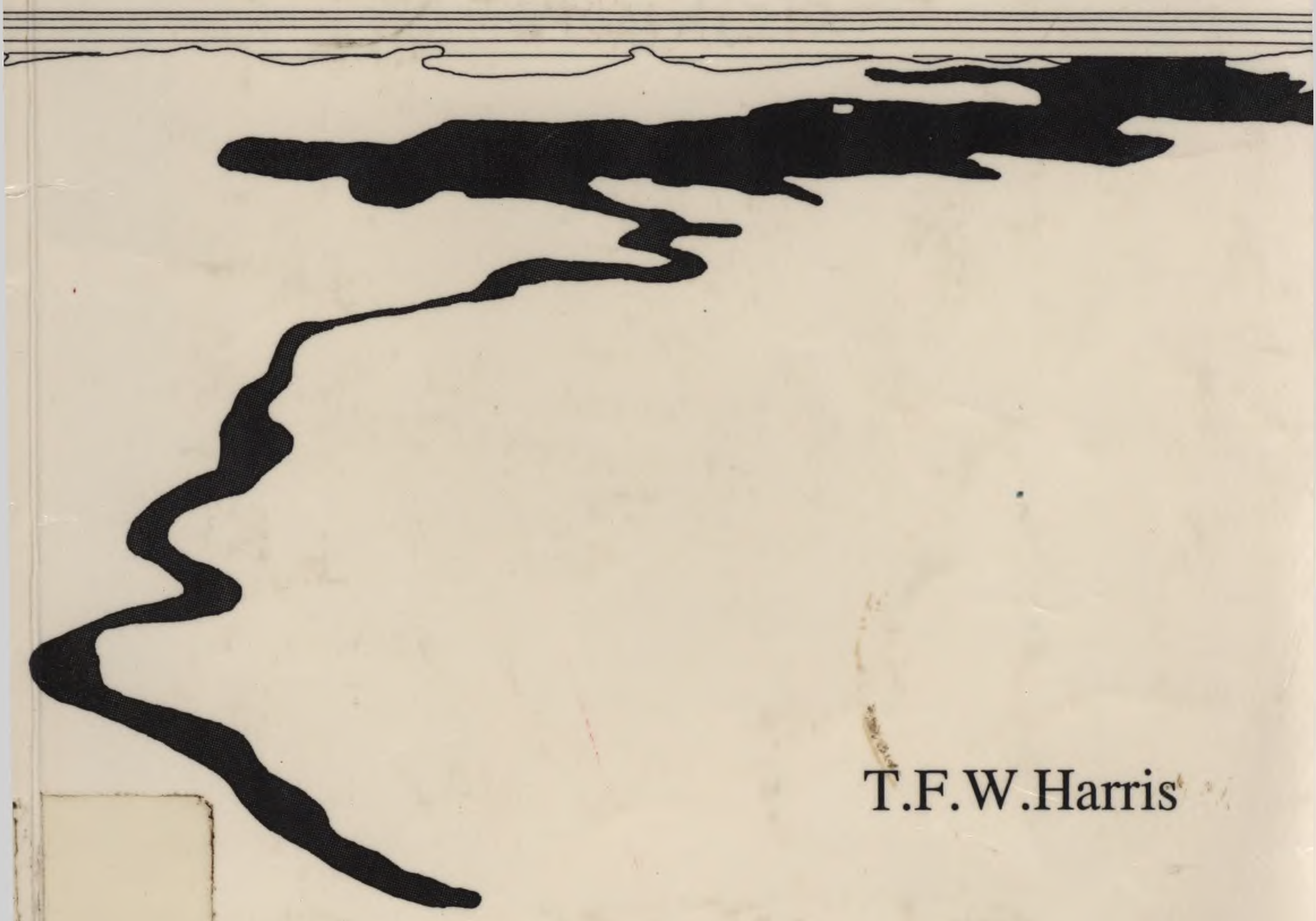
The Mahurangi System



T.F.W.Harris

Leigh Lab Bulletin No. 31

The Mahurangi System

Photographed from over Hamiltons Landing, this aerial view looks down the Mahurangi Harbour towards the Heads with the Whangaparaoa Peninsula in the background. Grants Island is in the centre of the picture. (Photo: Whites Aviation)

T.F.W.Harris

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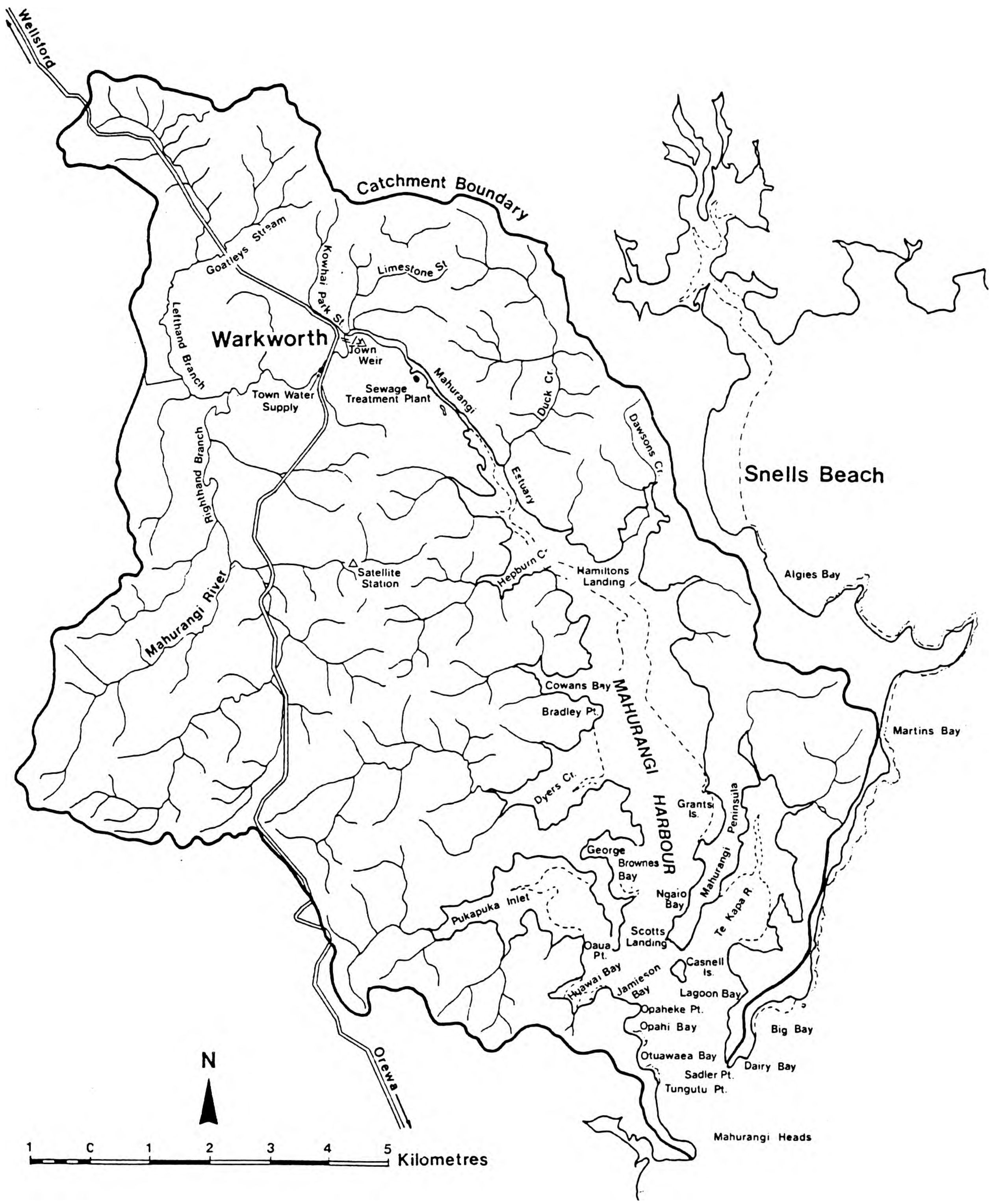

(From: Feeney 1984)

FOREWORD AND ACKNOWLEDGEMENTS

This account of the Mahurangi treats the system as an entity, consisting not only of a tideway, but also of freshwater and saltwater catchments, with habitats for flora and fauna and people. Together, these form what is called the Mahurangi System. To follow this treatment and keep it tractable in size, it has been necessary to make some selection of material and emphasis.

Acknowledgements

I am much indebted to many people for advice and assistance. Amongst them are:

For data (mainly unpublished):
The staff of the Auckland Regional Council, including, Ms C.M.Feeney (a most valuable report), Mr Royd Cummins (rainfall and river discharge records), Ms Turner (salinities), Mr Ken Becker (chemical analyses and fish survey data); Mr Graeme Austin of MAF (farming statistics); Mr Neil Dixon of the Warkworth Marina (tidal records and hydrograpic data); Mr John Lewington of Telecom Warkworth (rainfall records); Mr Mike Johnston (physical, biological and geological information from his excellent thesis); Mr Jo Evans of the University's Marine Laboratory (geophysical records); Mr Lee Sutherland (tideway sediments); Mr Atkins RNZN Hydrographic Office (depth soundings);
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I have had very valuable comments from the following who have read part or all of the manuscript: Dr Bob Creese of the Leigh Marine Laboratory; Mr Ken Becker, Mr Royd Cummings and Ms Bridget Thompson, of the Auckland Regional Council; Mr Craig Mountjoy and Mr Kit Brown of the Rodney District Council; Mr Jon Nicholson (an early draft on the tideway biological life); and Professor Ted Collins.

Dr Bill Ballantine, of the Leigh Marine Laboratory, assisted greatly with advice about the biological literature, and tideway fauna.

I am especially indebted to my wife for discussions on the work and practical assistance in the tideway hydrology study and prelimenary botanical survey.

The Auckland Regional Council assisted with the upgrading of many of the diagrams and photographs, and prepared the master sheets for reproduction. In this regard I should like to acknowledge my considerable obligation to Mr Don Abbott, whose cooperation was much appreciated.

To all these I am most grateful.

University of Auckland
Leigh Marine Laboratory
1993

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INTRODUCTION

The Mahurangi Estuary and Harbour belongs to a class of tideways which have been described as Hauraki Gulf Tideways, a classification based on common features, including mangroves, low freshwater inputs and shallow low-tide depths, leading to faunal similarities.

Our treatment of the Mahurangi System recognises that it is a product of the contribution from its two 'catchments'; the rivers and the sea. The latter has the general character of the Gulf coastal waters which have already been described (Harris 1993). The freshwater input, though small, is important because it reflects the catchment use. Ultimately, the continued good condition of the Tideway depends on what changes occur in the catchments; the consequences of human intervention.

The Components

The main elements of the Mahurangi System comprise the Mahurangi River, its Catchment and Estuary, the Harbour, and that part of the ocean immediately adjacent. The boundary between the Estuary and the Harbour is taken to be where the tideway broadens and deepens and where under normal flow conditions the salinity approximates to coastal water salinity; near Dawsons Creek. The physical features of the System are shown on the map in Section 1 below.

The whole system occupies about 148km^2 of which 83% is land and 17% tidal waters. The land catchment is mainly low lying, but rises up to hilltops of 330m in two places; near the Dome (336m) directly inland, and Moirs Hill (358m) on the western boundary. Essentially it is made up of attractive pasture which occupies 69% of the total area. There is a small remnant (11%) of native forest.

The western half is higher and more broken, and contrasts with the gentle undulations of the eastern side.
The land surrounding the Harbour is the well rounded landscape typical of the soft sandstones, mudstones and silt stones of the Waitemata Series.

The only significant river is the Mahurangi. Its basin reaches inland for a distance of 19km. The greater part of it is lower than 100m and it is possible by following the river valley to traverse nearly the whole distance and remain under 50m elevation.

Its catchment is small and consequently discharges only moderate amounts of water; 1400 litres (1.4 cubic metres) per second on average. The discharge can fall to 50 litres per second in prolonged dry weather. The river-water is nearly always turbid with the clays from the catchment. Pollution from farm effluents contribute to the nutrients.

The Estuary, about 6 km long, terminates at the waterfall at Warkworth, up to which point it is saline. At low tide the estuary comprises a shallow (a metre or so) small volume, low tide channel system. The high tide volume resulting from a 2.6m rise in level is about 5 times as great. There are extensive tidal flats and mangrove areas in the lower reaches.

The Harbour is one of New Zealand's larger coastal inlets (23 km^2). Depths increase from the Estuary to reach 18m near the Heads. There are two large side bays (Te Kapa River and Pukapuka Inlet).

Though the salinity in the relatively small volume Estuary shows the influence of the freshwater input, the salinity in the Harbour is normally only slightly less than that of the sea-water outside.

The Harbour opens out into northern Whangaparaoa Bay; not quite the open water of the Hauraki Gulf, but slightly influenced by coastal inputs.

The whole system is a particularly fine element of the New Zealand landscape.

The subject is dealt with under four main headings

* The freshwater component

* The salt water component

* The human habitat

* Management

SECTION 1: FRESHWATER COMPONENT

In this section we are concerned with the source and quality of freshwater, the rainfall, the influence of the catchment characteristics, and the nature of the main river feeding the Estuary.

SOURCES OF FRESHWATER

Rainfall

The characteristics of the rainfall are important because of their influence on the inputs of sediment and nutrients and on the salinity, so we shall look at them in some detail.

Rainfall records in the Mahurangi Catchment are available for stations at Redwoods, Turners, and the Satellite tracking station. Additional data from stations just outside the Mahurangi Catchment are recorded from Olliffs and Freshwater Farm (see map for locations) The data from these records, which have been used in this report, have been made available by the Auckland Regional Water Board and Telecom (Auckland) by personal communications.

Rainfall stations

S = Satellite station

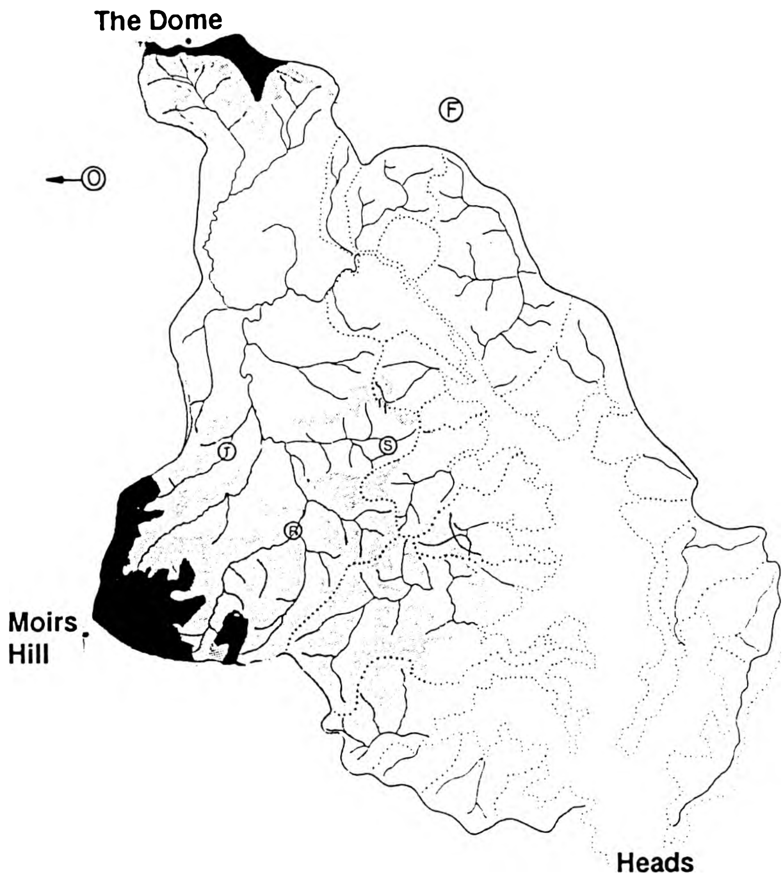
T = Turners

R = Redwoods

F = Freshwater Farm

O = Oliffs

altitudes 100-200m shaded
altitudes greater than 200m black



The following are the mean annual rainfall totals in millimetres, for overlapping records

	Satellite Stn.	**Redwoods**	**Turners**	**Fresh -water farm**	**Olliffs**
1982	1147	1312	-	1107	1240
1983	1318	1399	1089	1259	1470
1984	1428	1433	1274	1395	1524
1985	2026	1840	1869	2078	1909
1986	1439	1536	1351	1581	1475
1987	1368	1504	1329	1281	1411
1988	1808	1996	1964	1675	1804
1989	1589	1803	-	1728	1753

* missing data estimated for Turners 1986.

Total from					
1983	10972	11511	-	10997	11346

Mean of station totals (not Turners) 1983-1989 = 11206mm

Departure -234(2%)	305(3%)	-	209(2%)	140(1%)

There are obviously quite significant local differences in the annual rainfall.

To show the way the rainfall is distributed throughout the year, monthly means (millimetres) for the rainfall records of the Satellite tracking station near Warkworth are shown in the table below. See also Appendix 1.

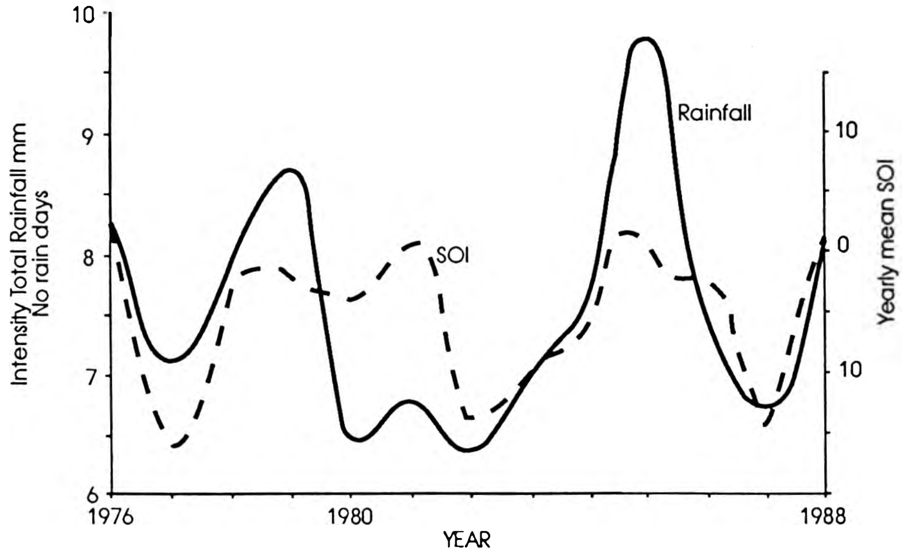
Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
126	103	122	104	127	123	159	157	141	111	97	153

annual minimum	1147mm in 1982
annual average	1515mm
annual maximum	2026mm in 1985
monthly average	125mm
lowest monthly	26mm in November 1982
highest monthly	348mm in July 1988
highest daily	200mm (next 86mm) on 22 May 1985
daily average	4mm

The common perception about monthly rainfall is that the winter months have the highest rainfall on average. Whereas this is true, it is noticeable from the data in Appendix 1, that for the years selected, the distribution of rainfall throughout the year was very variable. Thus, for example, there were four winter months which had less than 70mm. The inter-year variability is also most noteworthy. The rainfall in some years was twice as much as in others. See for example the years 1982 and 1985 at the Satellite tracking station.
The main influence causing these variations is almost certainly to be found in the changes in the meteorological conditions in the Equatorial Pacific, as measured by the Southern Oscillation Index. (See Gordon 1985 and Harris 1993) To illustrate the relationship between the Oscillation Index (SOI) and the rainfall intensity in the Mahurangi River catchment, the annual averages have been plotted on the graph below. These considerations are obviously important for water engineers and also, perhaps, for marine farmers.

High intensities are to be expected when the index is positive. Sediment loads would, presumably, also be higher.

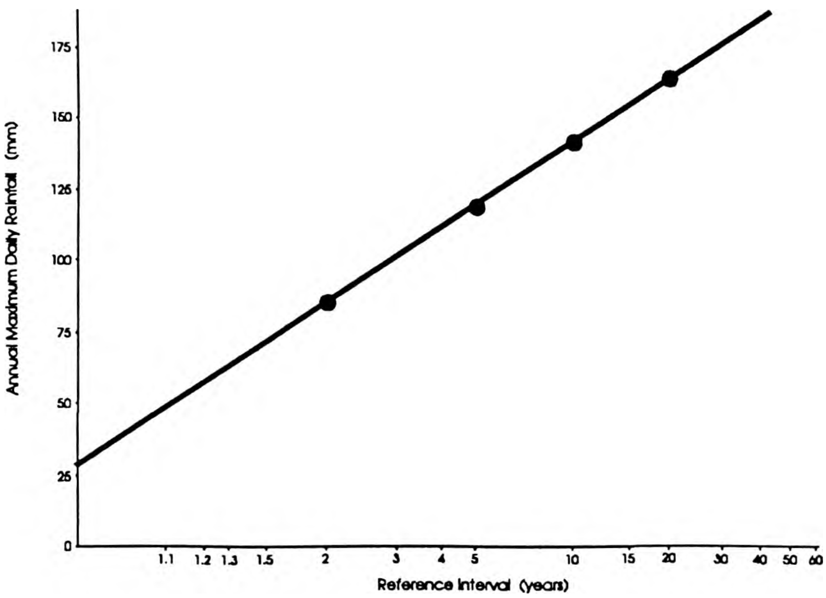
Rain intensity was lower in 1982/3 about 6.5mm as compared with 9.8mm per rain day in 1985. (The rain intensity is measured by the total annual rainfall divided by the number of rain days).



Comparison of yearly mean rainfall intensity at the Satellite Tracking Station gauge (mm) and the Southern Oscillation Index (SOI).

It is of interest that, for years for which we have river discharge data, the index was unusually negative in two of them (1982/3 and 1987) and moderately high in 1985. As will be shown later, in 1982-3 and 1987 discharge values were about half those of 1985.

The return periods for the highest annual daily maximum rainfall for the Warkworth Satellite Tracking Staion records are shown in the graph below. (R.Cummins personal communication).

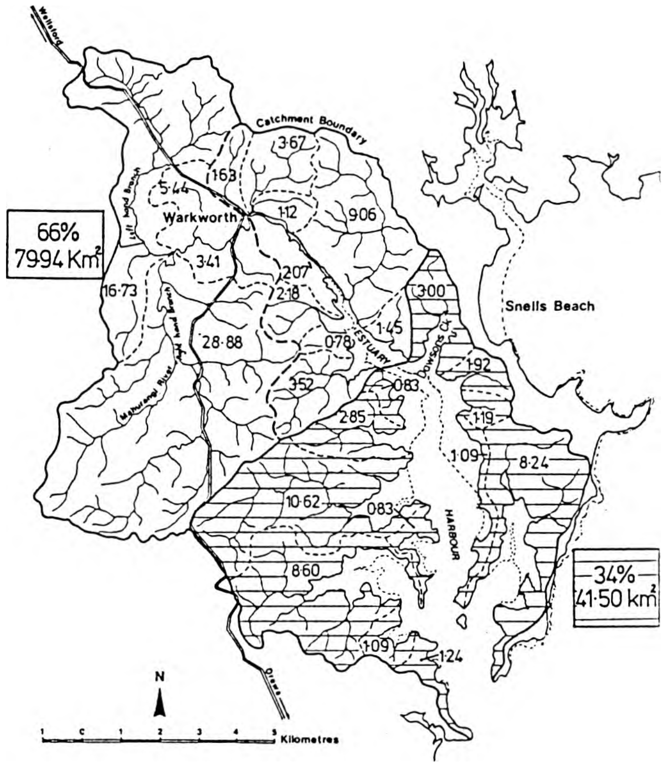


Graph of the return period (in years) of daily annual maximum rainfall (mm) at the Warkworth Satellite station. For frequency of occurrence data for recordings at the University of Auckland's Leigh Laboratory see Evans and Ballantine (1986).

Rivers

The Mahurangi River which drains 46.8km² (over a third of the whole catchment) is the main source of fresh water entering the estuary, but there are several small streams which also contribute e.g Hepburn Creek, Cowans Creek, Dyers Creek on the west bank and Duck Creek and another near Warkworth, on the east (see page 2). Their contribution has not been measured but some estimates can be made based on the area of each subcatchment, assuming rainfall run- offs. Feeney (1984) estimates these as between 47-51%. Catchment areas are shown on the diagram (Feeney 1984).

Areas in km² of catchments draining into the Estuary and the Harbour. (From Feeney (1984).



Catchment areas (km²) of the Creeks emptying into the Estuary and Harbour are as follows:

Mahurangi River	54.46 (44.8%)
Estuary	
Kowhai Stream	1.63
Lime works stream	3.67
Duck Creek	9.06
Hepburn Creek	3.52
Other	7.60
Total to Estuary	25.48 (21%)
Harbour	
Dawsons Creek	3.00
Cowans Creek	2.85
Dyers Creek	10.62
Pukapuka Inlet	8.60
Te Kapa River	8.24
Other	8.19
Total to Harbour	41.50 (34.2%)

The combined areas of the smaller catchments exceeds that of the Mahurangi River

Open water surface areas (Km²)

Harbour open water	22.68
Estuary open water	2.03
	Total 146.15

Rainfall and River discharge

In this section we examine the relationship between rainfall and the Mahurangi River flow as measured at the Woodcocks Road measuring site (data from the Auckland Regional Water Board). One of the problems in doing this is to decide which of the rainfall stations is most representative of the water reaching the river. From the annual rainfall figures given above it is evident that there can be significant differences between the quantity measured at the rain gauges in or near the catchment. An extreme example of this was the 22% difference between Turners and Redwoods in 1983. Here, two topographical features which might affect rainfall should be noted.

a. The river's two main tributaries (Right and Left branches) are aligned roughly north and south.

b. The catchment is mainly low-lying (below 100m). Higher ground is to be found towards Moirs Hill, and the Dome where a small area of the catchment is above the 200m contour and a very small area above 300m.

Choice of representative rainfall station

To investigate which sites are most representative, the annual average daily quantity of rain falling on the total area of the river catchment, using values of the rainfall for each station as if it was representative, was converted into a rate per second (using a run off coefficient, k, of 50%) and plotted against the annual average daily flow of water in the river (see figure).

The estimated equivalent flow rate for rainfall was calculated from the following relationship in which the catchment area above the river discharge measuring gauge is taken to be 46.8 km² and the annual total rainfall P is mm/year. Q is the calculated equivalent flow in units of m^3s^{-1}.

$$Q = 14.84 \times 10^{-4} \times 0.5 \times P$$

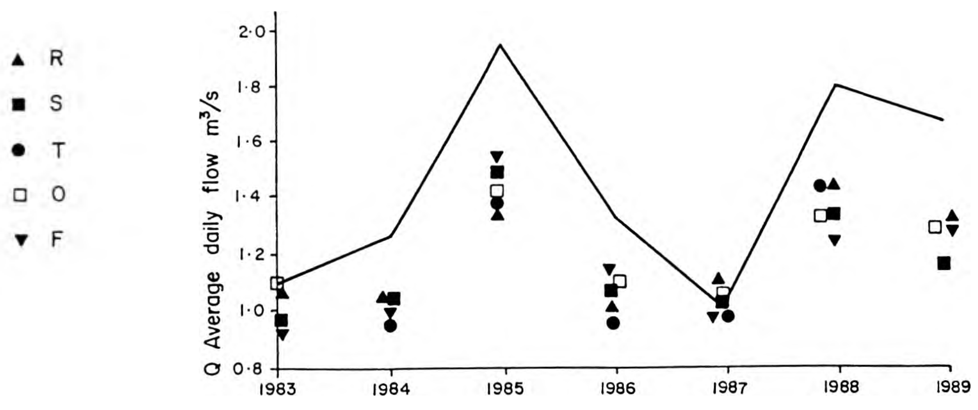
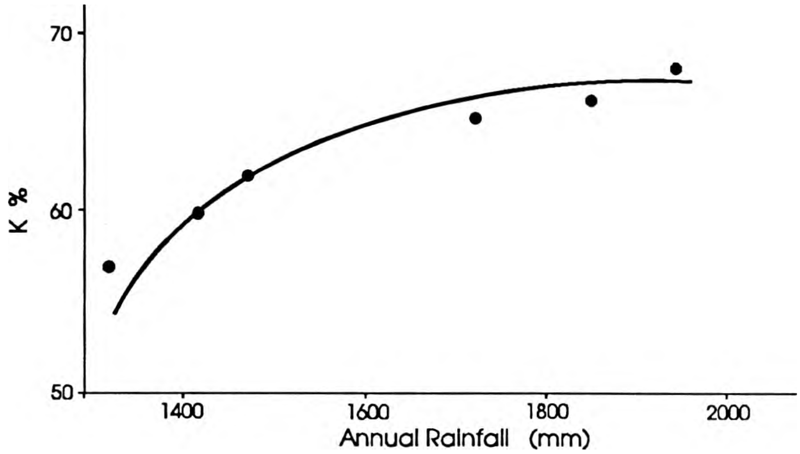


Figure showing the measured average daily river flow rate for the years 1983-1988 (full line) and the estimated rainfall equivalent flow rate (based on a 50% runoff for five measuring stations indicated by the symbols S=satellite station, R=Redwoods, T=Turners, F=Freshwater Farm, O=Olliffs.

Inspection suggests that Olliffs and Redwoods score marginally highest as representative stations.
Possibly, the former, being on the higher ground of the river's right hand branch measures best the rain from the east while the latter being situated to the west and closer to the left branch, best measures the rain brought in by the westerlies.

Runoff coefficient

Another fact which inspection suggests is that a 50% runoff coefficient, k, while being suitable for low flows, is too low for wet years, when runoffs constitute nearer to two thirds of the rainfall. This point is illustrated in the graph which shows the way the average value of k varies with annual rainfall P (taken as an average of the total rainfall for the year at all five stations).



Change of average runoff coefficient (k) with increasing annual rainfall (P in mm/year) averaged over 5 rainfall stations in or near the Mahurangi River Catchment for the years 1983-1989.

Because of the rather short time series of data available this result must be regarded with suitable caution but it does seem that, based on annual figures, the fraction (k) of the rain which finds its way into the river increases from 50% at low flows to 67% (and perhaps higher) at high flows. The increase is fast up to about 1450mm per year and tends to level off after that. The relationship is very roughly a semi-logarithmic one of the type

$$k = 0.2 \log_{10} P$$

where k is the fraction of the rain reflected in the river flow and P is the annual rainfall in millimetres.

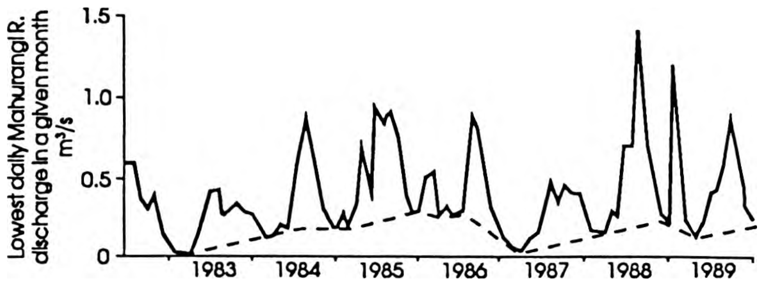
A useful rule of thumb is that the mean river flow in any year in units of litres per second is very roughly equal to the annual total of rainfall in millimetres. This is an artifice of the units.

Factors affecting runoff

There are, of course, many factors which control the fraction of the rain which finds its way into the river. Amongst them are:

a. the nature of the soil; its permeability. Since most of the Mahurangi River catchment has a clay soil it is to be expected that after the wetting of the top layers there will be a high runoff because of the low permeability of clay. The fraction of light rain reaching the river may well be less than that with heavy rain. It follows that the runoff will be less in the first half of a storm (some rain being required to saturate the soil). This effect may be exacerbated by the formation beneath old kauri forests, of an impermeable "pan", the consequence of the leaching of metals.

b. the degree of saturation in the antecedent conditions. Consider the accompanying figure which is a graph of the lowest daily Mahurangi River discharge in any given month i.e. the base flow to which the particular rainfall runoff is added. It is clear that the winter base flows are much greater than the summer ones, as one would expect.



Graph of lowest daily flow in the Mahurangi River in a given month in the period 1982-1987. The broken line shows the trend of the lowest of these values. (data from Auckland Regional Water Board, personal communication).

There are also very large inter-year differences in low flow values. In very dry years the clay dries out and contracts, leaving wide cracks and fissures which greatly enhance the penetration by rain. As a consequence the proportion of the rainfall reaching the river will vary depending on the season and on the particular year and its antecedent conditions. Thus in 1983 the land had dried out, the base flow was only about 50 l/s in the summer and 450 l/s in the winter, whereas in 1985, a wet year following a moderately wet year, the values were 200 and 900 l/s.

c. the intensity of the rain. Much of the rain in the Mahurangi catchment falls in fairly intense storms.

d. the phase of the rain episode. Rivers tend to rise rapidly in response to a substantial downpour, and then fall exponentially.

Response of the Mahurangi River; case histories

The river's response to rainfall is illustrated by the extreme case of very high rainfall on 22 May 1985 when 200 mm (as measured at Turners) fell in a day. That same day the gauging showed a rise in discharge from 400 litres per second to 40,000, an increase of two orders of magnitude.

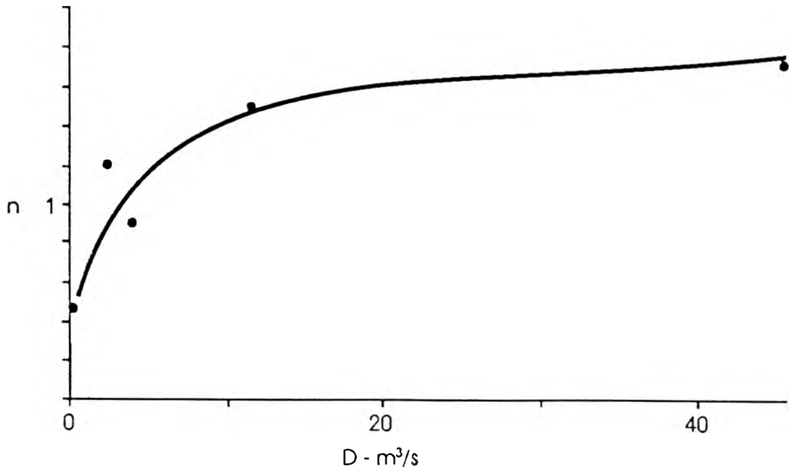
The decay after a rainfall event takes place in two stages; there is at first a very steep decline in discharge down to a value of about 3000 litres per second after which the decline is at a much slower rate. Very roughly, the decay regime is along two straight lines intersecting at the 3000 litres per second level.

Examples of the rise and fall of the River and the rainfall falling concurrently, are given for a number of occasions under a variety of rainfall intensities. The case histories selected describe, as far as possible, a single rainfall event lasting one or perhaps two days, and encompassing the river's rise from base flow and then the return to base flow. These examples show the rapid response and the slow decay over a period of the order of 5 or 6 days after the cessation of the rain. Also included with the river regime curves are the relevant surface atmospheric pressure charts which indicate the weather system which gave rise to the rain.

The decay curves are interesting in that their shape is similar irrespective of the magnitude of the rain storm. In general the reduction of the discharge during the decay (D litres per second) with time (T days after peak flow) depends on the maximum discharge (D_m litres per second) according to the relationship.

