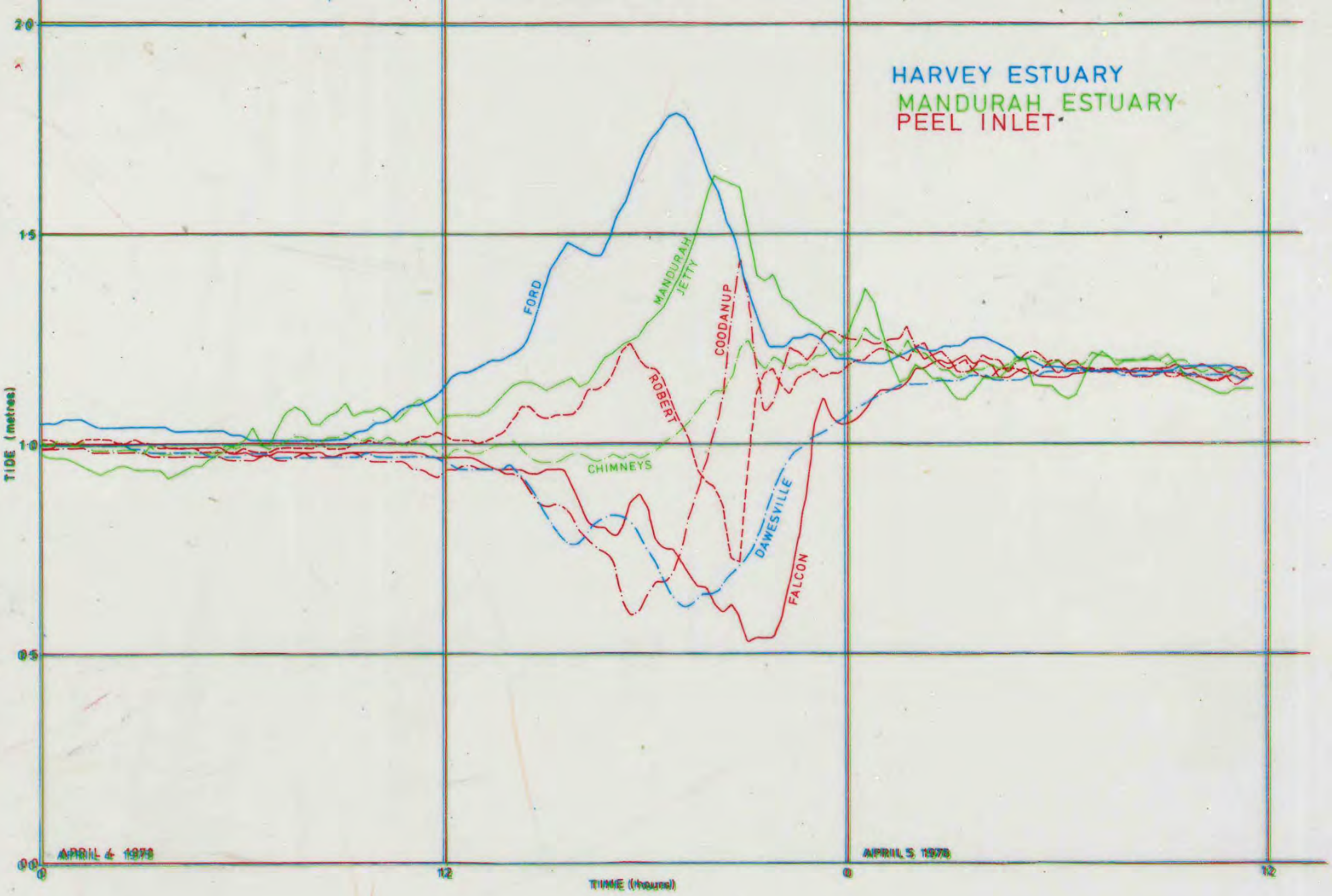

HARVEY ESTUARY
MANDURAH ESTUARY
PEEL INLET
FORD
MANDURAH JETTY
COODANUP
ROBERT
CHIMNEYS
DAWESVILLE
FALCON
TIDE (metres)
2·0
1·5
1·0
0·5
0·0
0
12
0
12
TIME (hours)
APRIL 4 1978
APRIL 5 1978

Figure 15.3: Effects of storm surge and wind stress due to Cyclone "Alby".

Young. The conceptual model for tidal data analysis (Fig.16) has the following components:

three tanks which represent the ocean, Peel, Harvey. The height in each tank is the height in the real system; river inputs are shown, as well as evaporation. Analysis to date has not included river flow, since there has not been any significant volume Between each tank is a hydraulic resistance.

The model applies to the "summer condition" with little or no river flow and quite high evaporation. The response of this summer system is characterised by the equations shown on Fig. 16.

There are two main reasons for tidal analysis:

1. to assess volume flux through Mandurah Channel; discussed later by Black.

2. to get a "feel" for the system, and to characterise its behaviour, particularly in comparison with that of similar systems elsewhere.

At the end, tidal analysis may not be as important as salinity analysis, which has the advantage of indicating "flushing" rather than simply volume changes. Also the tidal analysis may not be as important biologically for the same reason.

Different parts of the system have been analysed and modelled, for example the Murray River at Hughes Bridge, modelled from the flows upstream at gauging stations on the Hotham and Williams Rivers. This provides a partial test of the methodology. Figure 17 shows the results of a model built on one year's data and tested against data from another year.

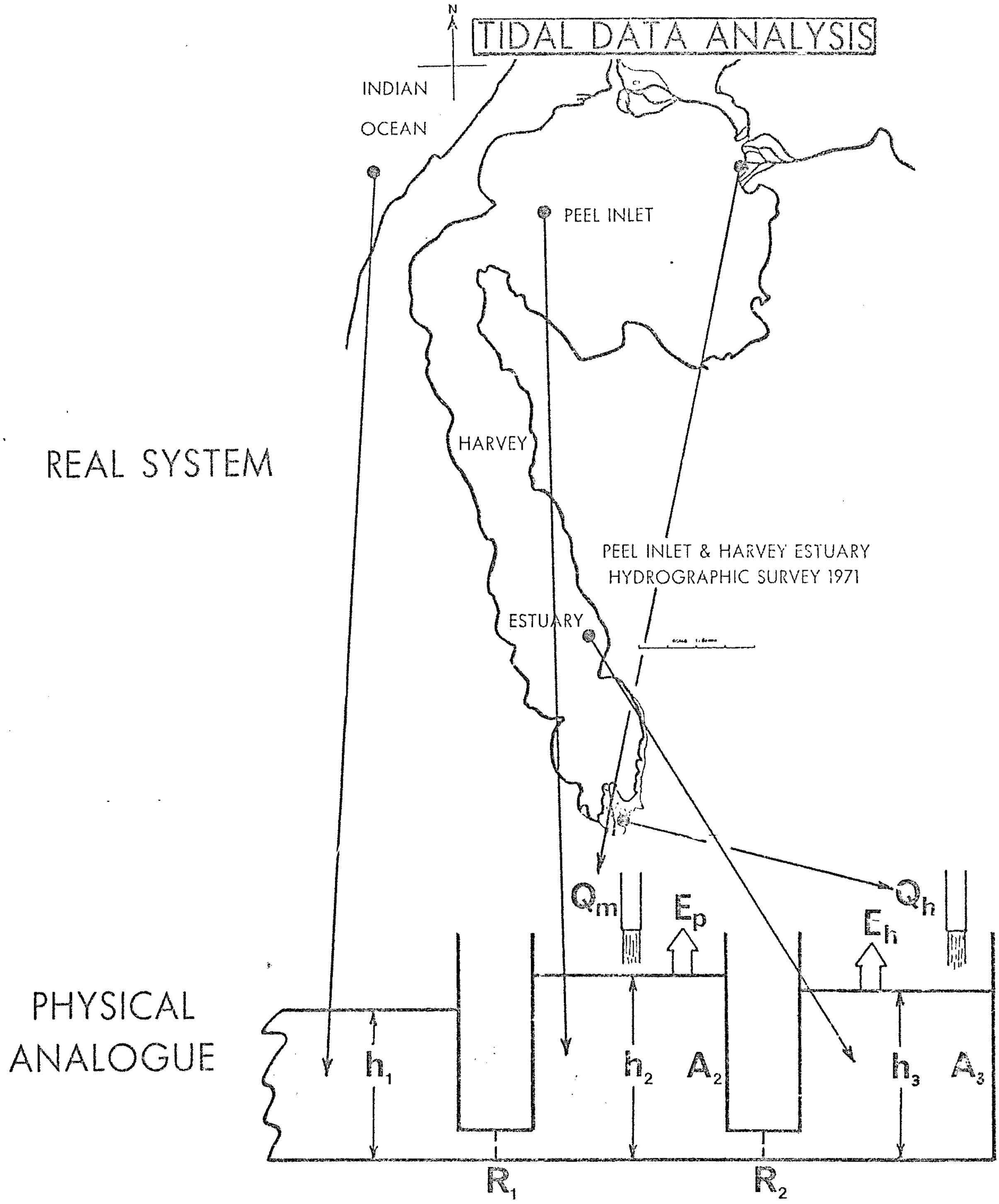
The approach will be extended to predict flows entering Peel Inlet, because of the lack of measured river flows downsteam of Hughes Bridge. The river flow models will be used to assess the magnitude of the effects of river input on the water budget of the Inlet, as well as to calculate nutrient inputs via the rivers.

Figure 18 is a plot of the unit hydrograph of the model; this is the resultant flow downstream for a unit increase in flow upstream.

TIDAL DATA ANALYSIS

Typical results of the tidal modelling are shown in Figure 19 based on an initial time series analysis with local means removed. The error in fit between the model's prediction and the observed level change is plotted below as the residual series. From this, we can conclude that the model is characterising the system quite well with a fixed model, which means that the properties of the system are stable.

Long term height changes are more important that the short-term astronomic tides. The data have been smoothed to remove the short-term fluctuations and the relationship between different parts of the system analysed using the smoothed data. Figure 20 shows the relationship between long term level changes at Mandurah and Coodanup.



MATHEMATICAL MODEL

$$A_1 \frac{dh_2}{dt} = \frac{h_1 - h_2}{R_1} - \frac{h_2 - h_3}{R_2} + Q_m - E_p$$

$$A \frac{dh_3}{dt} = \frac{h_2 - h_3}{R_2} + Q_h - E_h$$

FIGURE 16. Conceptual model for tidal data analysis.

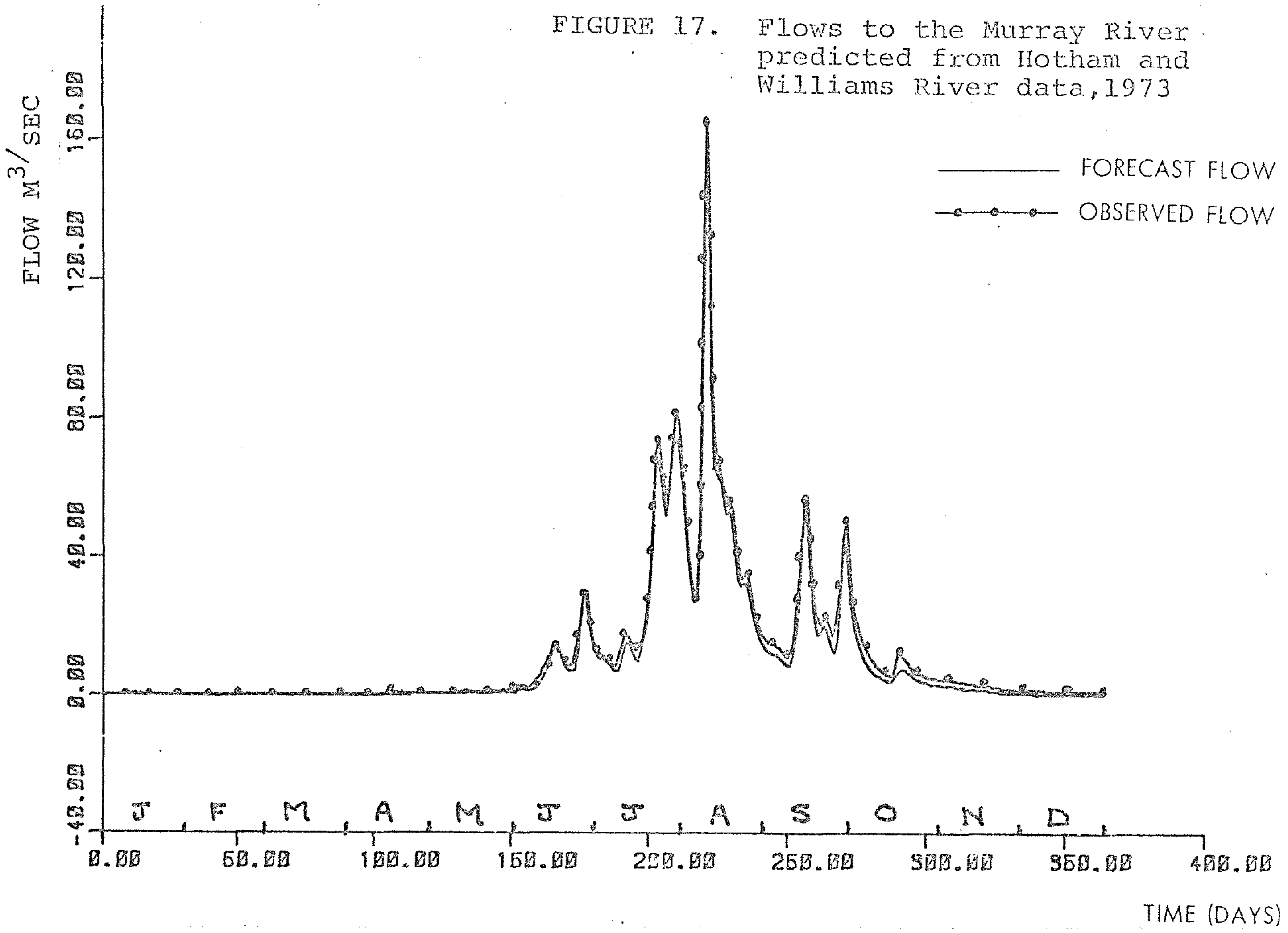


FIGURE 17. Flows to the Murray River predicted from Hotham and Williams River data, 1973

