Assessment of Potential Water Quality Impacts Resulting from Removal of Rustico Island Little Harbour Causeway, Prince Edward Island

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Executive Summary

Field studies were carried out to evaluate the potential impact of removal of Rustico Island Little Harbour Causeway, Prince Edward Island on water quality within Rustico Bay. This study was part of a larger project to evaluate various remediation scenarios proposed to improve both water quality within the Bay and navigability within the entrance to North Rustico Harbour. The project was carried out jointly between the Acadia Centre for Estuarine Research, the Geological Survey of Canada (Atlantic), Baird and Associates Ltd. and Challenger Oceanography. The major objectives of the water quality component of the project were to determine existing water quality within the Bay and the two rivers entering the Bay, and to determine how water quality would be affected by each of the proposed remediation alternatives.

A total of four water quality transects were carried out, one on the Hunter River system and three on the Wheatley River system. Parameters measured included salinity/temperature depth profiles, Secchi Disk depths, and concentrations of chlorophyll *a*, dissolved oxygen, suspended sediments, and nutrients. In addition, studies were carried out to determine the organic and nutrient concentration of sediments at 15 sites within the Bay in order to evaluate the potential water quality impact of sediment organic and nutrient resuspension that may occur as a result of the proposed remediation options.

The water quality survey indicated only the area of the Wheatley River above the highway bridge to be seriously degraded, particularly with respect to dissolved oxygen levels. The lower Wheatley estuary and the entire Hunter River system, although characterised by relatively high nutrient inputs, did not exhibit any evidence of low dissolved oxygen concentrations or excessively high algal concentrations. The relationships observed between nutrient concentration and salinity indicated that nutrient inputs to these areas are diluted by seawater. This, together with the high oxygen concentrations present in seawater and the lack of any significant water column stratification within the Bay, keeps Rustico Bay from becoming oxygen depleted.

There was little indication that any of the proposed remediation alternatives would have a significant impact on the degree of tidal flushing that presently exists within Rustico Bay and, as a result, little improvement in water quality is to be expected from their implementation. In addition, none of the proposed remediation options is predicted to result in significant resuspension of existing sediment nutrients and organics and it is unlikely that this would be a major concern in terms of impacting water quality.

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Assessment of Potential Water Quality Impacts Resulting from Removal of Rustico Island Little Harbour Causeway, Prince Edward Island

1. Introduction

This report presents the results of a study carried out to evaluate the potential impact of removal of Little Harbour Causeway, located between Rustico (Robinson's) Island and the mainland of Prince Edward Island, on water quality within Rustico Bay. It is part of a larger project to evaluate various remediation scenarios proposed to improve both water quality within the Bay and navigability within the entrance to North Rustico Harbour. The project was carried out jointly between the Acadia Centre for Estuarine Research, the Geological Survey of Canada (Atlantic), Baird and Associates Ltd. and Challenger Oceanography. The major objectives of the water quality component of the project were to (1) determine existing water quality within the Bay and the two rivers entering the Bay and; (2) determine how water quality would be affected by each of the proposed remediation scenarios.

2. Background

In 1956, Parks Canada, after several years of discussion, constructed a causeway across Little Harbour Inlet to connect Rustico Island to the mainland. The causeway was built partly to provide road access to Rustico Island and partly in the hope that diversion of the outflow of the Wheatley River to the North Rustico Channel would result in deepening of the channel leading to an increase in its navigability.

Prior to construction of the Little Harbour Causeway, the Hunter and Wheatley estuaries were inter-connected and the exchange of tidal waters took place through two entrance channels, the Little Harbour Inlet and the North Rustico Channel, located to the east and west of Rustico Island respectively. Although tidal flow through the North Rustico Channel initially increased after construction of Little Harbour Causeway, new channels began to develop across the west end of the Island, presumably as a result of storm breaches, and much of the tidal and river flow from the Wheatley estuary subsequently became diverted through these new channels. The new channels eventually began to migrate in an easterly direction and in the process nearly two km of the western end of Rustico Island became severely eroded. Much of the eroded material has accumulated as a sand bar between North Rustico and Anglo Rustico which has lead to the present condition in which the two estuaries now constitute nearly separate systems, one draining the Wheatley River and one draining the Hunter River. The result of these changes has been a decrease in the navigability of the North Rustico Channel, the main entrance to North Rustico Harbour. It has also been suggested that these changes have resulted in a decrease in water quality within Rustico Bay as a result of reduced tidal flushing.