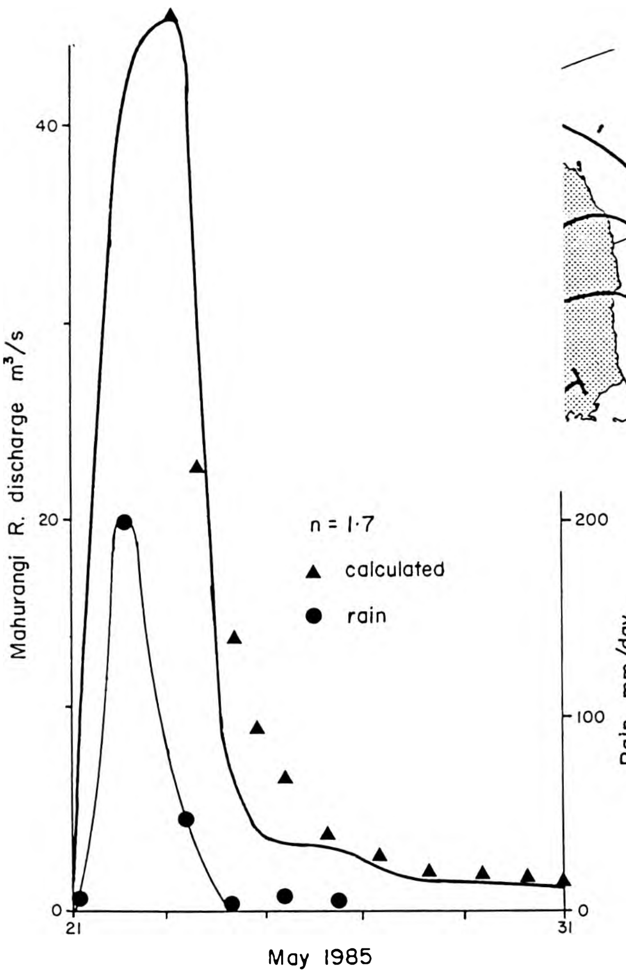
$$D = D_m/(1+T)^n$$

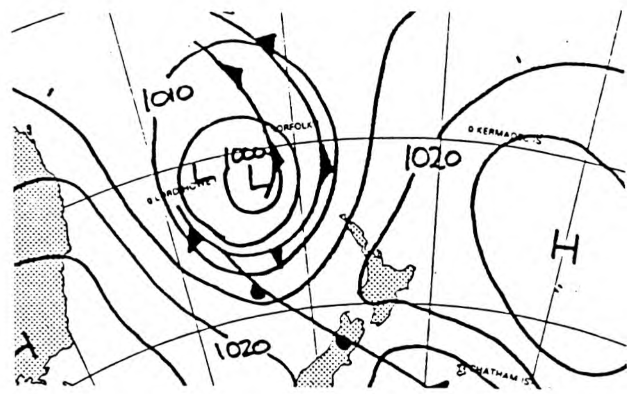
where n increases from about 0.9 at low values of D_m to 1.7 for high ones.



Graph showing the way "n" in the decay equation $D = D_m/(1+T)^n$ increases with the maximum discharge D_m for the event.

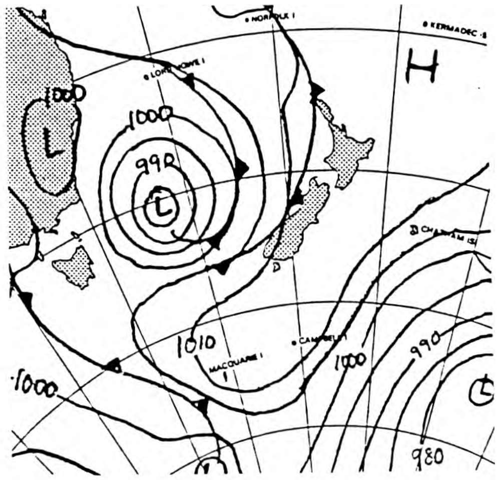
Response of the Mahurangi to rain. Example 1: Very heavy rain

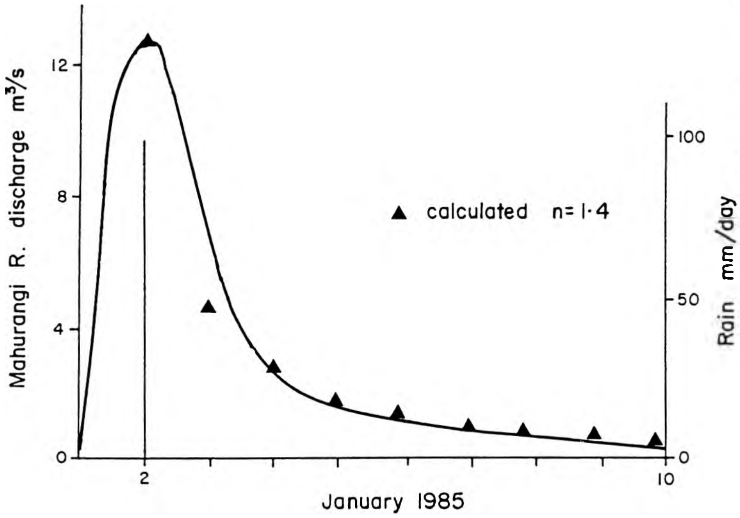




The highest discharge in the Mahurangi River in the years 1982 to 1989 was 46210 litres /second or 46.21 m^3/s, about 30 times the average flow and 100 times the initial base flow. It occurred on 23rd May 1985. The curve above (thick line) shows the rise and decay of the flood as well as the rainfall (thinner line with separate axis). The triangles are the computed river discharges with time after the peak of the flood using a value for n=1.7 in the equation discussed above. The accompanying surface atmospheric pressure chart shows that the weather system responsible was a subtropical cyclone centred initially on Lord Howe Island in the Tasman Sea and a blocking high pressure region to the east towards the Chatham Islands. The resulting northeast winds blew over a warm sea fetch stretching from the Kermadec Islands, bringing in moist air and depositing 200mm on 22nd May. The run off coefficient for this event may have been as high as 75%.

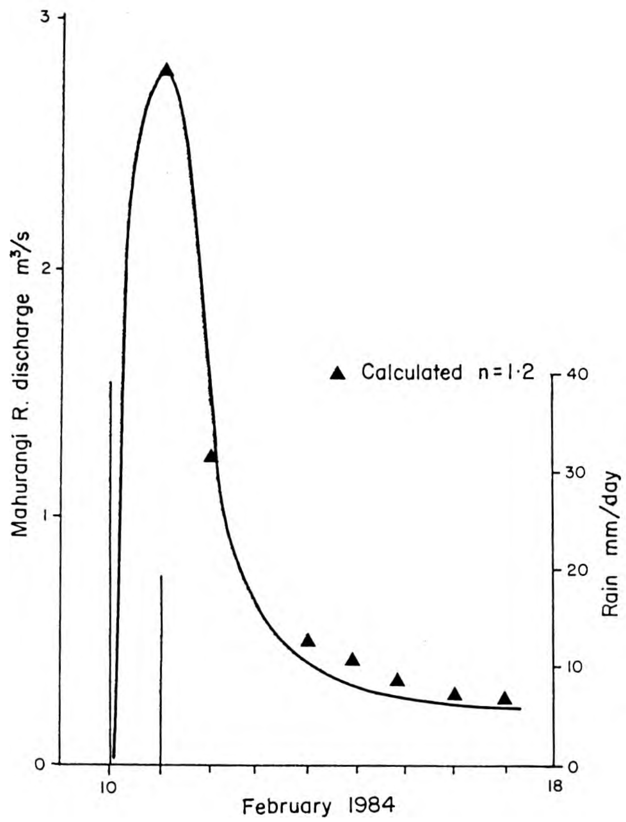
Response of the Mahurangi to rain Example 2: heavy rain

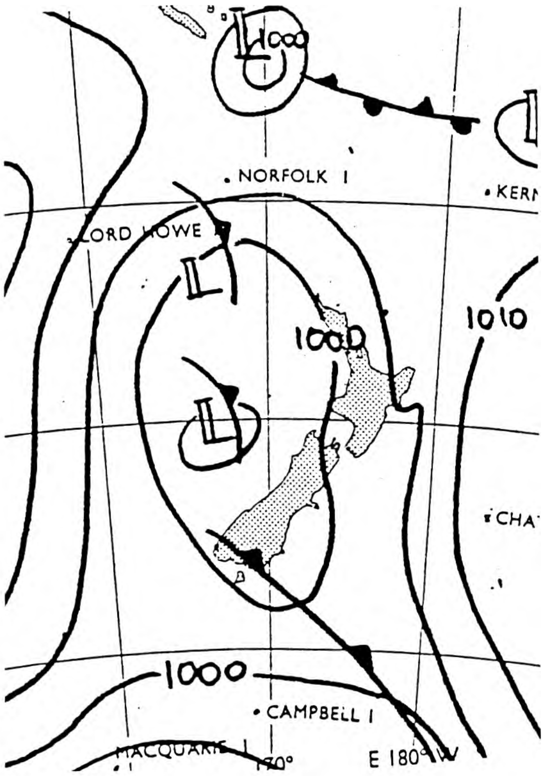




On 2nd January 1985 96mm of rain fell (thin line). The river rose from a base flow of 400 litres per second to a maximum of 12,760 litres per second. The decay curve is best simulated by the use of n=1.4.
The surface atmospheric chart indicates that the rain was a product of a deep low pressure region in the Tasman Sea.

Response of the Mahurangi to rain. Example 3: lighter rain



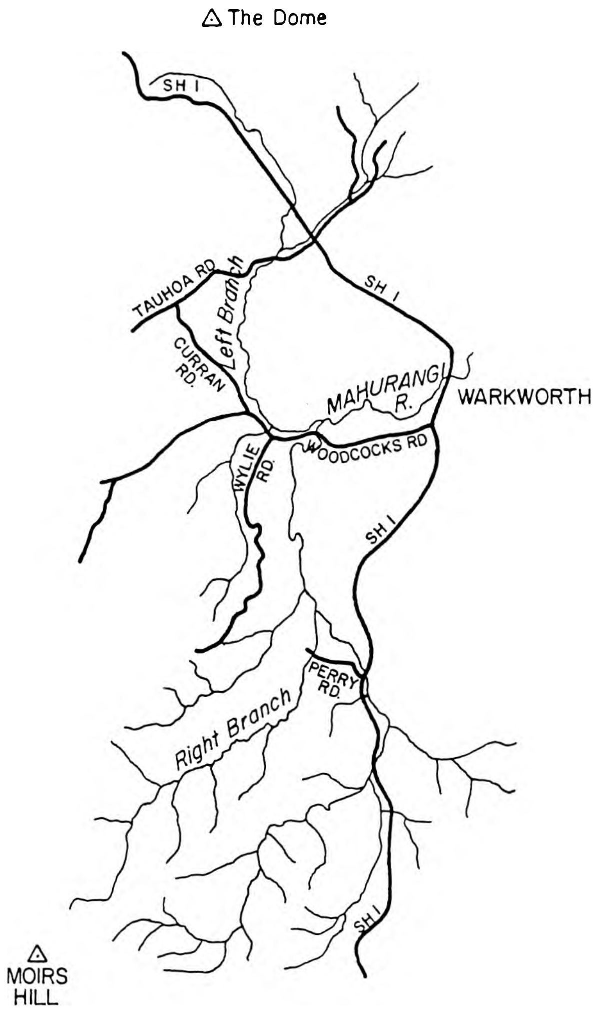


On 10th February 1984, 39mm of rain was recorded at the Satellite Tracking Station. A further 17.7mm fell the following day. Rainfall of this intensity is commonly experienced. The River's response was to rise to a flow of 2.8 m^3/s from a very low base flow of 0.2 m^3/s. Calculated values (triangles) were based on an 'n' value of 1.2 in the decay equation. The rain was associated with a cold front in a westerly wind system. The surface pressure chart shows the situation at 0000hrs on 11th February.

THE MAHURANGI RIVER AND ITS TRIBUTARIES

There are two main tributaries of the Mahurangi River; a short Left Branch originating in the vicinity of the Dome (336m high) and, draining a catchment of 16.73 km^2 and flowing southwards, and a Right Branch which is longer and has its source near Moirs Hill (358m). It drains a catchment of 28.88km^2 and flows north. The two merge about 2km above Warkworth to form the Mahurangi River proper which exists for a very short distance before discharging into the Estuary. The river beds are mainly soft with occasional rock outcrops, notably in the River between Falls Road and Warkworth.

The only measurements of the quantities flowing in the rivers and creeks are from an Auckland Regional Water Board gauge set up on the Mahurangi River near the College above Warkworth.



Left Branch

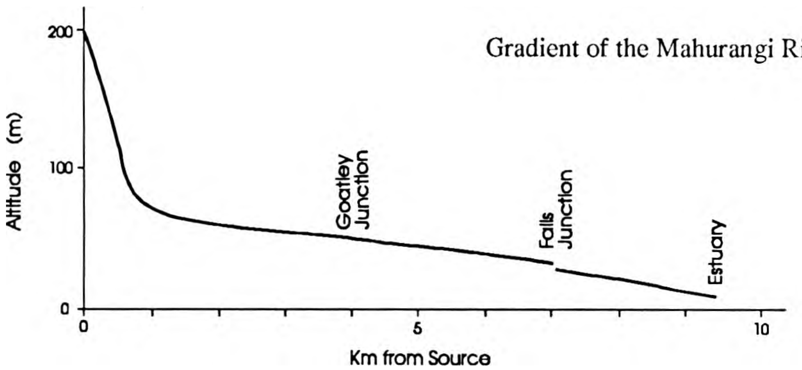
The head-waters fall swiftly off the high ground of the Dome escarpment and by the time they reach L. Philips' farm they are moving at 50cm a second in a channel about a metre wide and have a discharge of perhaps 0.25m^3/s. Up to this point the river has fallen quite quickly and the habitat for flora and fauna is fast moving water; a non-sedimentary regime.

After Grimmers Bridge, on State Highway 1, the stream leaves the Dome Valley. It widens to 2-3m and the flow becomes sluggish as it meanders over flat country until the Tauhoa Road Bridge, just above which it is joined by a major tributary the Goatly Road Stream. Below the junction the River increases speed and narrows. There is a small fall down- stream of the bridge

At Civil Farm bridge the flow is again sluggish. Meandering flow between totara lined banks continues until short of the Curran Road-Woodcocks Road intersection. Here the flow is more substantial. Speed was about 25cm per second and width 2.5m; discharge just under 1m^3/s. This lower part of the Left Hand Branch is more sedimentary and the stream life would be that suited to the habitat. For example weed growths are more noticeable.

At Falls Road the River tumbles down a 5m fall before its junction with the Right Hand Branch amid bush, which has a quantity of quite mature kauri trees.

Over its whole length (about 7km) the Left Branch is confined (during normal flow) to well vegetated banks which, at its latter end, are deeply incised. The diagram shows the profile of the river. The gradient for the first kilometre is 1:5 and for the remainder is 1:136.



Gradient of the Mahurangi River and its Left Branch.

Right Branch

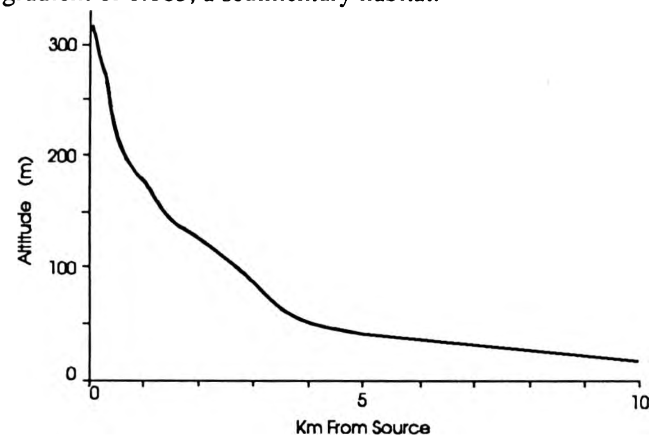
This branch is a little more complicated than the Left Hand Branch. As shown in the map above, it has several tributaries. The two longer ones, both of whose sources are within 1km of the summit of Moirs Hill at a height of just over 300m, flow either side of Redwoods Road. Other lesser ones include one nearer to State Highway 1 and one on the west side of the catchment running alongside Wylie Road. The longest distance from source to junction with the Left Branch is about 11km. The two main components merge just below Perry Road.

The main tributary flows initially through a native and pine forests and then descends to paddocks where it is normally about 1m wide, 0.2m deep and has a speed of 0.5m/s over shallow rocks. Where examined its banks were steep and seemed well vegetated. When viewed the water appeared slightly turbid.

The diagram shows the profile of the western-most of the main tributaries. There are three different gradients.

1 : 4 · 5

* steep fall of 1:45 in the first half kilometre which is essentially a non-sedimentary habitat
* a medium gradient of 1:20 over the next 3km
* and then a very flat gradient of 1:185, a sedimentary habitat.



Gradient of the main tributary of the Right Branch.

The Mahurangi River

The junction of the two main branches takes place just below the Woodcocks Road bridge. In its short journey to the Estuary at Warkworth, the River meanders and has several rapids or low falls. In this stretch of the river there is an abundance of floating weed which is a copious producer of oxygen during daylight, a factor which will bias oxygen measurements depending on what time of day they are made. Some changes in water properties occur in this section. (see below).

Discharge

An ARWB gauge on this part of the river near the school on Woodcocks Road has been operating since June 1982. A summary of the recordings over the period to September 1989 (in units of litres per second unless otherwise stated) is set out in the table below. It shows the monthly mean discharges. For economy of space, the quantities have been rounded off and divided by ten.

Area of Catchment to gauge 46.8km²
Total area for river to Warkworth weir 54.46km² (44.8% of the land catchment).

Table of monthly mean discharges in the Mahurangi River. **Figures in the table should be multiplied by 10 to give litres per second units.**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1982	-	-	-	-	-	-	202	849	124	115	312	150	
1983	10	10	18	78	47	199	171	82	105	265	80	234	109
1984	35	39	77	48	104	109	194	379	177	85	40	200	125
1985	128	122	184	202	393	238	281	227	211	85	137	126	195
1986	260	174	40	53	105	98	230	328	204	82	33	25	136
1987	16	9	21	57	27	73	204	81	206	114	138	268	102
1988	38	38	297	53	141	132	541	401	172	128	64	129	179
1989	570	72	28	31	71	137	108	349	333	196	102	38	167

* the greatest daily discharge rate is about 46000 l/s (46 cubic metres per second).
* the lowest daily flow is 40 l/s (0.04 cubic metres per second).
* the monthly mean flow is 1410 l/s (1.41 cubic metres) per second.
* after a storm it takes about 5 days before the river returns to 'normal base flow' (see below).
* the river discharges vary significantly from year to year Thus in 1985 the mean daily flow rate was about 2000 l/s, double that of 1983, reflecting different rainfall. As discussed above, inter-year differences are probably attributable to the differences in the index of the Southern Oscillation in the Equatorial Pacific

Minimum flow rate l/s	daily mean	40
	monthly mean	92
	annual mean	1018
Mean flow rate l/s	monthly mean	1410
Maximum flow rate l/s	daily	46210
	monthly mean	5699
	annual mean	1952

(One cubic metre per second is a thousand litres per second).

The frequency of occurrence of the river stages is given in the accompanying graph prepared by the Auckland Regional Water Board (personal communication).

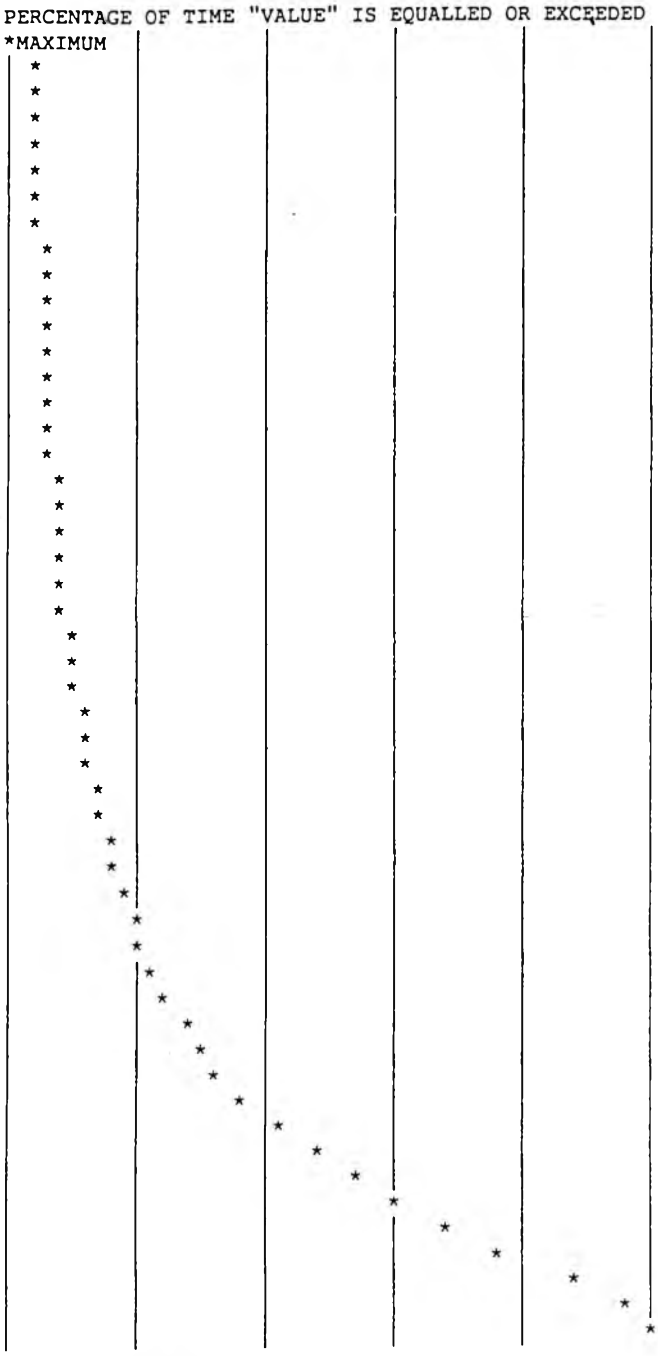
Site 6806 820611 131500 to 890220 144500 Item 1 Rating Applied

MAHURANGI at COLLEGE - DISCHARGE (ml/s)

DISTRIBUTION

PERCENTAGE OF TIME "VALUE" IS EQUALLED OR EXCEEDED

		204708368	*MAXIMUM
103	194421	4900000	4.2
2	111752	4800000	4.3
2	115521	4700000	4.4
3	34034	4600000	4.6
2	232818	4500000	4.7
3	43650	4400000	4.8
3	104849	4300000	5.0
3	124205	4200000	5.1
3	225821	4100000	5.3
4	65315	4000000	5.5
4	64514	3900000	5.6
4	75414	3800000	5.8
4	235111	3700000	6.0
5	132906	3600000	6.2
6	123511	3500000	6.5
6	84055	3400000	6.8
6	131511	3300000	7.0
7	101657	3200000	7.3
8	95439	3100000	7.7
9	11701	3000000	8.0
9	175858	2900000	8.4
9	112050	2800000	8.8
11	151241	2700000	9.3
12	193444	2600000	9.8
15	131113	2500000	10.
14	103642	2400000	11.
16	71140	2300000	12.
17	92301	2200000	12.
19	154317	2100000	13.
22	33248	2000000	14.
27	224333	1900000	15.
28	114751	1800000	16.
33	65440	1700000	18.
36	70200	1600000	19.
39	40658	1500000	21.
45	3904	1400000	23.
51	44419	1300000	25.
53	111821	1200000	27.
54	223034	1100000	29.
51	4438	1000000	31.
118	85230	900000	36.
129	225655	800000	42.
142	84540	700000	47.
164	101008	600000	54.
165	85202	500000	61.
174	235827	400000	68.
218	72610	300000	77.
270	135037	200000	88.
182	112706	100000	95.
112	30208	42490	100.
0	54500=GAPS		
2446	13000=TOTAL		



MEAN= 1421105.62 STD.DEV.= 0.383034E+07

Cumulative curve of frequency of occurrence (fourth column) of discharges equalling or exceeding the given value (ml/s, third column).

Mahurangi River Water Properties and Chemistry

Influence of the Catchment

Geology and soil

The characteristics of the soil have a profound effect on such tideway processes as the rate of sedimentation, the level of turbidity and the adsorption of nutrients, all of which combine to determine the kind of aquatic life.

The surface geology and soils conform closely to the general description given in Harris (1993). The dominant near-surface Waitemata Group of sandstones, mudstones and siltstones has weathered to clays, which are widespread as Warkworth and Whagaripo Clays. The former is more frequent in the north and east of the Harbour catchment. Small patches of Onerahi Breccia chaos occur near Sandspit and limestone on the west bank of the upper Estuary. Alluvium is to be found in the river valleys.

Work in the Upper Waitemata Harbour Catchments, with similar geology (van Roon 1983) has shown the extremely high stream sediment loads during storms.

Land use and vegetation

The kind of operations which are pursued on the land and the vegetation have an influence, sometimes important, on the quality of the water runoff.

Most of the original forest cover (kauri, pohutukawa, puriri etc) had been cleared by the late 1800's and given over to agriculture. Pasture is the dominant land use and only 11% of the 121km^2 catchment remains under native forest. The following is from Feeney (1984).

Land use	Area in hectares	Percent of catchment
Pasture	8,3318	68.6
Native forest	1,336	11.0
Exotic forest	1,093	9.0
Scrub	971	8.0
Urban residential	413	3.4

Land under pasture is used for dairy farming on the lower undulating country. The dozen or so dairy farms, with about 1500 cows, are mainly situated on the lower left branch of the Mahurangi River, or Duck Creek. This concentration of the dairy farms has some pollution implications which are dealt with in later sections about the nutrients and management. The 17 larger stock farms and small blocks support about 3000 head of cattle , while the 5000 sheep are mostly to be found on 3 large farms in the steeper areas towards the Heads on the west side. Pigs, goats and deer are also farmed.

The application of lime and fertilizers have altered the condition of the soil and the latter is a source of nutrients in runoff water.

Native forests are found in the high country of Moirs Hill and the Dome and in other areas on the banks of the Estuary and Harbour. Exotic forests of pines have been established on the west side of the catchment and a small area south of Pukapuka Inlet. Urban or residential areas are at Warkworth, Snells Beach the Mahurangi Peninsula, Jamieson Bay and Opahi Bay.

Water properties

The sampling and analysis of the fresh water properties have been carried out by the Auckland Regional Water Board. The two main branches of the Mahurangi, described above, have slightly different characteristics. The Left Branch has on the average a higher load of nutrients but lower faecal coliforms. It should however be emphasised that there is considerable variability and therefore the range of values is very large in both branches. The following table gives some mean values from sampling in the years up to 1992 (Auckland Regional Council personal communication) or 1978-1982 (Feeney 1984) denoted*.

Table of mean water properties for the Left (L) and Right (R) branches and the River after the confluence. (Selected maxima or minima in brackets).

	L Branch Falls Rd.	R Branch Woodcocks Rd	Mahurangi R Bridge
pH*	7.6	7.5	7.0
Non-filterable g/m^3	7.2(26)	6.4(17)	22.0(741)
Turbidity* NTU	6.7(9.8)	10.0(10)	14.7(90)
Temperature °C	14.0	14.2	15.7
Dissolved Oxygen % sat	96(44)	90(59)	92(10)
Nitrogen soluble			
Ammonia mgN/m^3	50(100)	90(400)	80(900)
Oxidized N mgN/m^3	1130(12600)	480(1300)	510(2500)
Phosphorus			
soluble mgP/m^3	170(3600)	30(100)	30(100)
total mgP/m^3	270(4200)	90(100)	100(1100)
BOD_5 $g.O/m^3$	1.4(3.3)	1.36(3.9)	2.(6.5)
Coliform pres*.MPN/100m	909	5573	16477
Pres faecal* MPN/100m	219	846	12060
Ratio total inorganic N / total soluble P	1180 / 170	570 / 30	590 / 30
N/P ratio	7:1	19:1	20:1
Catchment area km^2	16.73	28.8	54.46
Estimated discharge l/s*	502	866	1634

Note: the values given above are mean values. The averaging obscures the fact that for these water properties variability is high and standard deviations therefore large.

Nutrients

Since the ratio N/P of plant uptake in freshwater is usually taken to be 10:1 it appears that the main river and its right tributary are phosphorus limited and any relative increase in this element should be avoided.

The values for nutrients are very high (high enough to cause eutrophication) and we note that during the summer low flows the oxygen levels at the Woodcocks Rd site on the Right Hand Branch fell to less than 6 $g.O.m^{-3}$ on two sampling occasions. At the Falls Rd site on the Left Hand Branch growths of oxygen weed and sewage fungus were reported. High values of faecal coliforms have been reported from the Dome Valley Stream (Left hand branch) and the Mahurangi River itself.

Generally speaking neither branch of the Mahurangi River has a substantial discharge, nor does the flow over flat terrain offer much opportunity for re-aeration. It could be argued that their capacity to absorb nutrients has been nearly all committed and that the situation is not really comfortable. What is surprising is that more instances of algal blooms have not been reported. Possibly the reason lies in two factors.

* the turbidity reduces the light penetration and inhibits photosynthesis.

* the tributaries are short and residence time in them may be not be long enough to allow the production of a sufficient number of generations for the population explosion of a bloom to occur. This may be especially important when the increased load of nutrients washed in by the heavy rains is accompanied by shorter residence times during floods, consequent on the faster currents.

The Mahurangi itself carries the high nutrient load into the Estuary. An analysis (in 1984) of these inputs shows that the River is a major contributor, accounting for roughly three-quarters of the soluble nitrogen compounds, the biological oxygen demand, and non-filterable residue, together with two thirds of the phosphate and faecal coliform bacteria. (Feeney 1984).

Turbidity

Turbidity is important because it is a measure of the contribution of sediments to the Harbour and an indication of the possible light penetration which regulates photosynthesis. The clays in suspension play an important role in adsorbing phosphates and ultimately precipitating them into the sediments. From the average figures given above for turbidity it appears that, ordinarily, the waters of the Mahurangi and its two branches are turbid and there are instances when the values are high. As might be expected these are associated with rain in the catchment. For example,

* on 13.10.1975 the turbidity at the water intake site on the Mahurangi at Warkworth was 33 JTU. On that day the rainfall as measured at the satellite station was 11.7mm and had been 12.6,19.2, and 13 mm on successively previous days.
* on 22.8 1978. the value was 90 NTU and the rainfall was 19.5mm on that day and 38mm the day before.

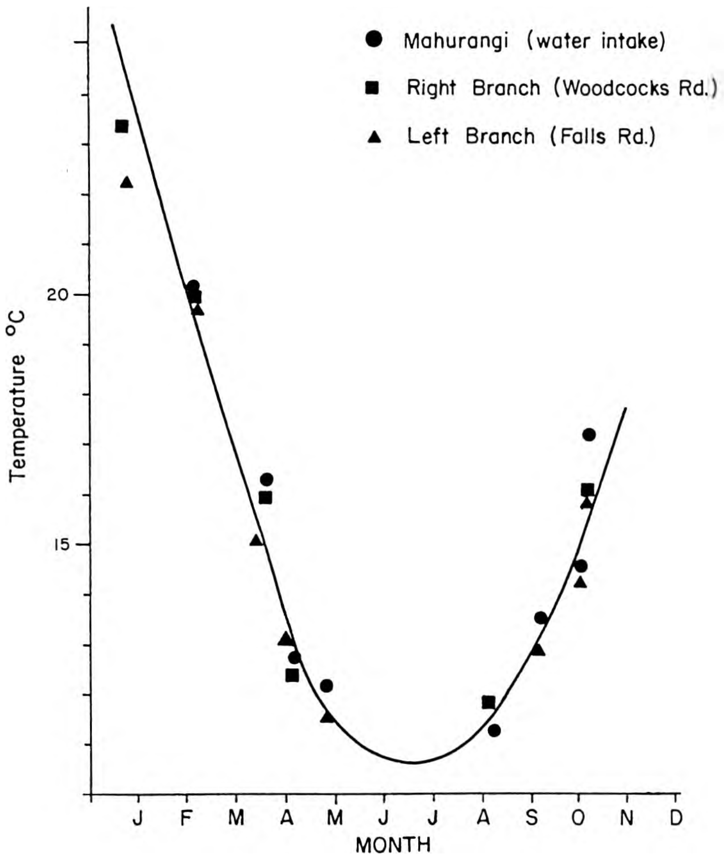
Low turbidities were 1.5 NTU after two weeks of dry weather. For some reason, which is not clear, turbidity figures for the Mahurangi are higher than those for either of its two main tributaries.

The turbidity also influences the public's perception of the rivers and tideway, diminishing their attractiveness.

Water temperatures

The change of monthly mean water temperatures, reported by Feeney (1984) for the years 1978 to 1981, have been plotted in the graph below.

Monthly mean water temperatures in the Mahurangi River and its tributaries.



FRESHWATER LIFE

The state of the freshwater biota reflects their integrated response to the prevailing stream conditions, and can therefore provide valuable information about the health of streams and supplement that from occasional spot chemical sampling. In general, diversity is desirable. It diminishes with increasing turbidity, sluggishness of flow, and of course pollution.

It will be evident from the above discussion of the physical setting that the available habitats include both those in the fast-flowing non-sedimentary upper reaches and slow-flowing sedimentary lower reaches with soft mud bottoms, as well as some intermediate habitats and some polluted with nutrient enrichment from paddock runoff. Unfortunately, there have been no comprehensive studies of the flora and fauna of the freshwater streams of the Mahurangi Catchment and that being so, the best that can be done is to have recourse to the work carried out on the analogous tideway, the Upper Waitemata Harbour (e.g. Briggs 1983). A summary of this work related to the Gulf Tideways can be found in Harris (1993). There have, however, been some preliminary surveys, on the flora and fauna (mainly fishes and aquatic plants) of Mahurangi streams. These are reported below.

Fauna.

K.Becker (pers comm.) reports finding the following,

freshwater shrimps, abundant
koura, occasional to rare
common bullys, common to absent
short and long finned eel, 1 to 8 per sampled site
inanga (*Galaxis maculatus),* rare
redfinned bully, rare

Flora.

The following is a list of apparently dominant aquatic and riparian plants which were collected (during March to May) during a preliminary reconnaissance of six reaches of the main Mahurangi River and its Right and Left Branches. Identifications were made by R. Wells and P. Champion of the Aquatic Plants Section, MAF. My wife (Mrs V.M. Harris) participated in the collection of specimens.

Freycinettia banksii (kiekie).
Egeria densa (oxygen weed).
Vinca major (periwinkle).
Selaginella kraussiana (club moss).
*Tra*descantia *fluminensis* (wandering jew).
Uncinia banksii.
Dicranoloma sp. (moss).
Elatostoma rugosa (parataniwha).
Melicytus ramiflorus (mahoe).
Callitriche stagnalis (starwort).
Uncinia uncinata (hookgrass).
Polygonum hydropiper (willow weed).
Polygonum salicifolium.Hypericum androsaemum (tutsan).
Leycesteria formosa (himalayan honeysuckle).
Ludwigia palustris (water purslane).
Crataegus monogyna (hawthorn).
Parthenocissus inserta (virginia creeper)?
Calystegia sepium (bindweed).
Rorippa nasturtium aquaticum or *microphyllum* (watercress).
Oplis mensus imbecillis.
Coprosma rhamnoides.
Ranunculus repens.
Epilobium alsinoides.
Nitella pseudoflabellata.
Festuca arundinoides.
Oedegonium sp.
Phormium tenax (flax).
Coprosma lucida (karamu).
Juncus effusus.
Leucobryum? (moss).
Cyperus eragrostis.
Carex subdola (sedge).

Coordinates of sampling sites on the national grid RO9 are 576 315,583 283, 585 317, 583,267, 579 266.

It should be noted that the selection of sites and judgement of what were dominant species were not made against a background of professional botany. In addition, the lack of assistants and practical considerations made it necessary to limit the study to a reconnaissance.
A comprehensive study with proper support should be undertaken before any further modification of the flora takes place.

SECTION 2. SALT WATER COMPONENT THE TIDEWAY: ESTUARY AND HARBOUR

Setting

The map below shows the Estuary and Harbour with their catchments. The east side is undulating but flatter, rising in only a few places to nearly 100m. The west side, in contrast, is more broken and rises to heights of 150m.

SEDIMENTS

The Mahurangi tideway floor is covered with the products of the erosion of the catchment. Soils of the catchment consist of clay and sand and sandy loams, and it is these, together with silt, which, in varying proportions, form accumulations ranging from fine mud to sand, which are the materials of the mangrove flats at the heads of the creeks and the tidal flats of the upper half of the harbour.

The way the erosion products of the catchment are distributed in the tideway depends to a large extent on the propensity of the clay material to flocculate on contact with saline water. It seems that this results in deposition taking place in the reach of the estuary opposite Hamiltons Landing where the salinity in the estuary increases from 20 to 30 ppm (see discussion on salinity below). This is a region of rapid accretion today.