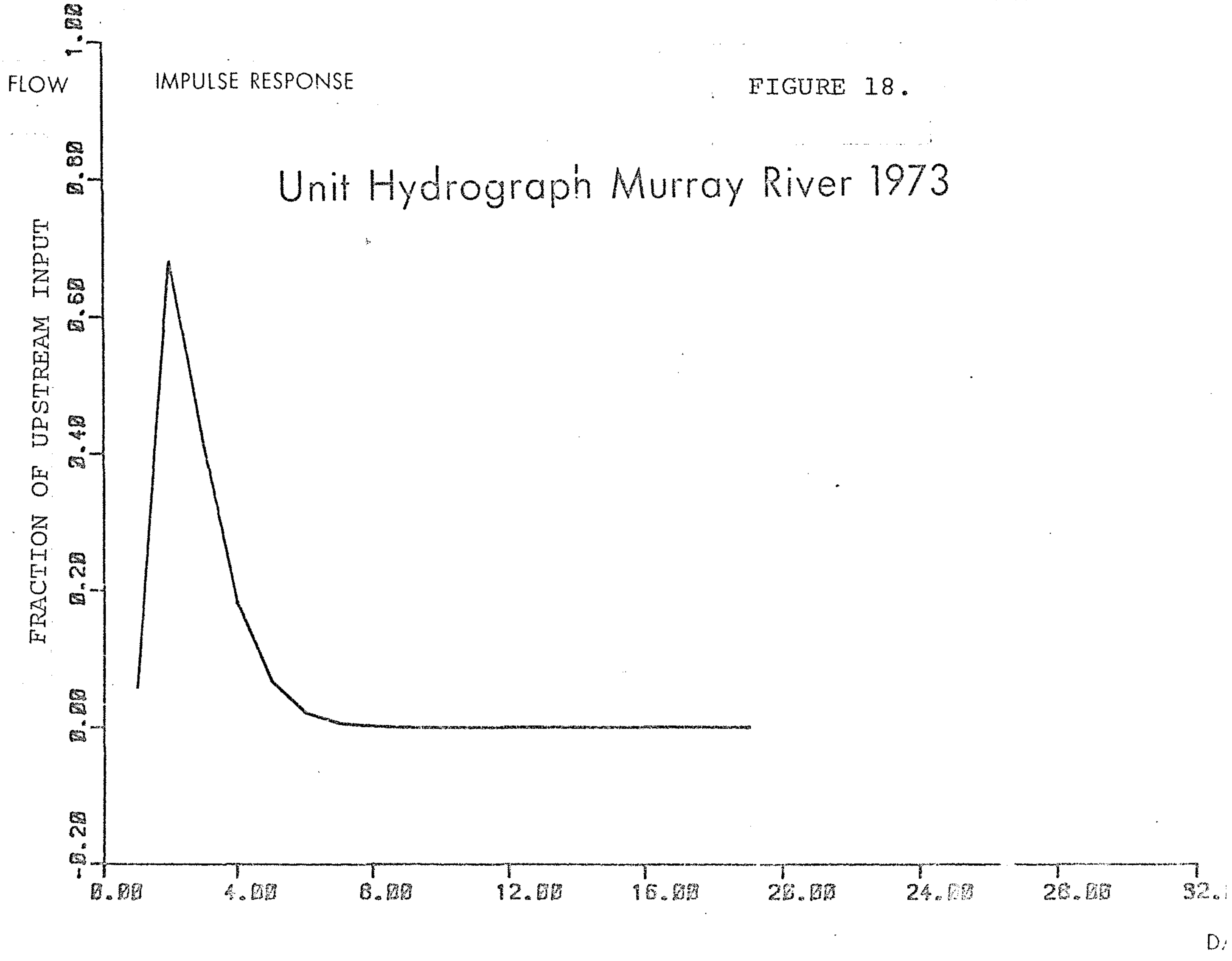
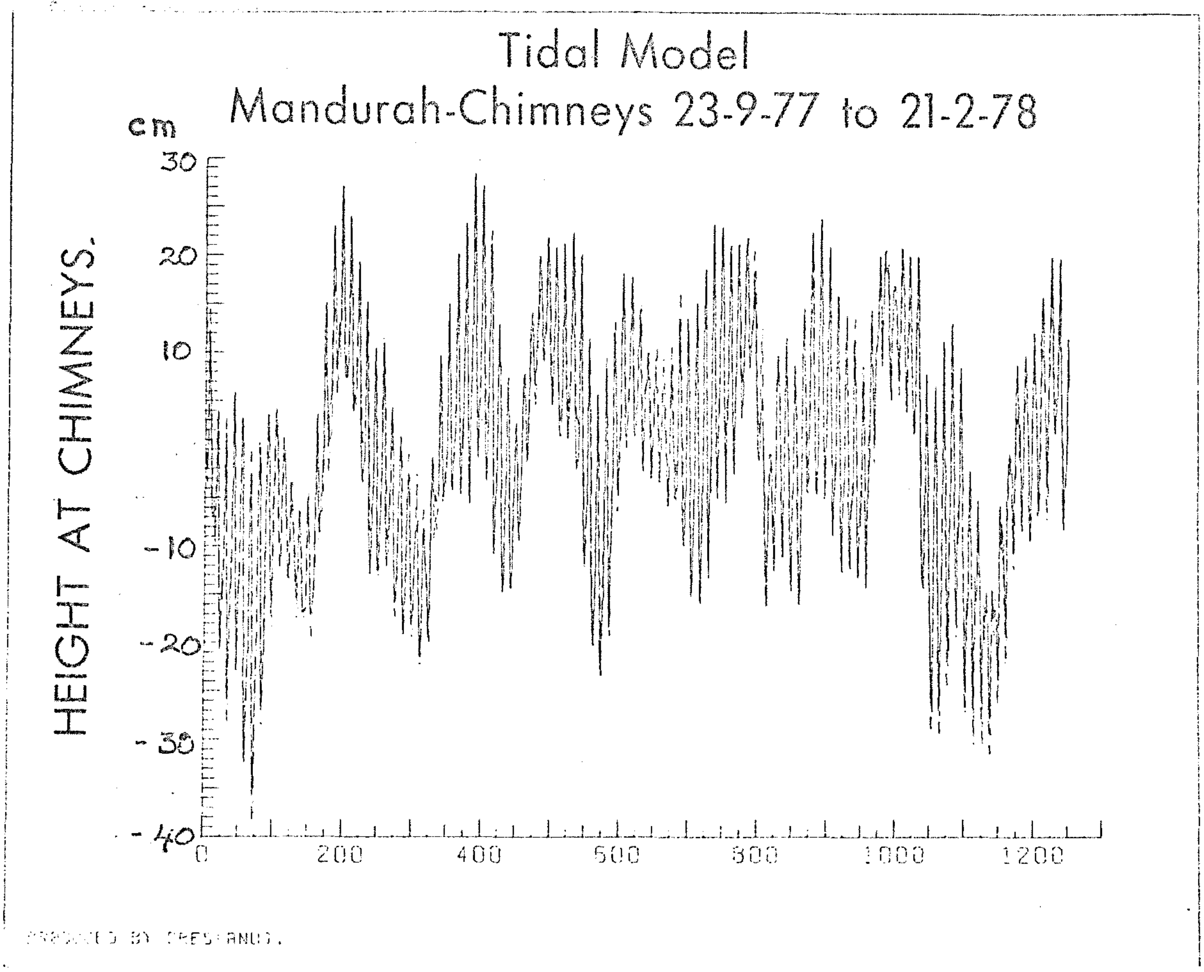


FIGURE 18.

FIGURE 19.


Tidal Model
Mandurah-Chimneys 23-9-77 to 21-2-78
cm
HEIGHT AT CHIMNEYS.
30
20
10
-10
-20
-30
-40
0
200
400
600
800
1000
1200
PRODUCED BY CRESTANUS.

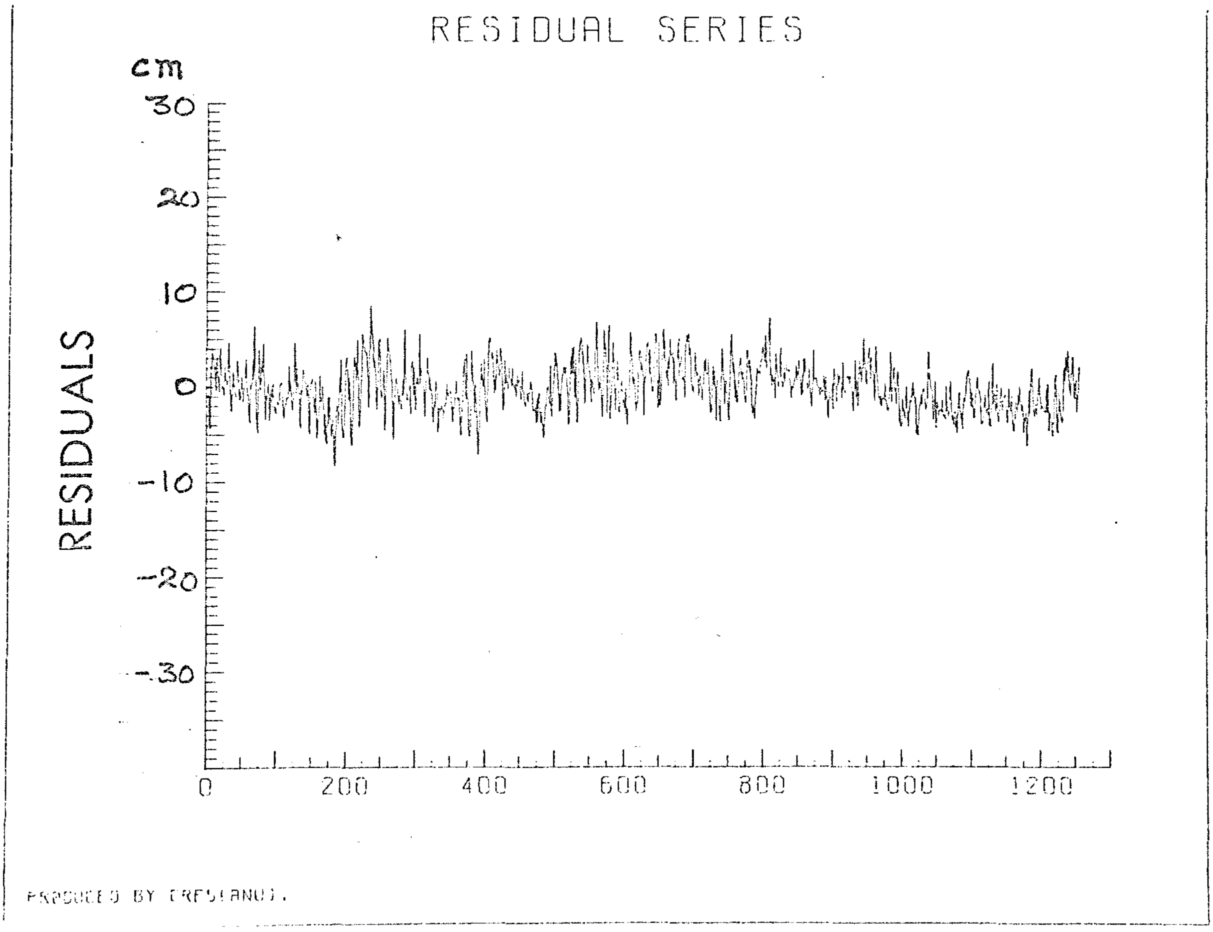
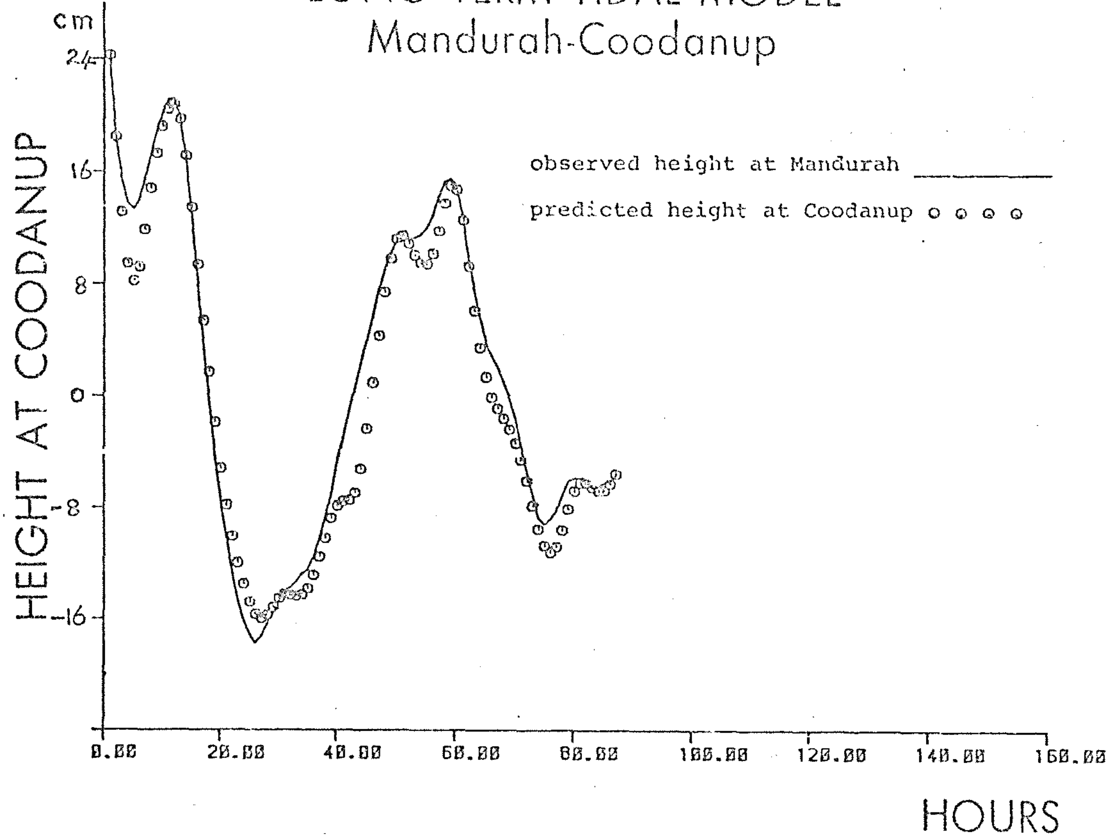
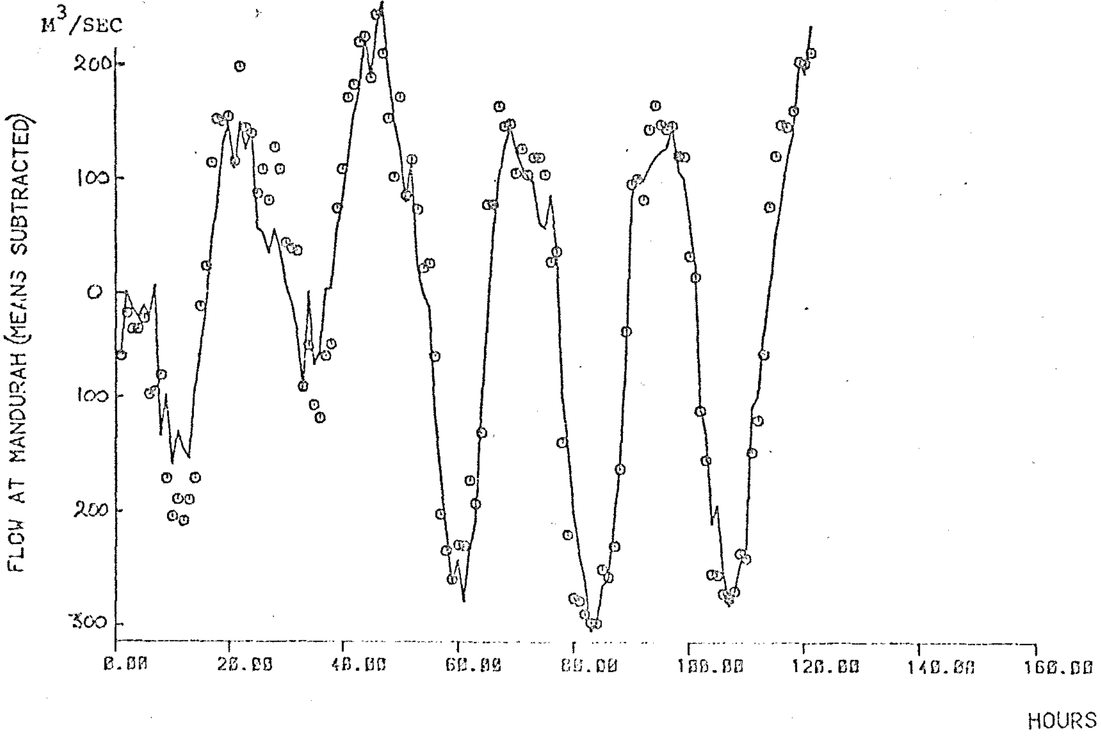

RESIDUAL SERIES
cm
RESIDUALS
30
20
10
0
-10
-20
-30
0
200
400
600
800
1000
1200
PRODUCED BY CRESTANUS.

Figure 20. LONG TERM TIDAL MODEL
Mandurah-Coodanup



OBSERVED FLOWS AND MODEL OUTPUT MANDURAH 12/2/78 - 17/2/78

Figure 21. Predicted Volume Flow at Mandurah from Height Difference Mandurah-Chimneys



The height at Coodanup is predicted from that at Mandurah. Again, the model structure is stable, implying a constant relationship between the two sites in the real system. This approach using smoothed data is similar to Wallace's spectral analysis, with which we have compared our results, with substantially the same conclusions.

A further analysis of tidal mechanisms was undertaken in association with Black. This related volume flow under Mandurah Bridge with the height difference measured between Chimneys and Mandurah.

Ron Black. Throughout the February exercise flow under the Mandurah Bridge was recorded at hourly intervals. Using only the height differences between the Mandurah and Chimneys gauges, flow was modelled and the resultant plot agreed well with the observed flow (Fig.21). The model then appears to work well for computing the volume of flow in and out of the estuary under summer conditions, but the experiment will need to be repeated when the river is flowing.

If the model is applied to comparing Mandurah and Coodanup water level changes there is a much poorer fit (Fig.22). The residual differences are likely to be attributable to wind stress. Because winds have both speed and direction the winds were resolved into N-S and E-W components (Fig.23). Putting this into the model reveals that there is some connection between the big discrepancies and the N-S component, or when there is NOT an E-W component. This suggests that this line of study is worth pursuing.

Figure 23.

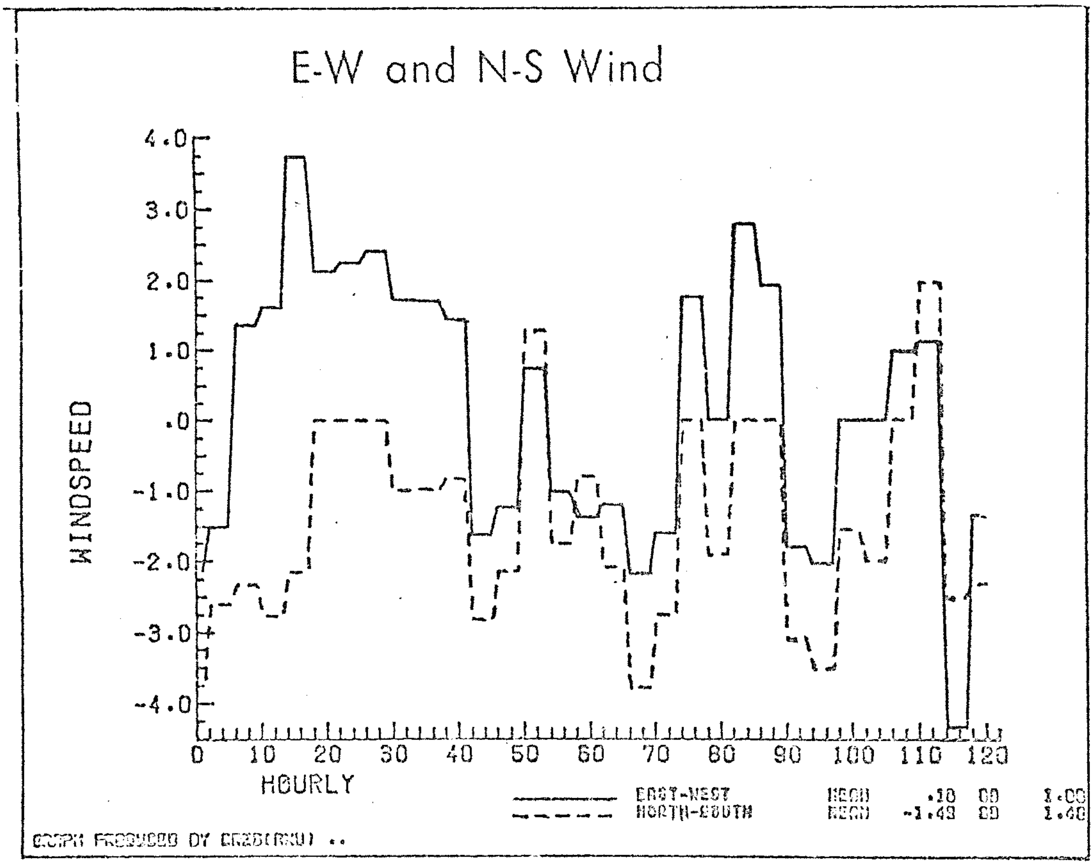
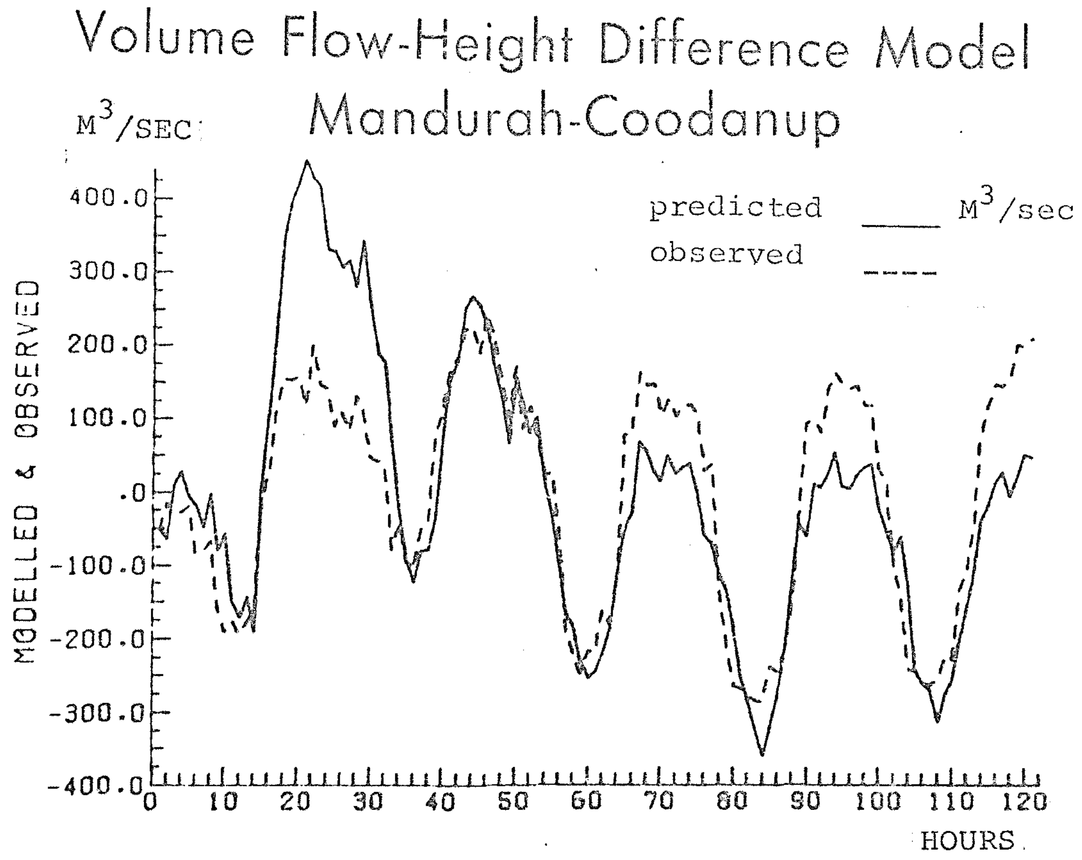
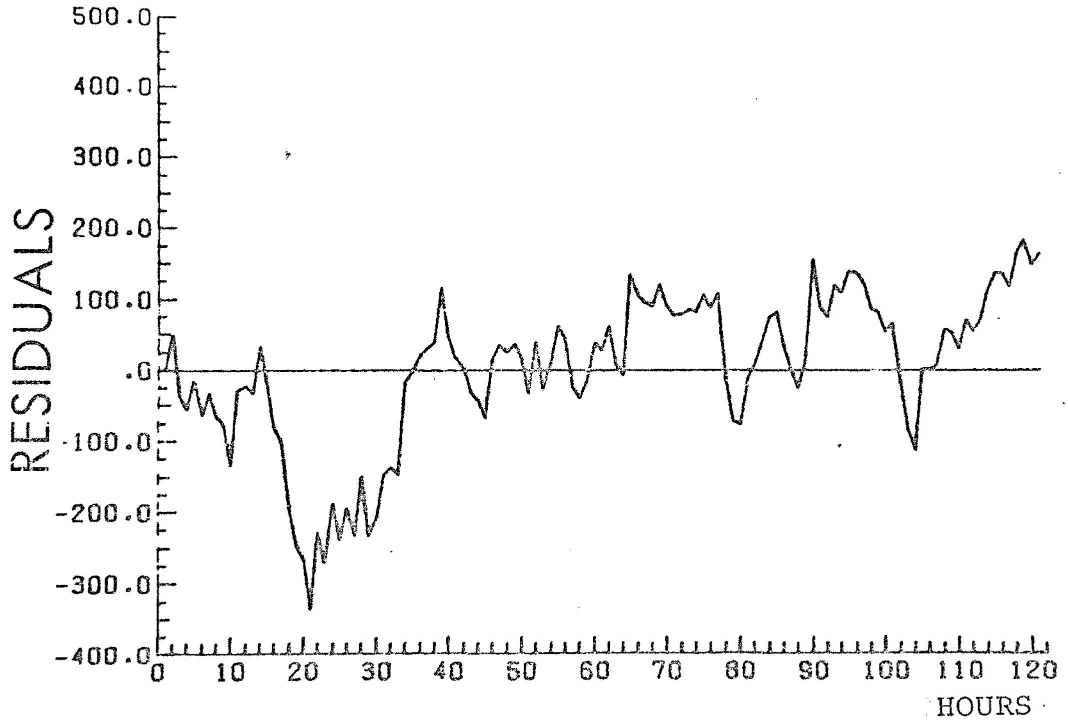


FIGURE 22.