Cores driven down into the sediments by Johnston (1984) revealed "alternating sequences of clayey silt and fine silty sands with occasional granular layers".
Trotter (1990) reported that the bulk of the sediment is fine, with particle sizes ranging from fine sand, 0.25mm to finer material of 0.0078mm (phi values 2-7).

The clays impart an almost permanent turbidity in the water (reducing light penetration) and (together with the organic material in silt) give a special character to the low tide mud flats and mangrove habitats. Because the fine clay particles compact so closely, air penetration is impeded and the muds of the tideway are anaerobic, black and fetid.

Of special importance is the organic material content of the sediments because, together with the particle size, it is very influential in characterising the habitats preferred by the various infaunal organisms (see later under biological section). Johnston (1984) has determined the organic/sand/clay content of samples from the tideway floor. He found that the organic content was greatest beneath the mangroves, and diminished towards the sandbanks and the channels. It also decreased towards the Heads. Furthermore he also analysed the three main sediment types and found their composition to be as follows:

Mangrove fields; predominantly equal parts of clay and silt

Tidal flats; predominantly sand (70-90%) and silt

Channels; similar to the flats but with a proportion of silt and clay

On the other hand, the sediments of the lower Harbour near the Heads comprise sand and shell. The sand almost certainly comes from outside in Kawau Bay. It is known that the ancestral Waikato River transported sandy sediments into the Gulf and, indeed, the beaches near the Heads are sandy. Transport of sandy sediments through the entrance into the Tideway would be quite feasible. The average depth across the Heads is, today, less than 10m and would have been shallower before sea level rose to its present height. Sea waves are quite capable of moving sandy sediments at 20m.

Additional sediments are formed from shell material.

Except at places on the banks of the Estuary and Harbour, the rocks which underlie the tideway (mainly sandstones) do not seem to outcrop.

Height contours, drawn at 40m intervals, are marked,in units of 10m. Heights greater than 80m are black.

Johnston (1984) found a rock platform just below the surface of the mangroves, extending about 200m off-shore from Hamiltons Landing. It can be seen on the east bank. It seems possible that it is this platform which causes the river to veer sharply westward just up-stream of it.

Limestone is reported to outcrop in a narrow band slanting obliquely up stream in the vicinity of the Old Cement Works and the old lime kilns and at the head of Pukapuka Inlet (Markham and Crippen 1981). Off the Cement Works the limestone forms the bottom of the Estuary. It is not covered by the usual mud.

Rate of accumulation

Averaged over the period since sea-level last rose, sedimentation has proceeded at the rate of the order of 1-2mm per year. For example seismic measurements made off Bradleys Point by Trotter (1990) suggest that the average rate at which the tidal flat there has accumulated is about 1.2mm per year (i.e. 7-8m in about 6500 years since the sea-level rose to fill the estuary). However, the technique of assessing the rate by dividing the depth of sediments by the time elapsed since the last inundation, implicitly makes the assumption that the rate has been uniform. While this assumption seems to be acceptable with a time scale of 1000s of years it does not seem to be valid over the shorter time scale of 100 years. The question of what the rate is or has been in the immediate past is more difficult. The evidence is conflicting.

Evidence from the studies on the Mahurangi Harbour by Johnston (1984) who used three different approaches, is as follows:

* By comparing the cross-sections from three historical naval charts drawn in 1836, 1904, and 1978 he concluded that in the Harbour, between Brownes Bay and the Heads, sediments were stable, but that there had been a period of sediment deposition prior to 1904, and subsequently a period of erosion of the deposited material. He found that the position of the channels was stable. Hume (1983) also using historical charts found that along the main axis of the Upper Waitemata Harbour over the period 1854-1979 there had been both accretion and erosion.

* From carbon dating of cockle shells embedded at a depth of 2m above chart datum in the channel bank off Hamiltons Landing, and others at chart datum depth in a tidal flat off Dawsons Creek, Johnston found them to be respectively roughly 6000 and 7000 years old.

* In cores up to about 1.5m in length, taken from the tidal flats Johnston found no "distinctive stratigraphy", i.e. no evidence of former forest burn-offs or deposition of fines and concluded that **"the Harbour sediments exposed on the tidal flats were deposited before about 5000BP and that the surficial sediments are being reworked by present day processes."** Johnstons conclusions refer to the lower Harbour.

The accretion rate of the Mahurangi has also been examined by Trotter (1990) whose investigatory methods included seismic profiling and the examination of cores for evidence of three indicators, charcoal from burn- offs, phosphorus indicating interference with the natural cycle of the catchment, and organic material. Cores up to 3m in length were taken from the tidal flats and mangroves. No radiometric dating was made but rather it was assumed that perturbations, such as increases in the quantities of indicators in the sediment column, could be taken as the time of human interference in the catchment.

Based on these assumptions, the rates from the core analysis averaged over the periods 1860-1910 and 1910 to the present were of the order of 5-10 times greater than the long term average indicated by the seismic evidence.

Comparison of naval soundings made in 1904/5 and 1975 lends support for the higher rate in recent years. The working sheets for chart BA 1998 for 1904/5 (Admiralty 1906) and for NZ 5321 of 1975, were kindly supplied by the RNZN Hydrographic Office. The Naval Tidal Officer has reviewed the datums for these two surveys and suggested that, after taking into consideration a sea level rise of 1 mm/year, the datum for the 1975 survey was 0.2m below that done in 1904/5. This has been taken into account when using them. Comparison of the depths in the two charts, separated by 70 years shows a high rate of sedimentation in some places in the lower Estuary.

The results of the comparison reveal that there were substantial changes in depth but that they were not homogeneous, so it is not possible to summarise them in a simple statement. Instead the Tideway has been divided into 9 reaches and the average net change calculated. These are shown on the chart below.

From the Heads to 0.5km north of Scotts Landing there has been little net change. On the other hand the local depth changes are the greatest in the whole system. These have been occasioned by deepening along the Scotts Landing side and a westward shift in the main channel nearer to the Heads. The deepest place in the Tideway has deepened by 3m (approx) and moved seaward. Such large local depth changes in this part of the tideway are to be expected.

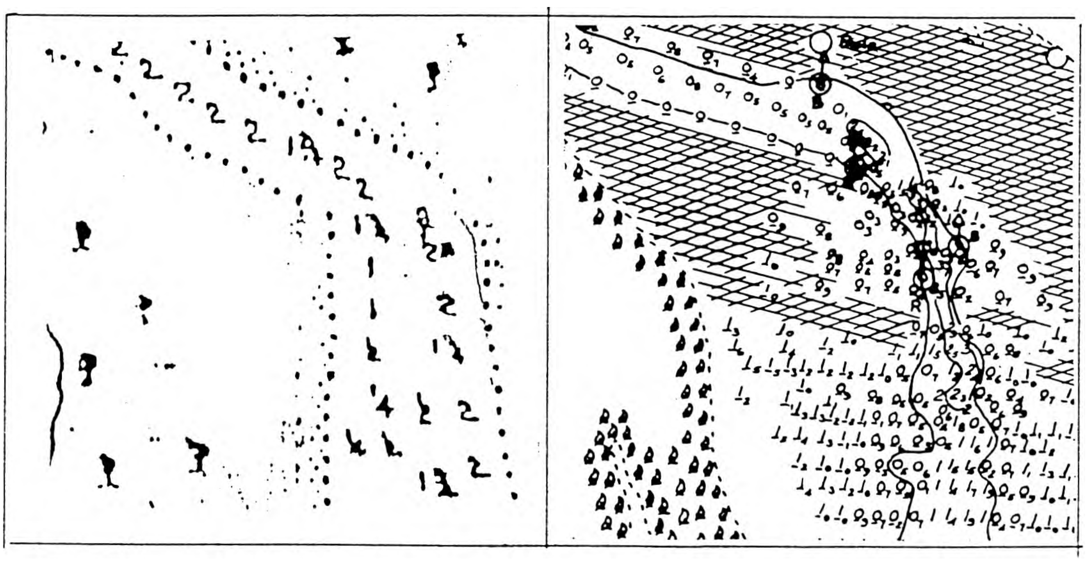
Chart of average depth reduction (m) over the low tide channel in in the 70 years prior to 1975. Over-bar signifies erosion.

In the reach opposite Brownes Bay the net accretion has been 1m, the greatest net gain in the Harbour. The reason for this may be that, in response to a non-tidal vertical circulation, the bedload movement in this reach may be directed up-harbour. Johnston (1984) discusses this.

On up to Bradley Head there has been less than 0.3-0.5m accretion in the main channel but a 1m erosion of a channel close to the east shore.

In the reach up to Dawsons Creek there has been 1m net accretion and some eastward displacement of the channel.

The deposition in the reach from the corner at Dawsons Creek to Red Bluff has been the greatest. For the first 700m the average accretion has been 2.9m (about 40mm per year) averaging along a single line of soundings. and 1.4m to Red Bluff corner. This is a reach where the sediment-bearing freshwater first encounters a comparatively high salinity receiving water (see section on salinity). Parts of the two charts for this reach are shown below.



Parts of working naval charts for the area at Dawsons Creek Corner for (left) the 1905 chart in fathoms and (right) for 1975 in metres and decimetres. Note rapid shoaling.

The shallowing above Dawsons Creek is supported by anecdotal evidence. Subsequent to Cyclone Bola a low tide island formed in the middle of the channel (Edwards, a riparian farmer, personal comment). This may have been the result of a large sediment accretion or just a redistribution of existing sediments, but soundings made in this region e.g. by Mr Dixon, of the Warkworth Marina, (personal report), confirm the shallowness in the region. The crucial importance of 'epic' events in sediment supply is illustrated by experience in the Upper Waitemata Harbour where 65% of the year's total input of sediments were supplied during one day (15 March 1980) as a consequence of Cyclone Sina. (Hume 1983).

From Red Bluff to Warkworth there has been an average accretion of 0.9m.

For the whole of the low tide channel of the main Tideway the average accretion in the 70 years has been 0.67m, nearly 10mm per year. However, as a measure of what has happened over all the Tideway, this is not a particularly useful figure because it does not reflect changes over the sand banks above chart datum.

Apart from chart datums there are of course other difficulties in comparing charts. There are uncertainties in the data because of possible errors in fixing the positions of soundings and in the superposition of charts whose coastal features are not accurately fixed. In the narrow estuary where there is only one line of soundings it is not certain that the two sets of soundings are coincident. A more intangible problem arises from the change of tidal characteristics within the tideway as a consequence of terrestrial modifications. Then there is the problem of seiching which is quite marked in the Mahurangi Estuary (see below). On account of these possible sources of error it is perhaps unrealistic to assign too much significance to apparent changes of less than about 0.5m.

From the above evidence it is tentatively concluded that while the rate of accretion in the Mahurangi Tideway averaged over its lifetime has been about 1-2mm per year, the rate averaged since the turn of the century has, in places, been an order of magnitude higher.

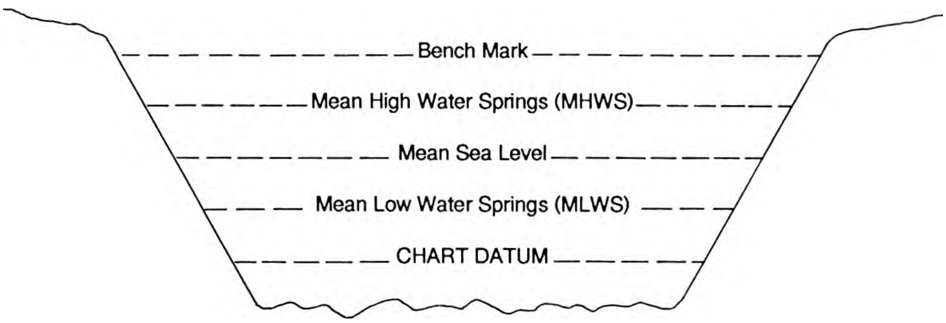
The cause of this higher rate in recent years is unclear. No doubt it must to some extent be ascribed to the clearing of forests, increased farming, and earthworks associated with roading and building. On the other hand one factor which must be taken into account is the changing influence of coastal shipping. While there was a regular steamship service to Warkworth the scouring action of ships' propellers would have counteracted the natural tendency for channels to silt up. The service began to decline after the turn of the century and had practically ceased by the 1930s. The apparent accretion shown by the naval chart of 1975 may reflect, in part, a redistribution of sediments into the channels, consequent on the cessation of ships' "dredging" activities.

PHYSICAL DIMENSIONS OF THE TIDEWAY

Reference levels

Before going on to consider the dimensions of the harbour it is necessary to be clear about reference water levels, because they will be required in establishing true, as opposed to chart depths, when such matters as tide heights, tidal volumes, and sedimentation rates are dealt with. There are few characteristics more difficult to establish than water depth in an estuary because it is always changing, whether on account of the astronomical tide, meteorological factors (wind set up or pressure), density changes or seiches with periods of the order of a few hours (discussed later). Water depths change 1cm for every atmospheric pressure change of 1 millibar (hPa). The pressure change during the passage of a typical low pressure system over the area may be from a high of 1025 to a low of 990, a drop of 35 cm, corresponding to a depth increase of the same amount.

The depths on naval charts are not the true depths below a certain state of tide, but slightly less since the true depths have been reduced, by referring them to a chart datum level, a little below that of say Mean Low Water Spring Tides (MLWS). The purpose of this is to introduce a factor of safety and to cater for unusually low tides. Chart datum is defined as the distance below a local bench mark established at the water's edge. The diagram illustrates the various levels commonly referred to.



While depths are distances below a chart datum, tide heights are distances above it.

Depth surveys of the Mahurangi

Our chief sources of depth data are the soundings made by the Naval Authorities. These are recorded on the following charts:

* Survey by the Royal Navy's Sloop Coromandel in 1820. This Comprised a single line of 10 soundings nearly to Grants Island. It established that the Harbour was deep enough to handle ships loading spars.

* British Admiralty Chart of 1834. Survey by HMSS Buffalo, extending from the Heads to Grants Island. The chart datum is taken to be MLWS, 30cm below the present chart datum. (based on advice from the Naval Hydrographer, Johnston 1984).

* British Admiralty Chart BA1998 based on a survey by HMS Penguin, first published in 1906 with a new addition in 1950 (already used above in connection with sediment accretion). Depths are referred to a chart datum 11.3ft (3.44m) below a bench mark in Bon Accord Harbour.

* Hydrographic Office of the Royal New Zealand Navy Chart 5321/10 of 1975 (already referred to) covering the whole tideway up to Warkworth and showing all soundings made and referred to a datum "3.53m below a bench mark concreted into the side of the parking area at Mahurangi Heads (Scotts Landing?) 3ft below HWL, 22ft from the western side of the parking area".

There are also depth measurements made by engineering consultants. Harrison and Grierson and Partners made soundings in the Harbour in 1974. Over a short reach of the Estuary at the Old Cement Works, a detailed survey, at about MLWS, was made by Bruce Wallace and Partners.

Tidal data

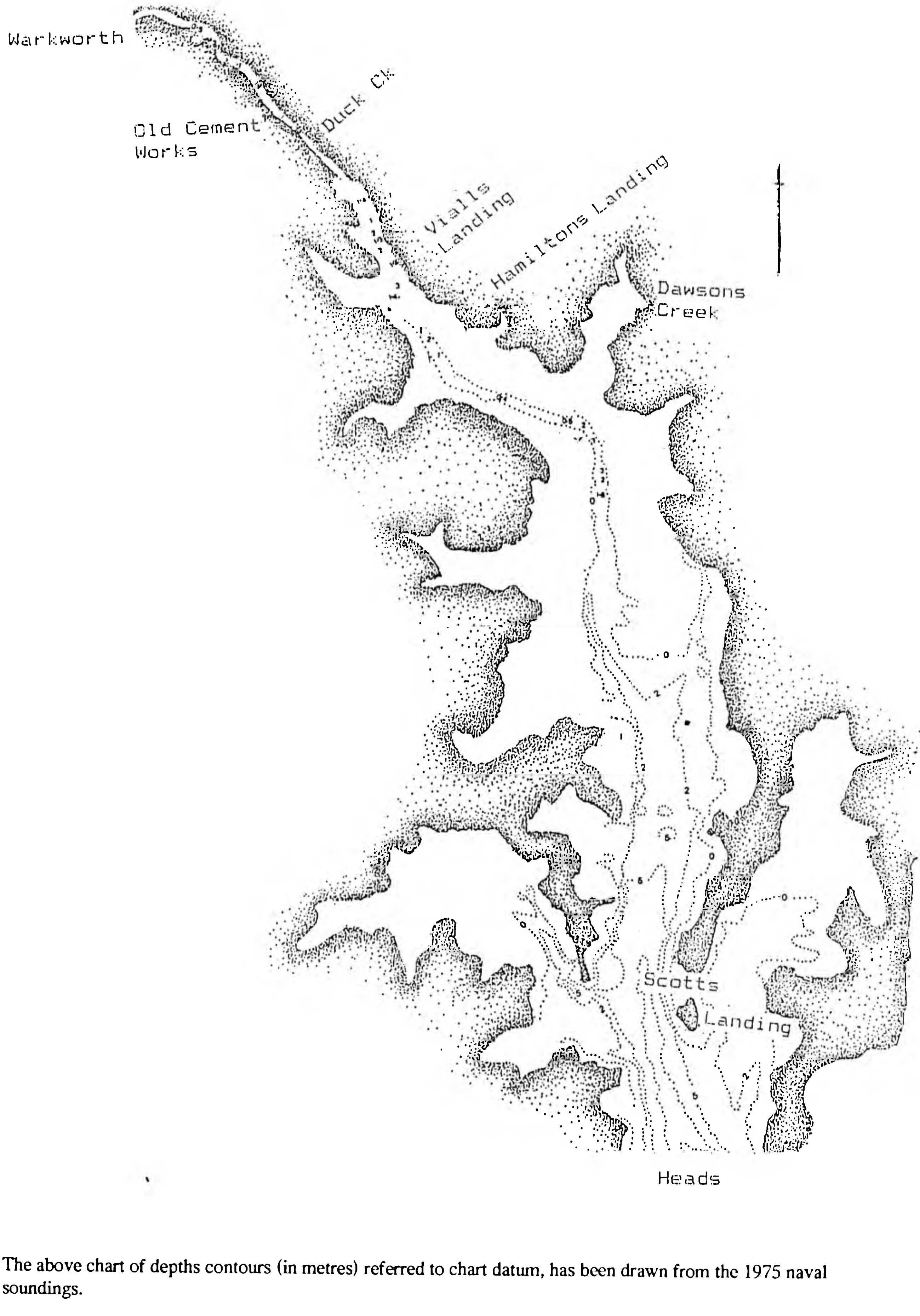
As to tidal data which are required for the estimation of tidal volumes, we have two sets of data. A fairly long time series (over several months) of tidal levels at Grants Island and the Old Cement Works was reported by Johnston (1984). This will be considered in more detail in the section on the tidal regime. It has been cross-referenced to chart datum at Queens Wharf Auckland. These data suggest that at the Old Cement Works the depths are greater by 30cm than those on the naval chart 5321/10. But it should be noted that apart from the ordinary sources of error, depth measurement in the Mahurangi, may at some states of the tide, be especially uncertain because of seiching.

The other tidal records come from measurements made by Harrison and Grierson and Partners at Scotts Landing and Dawsons Creek over seven successive tides in 1974.

Based on measurements by Johnston (1984) the main tide ranges in metres are.

	Old Cement Works	Grants Island
Spring tide range	2.98*	3.08*
Mean tide range	2.28	2.08
Neap tide range	1.48*	1.35*

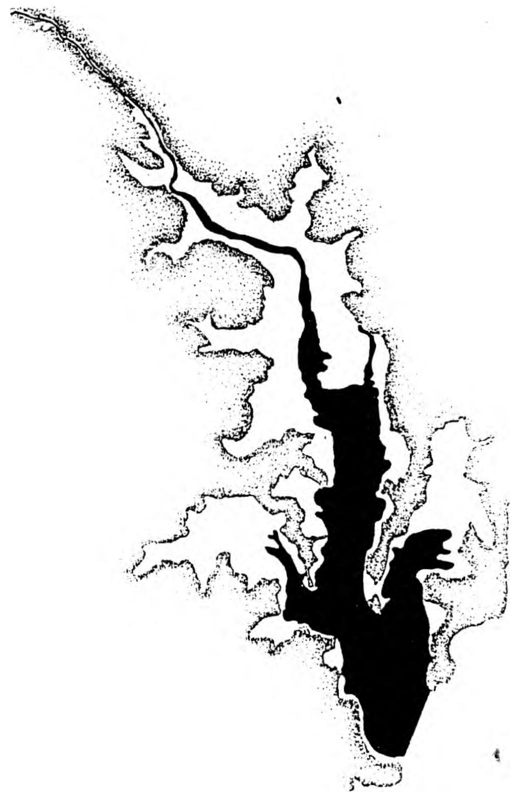
* reported as extremes measured.



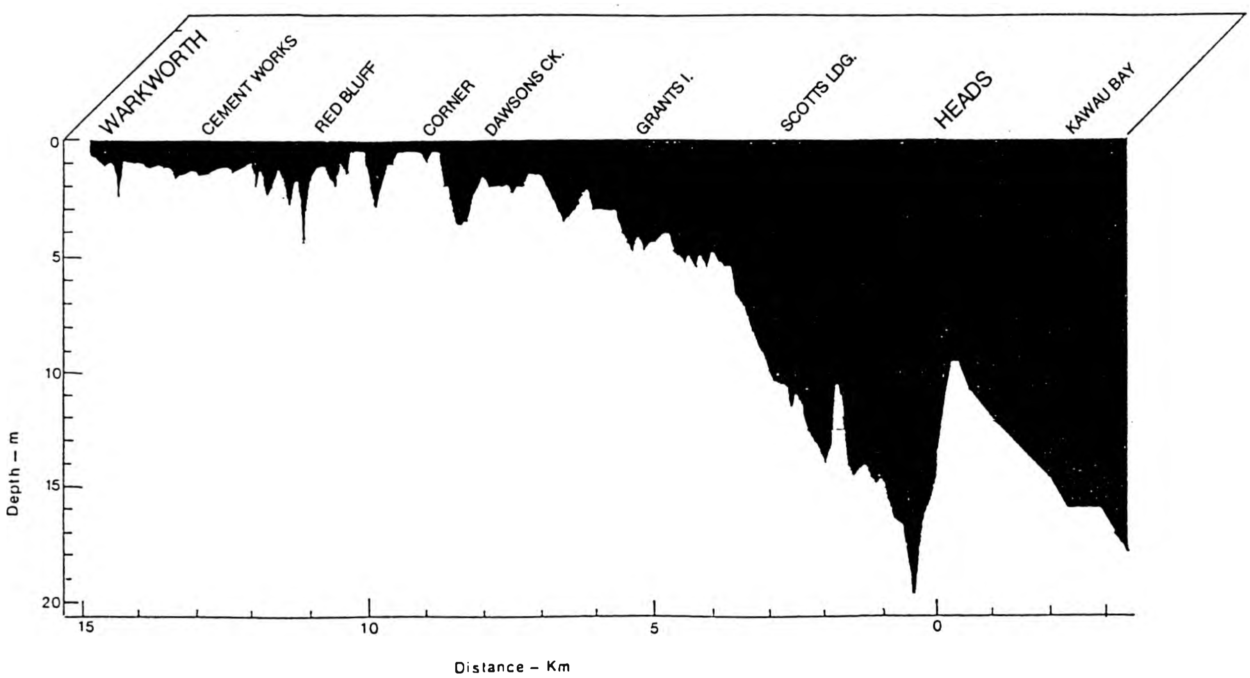
The above chart of depths contours (in metres) referred to chart datum, has been drawn from the 1975 naval soundings.

There is a very great difference in the area covered by water at low and high tide in the upper half of the tideway. This is illustrated below.

Chart showing the area covered at low tide (black) contrasted with that covered at high tide. Note the large differences in the upper part of the tideway.

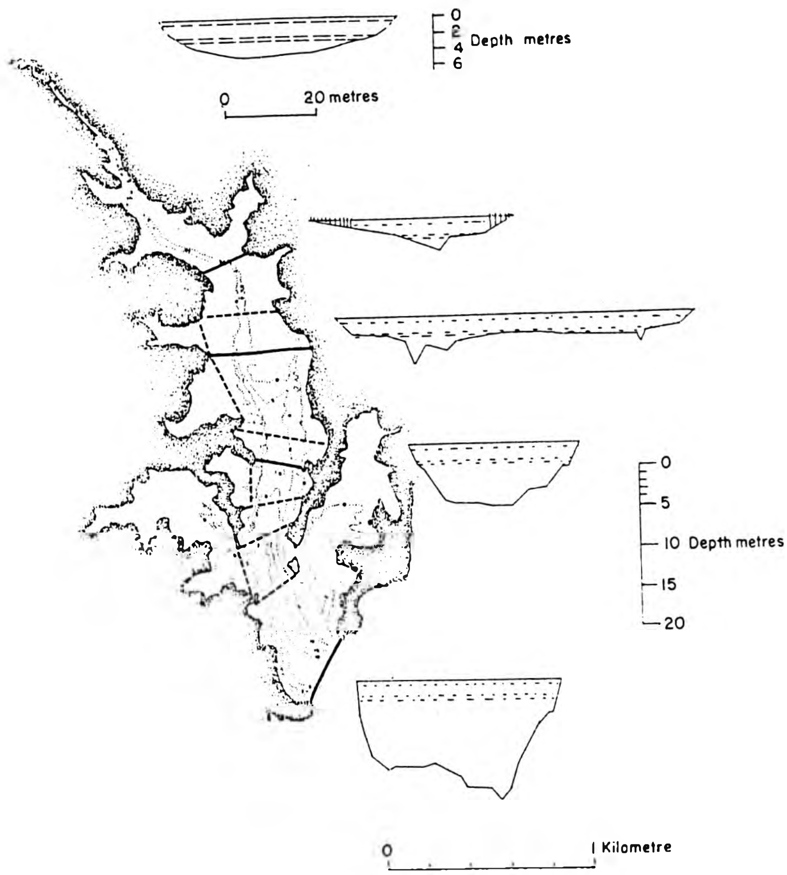


The water depths (referred to chart datum) up the axis of the Harbour range from 11m at the Heads to 1m off Dawsons Creek. Just inside the entrance there is a hole where the depths goes to 19m.



Profile of chart depths approximately along the axis of the tideway.

Shape of the Cross-sections



Representative cross-sections of the tideway at the indicated places (full lines). The four sections up to Dawsons Creek were reported (in feet) by Harrison and Grierson (1974). That at the Old Cement Works in the Estuary (data supplied by N Dixon) was surveyed (in metres) by Bruce Wallace. Here, it is drawn to a larger scale. Dashed lines mark additional boundaries of nine reaches for volume estimates by Harrison and Grierson.

Harbour volumes

A knowledge of the volumes of water at high and low tides is essential in the estimation of tidal prisms and the residence time of water in the tideway.

The high and low tide volumes of the tideway of the combined Harbour and Estuary, for both spring and neap tides have been calculated by Johnston (1984) who divided them into five loosely defined main areas. Another estimate by Harrison and Grierson (1974) used smaller areas (defined on the contoured chart) and excluded the side creeks. These estimates are reproduced below in units of $m^3 x 10^6$, rounded off (except totals). Johnston's estimates are:

Creek or reach	Mean spring tide			Mean neap tide		
	high	low	prism	high	low	prism
Pukapuka Inlet	6.5	0.7	5.8	5.3	2.6	2.7
Te Paka River	8.8	1.3	7.5	5.9	2.4	3.5
Outer Harbour	33.3	22.4	10.9	32.5	27.2	5.3
Middle Harbour	33.0	12.9	20.1	28.9	14.0	14.9
Inner Harbour	7.1	0.6	6.5	5.6	2.6	3.0
Totals	88.7	37.9	50.8	78.2	48.8	29.4

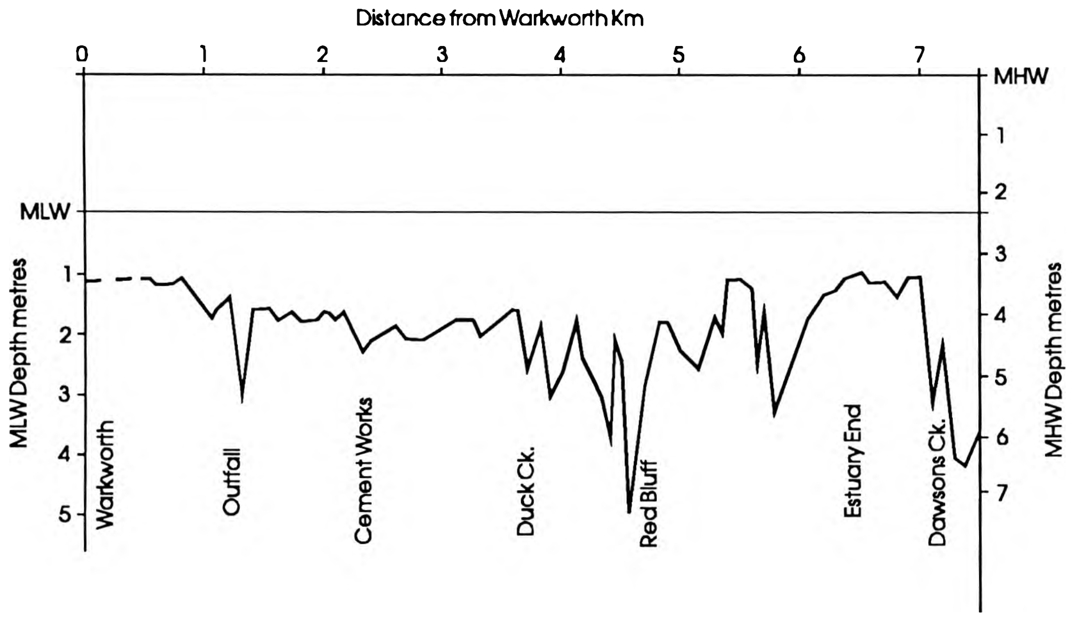
The estimates made by Harrison and Grierson ($x10^6 m^3$ and rounded off)are:

Reach	Spring tides			Neap tides		
	high	low	prism	high	low	prism
1	36.2	22.0	14.2	33.9	23.7	10.1
2	12.9	5.0	7.9	11.1	5.8	5.3
3	5.8	3.8	2.0	5.4	4.1	1.3
4	5.3	2.7	2.6	4.9	3.1	1.9
5	4.1	2.0	2.2	3.8	2.3	1.5
6	11.3	3.3	8.1	10.1	4.3	5.8.
7	4.2	0.6	3.6	3.4	1.0	2.4
8	3.5	0.3	3.2	2.8	0.6	2.2
9	5.8	0.8	5.0	4.0	1.2	2.8
Tot	89.5	40.4	48.9	79.2	46.1	33.1

Mean of both estimates for the mean tide prism is $40.54x10^6$ m^3.

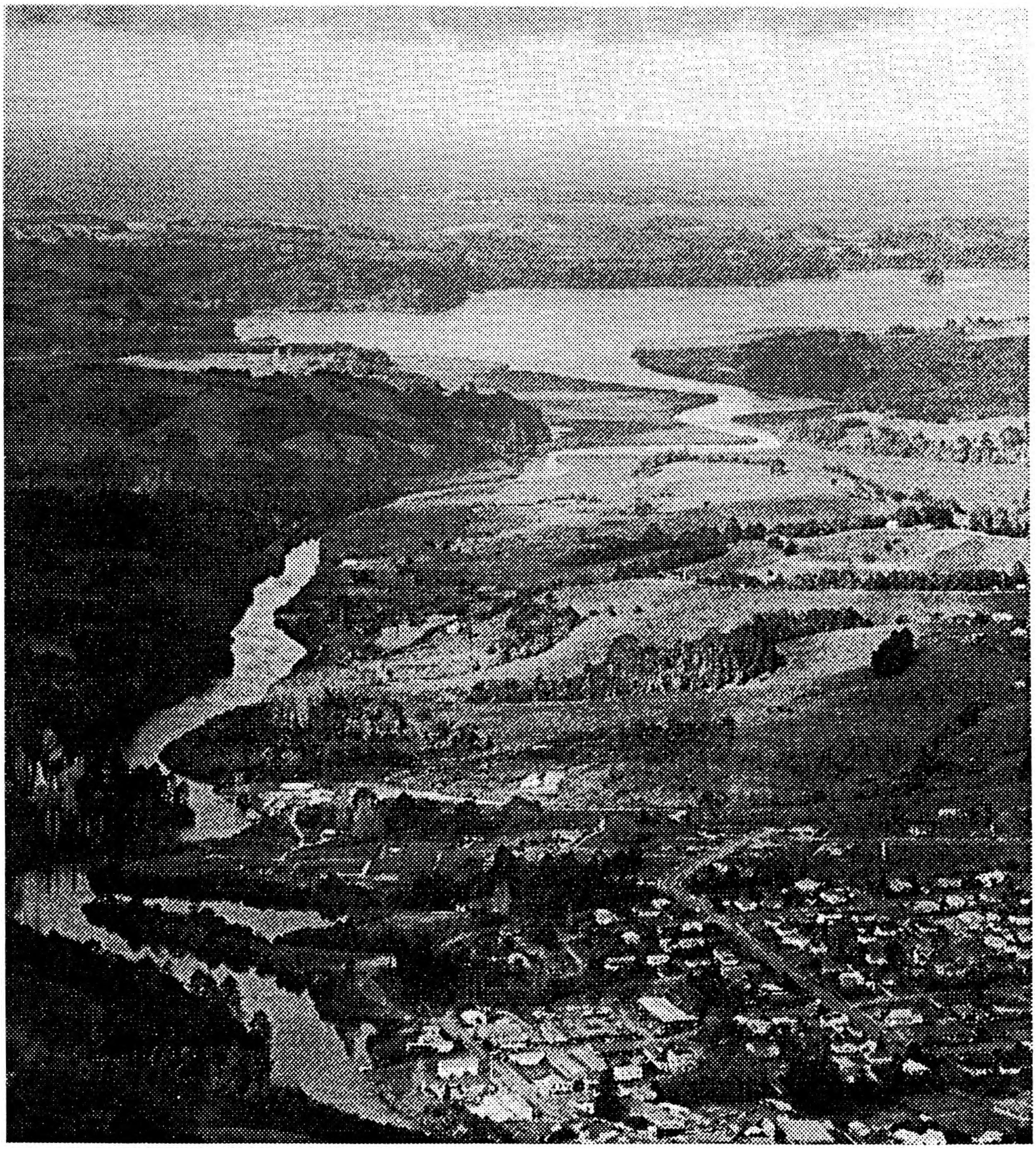
THE ESTUARY; PHYSICAL DIMENSIONS

The depths along the axis of the Estuary are shown in the diagram below. The main features are, the initial shallowing between Hamiltons Landing and Hepburn Creek, the deepening to the deepest part of the Estuary off Red Bluffs and the canal-like character of the rest of the Estuary until further shoaling to the Warkworth waterfall.



MHW depths (m) approximately along the axis of the Estuary.

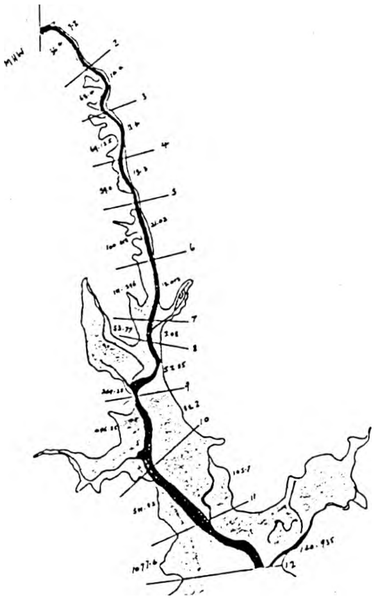
A point of particular interest, which has already been referred to, is the shallowing which is taking place in the Estuary upstream from Dawsons Creek. Recent measurements made off Hamiltons Landing by Mr Dixon (personal communication) show that at near low spring tide (0.6m at Auckland) the water depths were generally 0.3-0.5m except for a 1m wide channel where the depth was 1m. A mid-channel sand bank was exposed. Apart from being a hazard to boats this shoaling may provide a wave reflecting feature to which the seiching could be ascribed. This is discussed below.



Taken from above Warkworth, this aerial photograph looks down the Estuary towards part of the much wider Harbour, with Grants Island just visible on the righthand side. The entrance to the Harbour, the Heads, is further to the right just out of the field of vision. Towards its junction with the Harbour, the Estuary supports extensive areas of mangroves.

ESTUARY; VOLUMES

Estimates of the volumes of water, at Mean Low Water (MLW) and Mean High Water (MHW), for selected reaches in the Estuary from Warkworth to Dawsons Creek, have been made, based on the areas of the cross-sections and the distances of the reaches between them.
They are marked on the accompanying chart which shows the location of the cross-sections and also gives the high and low tide configurations of the Estuary.



High tide volumes are on the left and low tide volumes on the right, in units of 10^3 cubic metres.

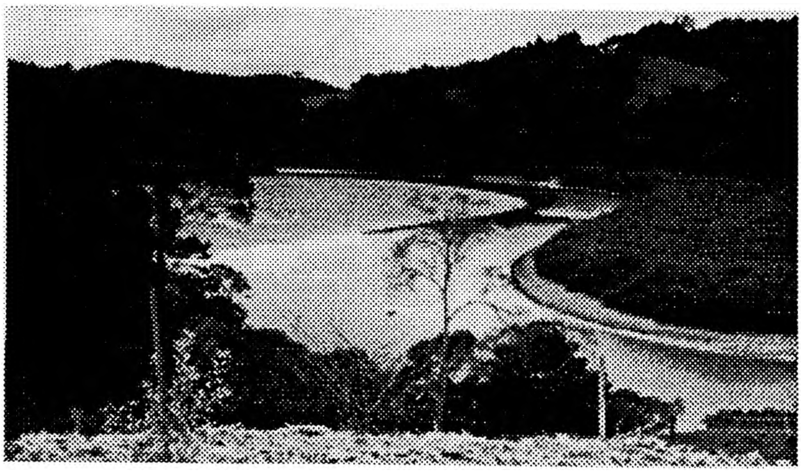
The following table gives the volumes of individual reaches at mean low and high water, as well as the separate contributions of the water over the mangroves. Areas of mangrove swamps were taken from large scale aerial photographs acquired from the Rodney District Council. Based on measurements made in the centre of the large mangroves at Hamiltons Landing and Hepburn Creek, it was assumed that at Mean High Water the swamps were covered by 40cm of water. Also given are the cumulative totals (Cum) and the distance from Warkworth of the downstream end of each reach in kilometres.

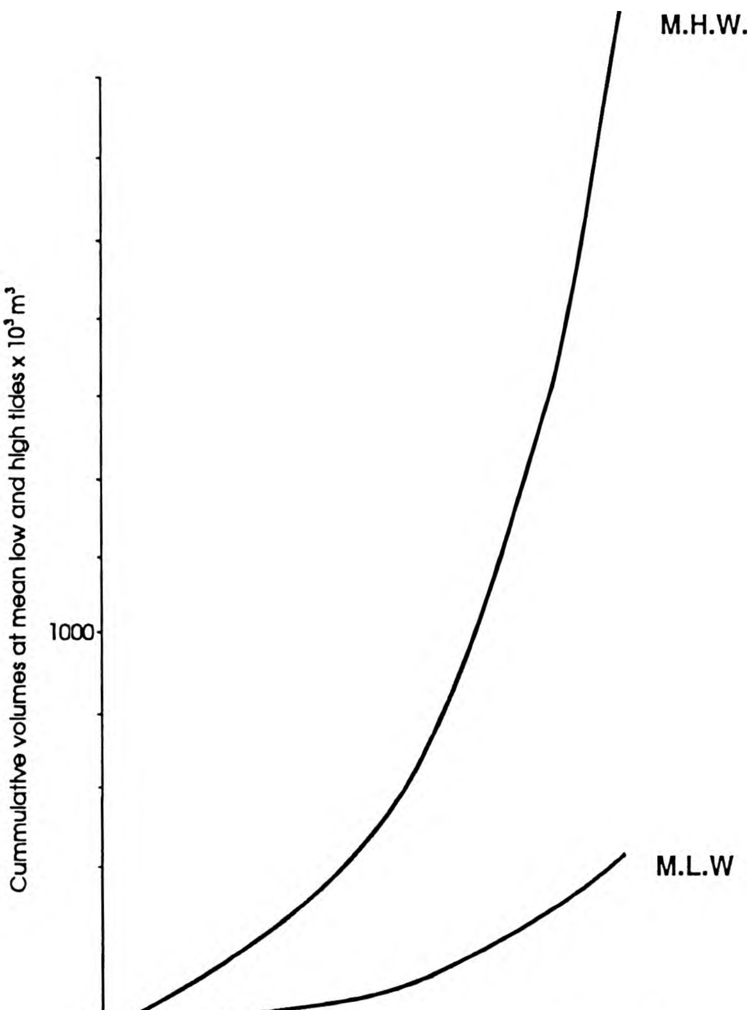
Reach	Dist	Volumes in $m^3 \times 10^3$							
No	km	At MLW		At MHW					
		Stream	Cum	Stream	Cum	Mang++	Cum	Total#	Cum#
1-2	0.6	7.2	7.2	56.4	56.4	-	-	56	56
2-3	1.2	14.4	21.6	62.4	118.8	6.0*	6.0	68	125
3-4	1.7	11.4	33.0	49.9	168.7	19.2	25.2	69	194
4-5	2.1	13.3	46.3	52.2	220.9	6.7	31.9	59	253
5-6	2.8	21.0	67.3	72.6	293.5	28.0	59.9	101	353
6-7	3.4	18.5	85.8	68.7	362.2	42.5	102.4	111	465
7-8	3.6	7.5	93.2	25.5	387.7	28.2	130.6	54	518
8-9	4.3	57.8	151.1	131.9	519.6	137.3+	267.9	269	787
9-10	5.2	88.2	239.3	334.3	853.9	162.5	430.4	497	1284
10-11	5.9	105.7	345.0	394.1	1248.0	147.7	578.1	542	1826
11-12	6.7	140.9	485.9	739.1	1987.1	338.5	916.6	1078	2904

* inlet. + mudbank included. ++ Area x 0.4. # rounded stream = excluding mangroves

From this table it appears that the volume of water stored in the estuary at MHW is about 6 times that of the MLW volume. About a third of this volume at MHW is that over the mangroves. The cumulative totals have been plotted against the distance from Warkworth on the accompanying diagram.

Looking upstream from Red Bluff towards Duck Creek, below which the high tide volume increases rapidly because of widening.





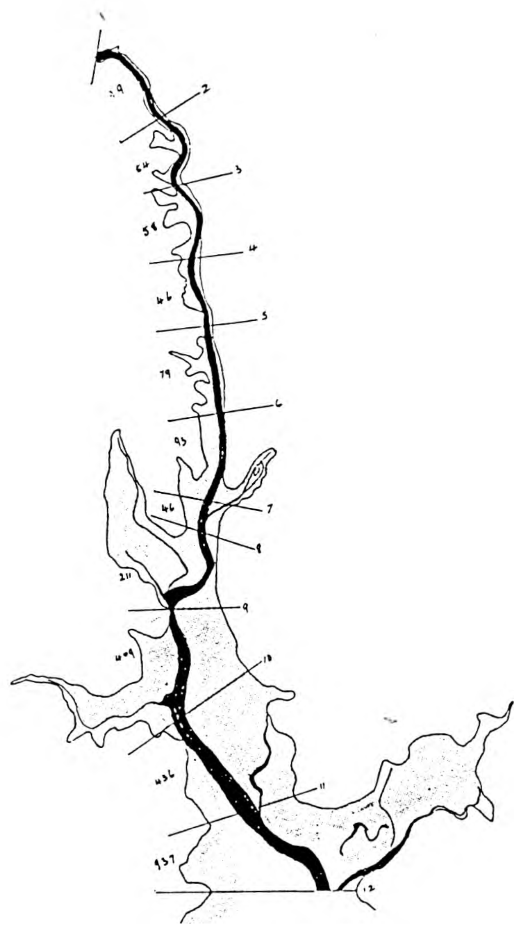
Graphs of the cumulative volumes in the Mahurangi Estuary with distance from Warkworth, at Mean High Water and Mean Low Water.

Tidal prisms of the Estuary

The volume of the tidal prism (the difference between the volumes at MHW and MLW) for the reaches is shown on the diagram and the cumulative totals with distance from Warkworth are listed below.

Distance from Warkworth km.	Cumulative Volume of tidal prism $m^3 \times 10^3$
0.6	49.2
1.2	103.4
1.7	106.9
2.1	206.5
2.8	286.1
3.4	378.8
3.6	425.1
4.3	636.4
5.2	1045.0
5.9	1481.5
6.7	2418.3

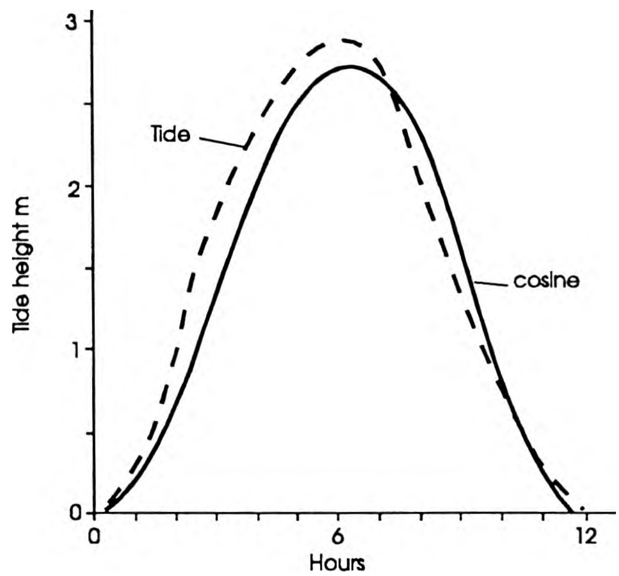
The mean tidal prism volumes for each of the eleven selected reaches, from Warkworth to Dawsons Ck in the Estuary, are shown on the diagram. The shaded area is that covered at high water and the black, low water



TIDAL REGIME

In the treatment of the common features of the Gulf Tideways (Harris 1993) it was noted that the open coast tide regime was diurnal and followed quite closely an undistorted sine curve, but that in shallow water embayments there were several factors which could induce considerable departures from this symmetry. In tideways local measurements are therefore essential. Tidal measurements made in the Mahurangi Harbour have been referred to above.

To illustrate the tidal curve distortion which is indeed occurring in the Mahurangi a sample of a record from Johnston (1984) is compared with a cosine curve, representative of the of the open coast tides, which have been recorded at the University of Auckland's Marine Laboratory at Leigh, by J.Evans (personal communication).



Comparison of the tidal curve at the Old Cement Works (dashed line) with a cosine curve (the kind of tide found at the open coast). Note the distortion of the former by the M4 component phased so that the flood curve is more convex. (the M4 tide is discussed in e.g. Harris 1993)

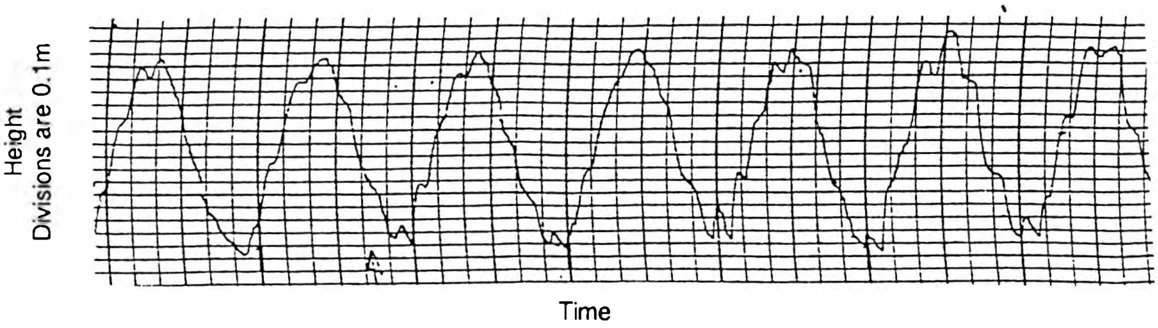
Johnston's data show that, compared with the tides at Queens Wharf in Auckland, the tides at Grant Island were 5 minutes earlier and at the Old Cement Works 15 minutes later. These are average values. The duration of the flood exceeds that of the ebb by about 30 minutes. Tide heights off Grants Island and the Old Cement Works for, the period 8.1.1982 to 22.2.1982, together with those predicted for Auckland, are as follows.

Tide height data (extreme and mean heights in metres above chart datum) for Queens Wharf Auckland (Auck), Grants Is (Grant) and the Old Cement Works (Cemen).

Gauge	Spring HT	LT	Max range	Neap HT	LT	Min range	Mean HT	LT	MSL	Range
Auck	3.52	0.05	3.44	2.58	1.17	1.49	3.06	0.62	1.84	2.44
Grant	3.18	0.03	3.08	2.02	1.08	1.35	2.72	0.64	1.68	2.08
Cemen	3.16	0.10	2.98	2.30	0.96	1.48	2.71	0.43	1.57	2.28

Note that the rise and fall of the tide is on average about 2m but can be as much as 3m.

An example of the tidal curve for neap tides at the Old Cement Works is given below. Of the greatest interest are the marked short period oscillations (about 7 to the tidal cycle) superimposed on the tidal record.



The short period oscillations (seiches)

The small fluctuations with periods of the order of an hour or so, are unusually clear. They were discovered by Johnston who ascribed them to a seiche of 1.5 hours period which resonated between the island off the Heads, Te Haupa Island, and the waterfall at Warkworth. He envisaged this as an internal wave. His theoretical argument is as follows.

The period (T) of the fundamental oscillation in an enclosed basin is given in terms of the basin length (L) and the wave phase speed $(gh)^{0.5}$, where g is gravity and h is the water depth.

$$T=2L(gh)^{-0.05}$$

Johnston assumed L=17000m, and the weighted mean depth of the deepest parts of the channel h=3.8m. T was therefore 1.55 hours.

No doubt the oscillations are due to something of the sort, though further analysis suggests that there may be an alternative or additional explanation. There are two important observations which need emphasis. The amplitude of the oscillations was greatest at low neap tides and greater at the Cement Works site than at the other measuring site at Grants Island. These suggest that a type of oscillation may be largely confined to the Estuary and that the low neap tide water depth is an optimum condition for a standing wave.

If the oscillations are largely within the estuary then they must arise from an open-ended oscillation which has a period given by

$$T=4L(gh)^{-0.5}$$

Examination of a piece of Johnston's tidal record for the period 1810hours on 8th January to 1200hours on 21st January during which the fluctuations were most pronounced shows that the there were 39 troughs in 6 tidal cycles i.e an average of 1.9hours period.

With L=6000m, the distance from Warkworth to Dawsons Creek where the narrow low water estuary gives way to the wide harbour, a standing wave of 1.9hours period would exist if the average depth was d=1.2m. This is the kind of depth which one would get if depths were averaged across and along the estuary at low neap tide. (The average maximum depth at low tide neaps, along the axis of the estuary from Warkworth to Hepburn Creek, is 2.15m).

As the tide rises and the water level deepens the phase velocity of the wave will be greater and the period of the standing wave would decrease. However it should be noted that in a cross section which has a low tide channel the average water depth does not increase as much as one might anticipate because the rising water covers an increasing proportion of shallow water as the water spreads out across the mud banks.

TIDAL STREAMS

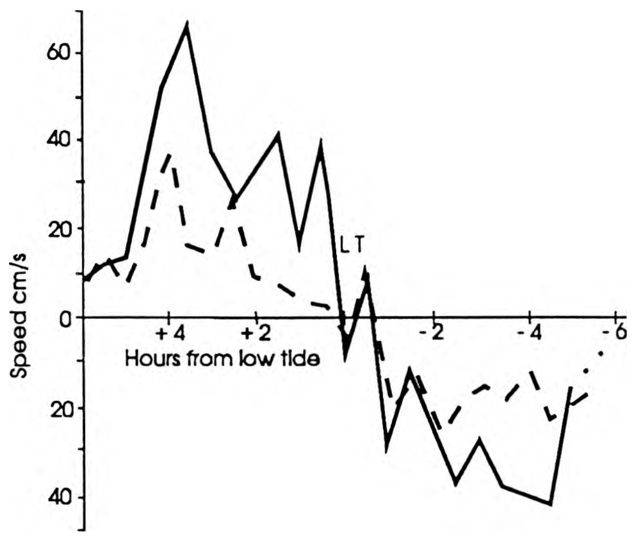
Tidal streams are reversing currents with maximum speeds at about half tide and zero speeds at the times of low and high waters. The speeds therefore rise and fall, out of phase with the tide. We shall find that speeds may be up to 0.7m/s at the time of spring tides and 0.4m/s at the neaps, and that the reversals of direction take place without much delay.

Tidal Streams in the Mahurangi Estuary

We examine first the tidal stream speeds in the Estuary. The only data available for both spring and neap tides are measurements made by Johnston at the site of the Old Cement Works. The tidal streams, at spring tides, have a maximum speed of about 0.5m/s (1 knot), speeds being greater on the ebb tide 0.7m/s and lower, 0.4m/s on the flood, perhaps reflecting both the tidal asymmetry and the influence of the freshwater flow. The tidal streams are largely coherent down the water column, though at Dawsons Creek there was a period at mid-tide when the surface water was ebbing while the bottom water was flooding. This is a very interesting feature which is perhaps associated with the shoaling that occurs there. The ebbing surface water may entrain the subsurface water and generate an upstream flow.

A feature of the velocity regime was the superposition of short period current reversals, a result of, and at periods comparable with, the short period seiching to which attention has been drawn above.

The following diagrams show the speeds over a spring and neap tide cycle at a height of 1m above the channel bed.



Tidal stream speeds 1m off the bottom at the Old Cement Works, during one cycle of a spring tide (3.5 m at Auckland) full line, and neap tide (2.8 m at Auckland) broken line. (Adapted from Johnston 1984)

It is notable that:
* because of the seiching the speeds are most erratic.
* the neap tide speeds are very much less than those of the spring tides; almost half.

	Spring tide		Neap tide	
	Ebb	**Flood**	**Ebb**	**Flood**
1m off bottom cm/s				
maximum	66.0	41.0	38.0	25.0
average	28.2	22.4	12.0	12.7

A knowledge of the water speeds near the bottom (especially the maxima) is useful when considering the threshold speed of sediment movement. For example, as Johnston (1984) has pointed out, only the spring tides speeds are sufficiently high to exceed the threshold speeds needed to erode Mahurangi mud. Average values are useful too because they can tell us something about tidal excursions.

If we wish to use these measurements, made 1m off the bed, to estimate the average speeds at which a coherent water mass would move, we need to know how representative they are of the average of speeds in the whole cross section. Since there has been no intensive work on the currents in a cross section in the Mahurangi, recourse has to be made to a study made in Lucas Creek in the Upper Waitemata Harbour (Williams and Rutherford 1983) where such measurements have been made. The Lucas Creek data have been used to derive relationships between the representative current speed called the weighted current speed and the speed at 1m and the maximum speed. They are as follows:

Hours after HT	Ratio weighted speed / speed at 1m	Ratio weighted speed / maximum speed
1	1.1	0.67
2	0.9	0.63
3	0.78	0.63
4	0.71	0.62

Apparently a measurement made 1 m off the floor would be representative of the weighted mean speed during the top half of the tide, but would be up to 25% too high when the water level fell towards low tide. It is worth noting here that the Lucas Creek data show up the two- dimensional character of the flow and reveal the real difficulty of trying to characterise current speeds from measurements made at only one point in a cross-section, as is often attempted.

On the other hand the weighted mean speed is approximately two thirds of the maximum at all stages of the tide. It is difficult to be sure that the above ratios, applicable to Lucas Creek, are transferable to the Mahurangi Estuary and all tides. Nevertheless the ratios have been used below.

Estimated values in the cross-section at the Old Cement Works.

	Spring tide		Neap tide	
	Ebb	Flood	Ebb	Flood
Weighted mean cm/s	25.7	18.7	11.6	11.1
Tidal excursions-km	5.5	4.0	2.5	2.4

Tidal excursions in the Estuary

The tidal excursion is the distance travelled by a parcel of water during the ebb or flood tide. It is important in that it throws some light on the time spent by the parcel in a particular reach of the tideway. This has implications on the disposal of wastes from the point of view of both purification and algal blooms.

The simplest approach is to calculate the excursion from the current speeds. Based on the weighted mean speeds at the Old Cement Works reach of the Estuary, the ebb tidal excursion of a coherent body of water would be 2.5km at neap tide and 5.5km at springs.

Another approach is to use the cumulative volume curves discussed above. From the graph of cumulative volumes at MHW and MLW plotted against distance from Warkworth, the tidal excursions at selected distances were found. It was assumed that the excursion is given by the difference in distance of the same volume at the two states of the tide. Here again the simplifying assumption is made that the stream speeds are the same in any one cross-section, which is not necessarily so. From the curves the following excursions are found.

Distance from Warkworth km	Tidal excursion of the mean tide km
2.5	1.8
3.0	2.1
3.5	2.5
4.0	2.8
4.5	3.0
5.0	3.1
5.5	3.15
6.0	3.0

On the basis of this argument, and assuming the water moves as a coherent mass, the length of the tidal excursion of the mean tide increases with distance down stream, until a limiting upper value of about 3km is reached. Thus, a parcel of water off Dawsons Creek at low tide will be found just below Duck Creek at high tide. Likewise a parcel of water at the sewage outfall at high tide would be found at 2.7km downstream just short of Red Bluff.

In practice the assumption of coherency is not valid for two reasons, as is demonstrated by the Lucas Creek data. Water near mid-channel moves more quickly than that near the sides. This current shear would be greater at spring tides. Furthermore, because of stratification the near-surface fresher water will tend to move at a greater speed on the ebb. As a consequence, excursions will not be the same for each parcel of water. To estimate the maximum possible excursion we need some estimate of the near surface flow in mid-stream. From the Lucas Creek data it appears that to convert weighted mean speeds to speeds measured near the surface it is necessary to multiply by a factor of about 1.56. This was done. The near surface waters on this basis have an ebb tide theoretical maximum excursion of about 3.7km at neap tides and 8.5km at springs

Another approach is to try to follow floats. Experiments with near surface floats, carried out on 20.11.91. on the ebb tide (Auckland tide 2.9m) indicated that those released near the present sewage plant outfall about 1km downstream from Warkworth, travelled as far as Hepburn Creek a distance of about 3.8km; some confirmation of the value calculated from speeds. In practice this kind of experiment is complicated by the fact that, at corners, the vertical circulation tends to strand the floats, necessitating their relocation in mid-stream.

In another experiment, conducted by Harrison and Grierson and Partners (1974), dye patches were traced from near Dawsons Creek. On the neap flood tide the dye patch moved a distance of just over 2km to a position between Red Bluff and Duck Creek.

With spring tides the excursions would presumably be greater, but we have no experimental evidence of what the increase might be.

Further evidence about tidal excursions can be had from a consideration of the salinity distribution at low and high tide. A rough guide to the excursion can be obtained if it is assumed that no mixing occurred between tides. Using Johnston's data of 19 April 1981, (high tide at Auckland 3.0m, low tide 0.6m) as shown in the diagram in the section on salinity below, we deduce the excursions to be;

Distance from Warkworth kms	Excursion km
3.3	2.5
6.5	3.7

Studies on the Upper Waitemata Harbour suggest that a maximum excursion of the order of 3 km is reasonable.

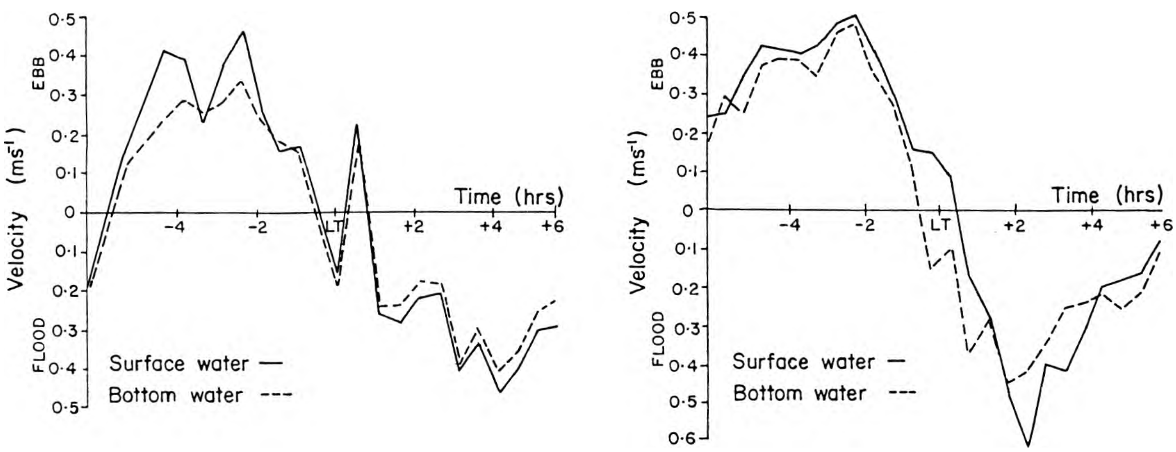
Tidal stream speeds in the Harbour

There are three sources of information about the tidal stream speeds in the Harbour. The Royal New Zealand Navy made log ship measurements in the Heads in 1975. In 1974 Harrison and Grierson and Partners carried out float and dye tracking experiments between Dawson Creek and the Heads, from which tidal stream speeds can be calculated. There are further current meter observations at the Heads and Dawsons Creek, together with float tests with drogues made by Johnston in 1984.

The naval measurements will be used later in a discussion on the exchange of Harbour water.

The results of Johnston's study of the near surface and near bottom spring tide speeds at the Heads and Dawsons Creek are shown in the diagrams below. Slightly higher speeds are attained at Dawsons Creek, up to 0.6m/s. In general the pattern and speed of bottom currents are similar to those at the surface, though the bottom current speeds were notably lower at mid-ebb tide at the Heads and at mid-flood tide at Dawsons Creek.

Johnston has suggested that the marked variability of the currents at the Heads might have been due to seiching.

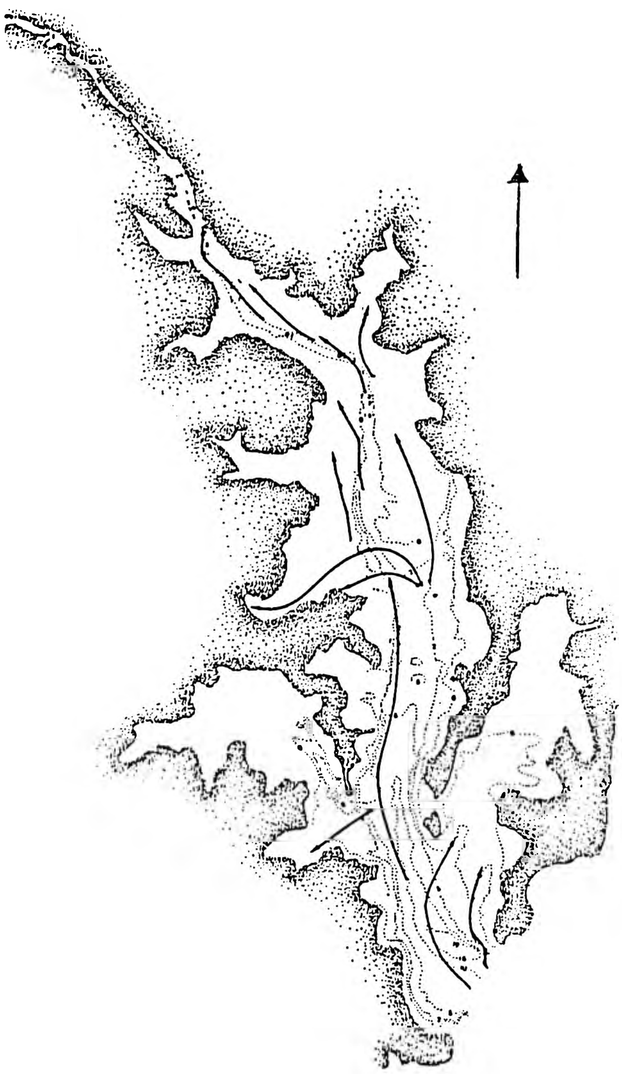


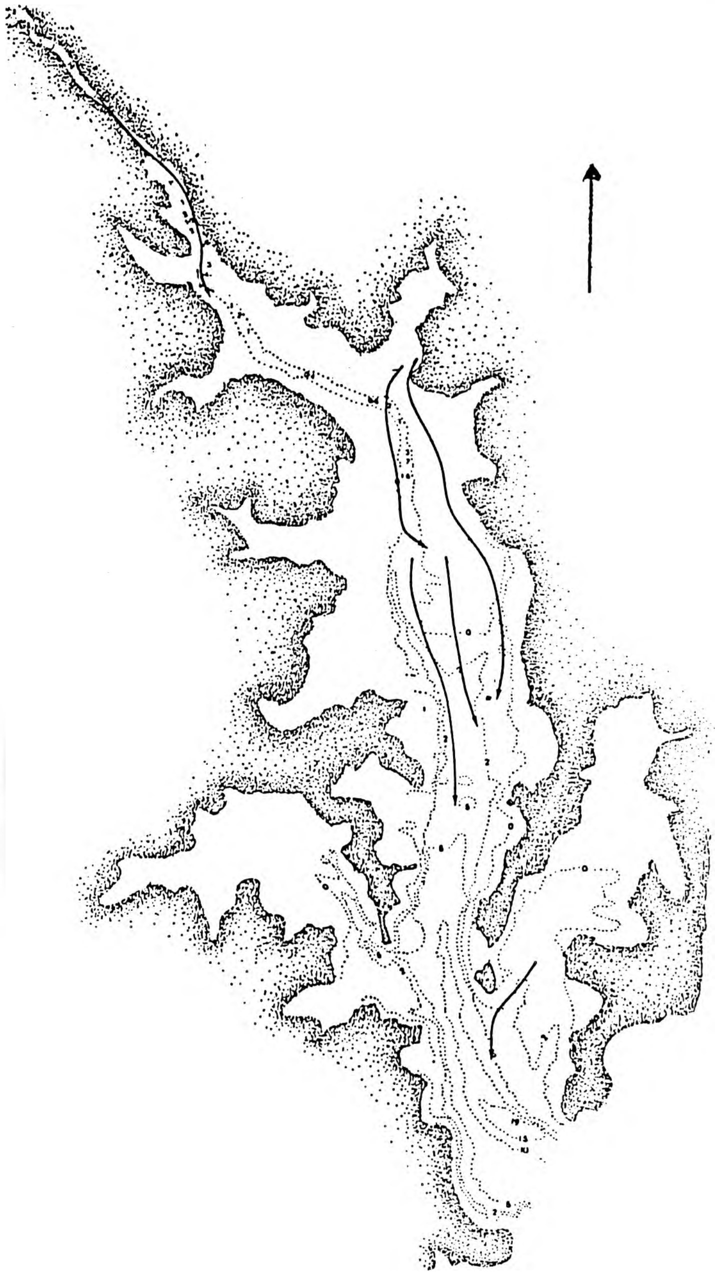
Surface and bottom current speeds during a spring tide cycle (right) off Dawsons Creek and (left) at the Heads (from Johnston 1984).

Tidal Excursions in the Harbour

The tracking of dye patches carried out by Harrison and Grierson and Partners is particularly interesting because the dyed water is a better tracer than floats which are always subject to wind and do not take part in vertical water movements. Spring tide tracking of dye patches between Dawsons Creek and Grants Island showed an ebb tidal excursion of about 4km; while from Bradley Point (just downstream of Dawsons Creek) up into the estuary as far as Hamiltons Landing, the flood tide excursion was predicted by the authors to be 3.5km. These results suggests thai the water masses are travelling at a mean speed of 16-18 cm/s.

The courses followed by tracked markers during tidal excursion studies are shown in the following figures.





Selected float and dye tracks on various occasions: left, during flood tides, right, during ebb tides. (All after Johnston(1984) or Harrison and Grierson (1974) except for the ebb in the Estuary which is after Harris, (unpublished).

SALINITIES

[the units of salinities are parts per thousand]

Under tidal action, water from Kawau Bay enters through the Heads, bringing with it the high salinity, near-oceanic, water at the rate of about 30 cubic metres per second at neap tides. The water is probably drawn in radially from the water outside the Heads. During spring tides this quantity is two thirds as much again. Comparing this inflow with that of the Mahurangi River discharge of perhaps 1-2 cubic metres per second mean flow, it is evident that the higher salinity water will be overwhelmingly the dominant component in the Harbour.

Since the 1970's, salinities between the Warkworth Town Basin and the Heads have been surveyed by the Auckland Regional Water Board. The Board collected samples from near the water surface and at 1m depth. Salinities were also measured by Johnston (1984). These data have been plotted on the two diagrams below, for those collected near high or low water (or usually within an hour of it).

The diagrams show the salinities measured over a number of years (1982-1987) at 5 localities along the tideway.

We note the following salinity measurements (in parts per thousand) made in the tideway off the following places:

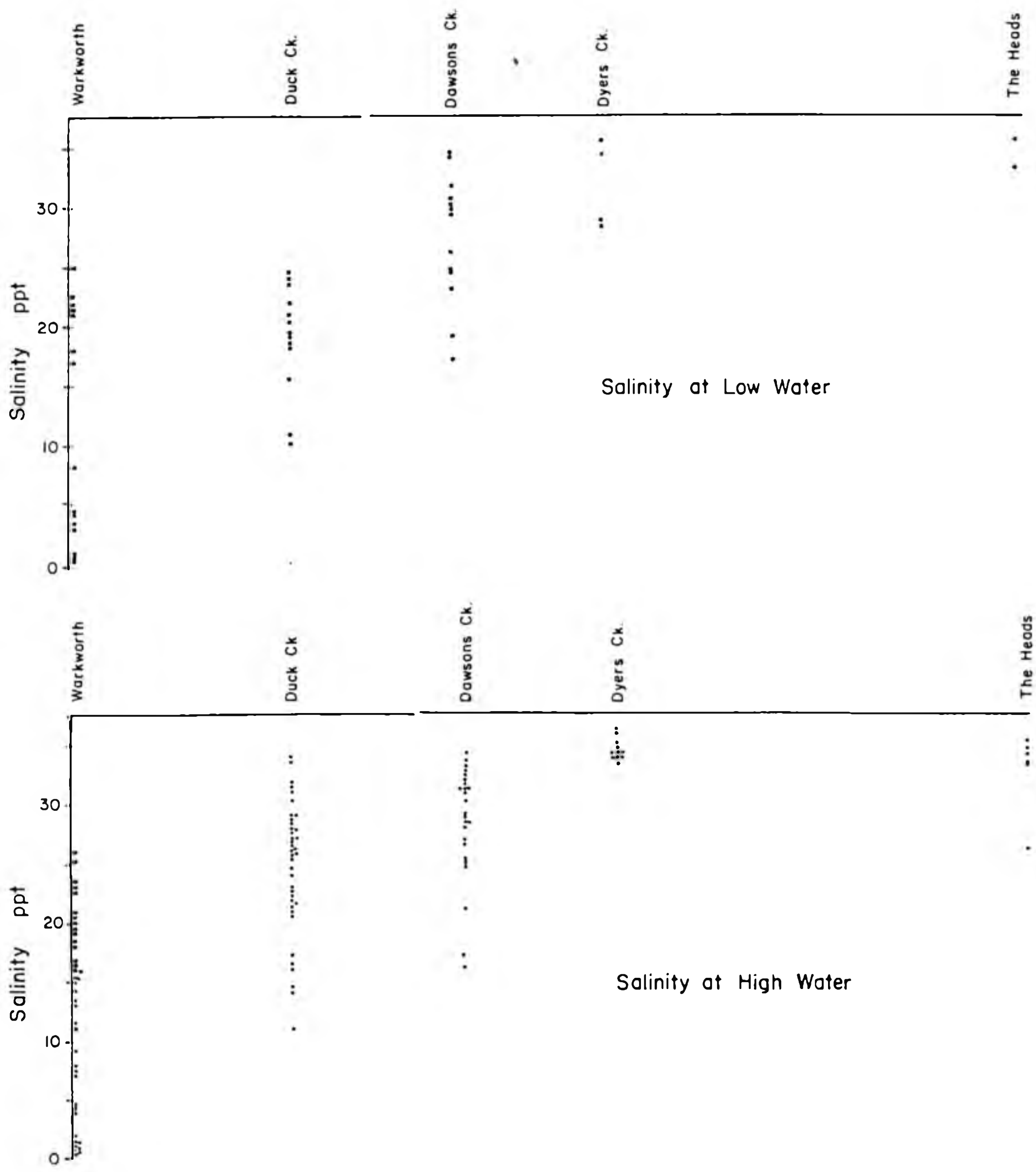
	Surface		At 1m depth	
Locality	Highest	Lowest	Highest	Lowest
Warkworth	21.0	0.5	26.0	7.0
Duck Creek	31.5	5.0	33.5	16.0
Dawsons Creek	34.0	16.0	34.5	17.0
Dyers Creek	36.0	23.5		
The Heads	35.0	26.0		

From these rather limited data it seems that:

* At Warkworth, high and low values may occur at any state of the tide. Presumably the stage of the Mahurangi River is the determining factor. Salinity stratification is marked in the upper metre; even when the surface value is at its lowest, the salinity at 1m may be 10 times saltier.