Volume Flow-Height Difference Model
Mandurah-Coodanup

RESIDUAL SERIES



Peter Young. Water exchange (as distinct from volume change) is likely to be important to the Cladophora situation. Salinity monitoring was used to estimate the exchange of a conservative dissolved substance between the Inlet and the ocean.

Figure 24 gives the conceptual framework of this analysis. The equations for this analysis are shown in this figure.

The system response with time is shown in the lower part of Figure 24. Evaporation will cause Inlet salinity to rise and exceed the input ocean salinity. The curve of salinity increase will flatten asymtotically as ocean exchange finally balances water loss by evaporation; assuming the situation remains stable.

In the real system (Figure 25) the behaviour is remarkably like the theoretical behaviour outlined in the previous figure. The small curves to the left of this figure show the actual behaviour of salinity with time for the different points indicated. The analysis of the real data gives estimates of the coefficients of the differential equation above, and allows us to estimate mean evaporation rate and flushing time over the period of the data set. One particular example is shown in Figure 26. showing the behaviour of salinity with time at Austin Bay. The model characterises the longer-term behaviour of the salinity over the summer.

Figure 27 shows estimates of flushing time and evaporation for different sites in the system. The time constant, or flushing time, is the time taken for two-thirds of the equilibrium condition to be attained. We are unable to fully resolve the discrepancy between the results of this analysis and that of Agnew but would point out that his analysis was applied only to data from the week of the February exercise, while our analysis covered the period October-February. Under such a restriction, different estimates of flushing time would be expected.

The evaporation is expressed as a percentage of the (unknown) volume per week. These evaporation figures differ because the effective volume at each site is different. As a check, the evaporation figures were averaged for the whole inlet (whose volume is known) and compared with those of Black. The estimate of the model was 4.3 mm/day, while Black's estimate was 4.5 mm/day, which tends to confirm the estimates of the model.

The pattern of exchange is similar to that outlined by Agnew earlier, with very long residence times in the southern bays of Peel and in Harvey Estuary, during the summer period.

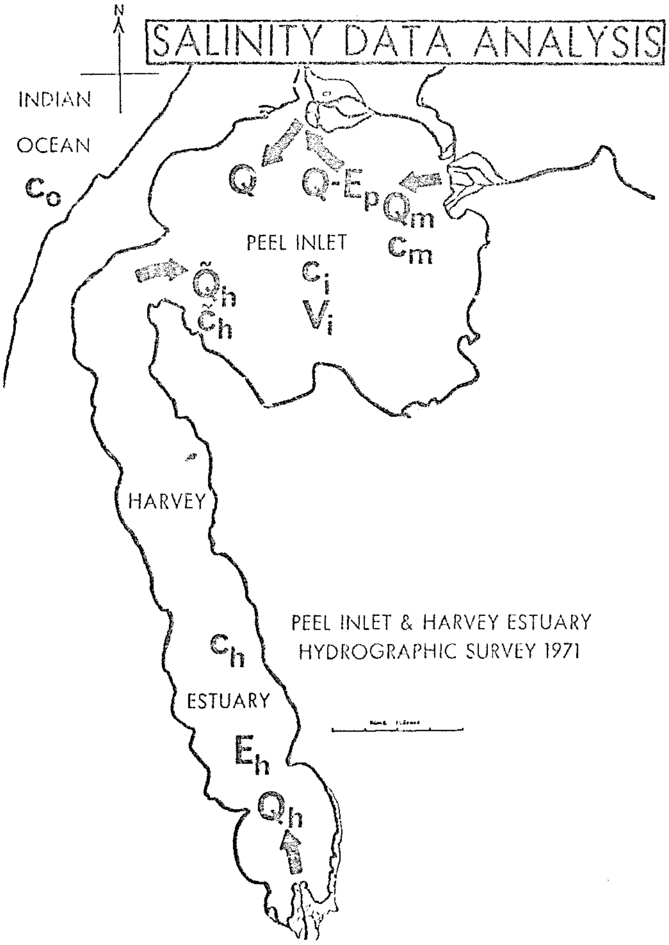
Cladophora Growth Model

Analysis of Cladophora growth mechanisms has been carried out in a slightly unconventional manner, with the use of a simulation model in which the coefficients are defined with a high degree of uncertainty. The actual structure of the model is explainable in dynamic biological terms. This part of the study has been largely carried out by Spear and Hornberger, and this is reported in their working paper (Eutrophication in Peel Inlet) to which reference should be made for further detail.

FIGURE 24.

SALINITY DATA ANALYSIS

REAL SYSTEM



PEEL INLET & HARVEY ESTUARY
HYDROGRAPHIC SURVEY 1971

MATHEMATICAL MODEL

for i-th compartment of Peel Inlet

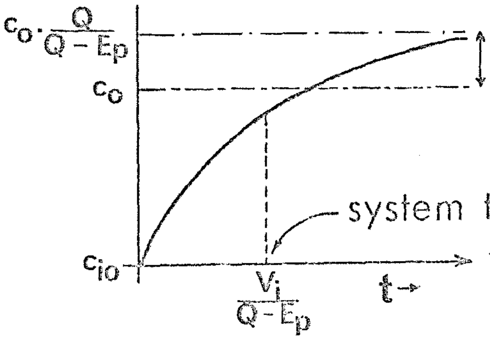
mass accumulation = mass in - mass out

$$V_i\frac{dc_i}{dt} = Qc_o - (Q-E_p)c_i + Q_m c_m + \tilde{Q}_h\tilde{c}_h$$

$$\frac{dc_i}{dt} = -\frac{Q-E_p}{V_i}c_i + \frac{Q}{V_i}c_o \text{ ; if } Q_m = \tilde{Q}_h = 0$$

SYSTEM RESPONSE

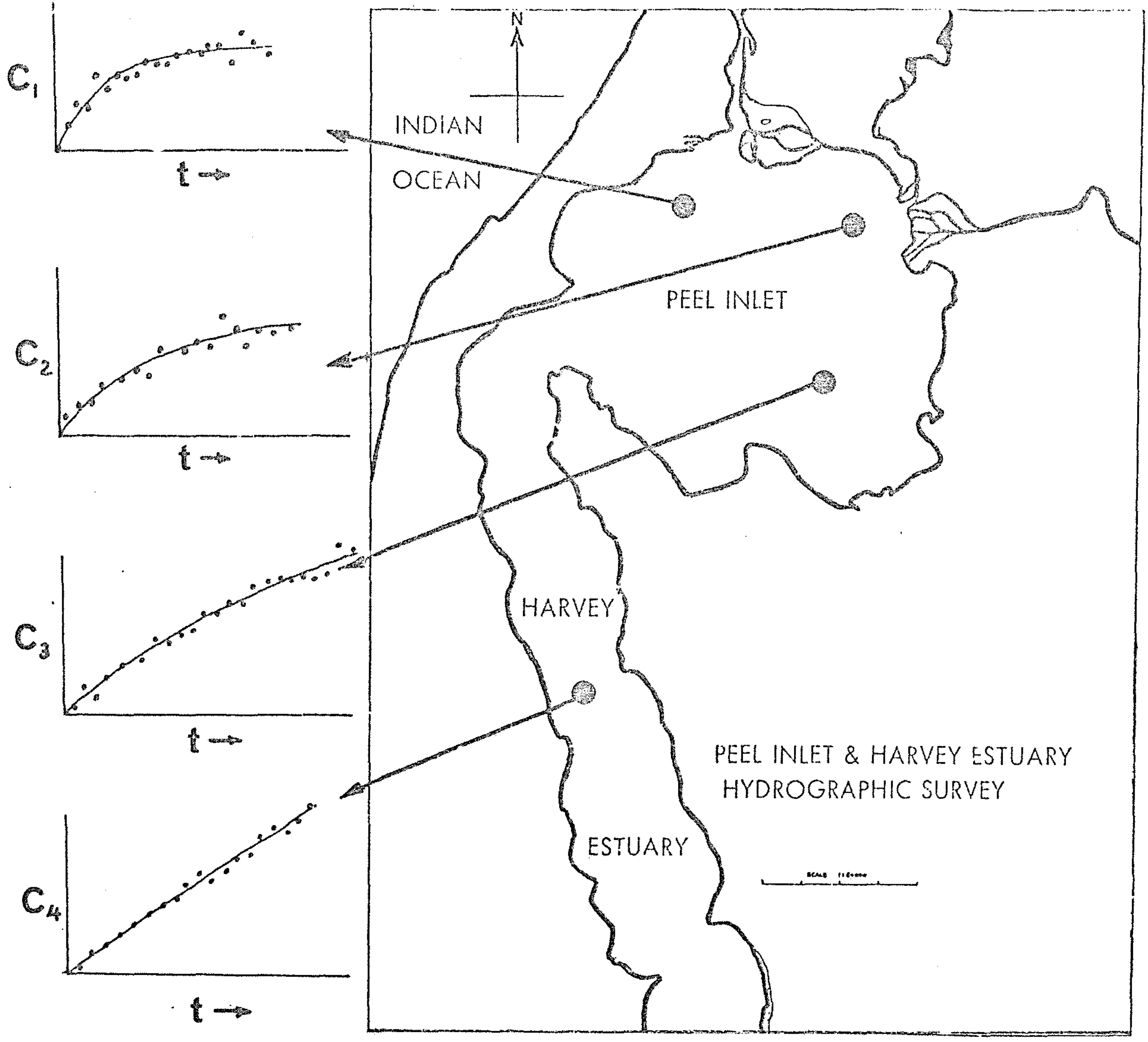
$c_i(t)$ response for constant c_o from initial c_{io} :