* Off Duck Creek there is some suggestion that minimum values tend to be higher towards high tide. Off Dawsons Creek this is certainly so. There is still some degree of stratification of salinity in the upper metre.

* Off Dawson Creek, when the Mahurangi River is discharging at the rate of a few hundred litres per second, the water is only very slightly fresher than sea water and stratification has disappeared. It seems that most of the mixing has already taken place. At higher river flows (of the order of 1000 litres per second) this is not yet so.



Salinities (in parts per thousand) in the tideway, sampled during 1978 to 1987, at the surface (dot) at 1m.(square), by Auckland Regional Water Board (Feeney 1984) and Johnston (1984). Upper, near low water. Lower, near high water.

* Off Dyers Creek there is not much influence of fresh water nor is there much stratification of salinity, at least not in the upper metre. This is also true off the Heads where the salinity is about 34ppt except on rare occasions, e.g on 29 November 1985 when the salinity was 26ppt (see below).

It appears that commonly, the mixing of fresh river water and sea water brought in by the tide, is achieved mainly in the estuary and that this process is ordinarily nearly complete off Dawsons Creek. (See Feeney 1984).

Salinity penetration into the Estuary (as defined by the 34 ppt isohaline) may, at high water and during dry periods when the Mahurangi River flow falls to about 200 litres per second, reach as far as Red Bluff on the surface, and Duck Creek at the base of the salt wedge.

There are notable departures from these generalisations resulting from three main causes; exceptionally large river flow, tidal effects and, perhaps, long term changes in sea-water salinity.

Varying river flow

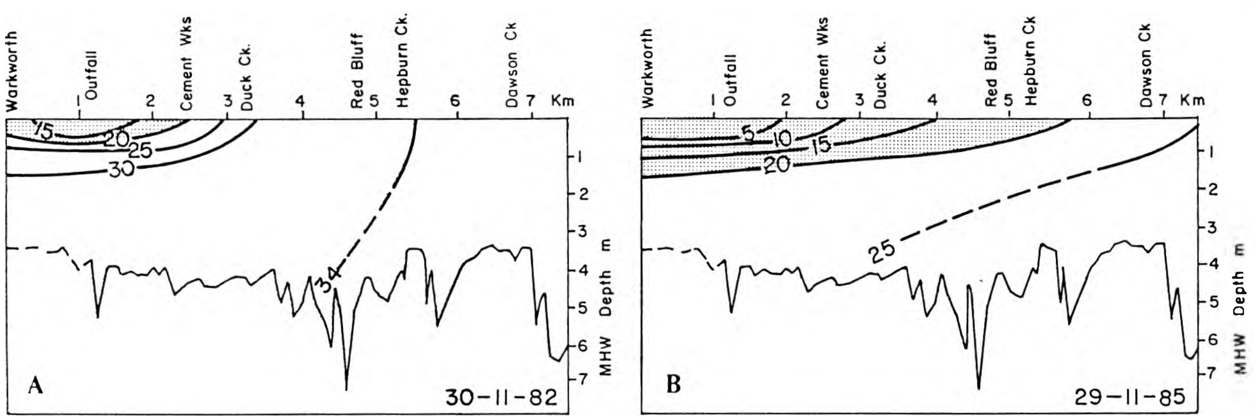
The freshwater discharge into the Harbour may materially reduce the salinity during times of exceptional rains. Thus, the lowest measured values recorded at the Heads, referred to above, occurred on 29.11.85 in the very wet year 1985, and followed about 100mm of rain over three previous days. On this occasion the surface salinity at the Heads fell to 26 ppt.

The actual rainfall at the Satellite Tracking Station near Warkworth, and the discharge of the Mahurangi River were as follows.

Date Nov 1985	Rainfall mm.	River discharge m³/s
23	35.3	970
24	24.7	3680
25	37.5	9880
26	8.2	3120
27	-	1740
28	-	1250
29	-	940

Note that it took some days for the pulse of freshwater to reach the Heads. A study of the residence times, considered below, suggests that a parcel of fresh water can remain in the Estuary for of the order of 8 tidal cycles.

The profound influence of the level of the Mahurangi River discharge on the salinity of the Estuary is illustrated by the diagram below which shows the salinity (or freshwater) distribution following times of low and high river discharges.



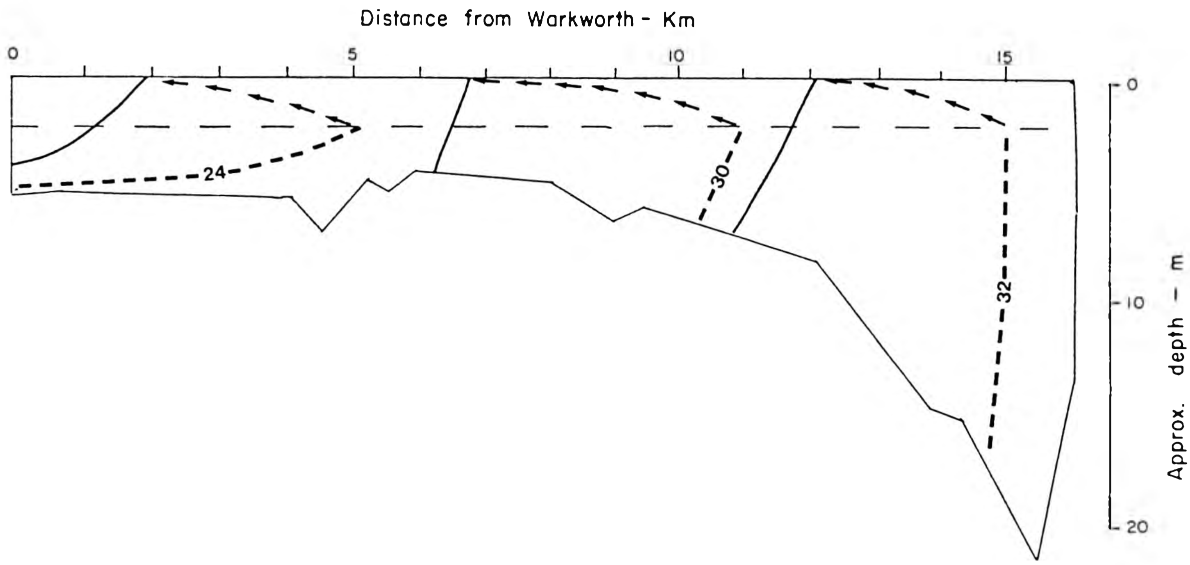
Diagrams showing the salinity distribution (parts per thousand) at high tide, (a) on 30th November 1982 after several days of river discharge of 200 litres per second (about a fifth of the average) and, (b) on 29th November 1985, after river discharges up to 10,000 litres per second within the previous 3 days. Salinities in the shaded areas are less than 20.

The tendency for rain to fall in heavy downpours and the response of the Mahurangi River to this, has already been treated.

Within the Harbour and Estuary there will be seasonal variations because of the trends of rainfall and evaporation. Thus rainfall is greatest in the winter months when evaporation is least (see Appendix 1) and we must expect that other things being equal, salinities will be lower in the winter. Then again, there are great inter-year differences in rainfall. There is substantial evidence that these are related to the El Nino phenomenon which has a repetition period of say 3-5 years. (see section on rainfall). Since the freshwater rides over the saltier, deeper, water this variability of rainfall effect will be reflected initially more strongly in the surface waters.

Tidal effects

There is of course a tendency for salinities to be higher at high tide .The influence of the tidal state is shown in the following diagram.



A salinity section along the axis of the tideway indicates the way the salinities (in parts per thousand) were distributed throughout the main channel on 19 April 1981 on a rising tide.. The dashed lines are isohalines (lines of equal salinity) at low tide, and the full lines those for the following high tide (3m at Auckland). In the previous eight days 120mm of rain had fallen in the catchment. Arrows indicate the excursion of isohalines between tides (data from Johnston, 1984).

Comparing the distribution at low and high tide we note that, as might be expected, the stratification in the estuary is least marked at high tide. With the rising tide, higher salinity moves landwards, isohalines become more vertical, and stratification decreases . The estimate of the tidal excursion based on the distance the isohalines move between low and high tide has already been discussed.

Open sea salinity variability

The salinity of the water entering through the Heads depends on the time of year. Salinities in the Gulf are greatest in the late summer and may reach about 3.55% while falling to 3.45% in the late winter, and one expects that the water in the Heads will follow these trends but be slightly lower.

In addition there will be inter-year variability.

TIDEWAY CHEMISTRY

The chemistry of the Mahurangi Catchment, Estuary and Harbour at 35 stations has been monitored for over a decade by the Auckland Regional Water Board, now the Auckland District Council. Feeney (1984) analysed the data available at that time, and reached conclusions about the chemical conditions which are summarised below.

Non-filterable residue (NFR). The Estuary is invariably turbid, more from resuspension by tide and wave of existing sediments than from the turbidity of the river inflow. Secchi disc distances are commonly a metre and frequently less than 0.3m. Water clarity improved down-Harbour. Apparently aerial observations under suitable conditions show clouds of sediments diffusing from the shore into the Harbour. (Feeney 1984). The turbidity has an important influence on the biology in determining the nature of life of the estuary.

Dissolved oxygen. Saturation values in the Estuary were in the range 60-80% with the lower values being found subsurface. There were tidal influences. In the Harbour values were near saturation.

BOD_5. In the Estuary the oxygen demand was about 2g O_2/ m^3 though it could go as high as 8. In the Harbour the mean value was 1 g O_2/m^3.

Nutrients.

Dissolved nitrogen concentrations diminished by an order of magnitude from several hundred milligrams per cubic metre at the top of the Estuary to an average value of 18 mgN/m^3 in the Harbour.

Phosphorus. Soluble reactive phosphorus changed little within the Estuary and Harbour, averaging from about 20mgP/m^3 at the top of the Estuary to about 10 at the Heads.

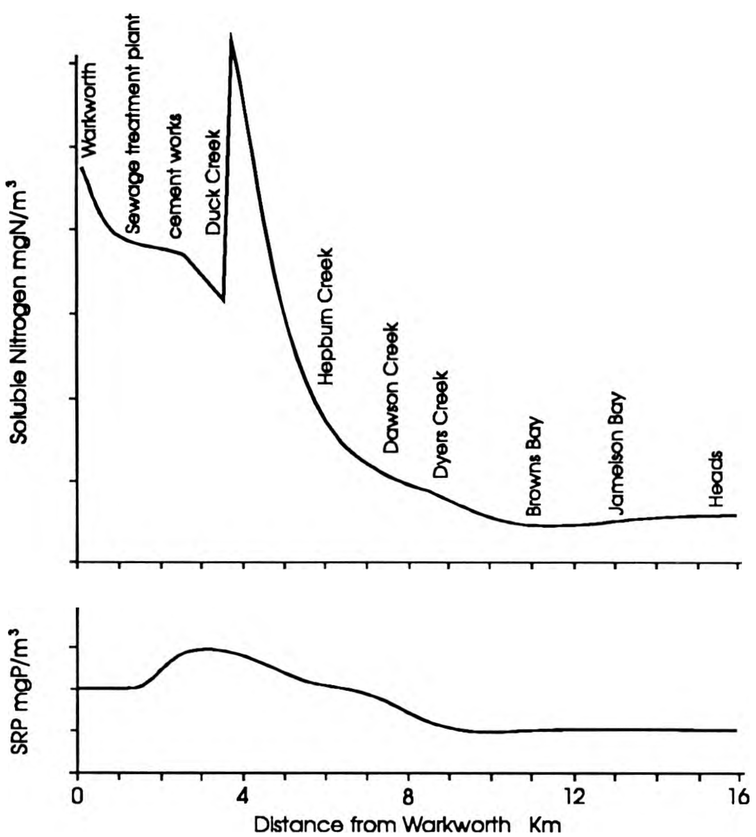
Feeney concluded that with regard to the ratios of nitrogen to phosphorus, the Estuary might be phosphate limited and the Harbour nitrogen limited.

An abstract of the latest analysis (March 1992) has been kindly supplied by the Council (K. Becker personal communication). This greatly extends the data base. Data for five selected stations within the Tideway, at Warkworth, downstream of the Old Cement Works and Duck Creek, and off Dawsons Creek and the Heads, are as follows. Data for the outfall from the Warkworth Sewage Treatment Plant have been added. Some have been rounded-off:

	Warkworth 1	Cement Works 2	Duck Ck 3	Dawsons Ck 4	Heads 5	Sewage Outfall 6
	1	2	3	4	5	6
NFR	26.1	32.3	34.8	33.1	11.2	8940
BOD	1.4	1.4	2.3	1.0	1.0	9.0
NH3	90	100	510	40	40	2340
NO3	360	260	140	70	0	8280
NO2	10	10	10	0	0	100
SRP	20	30	30	20	10	4760
TotP	100	120	150	70	20	5960
DO	81	78	75	88	86	40

NFR Non-filterable residue g/m^3; BOD Biological Oxygen Demand as g.O_2/m^3; Nitrogen as mgN/m^3, NH3 Ammonia, NO_3 Nitrate, NO_2 Nitrite; Phosphorus as mgP/m^3, SRP Soluble Reactive Phosphorus, Tot P total phosphorus. DO Dissolved oxygen saturation %.

The following diagram shows the average levels of nutrient.



Average concentrations (mg/m³) near the main axis of the Mahurangi Estuary and Harbour for (above) inorganic nitrogen, and (below) soluble reactive phosphorus.

The more up-to-date figures do no not substantially alter Feeney's conclusions. They do, however, emphasise the importance of the nutrient contribution from Duck Creek and the increasingly uncomfortable levels of nutrients in the Estuary. (see also under Section 4)

A point of interest is the, apparently, almost uniform level of average soluble reactive phosphorus concentrations (20-30 mgP/m³) throughout the whole Tideway. An explanation may lie in the fact that the suspended clay material has the property of adsorbing phosphorus. Possibly the system is buffered by a reserve of phosphates in the sediments, from which soluble phosphates can leach out.

FLUSHING RATE OR RESIDENCE TIME

The residence time is the time a parcel of water remains in the Tideway. It is important because it:

- **determines the ultimate concentrations of pollutants**
- **is critical to the local recruitment of certain larvae (e.g. oysters); will they settle or be flushed out?**
- **is a determinant for algal blooms; will there be time for the multiplication chain reaction to take place?**

Evidence about the residence time of the Mahurangi Estuary and Harbour comes from the following three sources.

Residence times in the Estuary

Larval history

Martin and Foster (1986) while studying the barnacle larvae in the Mahurangi found that the larvae of *Balanus variegatus* and *Elminius modestus* tended to aggregate in mid-harbour in the region between Grants Island and Dawsons Creek, even though they spawned in the mangroves of the upper harbour. The authors considered that they might be indigenous to the harbour. Noting that the development time for barnacle larvae from hatching to cyprid is 6 days it would seem that the retention time in the harbour must be greater than one day as calculated by a previous study.

Algal bloom residence time

In August 1980 a red bloom of *Mesodinium rubrum* about 0.5km long was noted in the reach of the Estuary below Duck Creek. On the following day the patch of bloom had expanded to 1.9km but still occupied the same reach. (Feeney 1984).

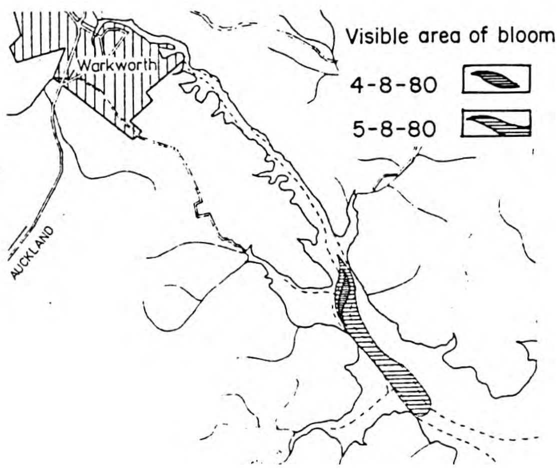


Diagram showing the location of a red bloom of *Mesodinium rubrum* within the estuary between Duck Creek and Hamiltons Landing, on 4-5.8.80. Darker shading for the 4th.(After Feeney 1984).

Tracer concentration changes

In this method we have used the salinity data to calculate the quantity of freshwater in the Estuary and assumed that it was contributed by the known Mahurangi River discharge. If S is the mean salinity of the Estuary or a segment of it and S_0 is the external salinity, then the quantity of freshwater F in a given volume V is:

$$F=V(S_0-S)/S_0$$

and if Q is the rate of freshwater inflow from the river (neglecting other sources and sinks) the residence time R is

$$R=F/Q$$

THe following are the results of making these calculations on a number of occasions. (The salinity and river discharge data came from Auckland Regional Council communications).

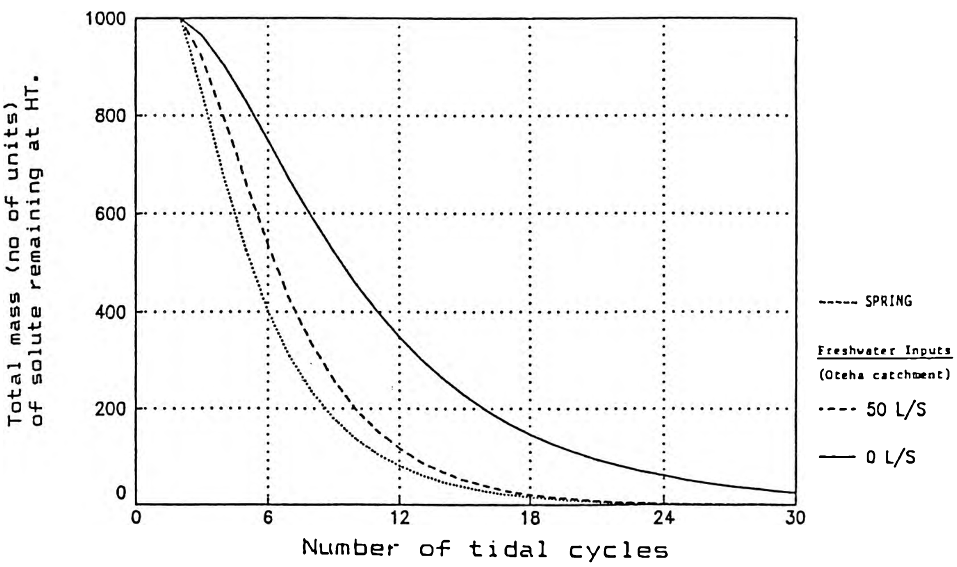
Date	River flow m^3s^{-1}					Fresh water vol m^3	Residence time (days)
	D-4	D-3	D-2	D-1	D		
4.10.82	1.8	1.1	1.5	1.9	1.2	508,868(HT)	4.2
30.11.82	1.9	1.7	1.7	1.	82.0	66,000(HT)	4.2
ditto	ditto					74,800(LT)	4.8
13.4.87.	1.0	1.2	4.4	2.9	2.0	129,000(HT)	5.7

Residence time estimates by the above method are necessarily approximate because of several shortcomings in the data. The salinity distribution data were usually not complete, only measurements at the surface and 1m depth, being available. This necessitated extrapolations which have a strong element of subjectivity. Then, the external reference salinity used to calculate the quantity of freshwater present was not always known. In these cases a value of 34 was adopted. Another difficulty arose in deciding what river discharge to use, observing that the inflows over several antecedent days might still have been influential. Some averaging had sometimes to be resorted to. Additionally there are the errors which arise from the estimates of the volumes in each sector, especially the quantity of water over the mangroves.

However, taken with the other evidence it seems that, under normal river flows, the residence time in the Mahurangi Estuary is certainly more than a day and probably 4-5 days i.e a parcel of water would pass through it in 4-5days.

Experimental data from the use of dyes in Lucas Creek in the Upper Waitemata Harbour have enabled the flushing regime to be modelled. The results are shown in graphs which predict the concentration of a 'slug' of material released in the upper reaches. The model was calibrated for an average tidal range. Three cases are considered, one with no river inflow, one with 50 l/s inflow and one with a spring tide.

The results show that it would take 9-17 tidal cycles for the concentration to be reduced to 20% of the initial value. The Lucas Creek and the Mahurangi Estuary have similarities.



Modelled rate of flushing of Lucas Creek in the Upper Waitemata Harbour, showing the mass of some solute from an initial "slug" of 1000 units, still resident in the Creek at high tide after the passage of a given number of tidal cycles, for different freshwater inputs. (After Williams and Rutherford 1983).

Presumably, the residence time depends to some extent on the tidal range (neap or spring) and on the river discharge, since a higher river stage will generate higher currents, especially near the surface.

Harbour exchange

The health of the tideways depends on the exchange of water with the outside receiving water, and it is noted that the exchange is much assisted by the very different modes of flow of the jet-like ebb tide and the radial inflow of the flood. (see Harris 1993)

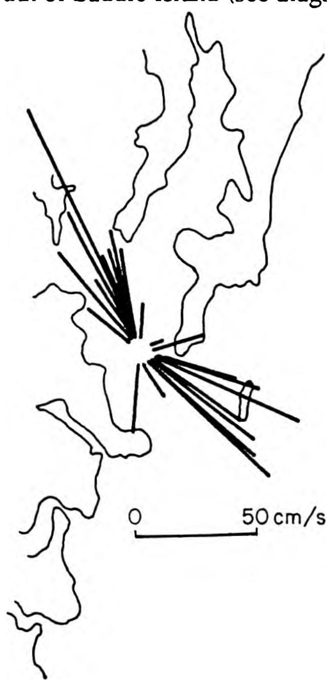
Schematic diagram illustrating the difference in the flow patterns outside the Harbour; the jet associated with the ebb (shaded) and the radial inflow with the flood tide (arrows). Exchange of Harbour water is facilitated by the fact that the flood tide water is not drawn only from that area of the ambient water into which the ebb tide flowed.

Furthermore, much of the mixing with the receiving water seems to arise from entrainment by the ebb tide jet. The situation at the Mahurangi Heads would be complicated by the presence of Saddle Island off the mouth. We have very little information about the water movements and mixing processes which actually take place outside the Harbour.

Evidence from float tests at Orewa (Harris 1993) suggests that the ebb-tide jet penetrates seaward a distance of about 1.5-2km before the turn of the tide. One would expect a greater penetration by the Mahurangi jet. Calculated on the basis of the results of small physical model experiments reported by Wilkinson (1978) it would be about 3-5km, but scaling up may be unreliable.

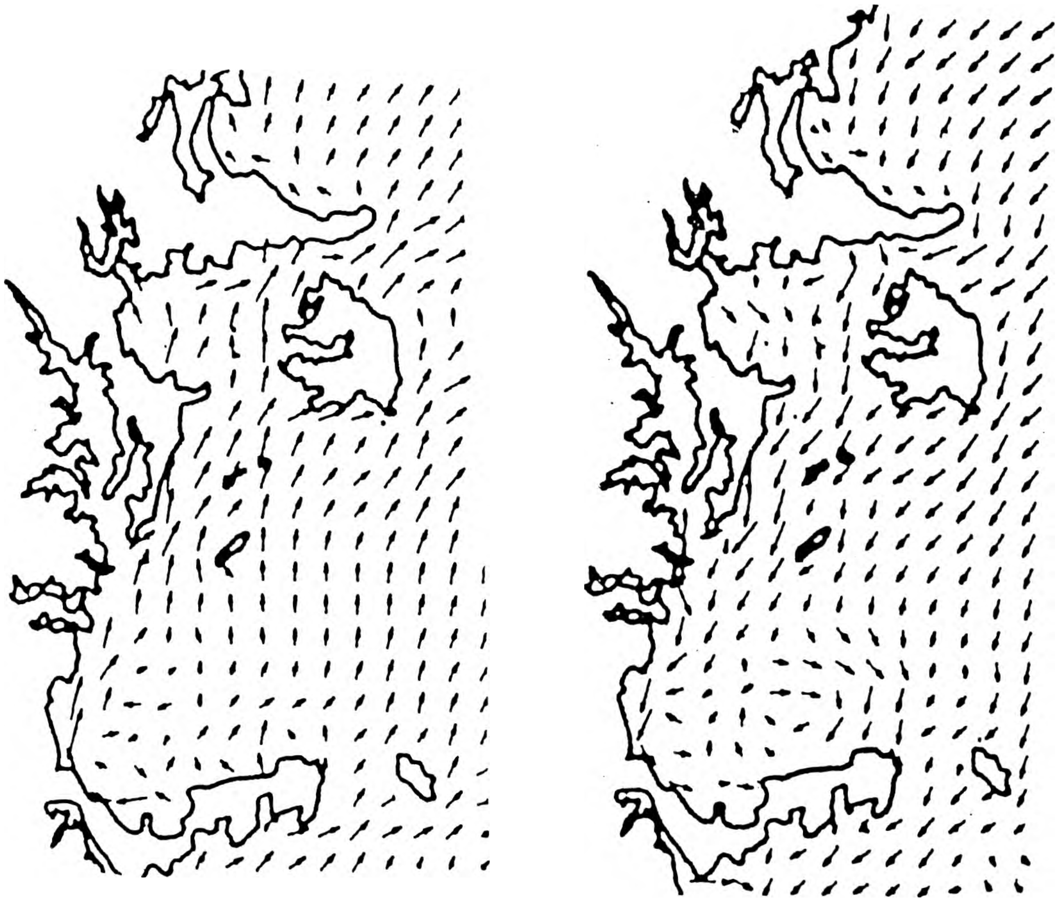
Current measurements made by the Royal New Zealand Navy (personal communication) show that just inside the Heads the ebb tide jet is directed between 120° and 144°T. Maximum speeds which are about 0.5m/s, occur at midtide. Currents are usually directed to pass to the south of Saddle Island (see diagram above).

Tidal current vectors measured by the RNZN near the Heads 21.5.1975. (RNZN Hydrographer pers.communication).



Consider now the boundaries of the sea from which the flood tide water is derived. Presumably the water is drawn in radially in the manner of potential flow, and, if this is so, a rough estimate can be made of the radius of the semicircle outside the Heads which would provide the volume required to fill the tidal prism. An area with a radius of the order of 2km would be necessary for the spring tide prism ($50x10^6m^3$) and about 1.5 km for the neap prism. Strictly speaking this area should be recognised as being a second Mahurangi Catchment.
It will be apparent that, by limiting the recycling of ebb tide water, the difference in the ebb and flood processes is central to the exchange process.

One additional complication is that the ambient water is of course subject to tidal motion and wind induced currents. In general these would tend to remove old ebb tide water from the area and assist exchange. Here again we are poorly informed about the currents in the ambient water. The ebb tidal current streams are not great; naval chart data for the Inner Channel i.e. along the coast north of the Heads, indicate a speed of 0.1-0.15 m/s to the north. In the absence of other currents therefore we would expect the issuing tidal jet to tend northwards. Wind drift currents are undoubtedly important here. Current vectors from the results of numerical modelling wind effects are shown below.

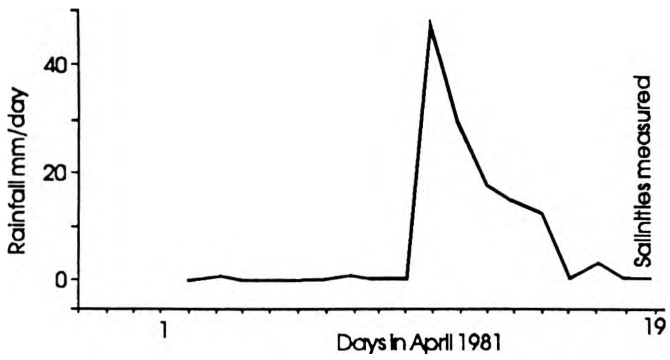


Current vectors of surface currents modelled for winds of 15m/s from, (left) the southwest and (right) the northeast. (After Proctor and Greig 1989).

There is also some fragmentary information about the destination of drift cards released by the Department of Agriculture and Fisheries just within the Harbour. Amongst the destinations of the cards were, Orewa, Red Beach, Kawau Island, Motuora Island, Pakiri and Snells Beach.

It is obviously important to try to get some quantitative estimate of the Harbour exchange and find out what proportion of the tidal prism does not recycle back into the Harbour on the succeeding flood tide. Since direct measurement of exchange is impractical, recourse has to be made to other means. In what follows, use is made of an occasion when there was a pulse of rain in an otherwise dry period. Subsequently salinity measurements on 19 April 1981 were made in the Estuary and Harbour by Johnston (1984). The volume of rain water runoff which had entered the system, and the quantity actually found, were calculated. The difference represented the quantity exported in a given time and hence gave the quantity exported per tidal cycle. This in turn enabled an estimate to be made of the fraction of the tidal prism which was exchanged during each tidal cycle. It was about 14%.

The details are as follows. The rainfall pulse is shown in the rainfall time series diagram below. The freshwater inflow was calculated as a product of the total rainfall and the catchment area draining to the Estuary using a runoff factor of 65%. Together with a base flow of $1m^3/s$ this gave a freshwater pulse of $7.085665 \times 10^6 m^3$.



Time series of daily rainfall (mm) illustrating the pulse of freshwater that passed through the tideway.

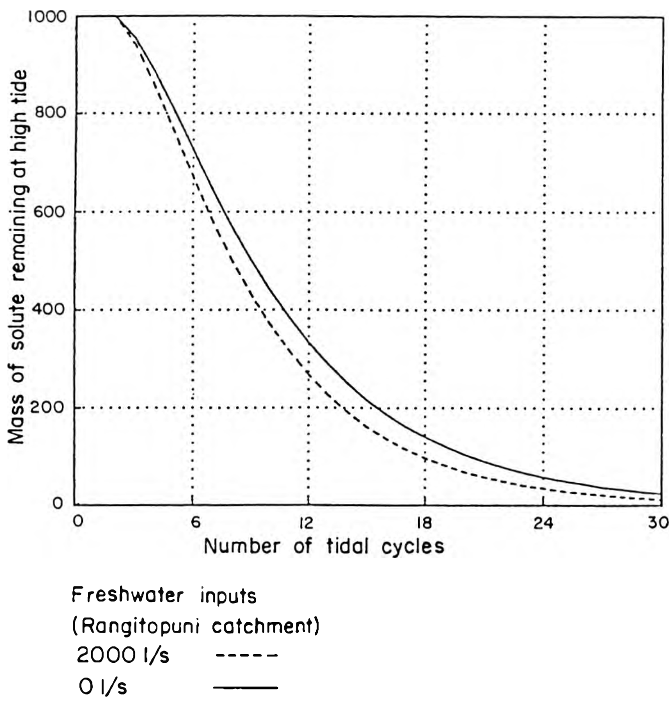
The quantity of freshwater in the tideway, 7 days after the pulse first entered it, was estimated from the salinity to be 2.4763 x10^6m^3 (the distribution of salinity for the 19 April 1881 has been shown above in the section on salinity). A quantity of 4.609365 x10^6m^3 of fresh water had therefore been exported. The rate of removal had therefore been 0.307291 x10^6m^3 per cycle. If the rate is assumed constant, the whole pulse would therefore be exported in about 11 days, about 22 tidal cycles.

[We note here that the relatively long residence time might be the primary reason why the tideway is so highly thought of by oyster farmers].

From the salinity at the Heads at low water (32ppt) it was estimated that this loss of freshwater must have been associated with an exchange of roughly a little more than one eighth (14%) of the mean tidal prism. The best that can be said of this estimate is that it is better than nothing.

Experience from the Upper Waitemata Catchment, whose similarity to the Mahurangi is discussed later, is also that flushing rates are probably rather slow and that the time taken for a slug of pollutant to clear the Harbour is of the order of tens of tidal cycles, perhaps as many as 15 before the concentration of the slug is reduced by 80%. The diagram illustrates the decay of concentration with time (Williams and Brickell 1983).

Modelled rate of flushing of the Upper Waitemata Harbour showing the mass of solute from an initial "slug" of 1000 units, resident in the harbour at high tide. (After Williams and Rutherford, 1983).



TIDEWAY BIOLOGY

In this part we treat the biology of the Mahurangi tidal waters; the kinds of habitats which are available, the biomass and the food production, and the plants and animals which make up the tideway community.

Available literature

As yet there are no comprehensive studies of the biology of the tidal waters. There have, however, been some limited investigations and these provide useful qualitative information about the flora and fauna in the Harbour. Notable amongst these sources are,

* A University of Auckland student study by J.E. Augustin (1980) of the ecology of the Harbour. It includes information on the trees and plant life as well as the macroinvertebrates, and references to fish and bird life.

* A survey made by Bioresearches Ltd (1975) in Dawsons Creek in connection with the Snells Beach oxidation pond investigations.

* A publication by the Friends of the Mahurangi (Keys Ed. undated) which includes a checklist of the fishes and notes on some invertebrates by J. Nicholson, and on the birds by M. Hamilton.

* The University of Waikato masters thesis by R.M.S. Johnston (1984) which, though primarily concerned with the sediments, does include a valuable list of the bivalves and gastropods, and a few diatoms, found in the Harbour.

* Reports of water quality surveys by the Auckland Regional Water Board (ARWB) (Feeney 1984) contain information about the bacteria, plankton (L.A. Levis) and several blooms and growths which developed consequent to pollution.

* B.S. Green (1991) has reported on a Harbour survey near the Heads, for the Parks Board.

* Two University of Auckland theses related to the oyster farms by B.M. Forrest (1991) and S.J.Handley (1992)

* A bird checklist has been compiled by the Auckland Ornithological Society.

In general the existing information gives a good preliminary qualitative picture of life in the Mahurangi. However, there are no quantitative data on such aspects as species distribution or productivity. For the present it is necessary to import this kind of information from elsewhere, justifying the assumption on grounds of perceived similarities.

There have been useful studies on other similar tideways including those on the following:

* Upper Waitemata Harbour Catchment: comprehensive study including quantitative research, coordinated by the Auckland Regional Council.

* Waiwera Estuary: reported by J. Morton and M. Miller in their classic book on the New Zealand Coast and most recently, an Auckland University thesis by M. Regtien (1992) about the impact of oxidation ponds on the tideway.

* Whangateau Harbour: the subject of many theses by University of Auckland's post graduate students based at the Marine Laboratory at Goat Island including those by Durbin (1969), on plankton, Larcombe (1968) and (1979), Grace (1972) on the macroinvertebrates, Davenport (1979) on the zooplankton and fishes, and a fish checklist by R. Grace (1971).

* Whangarei Harbour and other estuaries which provided material for publications such as those by L D. Ritchie (1982) on the fishes etc.

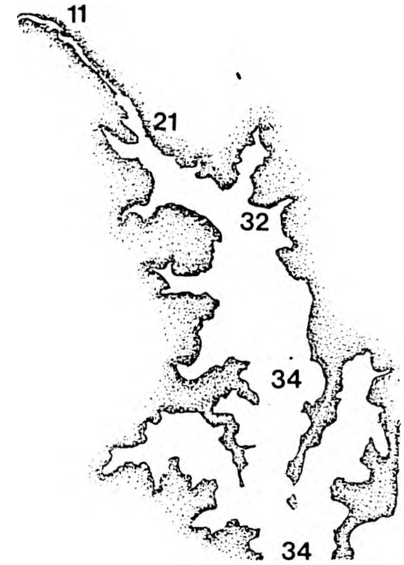
* Parts of a book by M. Bradstock (1985) deals with similar estuaries.

MAHURANGI TIDEWAY HABITATS

We recall first those geophysical or chemical characteristics which are determinants of habitats.

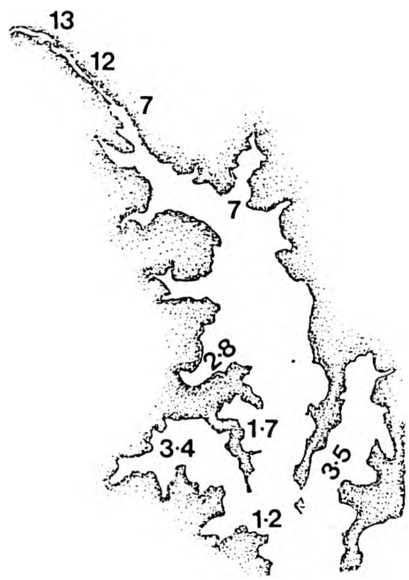
Salinity

The mean freshwater inflows, a few cubic metres per second, are small compared with the tidal prism water and the latter will dominate the salinity. There are the expected gradient of water salinity from the nearly fresh water inputs at the head of the Estuary and the creeks, to almost open ocean salinities of about 34 ppt at the Heads (see diagram of mean salinities; data from Johnston, 1984, and Feeney, 1984). This represents not only a wide range of potential osmotic pressures but also a range of chemicals, notably nutrients, which are associated with the two water types.



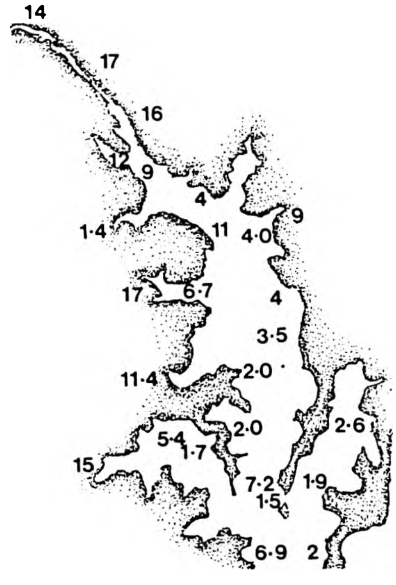
Turbidity

See diagram of Turbidity in NTU units (data from Feeney 1984). The fresh water inflow is sufficiently small and the harbour is sufficiently long for the influence of the clearer salt tidal water to ultimately dominate. There is therefore a range from turbid water introduced with the river waters. Additionally there is the turbidity introduced by wave and current turbulence in the shallower regions of the Estuary and Harbour (13 NTU) to clearer water in the deeper regions towards the Heads (2NTU),a tenfold decrease.



Organics in the Sediment

Because of the pastoral/dairy land use in the catchment, and the erodible clay nature of the soils, the nutrients and sediments carried by the freshwater are of very great importance. The sediments range from fine sand to silt. The percentage of organics in the substrate (see diagram) diminishes from 17% at the top of the Estuary and creeks (especially on the west side), to a low value less than 5 towards the Heads (data from Johnston 1984).



Inundation areas.

Extensive areas of the tideway floor are exposed at low water, a feature which influences the nature of food production and the kind of flora and fauna to be found.

The great difference in the area of water surface at high and low tide is a measure of the range of submergence times which are available. There is a very large inter-tidal zone. In the diagram the approximate mean low tide water area is shaded black.

Mangrove/mud habitat

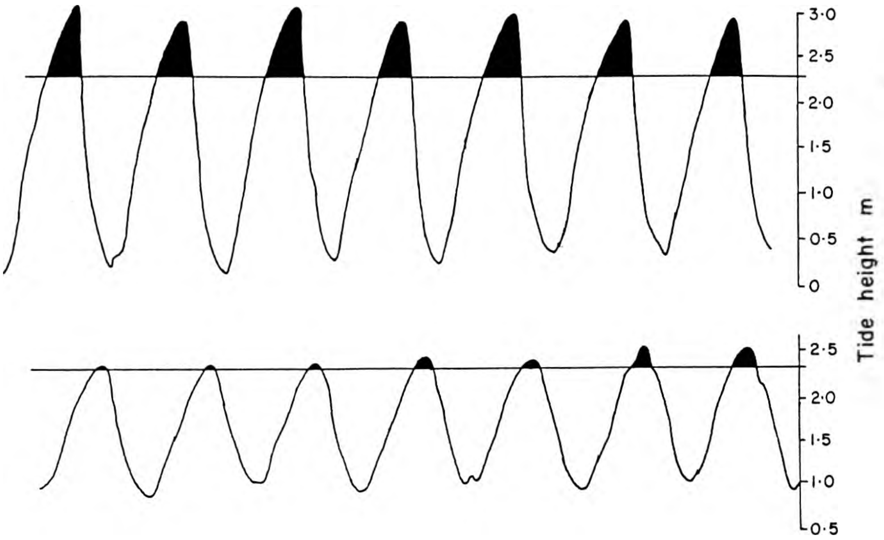
The clay soils of the catchment are efficient adsorbers of nutrient phosphate. With silt they form an organic rich mud substratum towards the heads of creeks. Sand and silt are the main constituents of the tidal flats.

The mud-mangrove associated community, (marked black in the diagram) is a substantial part of the tideway; 23%,of the area. It accounts for a major part of the food production and biomass in the Upper Waitemata Harbour.

Mangroves *(Avicennia marina)* thrive at the heads of creeks and along the banks of the Upper Harbour; and form an intertidal bush.

Measurements made at several points within the large mangrove field near Hamiltons Landing and in Hepburn Creek showed that, at the mean high water, the depth of water was generally about 40cm. This depth is important and has been used below in estimating inundation durations

The following diagram shows records of the spring and neap tidal heights at Grants Island. The portions blacked in show those parts of the cycle for which the plants in the middle of the the mangroves are inundated. Durations range from one hour at neap tides to four hours at springs; a small fraction of each tide at the top of the tide. For a mean tide, inundation is confined, to just over an hour either side of high water. Tidal stream speeds are a maximum at half tide, and zero at high water. Mangroves would therefore be unlikely to experience speeds of more than about 10cm/s; a low speed. Around the outer fringes of mangrove fields, however, the depths at mean high tide may be up to 80cm.



The portion of successive tidal cycles during which mangroves will be inundated (black) for, (above) spring tides, and (below) neap tides, at Grants Island. (Tidal data from Johnston, 1984)

Mangroves are commonly found growing in poorly consolidated clay-mud, subject to periodic inundations by the tide. The sediment is fine grained and poorly drained and without oxygen except in a thin surface layer.The latter condition leads to the production of unpleasant hydrogen sulphide gas and the black colour due the reduction of iron salts to black iron sulphides. Mangroves thrive in mud and it is this capacity to adapt to oxygen poor soil, as much as their tolerance of salt water, that accounts for their dominancy over the water-land interface. The clays of the weathered Waitemata series on the northeast coast stretching from Auckland to Whangarei, together with silt therefore forms a substrate suitable for mangroves. It is possible that microbial preparation of the soil is first necessary before successful colonisation can take place.

The air breathing roots which protrude out of the mud offer a special habitat.

The physical and chemical differences in the Estuary and Harbour have implications which are quite fundamental to the whole biology of the system.

THE ESTUARY

Most of the Estuary is turbid, shallow at low tide, and lined, with a rich mud. These, together with mangrove fields, some extensive, provide a habitat very suitable for a special community. In the estuary and the heads of the side creeks, these conditions favour a benthic oriented, characteristically mangrove community, reliant for food primarily on production at the mud-water interface and supporting deposit feeders.

The residence time of water in it is relatively long, say 8 tidal cycles, so the sewage effluent and Duck Creek water with high nutrients, discharged into it, make a significant impact on its water quality; the nutrients, the oxygen, BOD and bacterial count. Nutrients and N/P ratios are at eutrophic levels.

THE HARBOUR

The Upper Harbour has a low tide channel with sandy intertidal banks (with high sand content; 70-90%) and mangroves in its upper reaches. Towards the Heads the water is mainly too deep for intertidal banks to become exposed, though the rock platforms off headlands and islands and shell beds do.

It is clear that towards the Heads, the entrance, conditions are very different from those in the Estuary and at the heads of the creeks. Here, down harbour, the water is more saline and clearer, and there is less organic material and no mangroves. Consequently, it is more advantageous for food production to be based on plankton photosynthesis, congenial to a filter feeding community.

THE NATURAL POPULATION

On a rough order of magnitude basis, with the information so far available, the macro-faunal population of the tidal waters (apart from the innumerable bacteria, plankton, spat, ova and other microscopic organisms) is estimated to consist of the following species numbers.

Fauna	Number of species so far reported
Macroinvertebrates[1]	
bivalves	36
gastropods	19
crustaceans	11
polychaetes	26
Fishes	34
Birds[3]	
water fowl	10
wading birds	15
marsh birds	2
paddocks and bush birds	20

[1] from Augustin (1980), Johnston (1984), Bioresearches Ltd (1975), Handley (1992), Nicholson in Keys (undated) Green (1991), and Forrest (1991).
[2] based on a checklist by Nicholson (Keys undated).
[3] from Auckland Ornithological Society checklist and Hamilton in Keys (undated).

From these reports it seems that the macro faunal population of the Mahurangi might be of the order of 170 species.

Quantitative Assessment

In addition to the qualitative assessment of the faunal population given above, it is of interest to try to estimate the constitution of the biomass and the productivity, matters of importance in tideway management. As noted above we do not yet have information of this kind for the Mahurangi, but it does exist for the Upper Waitemata Harbour. We shall therefore have recourse to that tideway's specific biomasses (weights per unit area) and productivity per unit area.

There is some justification for making this information transfer, based on evidence that the habitats, kinds of life, and processes of the Mahurangi are similar to those in the Upper Waitemata Harbour (UWH).

The essential geophysical setting seems to be similar.

The soils of both catchments are, in the main, derived from Waitemata series rocks and the sediments, consist of fine sands, clays and silt. About a quarter of the area of each is covered with mangroves. Fresh water inflows in both average about 1-2m^3/s and over a tidal cycle this at least two orders of magnitude smaller than the mean low tide volume. Tide ranges are almost the same, and residence times are of the same order of magnitude.

Salinity ranges will tend to be similar.The range of habitats is therefore probably comparable.

Nutrients: average concentrations (mg/m³)

	Mahurangi to Dawsons Ck.	UWH
dissolved reactive phosphorus	18	15
total phosphorus	84	85
inorganic nitrogen	233	240

The average concentration of nutrients is very similar.

Macrofauna; Number of species

	Mahurangi	UWH
macroinvertebrates (molluscs and polychaetes)	92	69
birds	50	54
fishes	21	34

The partition of numbers amongst phyla suggests similar communities.

[Data for the Upper Waitemata Harbour from, Williams and Rutherford, Knox(b), and van Roon; all (1983).

The following, from Knox (1983a)is a first estimate of the relative quantities of flora and fauna in the Upper Waitemata Harbour. The estimates are expressed as grams of carbon per square metre.They may be applicable to the Mahurangi Tideway. However, since there are considerable difficulties in making these kinds of estimates they should be treated with reserve.

	Biomass	
Element	UWH g.C. m^{-2}	(%)
mangrove above ground	361.0	81
detrital microbial community	22.0	5
mangrove litter	40.8	9
sediment infauna (bivalves,worms)	7.50	1.7
benthic epifauna (snails, crabs)	5.35	1.2
benthic microalgae	3.95	0.9
phytoplankton	1.20.	27
fish	0.85	0.2
zooplankton	0.42	0.1
birds	0.04	0.01
Total	443.1	

Mahurangi areas

area of water surface at high tide	24.71 km^2
area of water surface at low tide	9.76 km^2
area of water surface at mid-tide	17.23 km^2
area of mangroves	5.68 km^2

93% of the biomass is associated with the mangroves or the tideway floor.

Food production (carbon) in the Mahurangi Tideway

Carbon dioxide and sunlight gives rise to primary production by algal macrophytes, vascular plants such as mangroves, benthic microflora which coat the inter-tidal tideway floor, and phytoplankton floating in the water. This production also requires *inter alia* the nutrients, notably nitrogen and phosphorus. Compared with production in the open sea, levels are high, perhaps twenty times higher. In addition rivers bring in organic detritus.

The relative importance of these producers depends on the type of tideway and especially on the water clarity and the sizes of the areas in which they operate.

In the absence of specific productivity figures for the Mahurangi we once again draw on experience gained in the Upper Waitemata Harbour Study (Knox 1983a). Production is expressed for convenience in terms of the equivalent amount of carbon rather than as the complicated compounds that are in fact produced. Unless otherwise stated the units are grams of carbon per square metre per year. Numbers have been rounded off to the nearest gram.

Net productivities in grams of carbon per square metre per year for the Upper Waitemata Harbour (UWH) are:

Source	UWH productivity $g.C\ m^{-2}y^{-1}$	%
benthic microflora	175.8	44.0
phytoplankton	140.0	35.1
mangrove litter*	40.8	10.2
rivers dissolved organic material	41.1	10.3
rivers particle organic matter	1.1	0.3

*(averaged over whole)

The algae on the tideway floor, are the most productive element. The contribution of the mangroves is interesting. Mangroves occupy an area of about 25% of the Upper Waitemata Harbour. Their productivity is comparatively very high $912g.C\ m^{-2}y^{-1}$ when calculated per unit area of the actual mangroves. On the same basis respiration is $602g.C\ m^{-2}y^{-1}$ and net production $310g.C\ m^{-2}y^{-1}$ of which the litter fall is $176g.C\ m^{-2}y^{-1}$. However when one views this litter fall as a production contribution to the whole harbour the productivity is only $40.8g\ C\ m^{-2}y^{-1}$. Therefore, though the mangrove is one of the two most important sources of primary production, its contribution to the harbour's food chain is by no means the greatest.

There are a number of aspects of the above assessment which call for reservations and the figures must be regarded as indicative rather than definitive.

If the above assumptions are valid, it is expected that a substantial part of the primary production in the Mahurangi Tideway takes place at the sediment/water interface and that bacteria play a very important part in making products available to the consumers, which include such detritus eaters as worms, snails and even some fish.

SPECIES OCCURRENCE

Though quantitative information about the frequency of occurrence of Gulf Tideway species is at present very sketchy, (and practically none is known for the Mahurangi), there are hints that the greater part of the biomass of the approximately 170 reported species of macrofauna in the Mahurangi is made up of quite a small fraction of this number and that a good deal about the working of the system can be learnt by concentrating on them. Considering only macrofauna, evidence from other tideways (Harris 1993) suggests that about 40 faunal species account for a very substantial proportion of the population, including 23 macroinvertebrates, 8 fishes, and 9 birds.

Assuming similitude of Gulf tideways, one might expect these dominant species to be:

Macroinvetrebrates
(Note: *Mollusca* nomenclature follows Powell (1979).
The numbers in brackets is the maximum species density per square metre in the Upper Waitemata Harbour.

Paphies australis , Chione stutchburyi (2050), Tellina liliana (50), Crassostrea glomerata, Xenostrobus pulex.

Cominella glandiformis (100), Cominella adspersa, Zeacumantus lutulentus, Amphibola crenata (202), Diloma subrostrata.

Hemigrapsus crenulatus, Helica crassa (424), Alpheus sp., Eliminius modestus, Palaemon affinis. Turbo smaragda. Macrophthalmus hirtipes, Ophicardelus costellaris.

Nicon aesturiense (450).

In the Upper Waitemata Harbour six or seven species account for 75% of the individuals of the macroinvertebrate community.

Fishes: Yelloweyed mullet (forms 40% of the fishes in the Upper Waitemata Harbour and are prominent in Whangateau Harbour), snapper, yellow belly flounder, spotty, parore, jack mackrel, kahawai, sand flounder.

Birds: A census in the Upper Waitemata Harbour found that 80% were made up of gulls, stilts, oyster catchers, herons, terns, shags and kingfishers.

What follows are the names of species which have so far been reported for the Mahurangi.

TIDEWAY ANIMALS
MACROINVERTEBRATES

The following macroinvertebrates have been reported in the Mahurangi from studies or partial surveys by Bioresearches Ltd (B), data for Dawsons Creek in Harrison et al (1974) and in Murray-North (1975), Nicholson (N) in Keys (undated). Johnston (J) 1984, Augustin (A) 1980, Martin & Foster (F) 1986, Green (G) 1991, Handley (H) 1992, Forrest (f) 1991.

Mangroves and Mud flats :		author
Bivalves		
On mangrove trunks		
Crassostrea glomerata	rock oyster	NB
Crassostrea gigas	Pacific oyster	NA
Xenostrobus pulex	black mussel	B
Xenostrobus securis	small brown mussel	B
Gastropods		
Amphibola crenata	mud flat snail	NB
Zeacumantus lutulentus	horn shell	J
Zeacumantus subcarinata		A
Cominella glandiformis	mud flat whelk	NBJA
Haminoea zelandica	fragile bubble shell	
Diloma subrostrata	mud flat topshell	A
Ophicardelus costellaris	snail	B
Potamopyrgus antipodarum		B
Quibulla quoyi	bubble shell	J
Crustacea		
Macrophthalmus hirtipes	crab	A
Helice crassa	mud crab	NBA
reported by Feeney (1984) to be widespread		
Elminius modestus	estuarine barnacle	NBA
Balanus variegatus	Darwin barnacle	F
peculiar to upper harbour mangroves.		
Alpheus sp.	snapping shrimp	B
Polychaetes		
Nicon aestuariense	nereid worm	B
Perinereis sp		B
Ficopomatus enigmaticus,		
previously, Mercierella enigmatica Fauvel.		

The presence of this tube-building polychaete in the Estuary about and below the sewage treatment outfall is a matter of special interest and is dealt with more fully below.

Muddy silty sand:

Bivalves		
Zenatia acinaces	scimitar mactra	J
Zeacopagia disculus		J
Tellina (Macomona) liliana	large wedge shell	JA
Chione stutchburyi	cockle	JA

Johnston (1984) has observed that cockles do not occur in large numbers in the Harbour today, though large beds of dead ones are found subsurface.

Paphies australis	pipi	A
Gari lineolata	sunset shell	A
Atrina zelandica	fan mussel	J

Gastropods

Cominella adspersa		A
Cominella vigata		A

Crustacea

Hemigrapsus crenulatus	crab	A
Reported by Feeney (1984) to be widespread		
Upogebia hirtifrons	burrowing shrimp	A
Struthiolaria (Pelicaria) vermis	small ostrich foot	J

Polychaetes

Pectinaria australis		A
Polydora websteri	infects oyster beds	H
Polydora hoplura	near oyster beds	H
Boccardia acus	near oyster beds	H
Boccardia chilensis	near oyster beds	H

Rock platforms and poles, middle and outer harbour:

Bivalves

Xenostrobus pulex	small black mussel	NJ
Mytilus edulis aoteanus	blue mussel	J
Chamaesipho collumna	barnacle	A
Anomia trigonopsis	golden oyster	J
Crassostrea gigas	Pacific oyster	A
Perna canaliculus	green mussel (subtidal)	N

Gastropods

Lepsiella scobina	oyster borer	A
Nerita atramentosa	dominant gastropod	A
Turbo smaragdus	cat's eye	J
Cominella maculosa	spotted whelk	J
Cookia sulcata	turban shell	A

Crustacea

Petrolisthes elongatus	half crab, dominant	A
Notomithrax minor		A
Hymenicus pubescens		A
Pagurus novaezelandiae	hermit crab	A
Palaemon affinis	prawn	A
in pools		

Subtidally:

Bivalves

Limaria orientalis		A
Pecten novaezelandiae	scallop	NA
Theora lubrica	dominant off Dawsons Creek	B

Scotts Landing, Puka puka, and Te Kapa

Atrina zelandica	horse mussel	N
Pecten novazelandiae	scallop	N

Subtidally between Grants Island and the Heads

[Note: Forrest's (f) study area included the oyster farms]

Bivalves

Theora lubrica	abundant	fG
Nucula hartvigiana	ridged nut shell	fG

Nucula nitidula	nut shell	G
Corbula zelandica	basket cockle	G
Venericardia purpurata		G
Dosinia zelandia		G
Leptomya retiaria		G
Pleuromeris zelandica		G
Terenochiton inquinatus?		G
Brachidontes senhousia	alien mud mussel	G
Mactra ovata		f
Zenatia sp		f
Chlamys sp		f
Tellina liliana		f
Chione stutchburyi		f
Dosinia anus		f
Gastropods		
Maoricolpus roseus		G
Austrofusus glans		f
Zemitrella sp		f
Amalda? novaezelandiae		f
Cominella adspersa		f
Struthiolaria vermis		f
Crustacea		
Notomithrax minor	masking crab	G
Balanus trigonus	barnacle	G
Pinnotheres novaelandiae		G
Halicarcinus varius	algal crab	G
Worms		
Terebellid		Gf
Ninoe leptognatha		G
Pectinaria australis		G
Lepidonotus sp.		G
Owenia fusiformis	tube worm	G
Boccardia polybranchia		Gf

Additional species reported by Forrest (1991)

Hetromastus filiformis	*Notomastus* sp
Cirratulus sp	*Cossura* sp
Dorvillea sp	*Glycera* sp
Ophioglycera sp	*Ophiodromus* sp
Lumbrineris sp	*Asychis ?capensis*
Euclymene sp	*Nephyts macroura*
Nicon sp	*Perinereis* sp
Armandia maculata	*Phylo ?capensis*
Paraonidess sp	*Paronis* sp
Pectinaria sp	*Prionospio cirrifera*
Prionospio cirrobranchiata	*Prionospio pinatta*
Sternapsis sp	

Exposed area of lower Harbour and outside sand (Perhaps not 'harbour' species):

Bivalves		
Venericardia purpurata	purple cockle	J
Dosinia anus	ringed dorsina	J
Tawera spissa	morning star shell	JA

Soletellina nitida	golden sunset shell	J
Protothaca crassicosta	ribbed venus shell	J
Glycymeris laticostata	large dog shell	J

Gastropods

Struthiolaria papulosa papulosa	large ostrich foot	J
Maoricolpus roseus	turret shell	J

Shell diversity tended to increase with increasing substrate coarseness generally towards the Heads (Johnston 1984)

Oysters

There are extensive oyster leases in the lower part of the Harbour where Pacific oysters are farmed. This species, with its shorter cycle, has replaced the indigenous rock oyster and is now dominant. It is an alien, possibly introduced to New Zealand waters from Japan on some vessel. Large breeding stocks occur on the mangroves, particularly near Dawsons Creek.

It is said that the Mahurangi is of "national significance to the oyster industry" (Feeney 1984). The advantage of the Harbour for oyster rearing was said to be that the Mahurangi was considered the best spat catching area. The larvae can swim but their movements are dominated by tide. There is evidence that they can move up harbour by ascending from the tideway floor into the swifter moving surface currents during the flood tide and therefore can settle in the upper estuary; higher numbers of larvae are reported in the plankton hauls at flood tide. Larval numbers in plankton hauls are about 20 per 500 litres.

Possibly the relatively high residence time of the Tideway is a contributing factor in the Mahurangi's suitability for oysters. The larval stage is free swimming but must settle on clean surface in the harbour within 3 weeks. Spawning requires water temperatures of 22° C approx. This temperature is near the upper limit for the Mahurangi and was not reached in the El Nino year of 1982-1983 (Nicholson, personal communication). See Auckland Regional Water Board Technical publication No 5 and the appendix to the Harrison and Grierson (1974) by the Fisheries Research Division of the Ministry of Agriculture and Fisheries, which refers mainly to oyster larvae.

FISHES

The following is a list of the fishes which have been reported in the Mahurangi. It follows (with permission) the account given by Jon Nicholson (Keys undated). Scientific names have been added. 34 species have been identified. There has been no quantitative survey. However, one has been done on the Upper Waitemata Harbour Catchment (Knox 1983b) and possibly the results are to some extent transferable. Of the 21 species in a 1008 fish sample collected in that survey by Bioresearches Ltd in summer, winter, spring of 1980, only 10 species accounted for 97% of the total number caught. In the check list below the number alongside each species, where available, is the percentage frequency of occurrence in the Upper Waitemata Harbour (UWH).

Also included below are some observations of feeding habits taken from other tideways (Ritchie 1979) and (Knox 1983b). Nomenclature follows Paulin *et al.* (1989). Where the modern species name is not clear, authors' nomenclatures have been retained in brackets.
R=rare C=common A=abundant

Species in The Mahurangi	% the UWH		Feeding habits
Aldrichetta forsteri yellow-eyed mullet	40.4	A	mud flat detritus fauna and benthic algae
Pagrus auratus snapper	9.8	C	mud crabs and snapping shrimps
Rhombosolea leporina yellow belly flounder	8.0	C	debris below oyster racks mud flat organisms
Girella tricuspidata parore	3.9	A	algae, mud flat fauna and detritus
Trachurus declivis jack mackerel	2.9	C	crustacea and small fish anchovies and pilchards
Arripis trutta kahawai	2.7	C	piscivore on anchovies, pilchards and bottom fauna
Rhombosolea plebeia sand flounder dab	2.5		mud flat organisms
Mugil cephalus grey mullet	1.5	C	mud flat algae and fauna
Galeorhinus galeus school shark	0.7	R	
Peltorhamphus novaezeelandiae sole	0.4	R	
Myliobatis tenuicaudatus eagle ray	0.3	C	mud crabs and snapping shrimps
Pseudpcaranx dendtex trevally	0.1	R	planktonic crustacea and bottom fauna.
Zeus faber John Dory	0.1	C	
Genyagnus monopterygius spotted stargazer	0.1	C	pisciverous
Tripterygion spp estuarine blennies	0.1	C	
Pseudolabrus celidotus spotty	4.1	A	
variable triple finned blenny		A	
whitebait (probably several species)		C	
Seriola lalandi kingfish		C	
Acanthoclinus [quadridactylus] black rockfish		C	

Upeneichthys lineatus goatfish (red mullet)	C
Thyrsites atun baracouta	R
Carcharhinus brachyurus bronze whaler shark	R
Hyporhampus ihi piper	C
Chelidonichthys kumu gurnard (red)	C
Xiphias gladius broadbill swordfish 1 caught 1940	
Rhombosolea retiaria black flounder	C
Mola mola sunfish	R
Alopias vulpinus thresher shark	R
Dasyatis thetidis long tailed stingray	C
Anguilla dieffenbachii long-finned eel	C
Anguilla australis short-finned eel	C
Orcinus orca killer whale	

Recreational and commercial fishing in the Mahurangi according to (Johnston 1984) is mainly for flounder *Rhombosolea sp.* but other fish such as parore (*Girella tricuspidata*), mullet *(Mugil cephalus)*, gurnard (*Chelidonichthys kumu*) and snapper (*Pagrus auratus)* are landed.

Dolphins of unknown species are occasionally seen up as far as Warkworth e.g. 1989 and 1991. Two types may be present. Killer whales are also seen. (Nicholson, personal communication).

Consideration of fish studies in the Gulf Tideways leads to the following observations which may apply to the Mahurangi.

*In the Upper Waitemata Harbour 21 species were noted. By far the most dominant were four species; yellow-eyed mullet, smoothhound, snapper and yellow-belly flounder, accounting for 80% of the fishes sampled. Yelloweyed mullet alone was 40.4% in the Upper Waitemata Catchment Survey, and are said (Davenport 1979) to constitute 95% of fishes in the mangrove regions of the Whangateau Harbour.

* 30 species have been reported inside the Whangateau Harbour (Grace 1971).

In view of the dominance of yellow-eyed mullet, it is of interest to know what it feeds on. Davenport (1979) analysed the stomach contents of 318 from the mangrove areas of Whangateau Harbour. He found the food most frequently occurring was fine mud and sediment, 52%. The next most frequent was plant detritus, 15%. It seems likely that the same situation obtains in the Mahurangi.

BIRDS

Knox (1983b) identifies 6 varieties of bird habitats in and around estuaries.

Aquatic: submerged at all times, occupied by water birds

Intertidal: occupied by waders and shore birds in a bivalve zone (cockles and pipis), and a mud-flat zone.

Mangrove zone: mangroves and crabs

Grass zone: pasture and shoreline

Bush zone: scrub, bush and exotic forest.

Birds of the tideway are listed by Auckland Ornithological Society (in a poster in the Scotts Landing house) and also referred to by Bioresearches Ltd.(1975) (B) for Dawsons Creek, Augustin (1980) (A), Hamilton (H)(in Keys undated); these together with feeding habits from Knox (1983b) based on experience in the Upper Waitemata Harbour (K) are set out below. Birds, other than water birds, are listed in Appendix 3.

Population statistics are not available. However, a superficial impression is that water birds are not plentiful and casual observation particularly along the Estuary does not reveal much more than a handful of birds usually herons, kingfishers, pied stilts, and shags with duck and mallard near Warkworth.

Wading birds

Sterna striata [white-fronted tern] fish H
Himantopus h. leucocephalus [pied stilt] shell beds K H
Haematopus unicolor [black oystercatcher]
H. reicheki [variable oystercatcher H
H. finschi [south island pied oystercatcher]
Limosa lapponica [eastern bar-tailed godwit] small invertebrates K
Hydroprogne caspia [caspian tern] shell beds B H
Ardea novaehollandiae [white-faced heron] crustaceans at the channel edges or at high water, small fishes observed from a vantage point in the overhanging totara trees K
Egretta sacra sacra [blue reef heron] bivalves K

Water fowl

Sula serrator [gannet] fish H
Larus dominicanus [southern black-backed gull]
L. scopulinus [red-billed gull]
Eudyptula minor [little blue penguin] H
Phalacrocorax varius [pied shag] fish K. H
P.carbo [black shag] fish K
P.melanoleucos [little shag] H
P.sulcirostris [little black shag] H
Halcyon sancta [kingfisher] crabs in the inter-tidal area BH
Anas superciliosa [grey duck] plentiful at Warkworth
Anas platyrhynchos [mallard] ditto H

Shore birds

Charadrius obscurus [New Zealand dotterel] small crustaceans K
Scolopacidae sp. [sandpiper]

Marsh birds

Himantopus h. leucocephalus [pied stilt]
Porphyrio melanotus [pukeko] pasture B H
Botaurus poiciloptilus [brown bittern] H

Paddocks and bush (see Appendix 3)

TIDEWAY PLANTS

Plankton

A water quality report on the Harbour by the Auckland Regional Water Board (Feeney 1984) contains the results of a survey of plankton by L.A. Lewis in November 1973. The following were recorded.

Nitzschia seriata, N. longissima, Leptocylindrus c.f. *danicus, Rhizosolenia* c.f. *stolterfothii*, *R.*c.f. *hebetata, Coscinodiscus, Skeletonema* c.f.*costatum*, , *Lorieas e.g. Tintinnopsis* sp., *Chaetoceros* c.f. *fragile, C.* c.f. *costatum, C.* c.f. *compressum, Bacteriastrum delicatalum, Peredinium* sp., *Synedra* sp.

More typically benthic organisms include *Pleurosigma/Gyrosigma sp., Navicula* sp., *Amphiphora* sp., *Nitzschia longissima, Cocconeis* sp.

In this study the total cell counts per sample were of the order of 500-1000 per millilitre. *Leptocylindrus* c.f. *danicus* contributed more than half the count in most samples. *Nitzschia seriatia* was also amongst the more abundant, and these two plankton together with *Rhizosolenia deliculata* were reported as the dominant species in Whangateau Harbour. (Durbin 1969).

Johnston (1984) found that the most numerous diatom at the Heads, Dawsons Creek and the Cement Works was *Chaetoceros compressum*. This diatom was identified by (Bartrom 1979) as one of the most common in the Harbour and estimated that *Chaetoceros* sp. could reach a maximum population density of 6 million cells per cubic metre.

Algae etc.

While investigating the impact of reclaiming 27 acres of Dawsons Creek for oxidation ponds, Bioresearches Ltd. (1975) reported that small algae *Caloglossa leprieurii* and *Catenella nipae* occur in places on the mangroves in the creek.

Augustin (1980) noted *Hormosira banksii*, on a rocky platforms near the Heads, *Enteromorpha* in the sheltered mid-eulittoral, and *Carpophyllum* spp. and *Cystophora* spp. on the exposed headlands near the mouth of the Harbour.

The Auckland Regional Water Board (Feeney 1984) reported a bloom of red *Mesodinium rubrum* in early August 1980. On the 4th. August 1980 the bloom was off Hepburn Creek and by the 5th it was elongated downstream nearly to Dawsons Creek. The bloom had an average of 1744 cells per millilitre. Oysters *Crassostrea gigas* at Dawsons Creek and *C. glomerata* at Dyers Creek were affected by it.

Apparently similar water discolouration had been noticed on other occasions by the public. Its possible that the blooms would be more common were it not for the turbid nature of the tideway which suppresses algal blooming.

According to anecdotal evidence (N.Dixon, personal communication) this red bloom occurs annually in the spring and has been noted for about the last 6 years (i.e. prior to 1991).

Other intertidal vegetation.

Augustin (1980) reported reeds, sedges and rushes, *Typha mueller i, Phormium tenax* in the swamp valleys. She also noted that inshore of the mangroves the plants of the *Juncus/Leptocarpus* salt marsh are found with *Cladium junceum* and, in the drier areas, *Salicornia australis* and *Cotula dioica*. Previously existing *Zostera* beds off Opahi Bay have disappeared under silt, supposedly from the increased earthworks.

Bioresearches Ltd (1975) reported the following in Dawson Creek.
Triglochin striatum, Cotula coronipifolia, Samolus repens, Leptocarpus simplex, Juncus maritimus var. *australiensis.*

Nicholson (personal communication) has observed *Spartina* sp. in Dawsons Creek

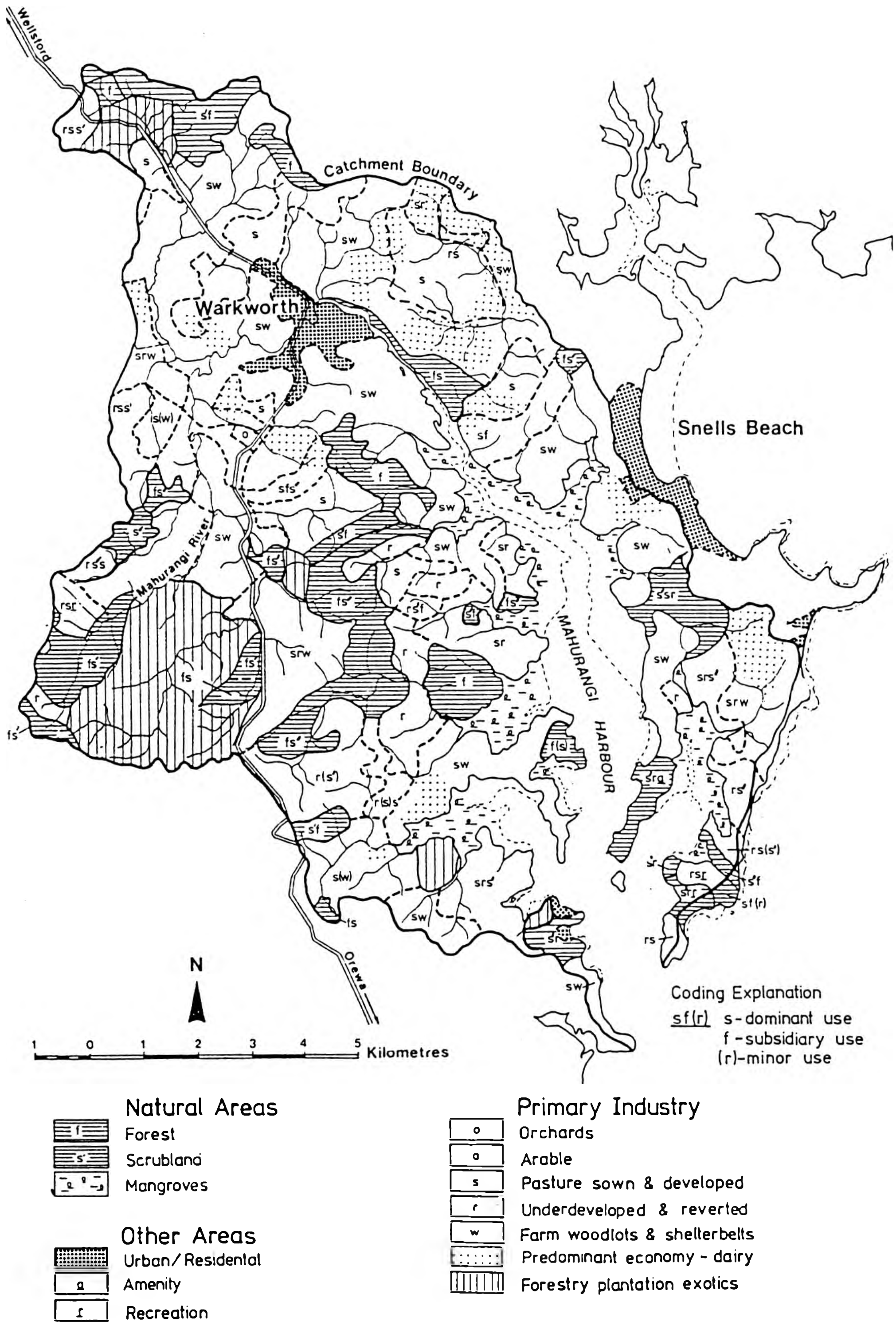
Mangroves

Throughout the Mahurangi Tideway there is only one species of mangrove, *Avicennia marina*. It dominates the biomass and is a very characteristic feature of the Tideway. It represents an integration of salinity, temperature, sediments, wave climate etc. Its very presence says much about the nature of the waterway and signals a special association of flora and fauna, adapted to a life in mud.