elevation of salinity due to evaporation

system time constant = flushing time

FIGURE 25. Salinity variations in the Peel - Harvey system



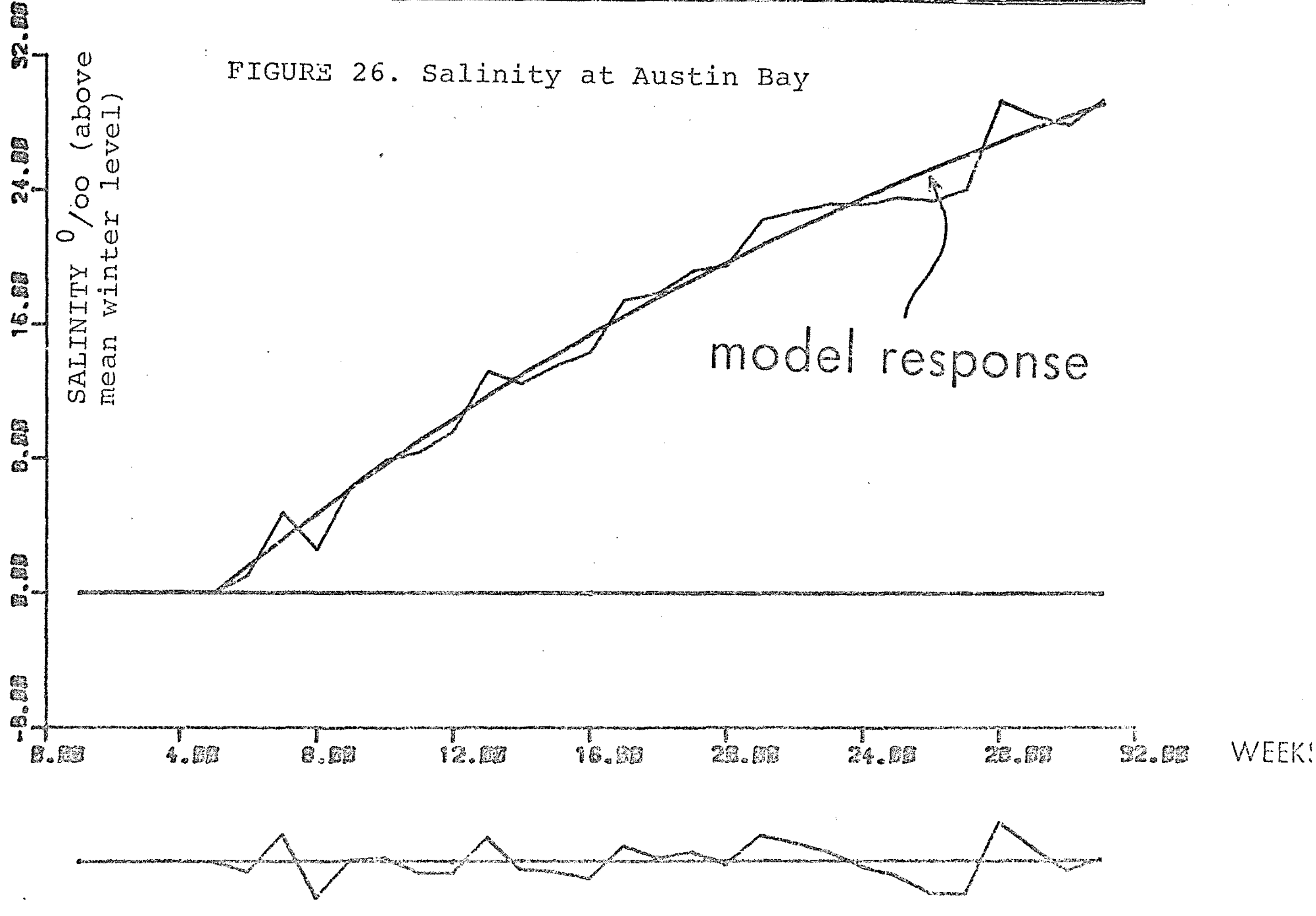
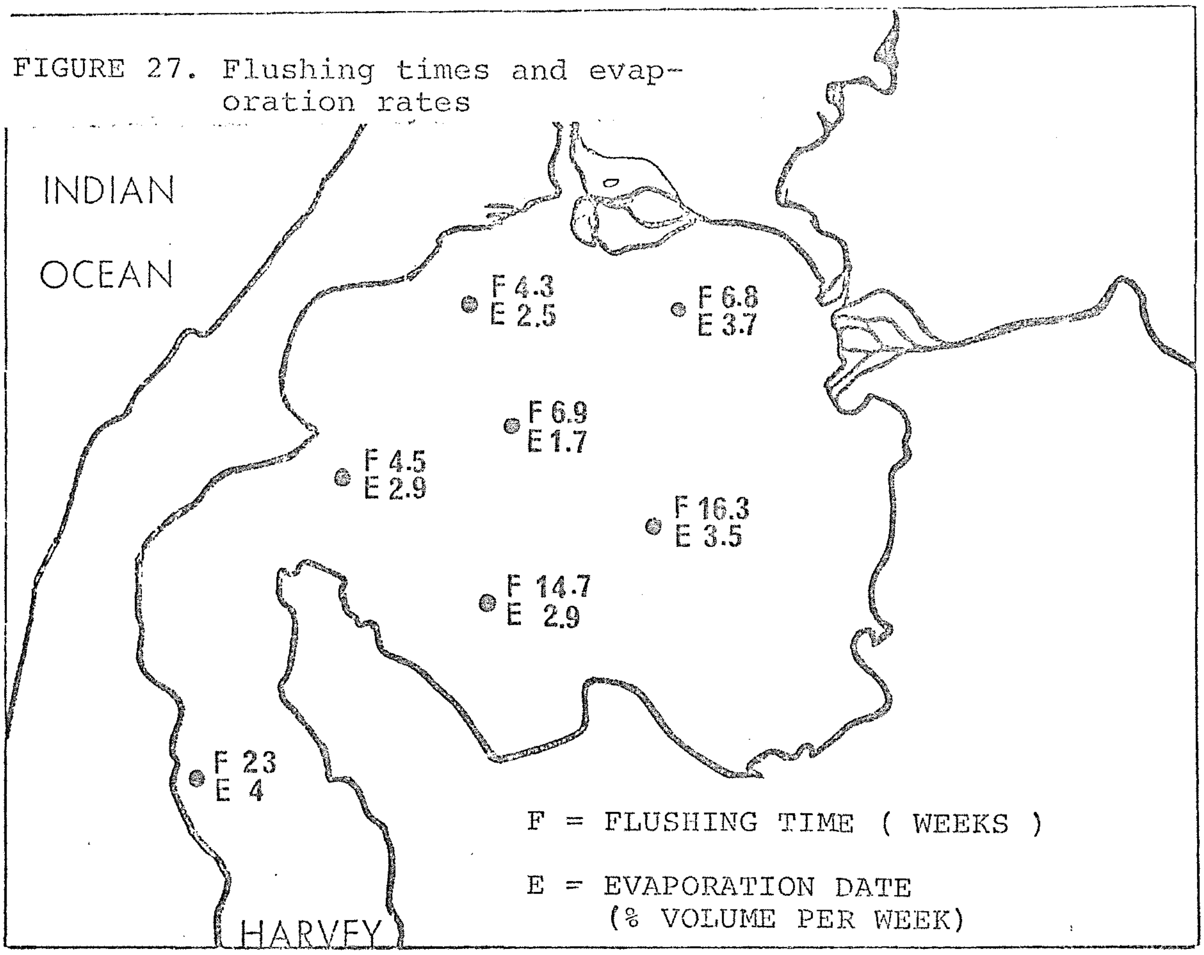


FIGURE 26. Salinity at Austin Bay

FIGURE 27. Flushing times and evaporation rates



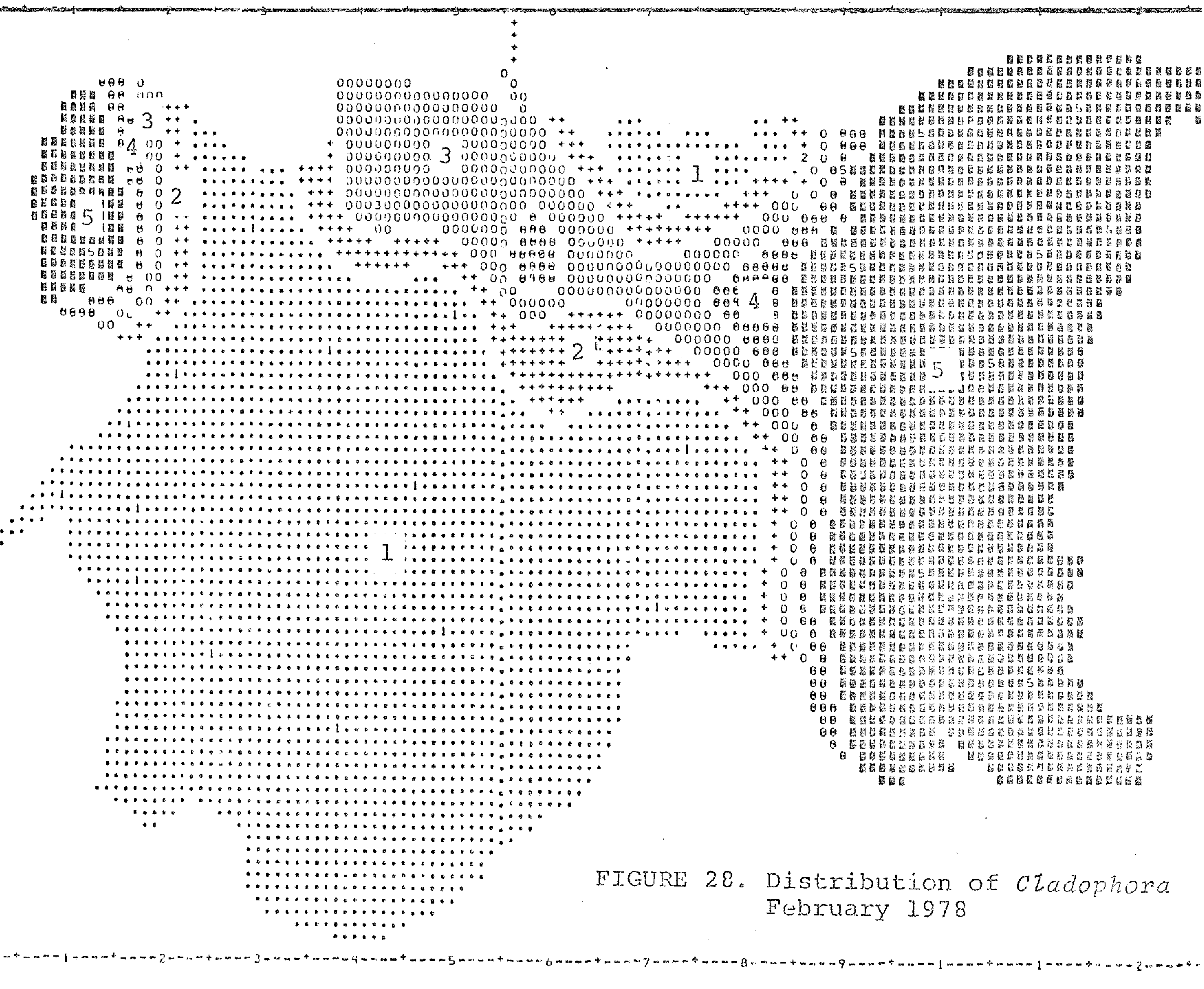


FIGURE 28. Distribution of *Cladophora* February 1978

Bob Humphries. Distribution of Cladophora was investigated by mapping percentage cover within the 0.5 m contour of the inlet as observed in February, 1978 (Figure 28).

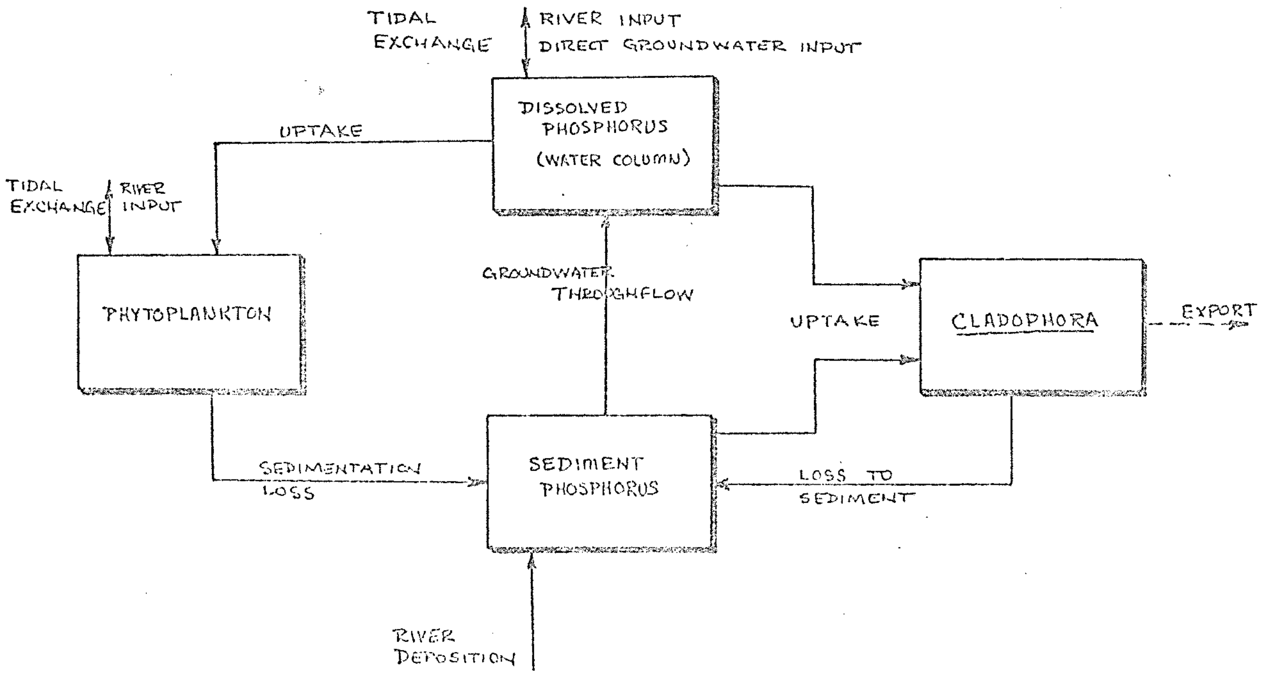
The Cladophora model applies to the NE corner of the inlet, off Coodanup, assuming that the majority of the Cladophora biomass occurs in this region.

The model is expressed in terms of a phosphorus mass balance of the defined"Cladophora growth area". In other words, the balance with time of phosphorus contained in Cladophora tissue, phytoplankton, the water column, and sediments of the growth area, is calcualted. The equations are linked together, so that transfers of P from one compartment to another are possible.

This phosphorus model is built assumming P limitation of growth - as a hypothesis only. The only other variables in these equations able to affect Cladophora growth, other than P, are available light and temperature. All other nutrients are considered sufficient (non-limiting) for the purpose of this exercise. Figure 29 shows the connection between the model compartments with the possible routes of P addition and subtraction from each compartment.

The model equations are outlinedas follows. The structure of each equation is assumed to be "known". This structure was based on literature research of work on similar systems, and consultation with group memebrs of this study. Note, however, that the definition of uncertain parameters effectively relaxes the assumption that the model structure is "known".

Figure 29



Real data is used for inputs where possible, otherwise literature values, or a best guess suffices. No parameter value is fixed, but is chosen at random for each run of the model.

RATIONALE FOR MODEL COMPARTMENTS

1. Cladophora Growth Compartment

The phosphorus mass-balance for the Cladophora compartment is an expression relating the net rate of change of biomass to growth, losses due to death, respiration and grazing, and transport out of the system. (We assume that there is no net transport of Cladophora biomass into the growth rate but we do allow for export of biomass to the beaches).

Growth of Cladophora is assumed to vary directly as a function of temperature and light. It is likely that Cladophora growth rates increase with temperature in the ranges encountered in Peel Inlet (Bellis, 1968; Adams and Stone 1973), but sufficient information is not available to elucidate the functional form of this increase. While a logarithmic relationship between temperature and growth rate is often used in modelling studies (e.g. see Bierman, 1976), we have chosen to adopt the approach of Di Toro et al (1971) who showed that the increase in growth rate for several phytoplankton species was linear with temperature over the range 5°C to 25°C. Likewise, there is a good deal of evidence that benthic algae do not become light saturated at naturally-occurring light intensities (Hornberger, et al. 1976; Pfeifer and McDiffett 1975; Naiman and Gerking 1975: Manning et al. 1938) and although data pertaining to the growth in Peel Inlet are not available, it is assumed that gross productivity is a linearly increasing function of light.