TERRESTRIAL PLANTS

For a glimpse of what the landscape was like before deforestation, the following extract from Mathew (1840) on the subject of Mahurangi Harbour is instructive. 'The hills on both sides are covered with Kowdi (sic) in the greatest profusion, down even to the water's edge.... Above the fall (Warkworth), the ground rises in a succession of gentle and beautiful undulations covered only with fern to a lofty wooded range in the north-west (the Dome?).....forming a beautiful little amphitheatre of about ten miles perhaps by five or six, ...".

Today the vegetation of the catchment is mainly grassland with some patches of native bush and scrub. The map below (Feeney 1984) shows the main types of land cover and use, and Appendix 4 has a list of trees and plants.



Source: NZMS 290

SECTION 3; THE HUMAN HABITAT
OCCUPATION AND MASTERY

Chronicle

Set out below is a chronicle of some of those activities which have impinged directly or indirectly on the Mahurangi. Amongst them are events which altered the system physically or chemically, together with some selected social practices which altered the character of the catchment or the public perception of the Tideway. Also included are occasions when knowledge of the system was notably advanced.

Chronology

Dates of salient events in connection
with the Mahurangi River and Tideway

10000BP	**Tideway formed. Sedimentation starts**
	Maori settlement. Forest fires
1820	First hydrographic survey of the Mahurangi Harbour by Royal Navy sloop *Coromandel*
1820	**Tree felling for timber and spars**
1834	Hydrographic survey by HM Supply ship *Buffalo*
1840	**Felton Mathew reported on Mahurangi as a possible capital and reported some hydrography of the Estuary**
1840	Sawmill established
1842	First settlers at Lower Matakana along the coast on either side of the river mouth. Brick kiln started. Boat building, timber felling and saw milling provided a living
1848	**and onwards, settlers in Upper Matakana came as far as the falls by boat**
1854	Warkworth subdivision first laid out
1854	First session of House of Representatives at Auckland
1859	Old lime kiln established
1860	Flour Mill operating
1863	First Highway Trustee established
1863	Post Office opened in Warkworth
1864	Warkworth land sales
1870	**First steamer entered the Warkworth-Auckland run**
1872	First steamer built at Auckland
1873	E. Morrison laid out orchards at Red Bluff
1873	**50 pounds voted for wharf at Warkworth**
1877	Boat-load of Aucklanders came for Warkworth races
1877	**Warkworth tidal wave**
	First Rodney County Council meeting
1881	**Unmetalled road to Auckland opened**
1885	McGregor Steamship Co entered the Auckland to Warkworth run
1885	Cement factory started at Warkworth
1886	Surveyor found Ti Point unoccupied
1886	**First coach service Auckland to Warkworth**
	Scotts Landing?
1898	McLeans Light Locomotive Bill. Permission for him to import a car. 3 pound licence fee payable to McLean for his trouble. 12mph speed limit.
1898	Settlers Steamship Co started and then taken over by Coastal Steamship Co
1899	First car in Auckland
1900	Lime and artificial fertilizer pasture top-dressing experiments begin at Ruakura
1902/3	Dairy factory built at Matakana
1903	**Railway through to Woodcocks**
1904	Steamship companies combined in the face of competition from rail
1905	**Weir built across the River below road bridge**
1906	Railway opened at Kaipara Flats
1908	Steamship company sold to Northern Steamship Co
1910	Dairy factory built at Pukapuka

1900-1920?	Mangrove creek in Warkworth filled in
1911	Postal deliveries started
1912	Twiggs motors began to be installed in scows
1922-23	Fireblight struck the fruit orchards
1924	Co-operative Dairy Co. founded in Warkworth
1924/5	Cement Works run down
	Weir above SH1 built for town water supply?
1920-1925	Number of cars in New Zealand rose from 40000 to 71000
1926	Petrol pumps at Whangateau and Matakana and cream stands set up at roadsides
1928	Cement Works closes
1930	Rodney Lime Co started
1930	Metalling of road to Auckland completed
	Regular motor service begun
1936	Northern Steamship Co withdraws
1937	30 mph speed limit introduced
	Still passenger services to Leigh, Takatu Pt and Kawau Island
1938	Removal of gates from main roads
1938	Big Matakana flood
1947	Rodney Fertilizer Distributors started for the bulk distribution of lime and fertilizer
1948	Butter from the dairy at Matakana still going to Auckland by scow
1950	Aerial top-dressing with fertilizer began
1950?	Water intake and works constructed
1950	T.F. Otway's thesis on Warkworth and the tideway
1955-65	Dredging at the head of Pukapuka Inlet
1967	Oyster farms delineated in Mahurangi Harbour
1967/68	Reclamation with spoil from new bridge site
1971	Water and Soil Conservation Act
1972	Warkworth water treatment plant began operations
1973	RCC's first environmental impact report, for Snells Beach/Algies Bay water supply scheme authorised. Dawsons Creek sewage disposal plant designed for 9000 people
1973	ARWB's first bacteriological survey
1975	RNZN intensive hydrographic survey. Benchmark constructed
1975	ARWB's water quality survey
1976	Population of Warkworth 1620.
1975/6	Tribunal on application for sewage disposal
1976	Warkworth Town Council's consultant claims 5km of Estuary could be used as a "buffer zone" as it "has no attraction for contact recreation"
1980	First ecological report by J.E. Augustin
1980	Warkworth sewage treatment plant commissioned August
1980	Red bloom first reported in the Estuary
1980	Oxygen weed first reported in Right Branch of River
1981	Sewage fungus first reported in R. Branch of River
1984	Comprehensive report on the Tideway by C.M. Feeney
1984	Comprehensive thesis by R.M. Johnston on the Tideway
	Marina established below Warkworth
1985	County Scheme includes Rural Coastal Conservation Zone concept.
1986?	Publication of "Mahurangi its Story"
1986	Tube worm infestation first noted in the Estuary
1988	Mahurangi in special planning zone category.
1990	S.A. Trotter's thesis on Tideway sediments
1991	Rodney District Council approves application of Warkworth Advisory Committee to concrete the Estuary bank at Warkworth
	Proposal for civic building to protrude into the Tideway at Warkworth
	Extensive rafts of *Egeria densa* weed in Mahurangi River.
1992	Auckland Regional Council Tribunal approves stone and cement bank for the Estuary at Warkworth

MAN-MADE INTERVENTIONS
CHANGES AND MODIFICATIONS

Below we look at some of the uses which have been made of the Mahurangi System and some of the consequences.

Organic loading.

Perhaps the most potent deleterious influence on the waterway has been the introduction of organic wastes from farming practices. These include the run-off from farm fertilisers, effluents from cowsheds and piggeries which have raised the level of organic material, nutrients (phosphates, nitrates, and ammonia near some effluent discharges) and bacterial content in the streams and creeks. The Mahurangi River is responsible for about three-quarters of the nitrogen brought into the Estuary which also receives treated sewage wastes.

As the tideway catchment becomes populated and receives an increasing quantity of foreign effluents, its capacity for flushing or replacement by new oceanic water, brought in with each flood tide, becomes an important matter. A long residence time is one of the characteristics of the Estuary i.e. from Warkworth to Dawsons Creek. It does not flush quickly. Wastes may spend of the order of up to a week in this part of the Tideway, so it is acting as a quasi-purifying element. Because its volume is very small it could be easily overloaded.

The potency of nutrients arises because, in the natural condition, the level of nutrients on which a healthy aquatic system can be in equilibrium is really very low; of the order of half a gram of inorganic nitrogen in a million of water, and a tenth of this for soluble phosphorus. With such small quantities as the norm, it is clear that a damaging excess can soon be reached by influents.

To gauge the extent of the increase of nutrients in the system we need a datum level of what conditions were like before man-made disturbances. An approximation to this level might be the lowest concentrations measured today.

These together with the average concentrations are set out in the table where the minimum values are set over the means i.e. minimum/mean using ARWB data (K. Becker, personal report). All concentrations are in mg/m^3 N or P. The data is recorded to two decimal places. Where minimum values have been reported as zero, a concentration of 10- has been used.

Table of Minimum and Mean values

Sampling site	Ammonia	Nitrate	SRP	Tot phosphate
Left Branch	20/50	340/1120	10-/170	50/270
Right Branch	30/230	250/510	10-/30	90/120
D/S Duck Ck.	10/510	10-/140	10-/30	70/150

The consequences of man-made changes have lifted concentrations at these sites to levels for incipient eutrophication. In the presence of excess nutrients, plankton and algae thrive, but when they die the oxygen required for their decomposition depletes the supply, sometimes to the point of exhaustion. By causing oxygen depletion, organic wastes attack the whole aquatic system at its weakest point, for as will be recalled, water carries at most about 10 parts of oxygen in a million of water.

Evidence of eutrophication and pollution are summarized here.

In the rivers there have been instances of:

* sewage fungus, *Sphaerotilus* (has been reported more than once in the Right-hand Branch near Woodcocks Road and *Lagorosiphon major* (oxygen weed) has also been reported at that site,

* oxygen down to 44% saturation,

* *Egeria densa,* an aquatic weed, infestation.

In the Estuary there have been instances of:

* algal blooms. A bloom of red plankton just below Duck Creek in August 1980 was reported by the Auckland Regional Water Board. The bloom lasted at least 5 days. Anecdotal evidence suggests these blooms occur annually.
The actual trigger mechanisms are not well understood.

* oxygen down to 32% saturation.

* tube worm infestation. An example is the invasion of the Mahurangi Estuary by the tube worm *Mercierella enigmatica*, now referred to as *Ficopomatus enigmaticus*; an alien which capitalized on an artificially created niche with high detritus nitrogen. This animal has some special characteristics which make it unwelcome. It is able to adapt easily to changes in salinity from that of seawater, 34ppt, to almost fresh, 2ppt. Ammonia is released into the system during osmo-regulation. In a suitable environment, it is capable of building reefs. Indeed its reefs are reported to occupy a third of the lac de Tunis in the Mediterranean.

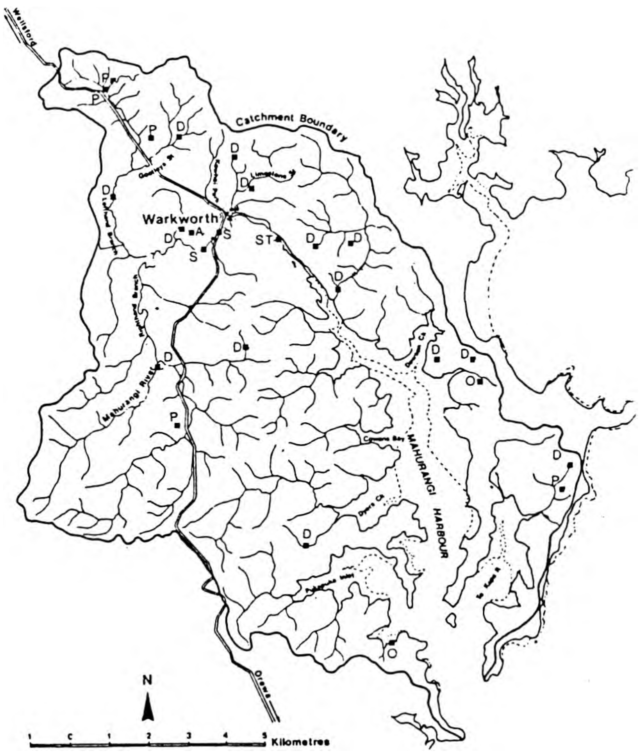
In the Estuary, it was first reported in Feeney (1984). It has spread and is a heavy infestation, a kilometre downstream, at the marina at the Old Cement Works site where it was first noticed in 1986, (Dixon, personal report), and now forms aggregations up to 30cm thick on the wharf and moored boats.

The main effluent discharges in the catchment come from the following sources:

Dairy sheds
Piggeries
Oyster processing
Sewage treatment
Abbatoir

They are organic wastes, most with high oxygen demands and nutrients.

The location of the sites are shown on the accompanying map. It is based on December 1983 data compiled by the Auckland Regional Water Board that was (Feeney 1984).



Symbols

P=piggery
D=dairy shed
O=oyster processing
ST=sewage treatment
S=swimming pool

Sites of major effluent sources (adapted from Feeney 1984).

Tree felling, the removal of bush and farming

The deforestation of the catchment must have been amongst the most potent changes which the catchment has undergone since it was formed. The main impact was presumably an increased rate of run-off of storm water, and the increase of inflows of erosion products. Studies on the Upper Waitemata Harbour noted that the effect there was to double the rate of sediment deposition to 3mm per year. The blanketing of receiving water habitats must have imposed considerable stress.

A less obvious, but nevertheless profound change, has been brought about by farming practices. The widespread sowing of clover and the broadcasting of phosphate fertilisers have radically altered both the nutrient component of the soil and its physical properties. In addition faster growing grasses have replaced the original subtropical types.

Commercial operations

Initially the Harbour was used by the Royal Navy and others later, as an access to the kauri forests, and as a harbour for loading. Later wharfs and boat ramps were constructed.

The early settlers used it as a place for ship building and the transport of heavy cargoes, even after the advent of the trunk roads and rail.

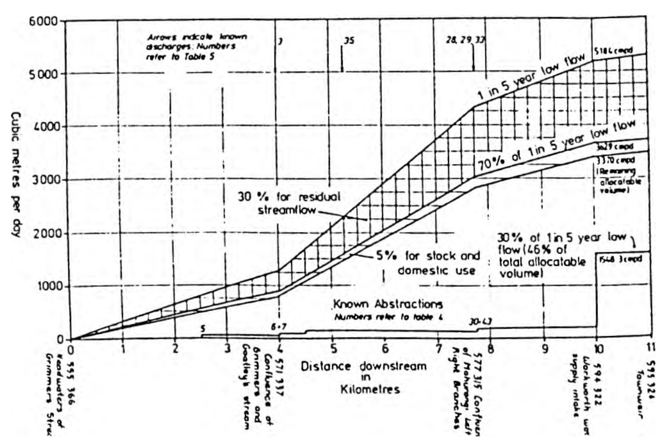
The harbour and marina has moorings for local and foreign boats. Though there are not a great number of boats using the Tideway at any one time, they do pose a potential pollution threat. In addition, and perhaps more importantly in the long run, use by foreign boats brings with it the risk of invasion by alien flora and fauna. Of course some of these can be assets e.g the Pacific oyster which has displaced the indigenous one.

Marine Farming

There are extensive oyster farms of specially constructed racks situated in the lower part of the Harbour, below Grants Island. The organisms cause local nutrient enrichment of sediments and some perturbation of the fauna. (Handley 1992). Commercial fishing is carried out from Scotts Landing.

Freshwater abstraction

As a source of water for the settlers, farmers and the Town of Warkworth, early settlers relied on boreholes for the town water supply. Later impoundment weirs were built, first for the Cement Works. Today the town is serviced by extraction from the Mahurangi River at an intake in the reach above the bridge on state highway 1.
Estimates of what is available and what is extracted is given in the diagram below. The estimates are made for the whole length of the river from the headwaters to the Estuary on the assumption that the quantity of water available for allocation is up to 70% of a 1 in 5 year low flow, 30% being retained in the river to sustain the natural life. Furthermore an allowance of 5% of the allocatable flow was assumed to be abstracted by riparian users. The river flow is expressed in units of cubic metres per day.



Estimated water demand and availability for the Mahurangi River for a 1 in 5 year low flow. (From Feeney 1984).

Impoundment weirs constructed at two places on the Mahurangi would have altered flow characteristics and sediment transport.

The reduction of the river flows can have a number of consequences:

*residence time can be altered.

*reduction of the maximum flow speed may diminish the flushing of silt and sediments,leading to changed turbidity, photosynthesis, interactions between particles during flocculation, and changes in the nature of the substratum.

*on the other hand, turbidity increases, by diminishing photosynthesis, may reduce the chances of algal blooms.

*salinity changes may lead to a redistribution of species. Circulation and mixing may change.

*temperature and oxygen distribution change.

*reduced flow may reduce nutrients, a certain level of which is required to maintain healthy life.

Transport conduit

It is in the matter of transport that there has been perhaps the most active intervention, first by Maoris as a waterway giving access to the inland regions, and then by settlers, to whom it was the main street of the early settlement.

Of course, the tideway formed part of the seaway to and from Auckland for settlers in the Warkworth District and inland, before the roads or rail were constructed.

Dredging of the Estuary

While steam ships used the Tideway the turbulent action of the screws was a factor in maintaining water depths. Possibly the cessation of shipping in the 1930's was an important factor in the rapid shoaling which became apparent when the soundings for the 1904 and the 1975 naval charts were compared (see above).

There was an occasion when the Estuary was dredged along the reach where it is now shallowest, just below Warkworth. Some dredging was also undertaken at the head of Pukapuka Inlet

During the life of the Cement Works old cockle shell beds were mined.

Reclamation

As has been noted in the section on the tidal regime, tidal characteristics of a tideway are those of the tide in the adjacent sea, modified by terrestrial factors such as tideway shape and cross-sections, which can cause asymmetry of the durations of the ebb and flood tides. Infilling creeks can therefore alter the tidal characteristics and affect the way the sediments are distributed, resulting, possibly, in erosion or siltation. Infilling also reduces the tidal volume.

In 1967/8 the spoil from the new bridge construction was used to alter the Warkworth bank of the Estuary. The dynamics of the estuary corner were probably changed locally.

Reclamation work was required for the construction of Scotts Landing and, presumably, for the wharf at the Old Cement Works. At the latter site the estuary appears to have been narrowed. The absence of sediments on that reach may be the result of scour by swifter currents there.

A creek which once crossed Queen Street in Warkworth, fed a mangrove field which was used as a tip and eventually in-filled. One effect of this was to reduce slightly the volume of the tidal prism in the upper reach of the estuary, thereby, *inter alia*, diminishing the effectiveness of it to cope with the dilution of the present day sewage plant effluent.

Attempts, unsuccessful, have been made to reclaim part of Dawsons Creek for stock grazing.

Removal of mangroves

The destruction of mangroves removes a vital habitat and site of food production, together with a range of flora and fauna which nurture young fish populations. The reclamations mentioned above at Dawsons Creek for sewage ponds, and for pasture, and at Warkworth for a tip, together with stock grazing, have resulted in a small reduction of the mangrove area.

Pleasure and recreation

The tideway has, since it was first inhabited, been a scene of recreation, including fishing and boating.

PROPERTY AND PEOPLE

Land subdivision, size distribution, tenure, zoning, use classification, and population.

After nutrient enrichment, the next most important man-made impact is of course land subdivision and occupation. Herein lies one of the most potential sources of conflict between those who seek the perpetuation of high quality landscapes and those concerned with the development of their own interests. The Mahurangi Tideway views are vital elements in the commerce of property.

Subdivision.

The present boundaries of the subdivisions are shown on the Lands and Survey map NZMS sheet R 09 Warkworth (Interim Edition) of 1981 in Appendix 2. Out of a total of some 150 sections (excluding those in built-up areas of Warkworth, Jamiesons Bay, the Mahurangi Peninsula and part of Snells Beach and Algies Bay) the breakdown of section sizes is given in the following table as percentages.

Size ha	0-10	10-20	20-30	30-40	40-70	70-100	100+
Number	26	19	19	13	12	6	5

Mostly the land is rural. There are ten small areas of reserves, 6 abutting the Estuary and Harbour, providing 7.5% of the water front. (see map Feeney 1984, in Appendix 2). These plus the frontage in Warkworth and small esplanade reserves together with launching ramps at Warkworth, Dawsons Creek, Scotts Landing and near Jamiesons Bay, are provisions for public access.

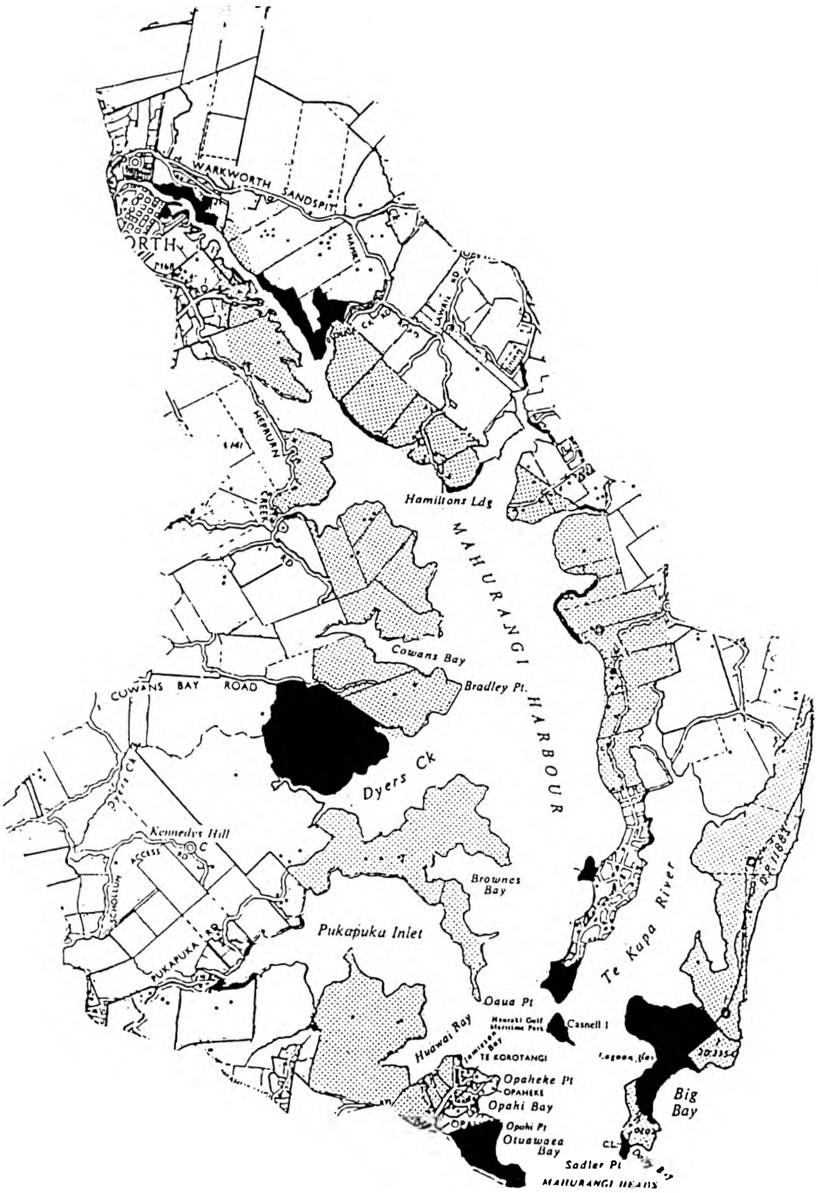
Predominantly the land is in private hands. 22% is freehold corporate and 5% is urban small-holdings with various tenures. (See map Feeney 1984) Subdivision maps for Warkworth, Snells Beach/Algies Bay, Mahurangi East and Jamieson Bay are also shown in Appendix 2.

Land use classification

The quality of the land in the Mahurangi Basin is on the whole rather poor. On a scale of 1-8 which, for example, classifies the arable land of Point Wells as Type 2, the bulk of the Mahurangi is Type 4 or 6. (see map in Appendix 2).

Zoning

Apart from the residential settlements at Warkworth at the head of the Estuary, Snells Beach/ Algies Bay (mostly just outside the catchment), Mahurangi Village, on the eastern side of the Harbour, and Jamieson Bay on the west side, the land is mostly zoned (in the District Scheme) Rural 1 (general farming) and Rural Conservation 3 (coastal landscape protection). The coastal landscape protection zones have been selected because of their high quality and openness and contiguity to the water. In addition there are the reserved areas, zoned recreational. The map below shows the areas of the last two zonal categories. There is also a special zoning for the water areas, the Mahurangi in particular.



Map of reserved lands (reserves, esplanades etc.) black, and rural zones with rural conservation (3 Coastal Landscape) shaded. (based on Rodney District Scheme).

Population

In the past, the population of Warkworth and the rest of the Catchment was determined by factors, the most important of which was transport. While the coastal traffic was really the only means of transport, the town of Warkworth was a nodal point, not only for the immediate district, but also for the region to the west up to the Kaipara Harbour. The building of the railway at the turn of the century, remote from Warkworth, altered this dominant position and the population actually declined. Nor did the opening of the all-weather road to Auckland in the 1930's and the introduction of farm machinery help. The former further diminished the importance of the town as a port and the latter diminished the size of the farm-hand population. It was not until 1960-1970 that substantial growth started again.

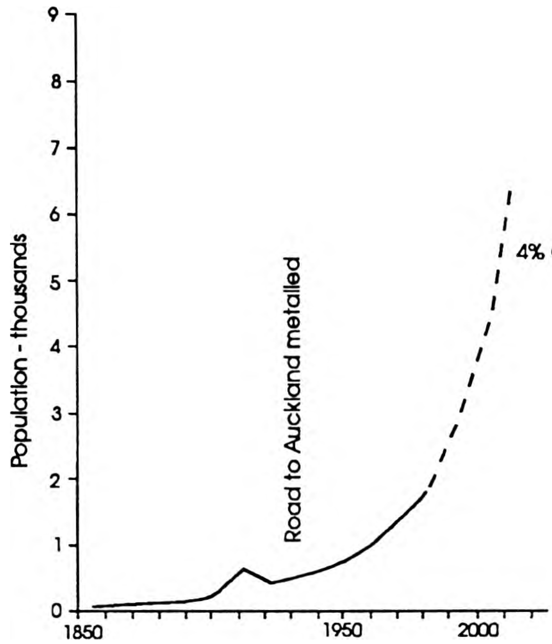
The growth of the population of Warkworth is 1-2% per year. Growth in the Snells Beach-Algies Bay area has been much faster (4-5% since 1976) and it has now outgrown Warkworth.

The future population

At the present time most of Snells Beach/Algies Bay area is technically just outside the Catchment boundary, but although there is still some alongshore space, major expansion of residential areas can only take place into the catchment. The same, of course, applies to Warkworth.

A factor in the future growth of the Catchment's population is State Highway 1 which, having been sealed and widened, has brought Auckland to within an hour's drive from Warkworth: commuting distance to much of the Catchment especially West Mahurangi. Now that the residential coastal land to the south of the Catchment, at Whangaparoa, Orewa, and Waiwera is nearing saturation, and with the development of commercial employment opportunities in these areas, it is to be expected that land on the west side of the Catchment will be in demand.

The rate of population growth since the early days of the Warkworth settlement is given in the Graph. Data up to 1960 comes from census statistics. Data from 1975 onwards with projections up to 2015, have been taken from Wallace and Sharplin (1985).



Historical and projected population statistics for Warkworth and Snells Beach/Algies Bay.

It is highly probable that the catchment must brace itself for a steep rise in population. In an Auckland Regional Council study (1990), in which the possibility of a high expansion future for the region was discussed, it was stated that, "At this stage a high expansion future may seem relatively hypothetical...., but the forces which could bring about this future are now emerging... a situation which may be compared with the Hibiscus Coast 20 years ago".

The distribution of population by area and the percentage participation in the work force is as follows (Rodney District Council 1992).

Area		Population		Labour force
	1981	1986	1991	1991 %
Snells B. area	1,492	2,234	3,100	52.7
Mahurangi East	65	159	181	52.5
Mahurangi West	329	417	365	74.7
Warkworth area	1766	2028	2264	59.5

The relatively low participation rate in the work force probably reflects the large retired component, no doubt attracted to the area by considerations of water front residences, low noise levels, and natural landscapes.

	Dwellings 1991	
Area	Occupied	Baches
Warkworth Urban area	903	3
Mahurangi West	144	76
Mahurangi East	65	51
Snells/Algies	1,138	789

Data from Rodney District Council Information Sheet PRG/1P303.

Challenge and response

Estuaries have always been in a state of flux. Viewed against a long time scale there have been the great changes of climate affecting rainfall and sea-level in the past. As a consequence there has been a build up or erosion of mud and sand, but the net result has been that estuaries have been filled in by erosion products from the catchment. There has also been an alternating freshening of the sea water, necessitating adaption by the living organisms, adaptions which were easily made by succeeding generations because the rate of change was slow compared with life spans. There is evidence that sea level is rising now at about 1 mm/year (Hannah 1990). The status quo has been constantly challenged and the tideway has responded. These long term changes proceed inexorably and are beyond our control.

There are however the man-made changes which are a different matter. Looked at against a shorter time scale, say a hundred years, the Mahurangi, catchment, river and tideway, has had to respond to some rapid changes.

CHANGING PERCEPTIONS OF THE MAHURANGI

The Arcadian Years

The above list of uses and abuses of the tideway reflect changes in our perception of it. Obviously the pioneers were concerned with survival and consolidation in an alien world. The felling and marketing of the native trees of the catchment provided a ready source of initial capital which "primed the pump". The tideway was a ideal way of transporting the heavy timber by scow or floating log rafts. There was no need to struggle with the clay tracks, almost impassable in wet weather. So initially the Tideway was primarily a medium for transport but also a source of food, the fishes. There was a certain harmony consequent on the need to understand the tidal rhythms and the migrations and habits of the tideway fauna and the seasonal harvesting of the numerous fruit orchards. Apart from the clearance of native bush there was of course some impact on the tideway, such as resulted from the construction of a few jetties and one or two yards for the construction of small wooden ships. But even doing their worst, the small population could make little deleterious impact on the tideway itself, especially on that important aspect, the water quality. One suspects that at no subsequent time has the tideway been so enjoyed. Contrast the schoolboy of those days who set his fishing lines before his journey to school by boat, with today's, waiting for the school bus. These were the Arcadian days for the Maori and the Settlers.

1900 Onwards; the years of indifference

Several factors caused a decline in the use made of the Tideway. An attitude of disregard for it gradually developed and processes inimical to its well-being began. The slide from harmony to indifference took place slowly, at a rate slower than was consciously noticed. If one had to assign a date to the process one might pick the period from 1900 to the late 1930's. Amongst the reasons for the changed attitude were,

* the car arrived, roads improved, road and rail gradually replaced water and horse drawn transport; the pace of life quickened, and the habit of contemplation of nature atrophied.

* fireblight devastated the fruit orchards so badly that they never fully recovered.

* the cement works, heavily dependent on water transport, closed.

* there was a move to dairy farming and more bush clearance. Stock pollution developed.

* top-dressing was introduced with increasing lime and fertilizer application and enhanced nutrient runoff.

* a weir was built across the river and direct water abstraction began.

On to the 1970s; years of domination

Respect for the Mahurangi was now at its lowest.
Population increase was coupled with water abstraction, sewage disposal, and oyster farming. The idea of the Estuary as a drain developed either consciously or by default. The natural turbidity detracted from its appeal and lowered the respect with which it was held.

After the '70s

There was a general awakening to environmental damage, exemplified by the Central Government's passing of the Water and Soil Conservation Act. The water pollution problems faced by the District Council increased. The proposed District Scheme of 1985, as mentioned above under zoning, included a zoning classification of coastal landscape conservation RC3, which also applies to estuaries. The declared policies included:

* preservation of the present varied high quality landscape

* preservation of open views from public roads

The declared strategy for conservation includes (as far as reasonably possible):

* discouraging the location of buildings where they will "dominate the natural landscape ...."

* retaining ... rivers ... in their natural state, except etc.

Some fuller extracts from the District Scheme are set out in Appendix 5.

The Water Zone was expanded to accord the Mahurangi Harbour and River a special status.

This inclusion in the District Scheme of a policy for maintaining the high quality landscape and a high water quality marks an interesting and important change in the perception of the Tideway. Compare for example the zoning in the previous (1980) District Scheme in Appendix 2. For more on this see Appendix 5.

But difficulties arise with the implementation of these coastal landscape protection measures.

* policies express intentions some of which lack the support of ordinances with a quantitative base. There is no quantitative standard of the kind there is for the chemistry of water quality. Decisions must necessarily be arbitrary, tailored to officials' interpretation and public thinking.

* their implementation may obviously involve a new curtailment of individual owners' rights.

Whether the aims of the new concepts will be achieved depends on the extent to which the focus of the local public's conservation outlook moves, from the rather remote problems of endangered species preservation, and the conservation of rain forests, to the local scene with its workhorse, the local river. Has the idea of a river or tideway as an entity requiring respect yet been taken up by the local community? Is rural public opinion ready for planning constraints? It is obviously difficult to give firm answers to these questions but some indication can be had from past planning applications and decisions. A few are considered here.

* During the Tribunal hearing on Warkworth sewage in 1975, referred to above, the Town's consultant claimed that 5km of Estuary could be used as a "buffer zone" as it "has no attraction for contact recreation". This perception was still that of the years of dominance.

When the Tribunal approved the Warkworth application to discharge its sewage plant wastes in to the Estuary it seems to not to have taken into account two considerations. One was that the waste was relatively rich in phosphate while the Estuary's tendency to eutrophication was phosphate limited. This effluent, it is estimated, contributes some 20% of the phosphate entering the Estuary.

The second factor, which was not foreseeable, was that the introduction of the waste disturbed the equilibria of the system and opened the way for the infestation by worms.

Science in its present state is able to predict, that if systems are overloaded with nutrient rich wastes, such as sewage, then ultimately worms will begin to dominate. That is common experience. But it cannot predict what sort of opportunist worm will be on hand to capitalize on the new artificially created niche.

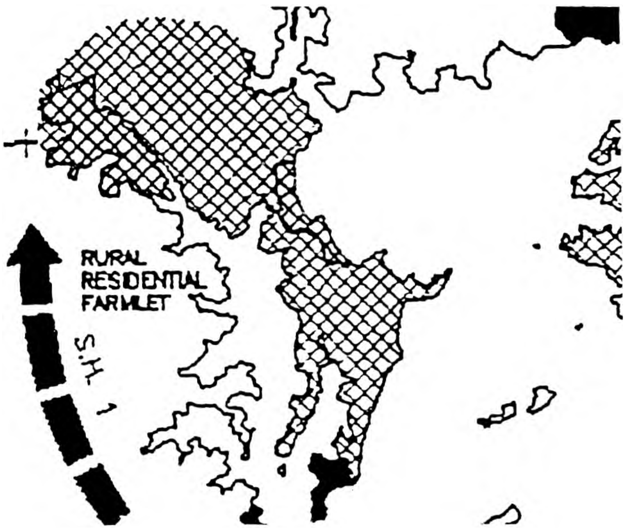
As it transpired, *Ficopomatus enigmaticus* was on hand, probably brought in on a boat. In passing we note that the presence of this animal points up one of the shortcomings of environmental impact reports. When impact reports are prepared, the scientists who write them can only base their predictions of impacts on the probable response of known existing organisms. What cannot be predicted is that changed conditions might be favourable for alien organisms, which have been brought in by ships perhaps, and which, having different and very undesireable characteristics, might be able to capitalize on the changed circumstances, with possibly highly unwelcome results.

* In the the Planning for the Mahurangi (Rodney District Council 1991) it is envisaged that the present sewage disposal arrangements at Warkworth (progressively upgraded) will be able to cope with demand for the next 20 years. However no special attention was given to whether the Estuary could continue to cope with the increased nutrient load from the effluent from the extra 20 years of population expansion.

* In 1991 the Citizens of Warkworth applied, and their application was approved by the local authority, to replace 130m of the natural river bank with a concrete wall and vehicle track for special use. In approving the application the local authority stated *inter alia* that **the concrete wall "would not cause significant detraction of the natural character of the river bank".** Subsequently the Dept of Conservation vetoed the wall as unnecessary. We have here a striking case of the standards being applied, even today, by the public and local authority, standards by which the replacement of a river bank with concrete panels could be regarded as causing little detraction to the estuary's natural character.

* About 1990 building approval was given by the local authority for a house to be built on the bank of the estuary. It was the first of its kind for many years to be built on what is now earmarked RC3 (see above). The building "dominates the natural landscape" of this reach of the estuary, something which the District Scheme (proposed) expressly aims to discourage.

* In a **draft discussion** report on strategic planning options, the Auckland Regional Council (1990) considered the possibility of high urban expansion in the Mahurangi region. The accompanying map shows where it is envisaged the urban expansion could possibly take place. It would cover nearly all the RC3 zoned land on the east side of the Harbour.



In the event of high urban expansion, the hatched areas on the the map show possible future expansion of Warkworth and Snells Beach . Auckland Regional Council (1990).

While the above cases are insufficient to be definitive, they are interesting and indicative, and they do raise doubts as to whether there has been any substantial shift in public perceptions, and whether the standards used by officials have changed sufficiently for the new thinking, implicit in the RC3 concept and the special Water Zone, to have much chance of influencing the course of events.

SECTION 4: MANAGEMENT

The two objectives of management of the Mahurangi System, which are the concern of this report, are the maintenance of both the health of the waterways and the natural character of the landscape. The importance of these objectives is not in dispute. Indeed they are now part of declared local authority policy. What follows includes some observations on the difficulty of putting policy into practice.

Healthy waterways

There are two views about what constitutes a healthy waterway. Both are important.

*One is the external view of society; the look and smell of the water; odourless clarity is the ideal specification in this case.

*The other is the intrinsic natural balance of both structure, i.e.the kinds and distribution of the flora and fauna present, and function or rate of processes in the system. Ill health arises from imposed stress such as pollution, or the destruction of habitats.

The chemical prescription for an internally healthy waterway is quite well known and the standards which have evolved need not be rehearsed here, except to emphasise the following.

Nutrients

The reach of the Estuary, just down stream of Duck Creek, emerges as the place which should be of greatest concern. It is the place of confluence of the nutrient loads from the pasture and dairy sheds by way of the rivers; especially the Mahurangi and Duck Creek, and the effluent of the Warkworth Sewage Treatment Plant. A significant fact is that the average concentration of total inorganic nitrogen (up to 1992) was 660 mg/m^3 nearly twice the level assumed for incipient eutrophication. This is a fourfold increase on the 1984 figure of 151 mg/m^3. Algal blooms have been noted in this reach, which has a substantial residence time (see above).

Upstream of it, a tube worm infestation is well established.

As Feeney (1984) noted, phosphorus is limiting in the Estuary. Increased input of it into the Estuary should be discouraged. In this respect the implications of the County Council's future plans for Warkworth sewage (Rodney County Council 1992) should be carefully examined.

Nutrient levels in the two tributaries of the Mahurangi River are also uncomfortably high. There are signs of stress, and the *Egeria densa* infestation after the junction is a matter for concern.

These two tributaries, together with Duck Creek, "service" the effluent from 7 dairy sheds with about 1000 cows.

Studies by Hickey *et al.* (1989) suggest that, for a 220 cow herd, the effluent from the oxidation pond, of 0.23 l/s. will meet the quality criteria if it is diluted by the following amounts

Chemical property	Effluent conc. median g/m^3	Dilution required	Reason
Dissolved oxygen	2.8	1.8	biota respiration
Dissolved phosphorus	12.2	1710	ditto
Ammonia-N	75	248	fish toxicity and algal growths
Dissolved inorg. nitrogen	75	940	algal growths
Faecal coliforms (numbers/100ml)	70,000	270	drinking

These estimates are necessarily somewhat crude, but they represent about the best approach to predicting the limited number of dairy herds which a Catchment can sustain.

Allowing, arbitrarily, for some soluble phosphorus reduction by adsorption on to clay particles, it seems reasonable to aim at a 'planning' dilution of 10^3 which would require a flow of about 1 l/s for every cow. On this basis the Mahurangi River is operating to capacity and Duck Creek is overloaded.

Turbidity

The turbidity of the Mahurangi Tideway is an unfortunate characteristic which diminishes the respect felt for the tideway. It is a natural state. The catchment soil is nearly all clay which can remain in suspension in freshwater for weeks. After flocculation in the Estuary it is very easily stirred back in suspension by wave action over the low water shallows. Its unlikely that any management strategy can diminish the turbidity significantly.

Sedimentation

The apparently high rate of sedimentation is now threatening the navigability of the Estuary at low water. In the Red Bluff Reach there is no more than about 30cm of water at mean low tide. The rate is much higher than that found in the Upper Waitemata Harbour. This is a pressing management problem and needs investigation.

It is notable that in the study of the Upper Waitemata Catchment (van Roon 1983), it was found that the suspended load from big storms can be almost the equal of a year's sediment transport. Two other findings were interesting from a management point of view.

In an Urban stream with earthworks in the catchment, the suspended solid concentration, both base flow and storm peak, was 20 times higher than for other streams.

Forest streams do not, as is the received wisdom, have lower solids concentration than pasture or urban ones. Suspended solids in a forest stream were no higher after felling than in the pre-felling period (van Roon 1983).

No doubt there is some merit in riparian strips, but in a geologically new catchment of clay, which is subject to occasional but fairly frequent tropical and subtropical storms, it is not immediately obvious what management can do to significantly diminish sediment loads.

Bacteria

The situation regarding faecal organisms, especially pathogens, is not dealt with in this report. It is a very specialist aspect which in view of the oyster farming in the Harbour is carefully monitored by the health authorities.

Flora and Fauna

An outline of the kinds of flora and fauna which have been reported in the Mahurangi, has been given above. Clearly the existing data are insufficient to define the structure or the functions. However, broadly speaking, the kind of life which has been reported is comparable with that in other Hauraki Gulf Tideways. A thorough survey is required, and known local abnormalities, such as the scarcity of cockles, the tube worm infestation, algal blooms, sewage fungus and aquatic weeds, need monitoring.

The natural character of the landscape

This management objective will be the most difficult to achieve. Some of the difficulties are as follows.

The planning policy seems to be ahead of public perceptions.

The concept of natural character does not seem to be valued above, or even on a par, with social and commercial goals.

The important parts of the policy, for example those relating to house siting and design character, are, as noted above, not quantitative. Interpretations and judgements about District Schemes ordinances and other laws change with perceived public opinion.

The statement of policy is hedged about with many broad reservations depending on the interpretation of such concepts as "in the public interest", "while accepting that changes may occur" and " while permitting compatible residential development of a scale and intensity which will not detract from the landscape values of those areas".

In practice it is only mandatory, unequivocal planning constraints which seem to really matter.

Towards the management of the Mahurangi

The Mahurangi Catchment, Estuary and Harbour constitute an organic whole. It needs management to match. A step in this direction has been the unification of planning and enviromental monitoring under one department in the Auckland Regional Council.

The present district administration evolved from Road Boards which met the overriding pioneer necessity for infra-structure, the provision of services and ultimately the orderly subdivision for settlements. These aims have largely been met. We have good roads, the major settlements have been decided, and now services tend to be contracted out.

The pioneer stage is over. Emphasis must now move to new problems with different administrative boundaries and requiring management more logically tailored. Conservation is one such new problem, likely, according to projections, to be subjected in the Mahurangi to increasing strain by a burgeoning population.

Recognizing the nature of this new administrative problem, it would be worth considering giving a staff member special responsibility for monitoring the management of the Mahurangi as a whole. This would, *inter alia*, entail:

*representing the tideways rights and looking after its interests.

*scrutinizing all planning applications.

*helping to establish standards of flora and fauna, and chemistry, in the waterways and seeing that these standards are maintained.

*helping to maintain the natural landscape in line with the policy already adumbrated in the proposed district scheme.

*keeping close contact with the research organisations, to encourage research and formally integrate the existing keen local interests with the excellent work of the Regional Council.

An important additional responsibility should be the organisation of a programme of education for environmental literacy, encouraging respect for the waterways and the landscape, and involving the local population.

Action is needed to:

***Arrange for quantitative surveys of the fish and macroinvertebrate life which would establish a datum against which to measure the effectiveness of the policy of "maintaining the ecological environment".**

***Institute an intensive nutrient audit.**

***Arrange for a computer topographical model of the catchment which will assist in the siting of new buildings so that the natural landscape suffers least.**

***Arrange for an investigation of the reasons for the apparently high rate of sedimentation, in the lower Estuary since the turn of the century.**

***Arrange for the establishment of a number of surveyed baseline sections against which the rate of shoaling can be monitored.**

APPENDICES

Appendix 1. Climate data; rainfall, frosts, fog, winds, evaporation, temperatures (air and sea).

Appendix 2 Figures showing: subdivision and section sizes, builtup areas, land tenure, land zoning 1980, land use capability and oyster leases.

Appendix 3 Bird checklist continued. Birds of paddock and bush.

Appendix 4 Terrestial plants continued. Trees and Plants.

Appendix 5 Selections from the District scheme (proposed) referring to zoning of Rural Conservation Coastal and Water and the Mahurangi.

Appendix 1 CLIMATE DATA

Rainfall at the Satellite Tracking Station

Winds at Warkworth

Frosts at Warkworth

Fog at Warkworth

Evaporation at the Leigh Marine Laboratory

Air temperature at Warkworth

Sea temperatures at the Leigh Marine Laboratory

Appendix. 1 CLIMATE DATA

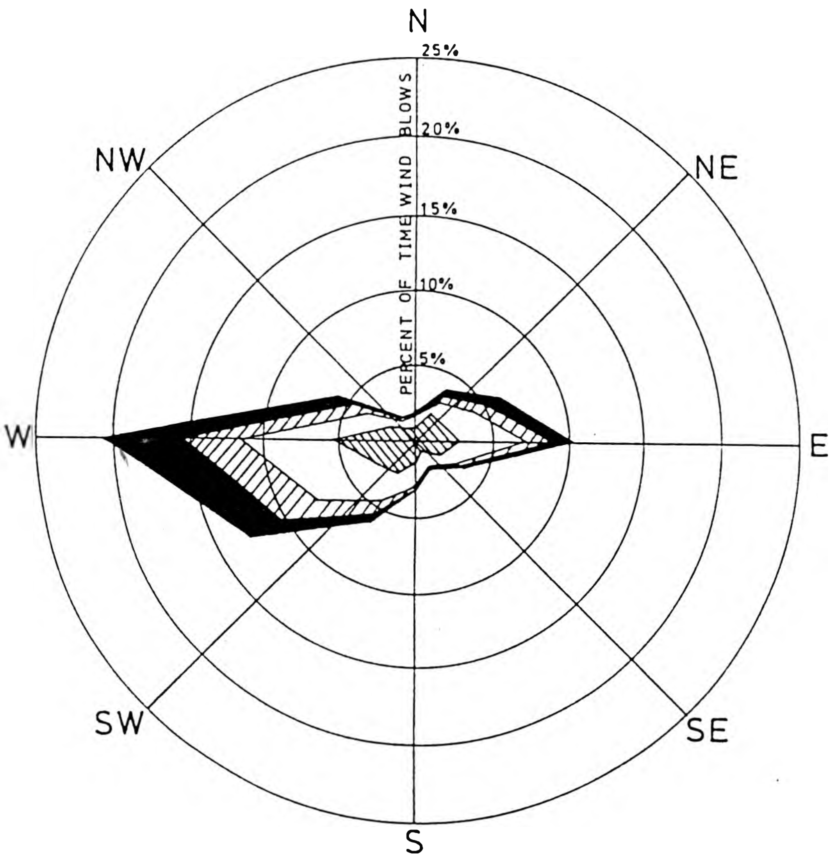
Rainfall

Monthly rainfall totals (to the nearest millimetre) at the Satellite Tracking Station, near Warkworth, are shown in the table below. (Telecom staff, personal communication).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year
1982	56	151	74	192	81	88	165	39	119	117	26	41	1147
1983	53	38	107	131	74	178	66	69	114	201	56	229	1318
1984	79	88	168	33	119	96	149	216	130	32	71	246	1428
1985	177	183	166	168	298	145	139	151	142	87	165	203	2026
1986	262	165	26	46	120	101	176	220	127	94	50	52	1439
1987	76	26	113	106	50	106	150	63	165	127	155	231	1368
1988	18	141	278	67	165	79	348	236	130	81	104	162	1808
1989	287	34	43	93	113	112	82	265	205	148	147	58	1589
Mean	126	103	122	104	127	123	159	157	141	111	97	153	

Winds

The prevailing wind directions at Warkworth are westerly (40%), easterly (19%), with 25% calms. To some extent there is orographic control channelling the air flow through the low-lying gap between the high ground of the Dome and Moirs Hill , as well as tending to direct winds up or down the Estuary and Harbour. A wind rose for Warkworth (from Harrison and Grierson 1974) is shown below. Speeds are graded in 5 knot intervals, black representing greater than 15 knots.



(24·73% of the time is calm)

Appendix 1. continued

Frosts at Warkworth (Hessell 1988)

Days of ground frost. Average days per year	12.8
Days of air frost per year	2.6
Lowest air minimum temperature	-2.4

Fog

Warkworth experiences on the average, 3-6 days of fog per year. It is most frequent in March and April.

Evaporation

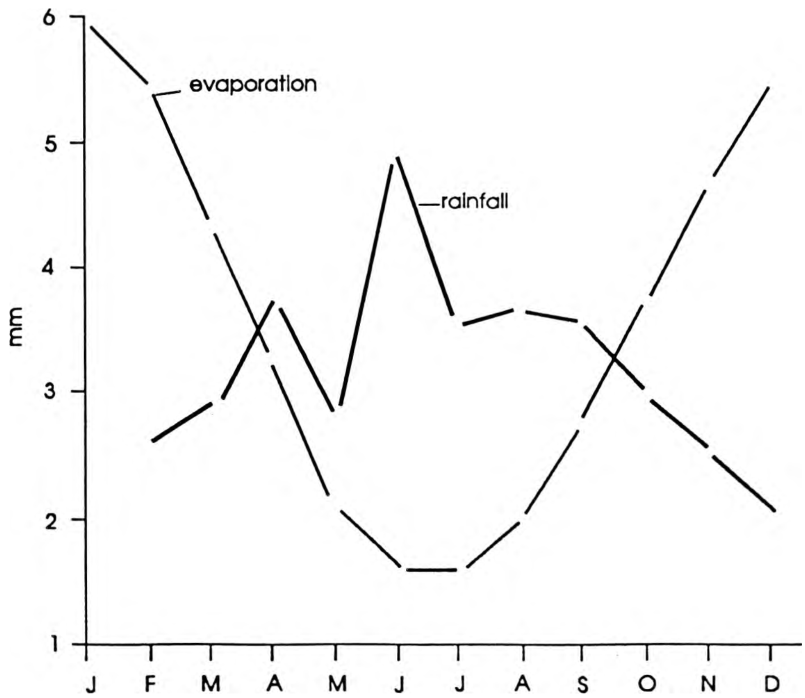
There are no statistics of the rate of evaporation for the catchment, but there are some for the University of Auckland's Marine Laboratory on the coast at Goat Island near Leigh (Evans 1992). Measurements there, over a number of years, show that while there is a marked seasonal trend there is much less variability than rainfall. The following table shows the seasonal changes.

Table of daily mean evaporation in millimetres averaged over the years 1967-1991.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5.8	5.6	4.4	3.3	2.2	1.6	1.6	2.1.	2.8	3.7	4.7	5.5

Evaporation exceeds rainfall in the months October-March inclusive, so that over open water such as the Mahurangi Harbour, there is a net loss of fresh water in these months, and salinities in the Harbour will be correspondingly affected. In the months of April-May and September-October the evaporation equals the rainfall.

The average precipitation at Warkworth and evaporation values are shown in the graph (mm). It is assumed that the Goat Island evaporation data applies in the Mahurangi Catchment.



Appendix 1. continued

Air and Sea temperatures (°C)

Monthly mean daily air temperatures at Warkworth between the years 1972 and 1980 (NZ Meteorological Service) and sea temperatures off the University of Auckland's Marine Laboratory at Goat Island near Leigh, between 1967 and 1991 (Evans 1992) are set out in the following table.

Month	Average Daily Air Temperature at Warkworth			Average Sea temperatures near Leigh
	Max	Mean	Min	
January	23.7	18.8	13.8	19.9
February	23.8	18.9	13.9	20.6
March	22.5	18.2	13.9	20.5
April	19.9	15.8	11.6	19.2
May	17.2	13.1	8.9	17.3
June	14.8	11.1	7.3	15.6
July	14.3	10.3	6.3	14.4
August	14.8	10.8	6.8	14.0
September	15.8	12.0	8.2	14.4
October	17.7	13.7	9.5	15.3
November	19.7	15.3	11.1	16.8
December	21.5	16.8	12.0	18.4

Appendix 2 Maps

Land subdivisions

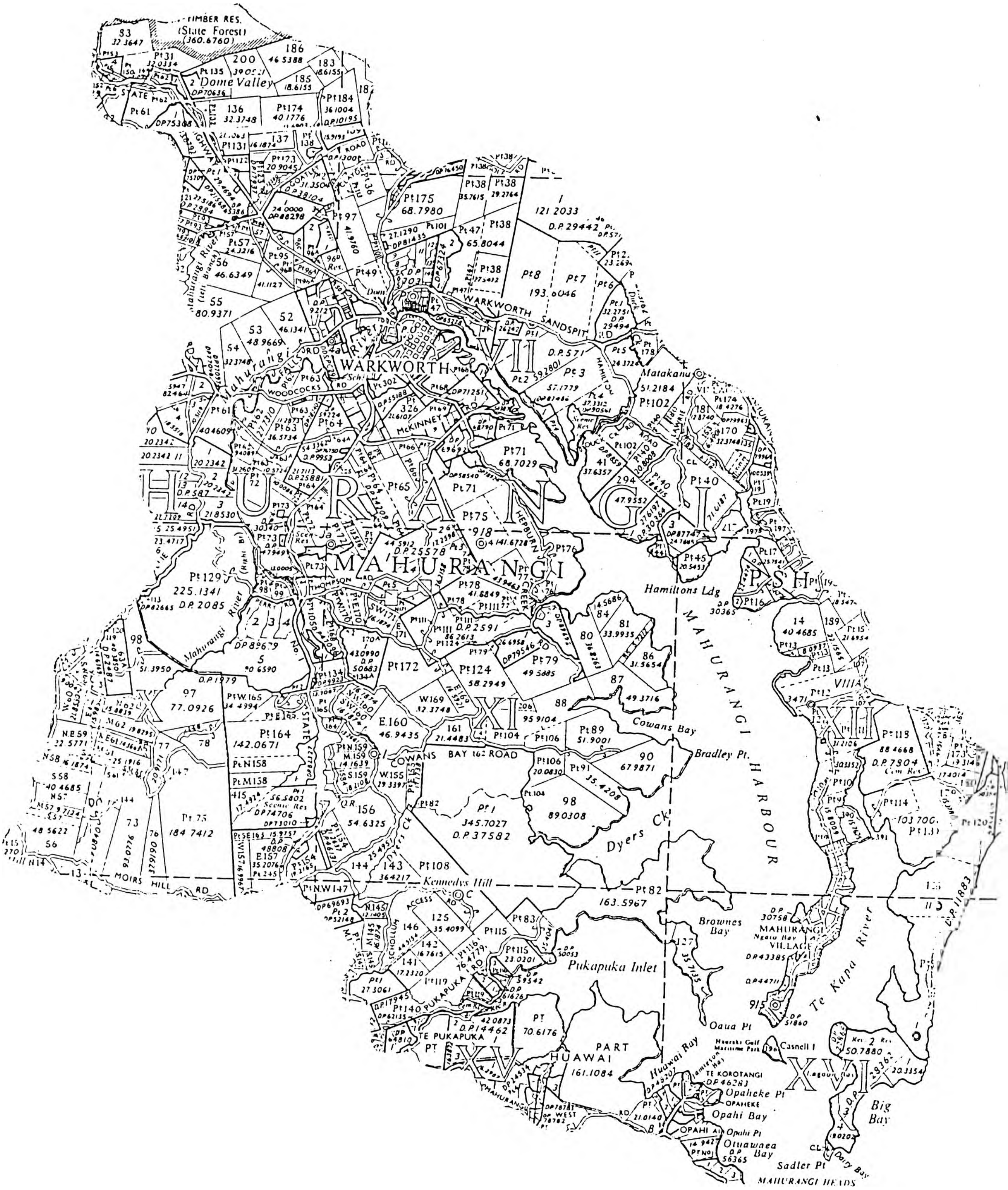
Built-up areas of Warkworth, Sandspit/Algies Bay, Jamiesons Bay, and Mahurangi Village

Oyster farms

Land zoning 1980

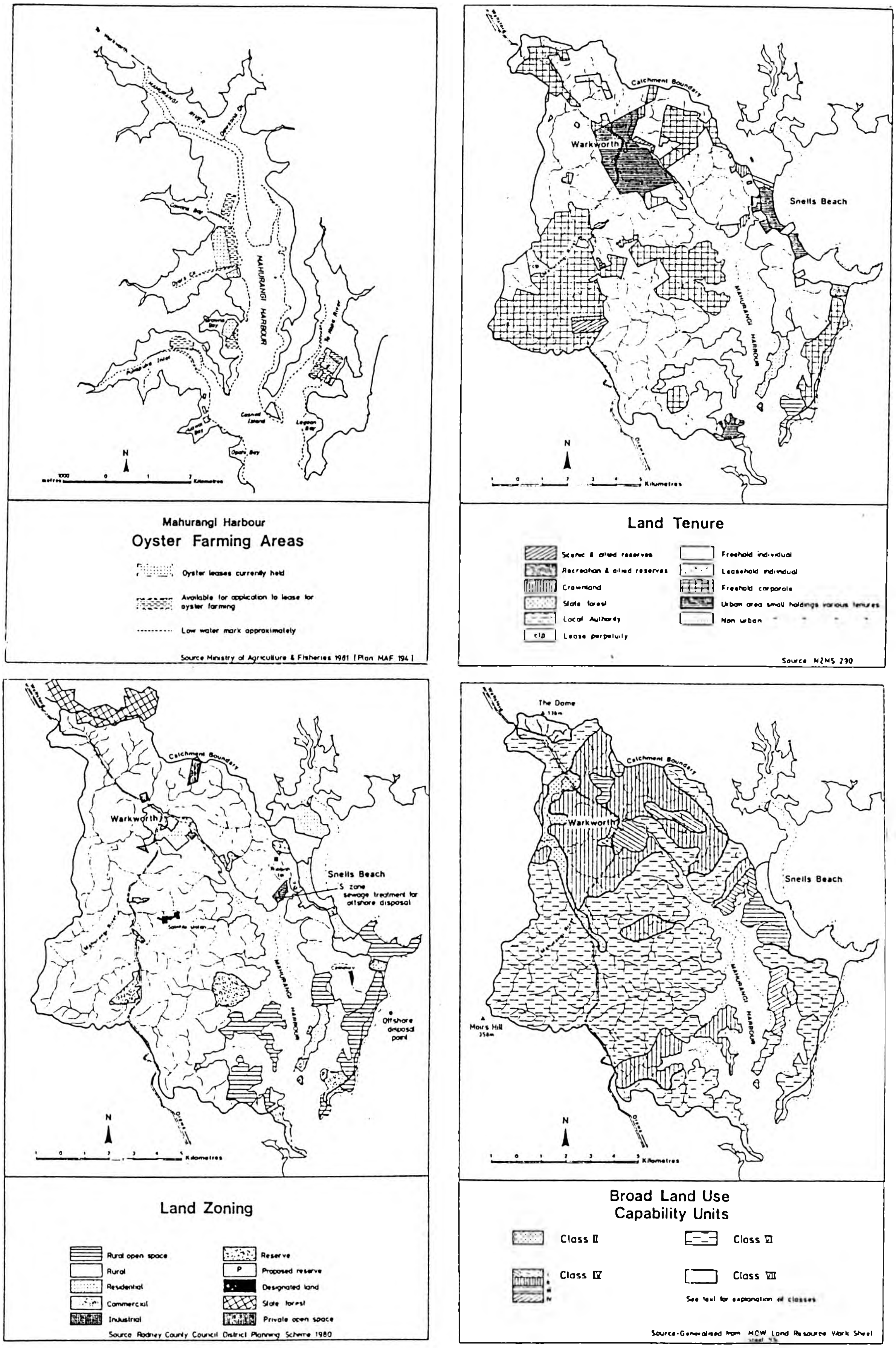
Land tenure

Land use classification



Land subdivisions in the Mahurangi catchment, as shown on New Zealand Cadastral Map NZMS 261 Sheet R09 Warkworth, Interim Edition published by the Department of Lands and Survey 1981.

Built-up areas of Warkworth, Mahurangi East, Jamieson Bay, and Snells Beach/Algies Bay. (After Rodney District Council district scheme; proposed 1988)



Diagrams from Feeney (1984).

Appendix 3 BIRD CHECK LIST continued from page 79

"H" denotes birds reported by Hamilton in Keys (undated)

Paddocks and bush

Sturnus vulgaris [starling]
Turdus merula [blackbirds] paddocks H
Emberiza citrinella [yellowhammer]
Alauda arvensis [skylark]
Passer domesticus [house sparrow] H
Lophortyx californica [quail]
Carduelis carduelis [gold finch] H
Phasianus colchicus [pheasant]
Prosthemadera novaeseelandiae [tui] honey eater H
Platyiercus eximius [eastern rosella] H
Bowdleria punctata vealeae [fern bird]
Chalcites lucidus [shining cuckoo] H
Nixon novaeseelandiae [morepork]
Zosterops lateralis [silver eye] H
Hemiphaga novaeseelandiae [native pigeon]
Rhipiaura fuliginosa placabilis [fantail] H
Rhipidura fuliginosa [fantail]
Gerygone igata [grey warbler] H
Anthornis melanura [bellbird]
Dacelo gigas [kookaburra] H
Hemipgaga novaeseelandiae [New Zealand pigeon] H
Hirundinidae neoxena [welcome swallow] H
Circus approximans [harrier hawk] H
Acridotheres tristic [myna] H
Gymnorhina tibicen [white backed magpie]
Turdus philomelos [song thrush] H

Appendix 4 TERRESTIAL PLANTS continued from page 82

Amongst the trees and plants to be found today around the Tideway, Bioresearches Ltd in Murray-North (1975) and Augustin (1980) reported the following. Tree nomenclature follows Salmon (1980).

Cordyline australis	cabbage tree
Agathis australis	kauri
Podocarpus (Dacrycarpus) dacrydioides	kahikitea
Pittosporum crassifolium	karo
Corynocarpus laevigatus	karaka
Leptospermum ericoides	kanuka
Sophora microphylla	kowhai
Leptospermum scoparium	manuka
Rhopalostylis sapida	nikau
Metrosideros exelsa	pohutukawa
Pseudopanax lessonii	houpara
Vitex lucens	puriri
Brachyglottis repanda	rangiora
Coprosma sp.	tree
Cyathea sp.	tree fern
Dicksonia sp	fern
Astelia trinervia	native grass
Rhipogonum scandens	supple jack
Typha muelleri	bullrush
Phormium tenax	flax
Blechnum capense	fern

Appendix 5 EXTRACTS FROM THE DISTRICT SCHEME

Extracts from the Rodney District Council District Scheme (Proposed) 1988.

Statements on the Water Zone including that for the Mahurangi.

Statements on the Rural Conservation Coastal Protection Zone.

7. Environmental Objectives and Policies

Objectives

(a) To maintain, enhance and where opportunities arise to restore healthy ecological environments in all the water and foreshore areas in recognition of their importance for recreational and resource uses and for scientific and educational purposes.

(b) To maintain and enhance the water quality of all water areas, in order to permit the safe use and enjoyment of the water for recreational uses, and to provide a healthy habitat for marine species and wildlife.

(c) To protect the exceptional ecological value of estuaries, tidal rivers and estuarine wetlands from unnecessary damage.

(d) To protect environments with important ecological and wildlife values.

(e) To protect the visual and landscape qualities of the water areas and their surrounding visual catchments and to preserve and enhance public views of the harbours, rivers and lakes.

(f) To protect the water and foreshore areas from erosion, scouring and silting, to protect the stability of adjacent land and to recognise the implications of any forecast rises in mean sea levels.

(g) To recognise the present function of the water areas as receivers and disposers of effluent discharges and of sediment from the land, while seeking to minimise the number and effects of these pollutants where possible and to discourage the view that disposal of effluent to water is automatically an acceptable procedure.

Policies

(a) To take into account when assessing applications for activities, uses, works or structures the extent to which they create, maintain, enhance, restore, modify or adversely affect a healthy ecological environment or provide opportunities for scientific or educational study of the water environment.

(b) To assess all activities, uses, works, and structures that require a planning application against a number of criteria concerned with the protection and conservation of the physical environment of the water areas and the stability of the foreshore and adjacent land.

(c) To require that works and structures for discharges into the water areas are designed, sited and, where appropriate, operated to minimise the effects of the discharge on the quality of the receiving water.

(d) To recognise that each water area has individual visual qualities arising from the unique combination of channels, tidal flats, beaches, the form of the coastal edge, coastal vegetation and surrounding landforms and vegetation, and assessing any applications for works and structures against the effect on these qualities.

(e) To control damage to, or the destruction or removal of naturally-occurring native plants and in particular mangroves from the water and foreshore areas.

(f) To maintain the hydraulic system of the water areas so that the movement seaward of sand, silt and discharges to open waters occurs as efficiently as possible.

(g) To make no provision for general reclamations or dumping in the water and foreshore areas in the District, except for specifically authorised coastal protection works, specifically authorised minor reclamations and reclamations shown to be necessary in association with marinas.

(h) To make no provision for the use of the foreshore or water areas for refuse disposal.

(d) Mahurangi River and Harbour

(i) Generally to preserve the present varied high quality landscape character of the harbour and river, and those parts of the visual catchment with a high landscape value, as defined by the Rural Conservation and Urban Coastal Landscape Protection zonings, while accepting that changes may occur:

- to enable shellfish farming to be undertaken, both in the water areas appearing on MAF map 194 and where the crop is landed.

- to enable boat-building, maintenance and chartering to take place from the two areas of land zoned for such purposes at the Old Cement Works and Robertson Brothers Boatyard at Warkworth, and

- to enable land with a residential zoning to be built on.

(ii) To preserve open views of the harbour from public roads and other public land, while acknowledging that this may not be possible where the intervening land is zoned for residential use.

(iii) To enhance the recreational potential of the harbour in ways that do not significantly detract from its environmental qualities.

(iv) To maintain the natural water quality at a high level, for the benefit of shellfish farming and for recreational, aesthetic and ecological reasons, and the Warkworth town water supply.

(v) To limit commercial boat-building and maintenance facilities in the Mahurangi to sites within the two areas zoned for the purpose at Warkworth.

(vi) To acknowledge the use made by commercial fishermen of the moorings and jetty at Scotts Landing, but not to allow any significant extension of facilities for commercial fishing at that location.

10A STRATEGY

1. General Statement

The character and amenities of the district owe much to the natural environment. In particular, the rural and coastal areas of the district contain a wide range of natural assets such as stands of native bush, rivers, remote coastal landscapes, and wildlife habitats. These features, among others, make a significant contribution to the County's attractiveness as a living environment.

While the rural environment in general provides an important contrast to developed urban land, there are distinctive landscape types of special quality. These areas are particularly sensitive to development and require special protection which cannot be provided through the provisions of the general rural zone.

Four Rural Conservation zones are used to provide greater protection for these areas. They are:

Rural Conservation 1 (Nature Conservation) Zone
Rural Conservation 2 (Bush Landscape Protection) Zone
Rural Conservation 3 (Coastal Landscape Protection) Zone
Rural Conservation 4 (Kawau Island Bush) Zone.

10B ZONING

1. General Objectives and Policies

General Objective

To conserve and enhance where practicable those features of the natural environment that contribute significantly to the amenities of rural, coastal, and water areas.

General Policies - Zoning

(a) To provide greatest protection to those areas with particularly significant natural features.

(b) To make provision for the protection of extensive areas of the coastal, rural and island portions of the distsrict, while permitting compatible rural and residential development of a scale and intensity which does not detract from the landscape values of those areas.

(c) To protect significant areas of native bush and trees where they contribute to the amenities of a locality, function as important wildlife habitats, or prevent land instability or erosion.

(d) To permit outdoor recreational activities and visitor facilities based upon but not detrimental to the natural resources of the area.

(e) To preserve the natural character of the coastal environment by prohibiting the obtrusive location of buildings, by limiting their height and bulk, and by controlling their design and external appearance.

(f) To make provision for further subdivision based upon the economic use of the land, or for the preservation of the natural environment.

(g) To make provision for facilities associated with fishing and marine cultivation and for processing and/or storing produce of the sea or inland waters where there is justification for not locating in a service town or township.

4. Rural Conservation 3 (Coastal Landscape Protection) Zone

Zone Objectives

(a) To preserve the landscape qualities of open space and remoteness in coastal and rural areas.

(b) To protect significant areas of native bush and trees from unnecessary clearance.

10E CONSERVATION OF LANDSCAPE

1. General Objective

To protect those features of the natural environment which have resulted in the special quality and distinctive landscape types of the Rural Conservation Zones.

2. Policies - Conservation of Landscape

(a) In the Rural Conservation 1 Zone to prevent any alteration to landform, trees or bush, or any other physical feature and provide for the comprehensive protection of such features, unless such alteration will result in the better protection of the natural resources of the area, or is of such minor nature that damage to natural resources will not occur.

(b) In the other Rural Conservation Zones:

(i) To protect native trees exceeding 3 m in height, and prevent the clearing of areas of native trees and vegetation except as necessary to provide stable building areas, access and servicing, to retain the natural character of these areas and significant wildlife habitats.

(ii) To subject earthworks, excavation and the removal of topsoil (other than that associated with site preparation for building) to Council scrutiny to assess the necessity of those activities.

(iii) To protect coastal edges from development and physical alterations which would adversely effect the existing natural environment.

(iv) To retain river and stream courses in their natural state where they contribute to the amenities of a locality except where works are warranted in the public interest.

10.3.1 ASSESSMENT CRITERIA

The following assessment criteria shall apply to the uses listed.

(a) All Controlled Uses

(i) Building Location

The Council will discourage the location of buildings on prominent ridges, knolls or skylines where such buildings would dominate the natural landscape and detract from the amenities of an area. Buildings should be located below the crests of hills to reduce their visual impact on the landscape. The siting of buildings will also need to take into account the visual impact on panoramic views of an area, from public viewpoints, generally roads and reserves.

Where a building is proposed for a prominent location, and where no other practicable building platform exists, the Council may require screen and/or background planting to limit the building's visual impact.

(ii) Design and External Appearance

The scale and form of buildings, particularly those located in prominant positions, should be such that a building complements the natural landscape. Building profiles should generally reflect the contours of the surrounding landscape.

The Council may require the use of materials and colours which blend a building with the natural environment. Large areas of reflective material, such as unpainted roofs, are not desirable.

(Note: For buildings in the visual catchment of the Mahurangi River and Harbour, The Friends of the Mahurangi offer free advice on building location and design. They may be contacted through Mr Robin Pendred,

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