The nutrient limitation term is the routinely used Monod kinetics formulation. We recognise that the luxury uptake phenomenon has been reported for Cladophora species (Fitzgerald 1969; Lin 1977) and that models that include this effect have been propsed (e.g. Droop 1973; Genney et al 1973: Bierman 1976). However, we felt that the added complexity inherent in the description of luxury uptake was not warranted for our simple models and that for the time scale of interest in this study it was not really necessary to distinguish between growth and uptake. The nutrient concentration available to the Cladophora is higher than than in the water column because the algae are in intimate contact with sediment and decomposed organic material which contains a large quantity of available phosphorus. On the other hand, the algae cannot utilise interstitial water directly so we know very little about the precise value of the "correct" concentration; consequently, we use a concentration intermediate between water and sediment concentrations, and use a parameter to reflect our uncertainty.

The biomass available for active photosynthesis is equal to the Cladophora biomass in terms of phosphorous content at low values, but asymtotically approaches a constant value. This function thus simulates the self-limitation of the Cladophora bed due to the fact that only the top layer can actively photosynthesise, the underlying material being screened from sunlight by overlying algae. The available biomass is deemed to be about 2 balls thickness of Cladophora, which approximates McComb's 2.3 cm measure. The form for the function is suggested by the data presented by Pfeifer and McDiffett (1975) which shows productivity per unit biomass of a riverine Cladophora species decreasing with biomass and approaching a relatively constant value at high levels of biomass. McIntire (1973) has also used a similar function to describe the self-limitation of the growth of periphyton in a river. We use an equation which gives a nearly linear increase up to biomass of constant value (above) and then a sharp cutoff to remain at this level. This is the maximum photosynthesising biomass, which becomes a model parameter.

The in situ loss term is a rather simplified method for simulating the complex processes by which algae disappear from the system. Since our modelling approach is not aimed at accurate prediction of the absolute magnitude of state variables but rather at looking at general patterns of behaviour, we feel that this approach, which incidentially is common to most phytoplankton models (e.g. Chen and Orlob 1972; Di Toro et al 1971) is adequate for our purposes.

2. Phytoplankton Growth Model

The major innovations introduced in the phytoplankton compartment are the terms to account for light saturation of photosynthesis and the terms to describe advection of phytoplankton. In the former, the term chosen is in the form of the well accepted saturation curve modified to represent average conditions over depth and over a one-day period by Di Toro et al., (1971). The latter are straightforward throughflow terms. The light attenuation coefficient for phytoplankton is assumed to be linearly related to the biomass concentration.

NOTE that river flow rate is derived from the 1976-77 hydrograph for the Murray River at Hughes Bridge. Daily tidal inflow is calculated from a tidal sub-model developed by Hornberger, Spear and Whitehead, which calculates the net volume change of the circumscribed Cladophora growth area. In the model there are linkages between Cladophora and phytoplankton in terms of growth and nutrients fluxes, because

(i) phytoplankton is in the water column above Cladophora and can affect light availability,

(ii) phytoplankton remove nutrients from the water column,

(iii) they are a possible source of available nutrients to Cladophora through the sedimentation loss rate.

3. Dissolved Phosphorus in Water Column

This model is a simple mass balance expressed in differential equation form and takes account of physical inputs and biological removal and additional terms. .

A parameter is introduced to allow a fraction of the ground water flow to go directly into the water column with the remaining fraction being routed through the sediment compartment. This mechanism is in recognition of the fact that a portion of the ground water can be thought of as flowing through the "sides"

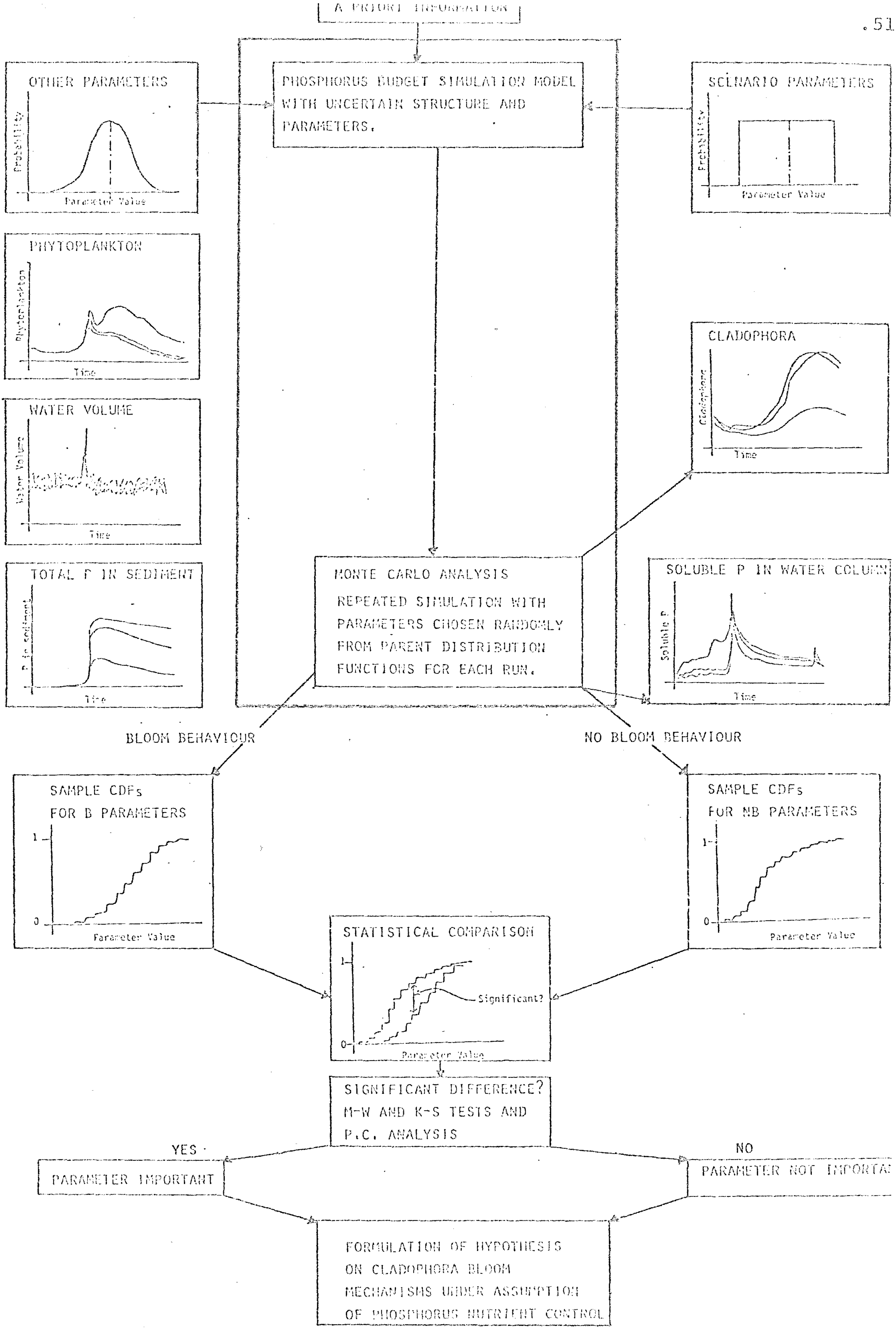


Figure 30: Cladophora growth mechanism analysis

of the growth volume and not upward through the sediment underlying the Cladophora beds. The transfer of nutrient from sediment to water is treated using a first-order kinetic model of the diffusion process, an approach used recently by Freedman and Canale (1977) in describing the phosphorus budget of a lake.

4. Sediment Phosphorus

The equation for the sediment compartment is decomposed into two equations for convenience. The reason for introducing this refinement is to allow the concentration of phosphorus in interstitial water to be calculated without specifying a fixed volume for the active sediment layer. The total amount of phosphorus in the sediment compartment is the product of concentration and volume.

We allow concentrations to build up to a maximum in the interstitial water with further additions of phosphorus to the sediment compartment causing expansion of the active layer.

A concentration-limiting function, prevents concentration of phosphorus in sediment from exceeding that in interstitial water, a somewhat arbitrary limit for phosphorus concentration in sediment. As the former grows from zero toward the latter, increments in input to the sediment compartment cause proportionately larger increases in sediment volume relative to changes in concentrations, thus constraining the concentration while conserving mass.

The above scheme for treating the sediment compartment is admittedly somewhat arbitrary but is justified because the parametric uncertainty is relegated to the maximum concentration of phosphorus in interstitial water, a quantity which can be interpreted on a physical basis. As the concentration in the near-surface layer increases, sharp gradients will result in downward migration of phosphorus, i.e. in an expansion of the "active sediment zone", and, depending upon the rate of phosphorus input to sediment and the physical-chemical properties of the sediment, there will be an effective upper limit on concentration in the active layer. Thus, uncertainty in sediment porosity, hydraulic conductivity, cation exchange capacity etc., is lumped into this parameter. Not only is this consistent with our overall lumped-parameter approach, but it satisfies the objective of transferability of information from the literature since values of sediment phosphorus concentrations for eutrophic lakes and estuaries are available.

At this point the model equations contain a number of explicitly stated parameters but also involve numerous data inputs, some of which are unlikely to be completely known in a preliminary study. In general then, it will be necessary to introduce additional parameters to describe certain of the input functions.

5. Mass Conservation of Water

Water mass balance is also expressed by an equation not explicitly stated in the box diagram.

In the present version of the phosphorus model, rainfall in the water surface is not included.

P.C. Young, Model Execution.

It is stressed that although the model is deterministic in form, it is a very uncertain model because parameter values are not fixed and were randomly chosen for each run of the model. The logic of the method outlined in this section is shown in Figure 30. It is this uncertainty which is built into the model that changes the way in which various relationships between compartments occur.

Some of the coefficients are not known exactly. Some parameters are assumed to have mean values and the actual value in the system could be anywhere in a probability distribution defined in a Gaussian way. Other parameters (the scenario parameters) are so badly known that their values are only set as lying in a given range and therefore they have a rectangular distribution.

The model is used by choosing parameters at random from those distributions, with the different responses (of the model run) recorded for each random choice of parameters, so that an ensemble of models results. One now looks for patterns of behaviour seen in the Peel-Harvey system and to establish why one might get such responses. A Peel Harvey "behaviour" is characterised by a bloom of Cladophora with low phytoplankton and low soluble nutrient levels at the same time - all factors which make the "Peel-Harvey" bloom special.

Different runs of the model are separated into bloom behaviour and no-bloom non-behaviour responses and a cumulative distribution function for each parameter is calculated for all of the bloom and no-bloom model runs.

For each parameter, the distributions are compared using two independent statistical tests (Figure 31). If there is no statistically significant difference between the distributions, that parameter is regarded as not important. If, on the other hand, there is a statistically significant difference between distributions, the parameter is important. It is a parameter associated with a "Peel Harvey" bloom and a hypothesis is formulated on the basis of those parameters shown to be important.

Three of 200 runs were shown to demonstrate differences in behaviour, some of which correspond to "Peel Harvey" blooms. The results of the 3 runs are plotted for Cladophora biomass, phytoplankton, soluble P in the water column, total sediment P and water volume of the growth area (Figures 32-36). Each model run on these figures is distinguished by a number on the right-hand end of the curve - 1,2 or 3. The parameter values producing these results were different for each run, and were chosen at random from the possible range of values allowed for each parameter. Curve 2 responds to a "Peel-Harvey" bloom, a "behaviour", because the Cladophora blooms with the correct timing and phytoplankton remains low. Curves 1 and 3 do not correspond to "behaviours" because phytoplankton levels become too high in 1, and Cladophora does not achieve a high enough biomass in 3.

Figure 31. Sample cumulative distribution functions

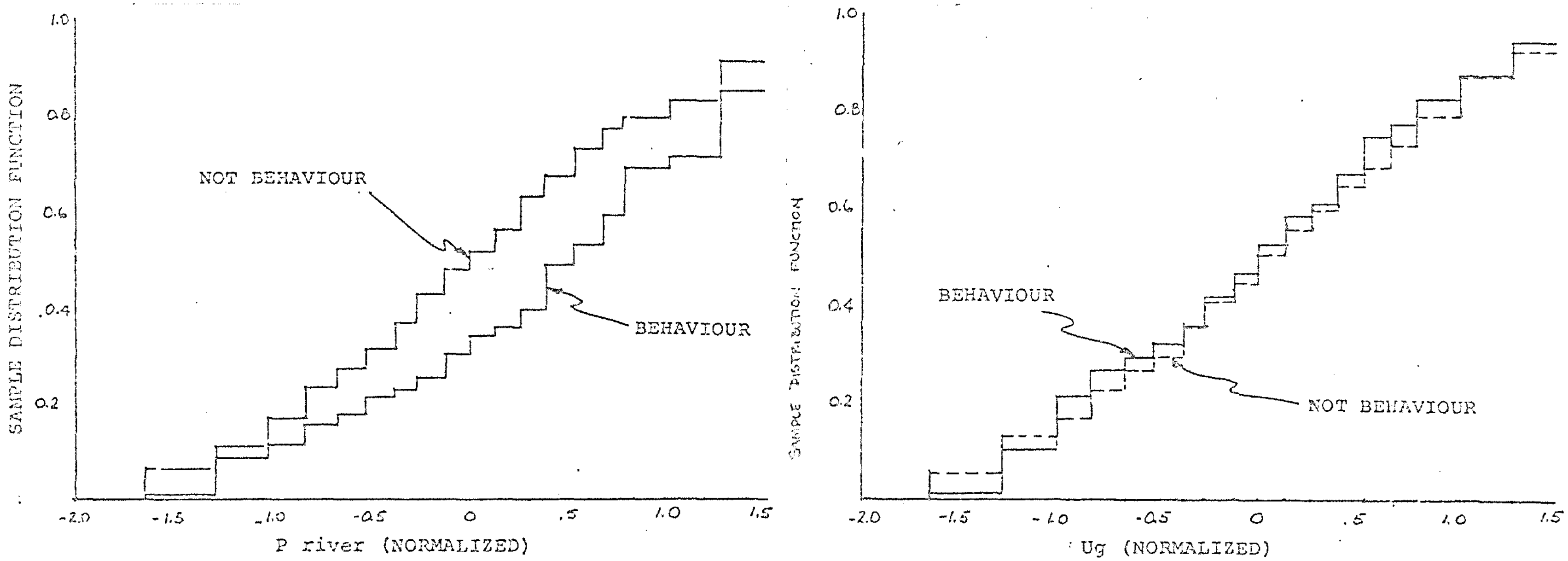


FIGURE 32.

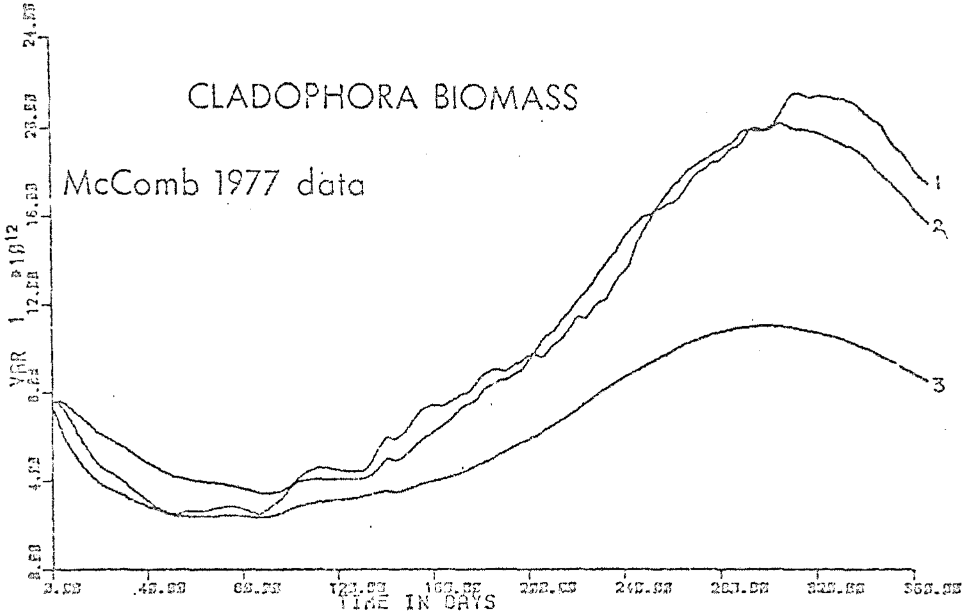


Figure 33.

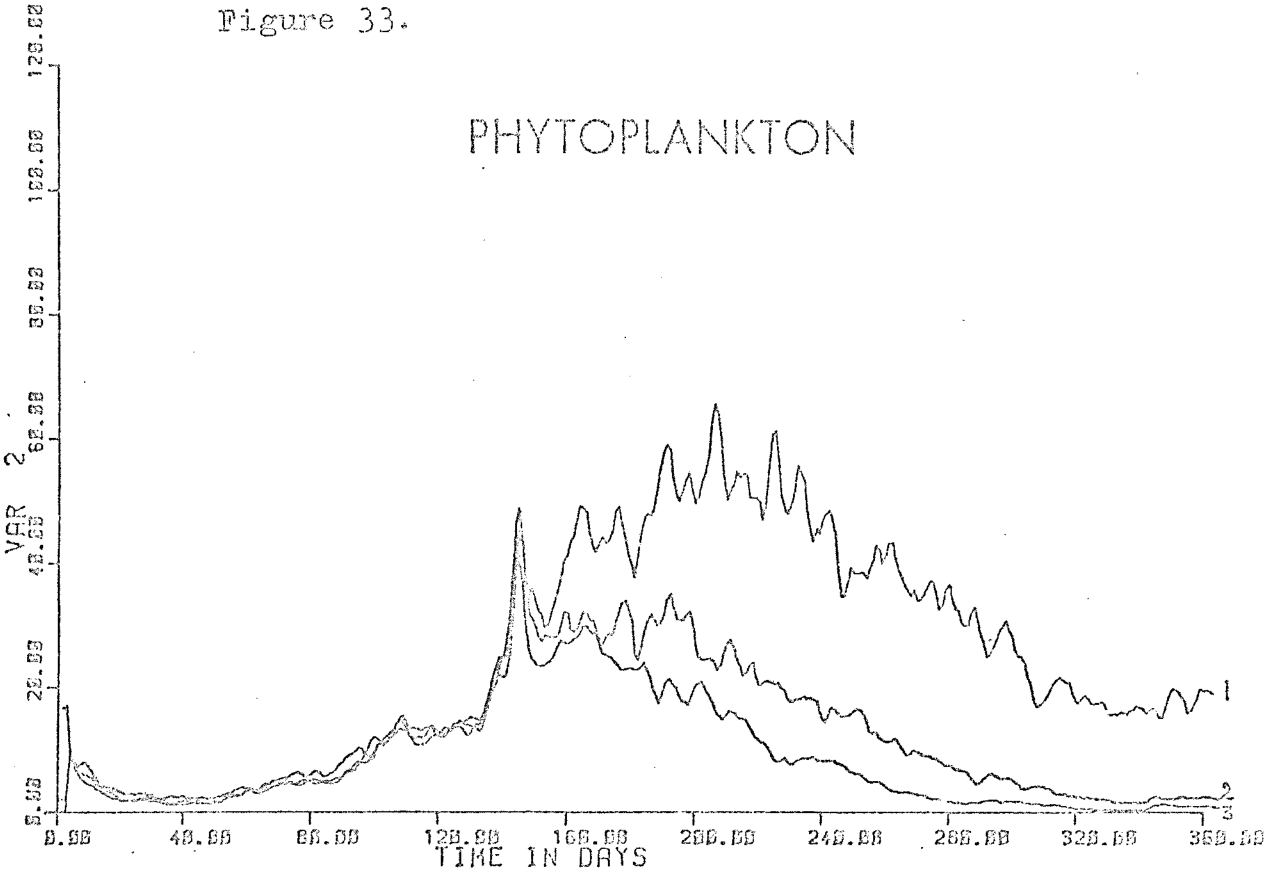


Figure 34.

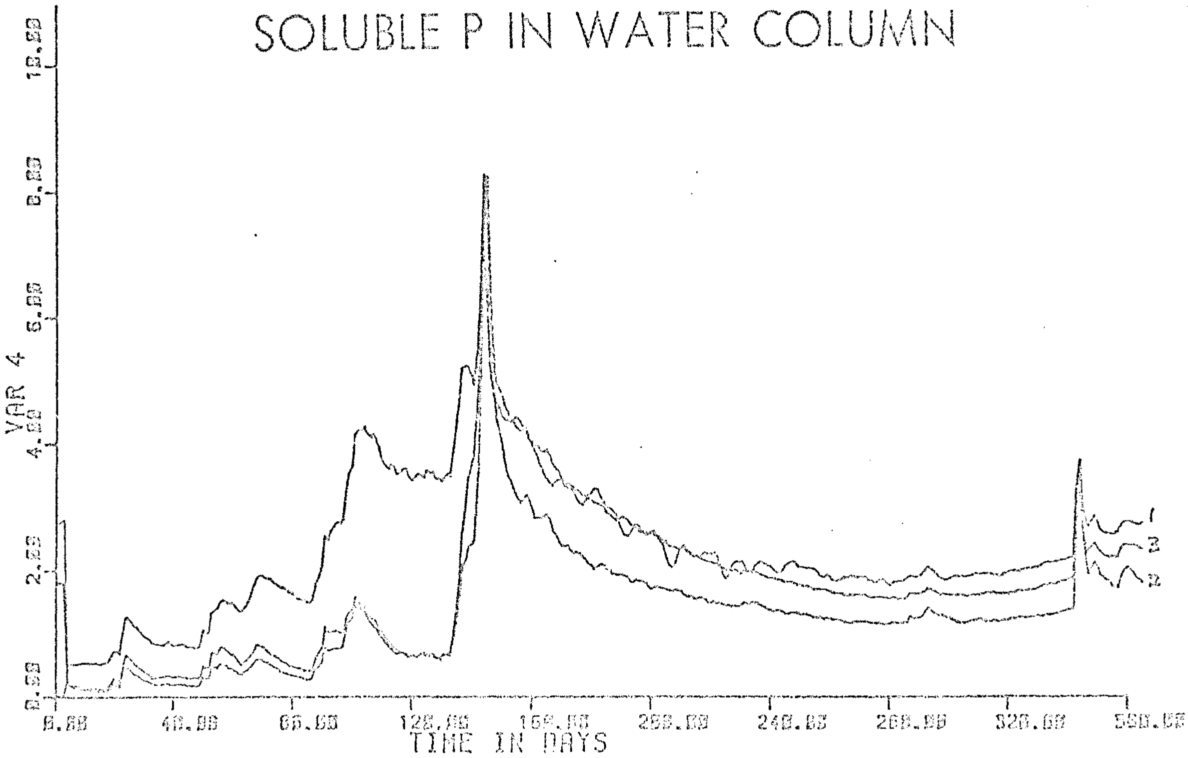


Figure 35.

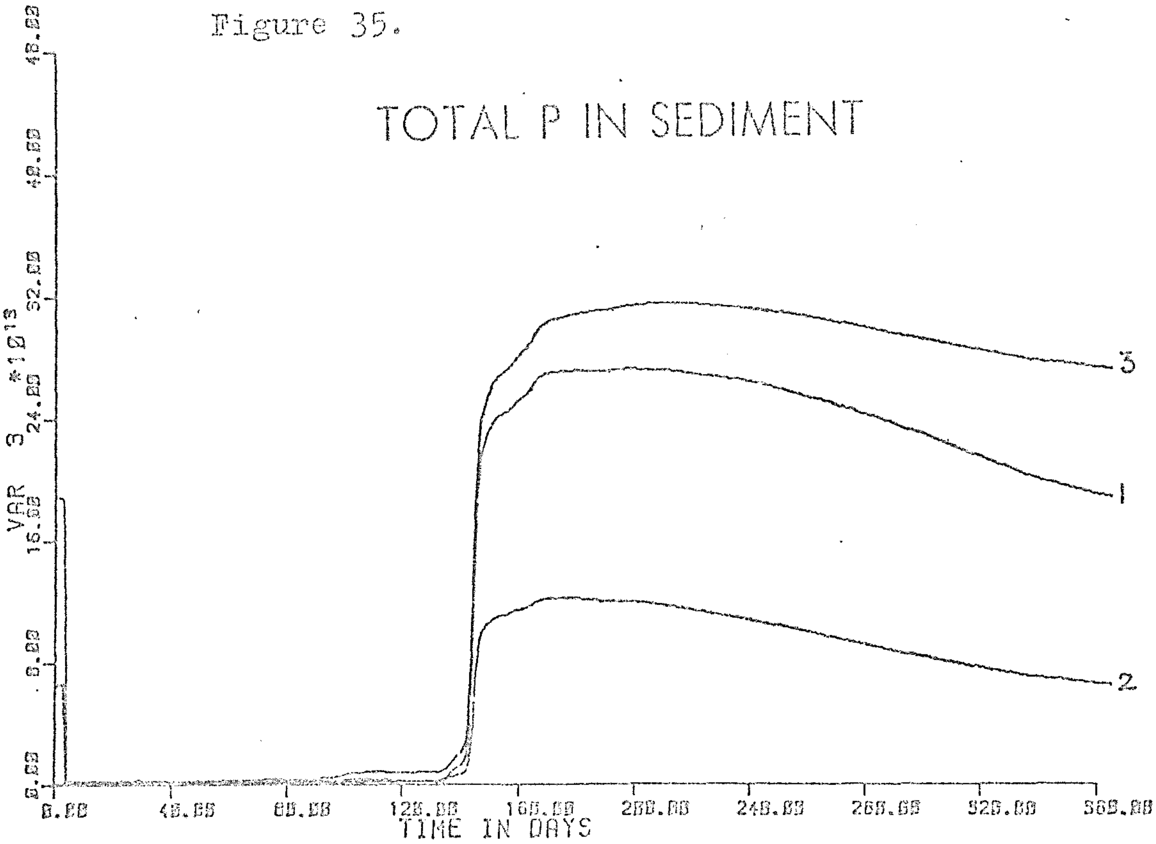
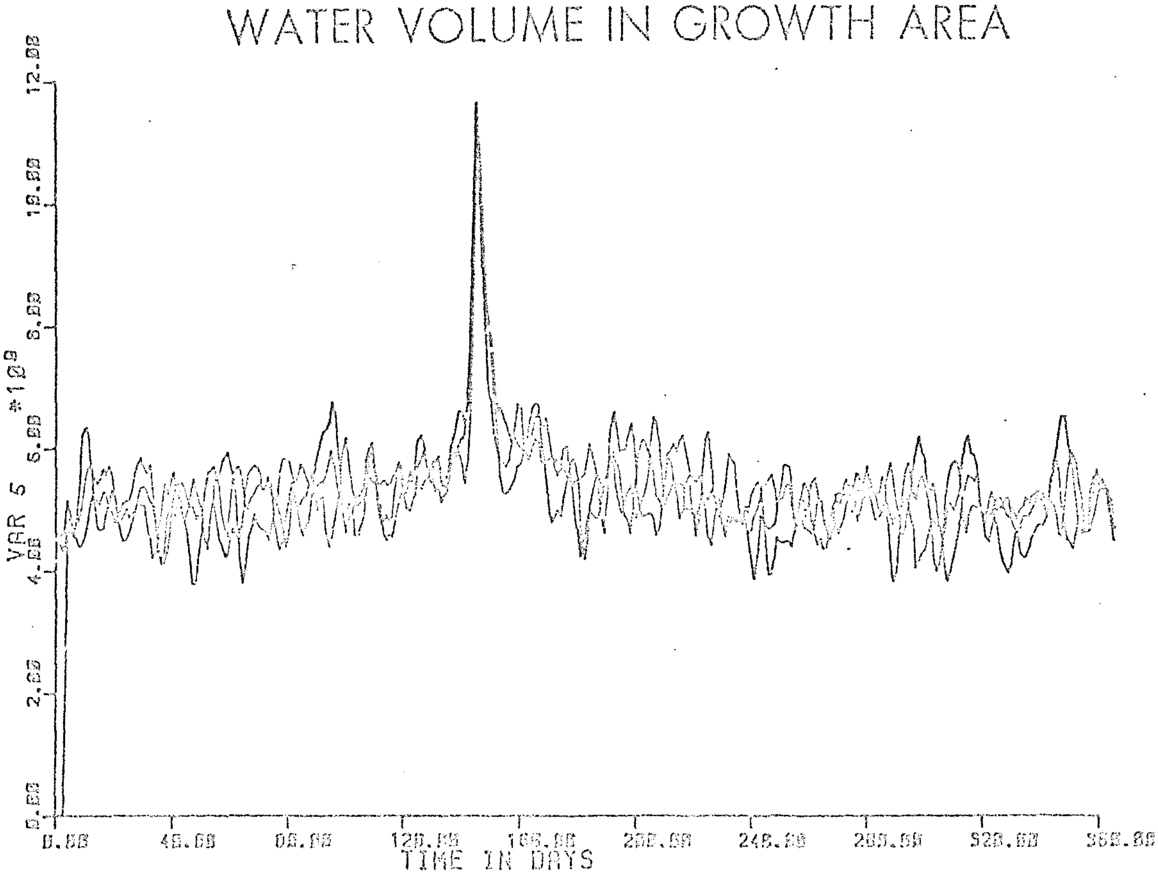


Figure 36.



The most important parameters are those defining:

1. photosynthesising biomass
2. particulate phosphorus levels in River Murray
3. Cladophora growth coefficient.

The importance of particulate phosphorus levels is shown from Figure 35 where high flows in the Murray River led to very rapid increases of phosphorus in sediments, which is possibly very important. (Compare Figures 35 and 36).

R.B. Humphries . Mindful of the constraints of the assumption of phosphorus limitation, three points arise from these results.

1. the higher levels of nutrients in the Cladophora mat versus the water column tend to support the assumed model structure.

2. it suggests that phosphorus could be the limiting nutrient. Under the assumption of phosphorus limitation the simulated pattern of behaviour is seen to correspond to those encountered in the real system.

3. the 2.5 cm layer of Cladophora is the actively photosynthesising unit on top of the mat and is the basic physiologically active part of the system because of self-shading. This confirms the importance of the maximum photosynthesising biomass and self-shading is an inbuilt control to the level of Cladophora that can be in the growth area at any one time. Death and export processes would have to be very high to sustain a continued high growth rate.

Activity in the system appears to start in October in response to winter river flow, and increases in solar radiation and peaks later in the year, followed by a rapid fall.

The primary importance of the model to the direction of the Peel Harvey study is that we should now measure particulate phosphorus levels in high flow periods, to test the hypothesis so generated.

NOTE: These conclusions have been modified in the light of subsequent work, which suggests that, under the assumption of phosphorus limitation, light is the dominant factor controlling the pattern of Cladophora growth observed in 1976-77.

SUPPLEMENTARY STUDIES

Reports were tabled at the meeting. They are summarised briefly below.

Mollusc studies F.E. Wells and B.R. Wilson, W.A. Museum.

This study started in March 1977 and is expected to continue until June 1979.

The biology of the hydrobiid snail *Hydrococcus graniformis* and the bivalve *Arthritica helmsii* is being studied. Both are small, about 2 mm when full grown, but both are very abundant in the surface sediments of the Inlets, thousands per m^2, and may be an important link in recycling detrital material. They are probably also an important part of the food of fish and wading birds.

Both species produce a few large eggs which hatch as small benthic animals. (*Hydrococcus* 0.25 mm shell length and *Arthritica* 0.5 mm long). *Hydrococcus* eggs are laid in capsules attached to shells and other solid objects. *Arthritica* eggs are brooded in the mantle cavity of the bivalve. Both species reproduce throughout the year with peaks in February (*Hydrococcus*) and autumn and early winter (*Arthritica*). It seems probable that growth is slow and that both species take about a year to reach maturity and spawn.

Other aspects of the biology of these species are being studied, including salinity tolerance, and a quantitative survey of the Peel-Harvey system was made in January and will be repeated at another season.

Waterbirds J.A. Lane, Department of Fisheries and Wildlife.

This is part of a continuing survey of the estuaries of the south west which concentrated on Peel and the southern end of Harvey during the period August 1976 to June 1977.

It is clear from this that the Peel-Harvey estuarine system has the largest waterbird populations of any estuary and is probably the most important estuarine conservation area of the south west. The areas especially favoured by waterbirds are the Creery Island - Channel Island area, the south-eastern areas of Peel Inlet and the southern end of Harvey Estuary. These have been recommended for reservation through the System 6 Committee.

In all 70 species of waterbird populations of 1,000 birds in the surveys and 5 had 10,000 birds (hoary-headed grebe, grey teal, coot, red-necked stint, banded stilt). Up to 8,000 black swans have been seen at a single survey (about half of the population of all south west estuaries), and it is evident that here as at the Blackwood they are a very important element in the estuarine ecosystem. Indeed it is tempting to think that the increase in swan populations over recent years may be the reason for the decrease in sea grasses (*Ruppia* and *Halophila*) reported by fishermen. To take this admittedly tenuous reasoning one stage further, one can postulate that loss of rooted plants has resulted in more nutrients being available for release from the sediments, thus contributing to the present algal problem.

Benthic fauna R.J. Rippingale and students, Department of Biology, WAIT.

A quantitative survey of the benthic fauna of Peel and Harvey Inlets was made during the summer of 1976-77. A series of core samples were taken along transects across the basins.

The poverty of the fauna, in species numbers, was confirmed. Only six species of mollusc were taken in the survey, although small numbers of another six have been found at other times. For comparison, there were 18 species in the Blackwood estuary. The extreme patchiness of populations makes any valid estimate of density very difficult to obtain without undertaking a much more intensive survey than was attempted.

All the molluscs are small species, but two are very abundant: the bivalve *Arthritica semen* (= *A. helmsii*) and the snail *Potamopyrgus* sp. *Arthritica* is widely distributed throughout both basins, but numbers were small where there was fine silt and accumulations of algae. *Potamopyrgus* was only abundant in Peel Inlet. Two other snails were abundant in the North and North-east part of Peel Inlet only, *Batillaria estuarina* and *Diala lauta*, and a third, *Liloa brevis*, was confined to the immediate vicinity of the Sticks channel.

Two puzzling features are: first the small numbers of the small mussel *Anticorbula amara*, despite the vast numbers of recently dead shells washed up on some beaches and the abundance of this species in the shallows of the Blackwood estuary. Second, the presence of a localised population of *Spisula trigonella* (not found in this survey) in the middle of Harvey estuary which suggests that it may have been introduced deliberately. It is abundant in the Swan estuary and some south coast estuaries (not in the Blackwood). Five species of polychaete worms were taken. They were only abundant in transects at the south end of Harvey and, one species, near Creery Island.

Crustacea were not sampled in this survey because of the sampling method used. However, it should be noted that three amphipod species are very abundant amongst weed, and also the shrimp *Palaemonetes australis*. They were taken in the night plankton hauls, *q.v.*

Plankton R.J. Rippingale and students Department of Biology WAIT.

This study aimed to determine what differences if any there are between the plankton of Peel Inlet and Harvey Estuary, what changes take place over short periods of time, and what potential losses of plankton biomass there may be with tidal exchange. Sampling was undertaken under summer conditions, in December 1976 and January 1977. Salinity varied from $14^{o}/oo$ to $39^{o}/oo$.

Daytime net hauls in Peel Inlet produced nothing and the abundant crustacean fauna taken in night hauls consisted almost entirely of animals which are normally regarded as benthic: several species of amphipods, mysids, harpacticoid and cyclopoid copepods. Even the calanoid copepods which are generally regarded as planktonic must retreat to the bottom during daylight in this shallow water. Numbers of most species were greater in Harvey Estuary than in Peel Inlet and this is thought to reflect the greater stability of Harvey water and tidal loss to the sea from Peel Inlet, possibly also the higher chlorophyll *a* levels in Harvey waters.

Phytoplankton was more abundant in Harvey than in Peel but in both it was sparser than in samples taken in spring of 1974 and 1975. Harvey water also contained more unidentifiable debris than Peel water. Diatoms were identified and the genera found are listed in the report. Much the same suite of diatoms was taken in both Peel and Harvey, but a few species were found only in one or the other and some species were much more abundant in one than the other. This probably reflects the more marine conditions in Peel than Harvey.

Peripheral vegetation D.J. Backshall, supervised by P. Bridgewater, Murdoch University.

The vegetation bordering Peel and Harvey and under the influence of estuarine water was identified and mapped on a scale of 1:25,000. A number of transects were examined in detail and the flora listed is related to level, distance from the water, and soil type.

Salt marsh development was observed in a number of places, particularly on the eastern, windward, shore of Harvey Estuary. Spits and sand bars are colonised by *Salicornia*, and when this traps sediments and builds up *Suaeda* becomes established. Beach ridges build up with the accumulation of blown sand in summer and these are colonised by *Juncus*, *Scirpus* and *Melaleuca cuticularis*. *Arthrocnemum* is also common in the well-established marshes.

Elsewhere, especially on the north and west shores of Peel Inlet, the marginal vegetation is receding. Quantities of *Cladophora*, and other aquatic plants accumulate on the *Juncus* fringe, killing this and allowing waves to erode the beach ridges. The roots of *Melaleuca* and *Casuarina* then become exposed and undermined. In spring the exposed shore may be colonised by *Salicornia*, *Suaeda* and *Scirpus*.

SOME PRELIMINARY COMMENTS ON THE FISHES OF THE PEEL-HARVEY ESTUARINE SYSTEM

It is very difficult to make any, other than very general conclusions from such a superficial look at the data available on fishes of the estuary. However, from the commercial catch statistics, and the results of the brief surveys by Scott and Chalmer (1974) and ourselves the following general statements can be made :-

1. The fish species composition of the estuary appears to be typical of other west coast estuaries of temperate Western Australia. (See summary of species list from the Peel-Harvey, Swan Canning, Murchison and Blackwood River estuaries attached). However, there are marked differences between the fish fauna of west and south coast estuaries based mostly on a comparison of the fishes from the Swan and Blackwood River estuaries (see discussion of paper "An annotated checklist of fishes of the Swan River, Western Australia" attached).

2. There appears during summer at least, to be a decrease in species diversity between the mouth of the estuarine system and the top end of Harvey estuary, due probably to the increasing salinity gradient between the two areas, i.e. 39% at the estuary channel to 52% at the upper end of Harvey estuary during early April, 1978.

3. The composition of the commercial catches does not appear to have changed markedly between 1952 and 1975. However, there are one or two changes that may be of interest.

    (i) Large catches of crabs were not common until the early 1960's.

    (ii) There appeared to be a greater proportion of mulloway and black bream in the catches during the 50's and 60's.

    (iii) Scaley mackerel and pilchards first appeared in the catches during the early 1960's

4. Over the period 1970-1974 (incl.), comparisons of the catches of species from both the Swan-Canning and Peel-Harvey system whose mean annual production was over 1,000 kg revealed some interesting points.

(i) Sea mullet, yelloweye mullet, cobbler and Perth herring were amongst the top producers for each system.

(ii) The catches of King George whiting and western sand whiting were much greater in the Peel-Harvey system.

(iii) Catches of mulloway and flathead were much greater in the Swan-Canning system.

(iv) Catches of pilchards and scaley mackerel were slightly greater in the Peel-Harvey system.

(v) Catches of prawns were much greater in the Peel-Harvey system.

The differences illustrated in points (ii) and (iii) above probably reflect the preference, by whiting for extensive shallow flats, and by mulloway and flathead for the deeper estuarine areas.

The greater prawn catches from Peel-Harvey are mostly due to the fact that the traditional professional fishery for them is better developed in this estuarine system.

N.B. We are presently working on the preparation of a preliminary checklist of fishes of the lower west coast estuaries. This document, together with all the other information available on the fishes of the Peel-Harvey system would provide sufficient basis for the preparation of a reasonably comprehensive account of the fish fauna of this system. I would be prepared to write such a document, provided I could be guaranteed a month or two off other duties to complete the document.

Rod. Lenanton

R. Lenanton,
Senior Research Officer.

5 May, 1978.