the harbour entrance. A modification of this model was later used to evaluate the effect of opening Little Harbour Causeway on water quality in Rustico Bay (Baird and Associates 1990). The results indicated that Little Harbour Causeway, as it presently exists, has little influence on the tidal prism (and therefore flushing) of the Rustico Bay system. This was also found to be true of the Wheatley River Bridge Causeway. In addition, the model simulations indicated that there would be little change in flushing of the estuary as a result of removal of the Little Harbour Causeway. The increased flow into Rustico Bay resulting from opening Little Harbour Causeway would be offset by a reduced flow through the main entrance of the North Rustico Channel, the net result being little change in the total amount of water entering the Bay. The model was also used to carry out simulations of the dispersion of pollutants entering the estuary at various points. These simulations also suggested little difference in flushing of the estuary with and without the presence of the Little Harbour Causeway. These conclusions, however, were considered very tentative because the model was not explicitly designed to simulate the inner portion of Rustico Bay. In particular, there was limited information on bathymetry and there was little information available on water depths and current velocities that could be used for model calibration.

Although not directly concerned with water quality, in 1973 the Prince Edward Island Department of Fisheries (MacWilliams 1974) carried out a resource inventory of Rustico Bay to determine the extent of shellfish resources within the Bay. The results of the survey indicated that, although scattered populations of shellfish occurred in the Bay, they were not present in commercial quantities due to the lack of suitable habitat. Mussels were the most abundant shellfish and were confined largely to areas of hard bottom along the shorelines. Oysters were the least abundant shellfish and were confined mainly to areas of existing commercial leases. Soft shelled clams were moderately abundant but were small in size, presumably as a result of heavy pressure from recreational harvesting.

2.3. Description of Study Area

The Rustico Bay system is located in the north central part of Queens County, PEI and lies behind a system of barrier islands composed of Rustico Island and the eastern end of Brackley Beach, both of which form part of the Prince Edward Island National Park (Figure 2.1). The barrier islands are largely composed of sand dunes and scrub forests. A breach in the barrier islands at the western tip of Rustico Island provides an entrance to North Rustico Harbour at North Rustico, a small community that relies primarily on lobster fishing and tourism, including recreational sport fishing, for its economic viability. There are also considerable shellfish aquaculture operations, mainly mussels and oysters, carried out in various parts of the Bay.

Rustico Bay is approximately 8 km wide in an east-west direction and 2 km wide in a north-south direction. It receives fresh water inputs from two major rivers, the Hunter on the southwest and the Wheatley on the Southeast. There are also a number of smaller rivers that drain into the Bay. The Bay opens to the north through a series of small

3. Methodology

3.1. Water Quality Survey

A total of four water quality transects were carried out, one on the Hunter River system and three on the Wheatley River system. The Hunter River transect was carried out on 28 July and included a total of 11 stations extending from the bridge at New Glasglow to the centre of North Rustico Harbour (Figure 3.1). The three Wheatley River transects were carried out on 17-18, 19 and 29 July and included 10, 8 and 13 stations respectively (Figures 3.2-3.4). The uppermost stations were at the bridge at the town of Wheatley River and the lowermost stations extended to the lower part of Rustico Bay. The location of each sampling station was determined using a Magellan 3000 GPS Field navigator. Table 3.1 lists the water quality and related parameters measured at each station of the transects.

Table 3.1. Water quality parameters measured at each station of the water quality transects.

Salinity/Temperature Depth Profiles
Secchi Disk Depth
Dissolved Oxygen Concentration
Percent Dissolved Oxygen Saturation
Chlorophyll *a* Concentration
Total Phosphorous
Total Nitrogen
Nitrate
Ammonium
Total Suspended Particulate matter
Suspended Particulate Inorganic Matter
Suspended Particulate Organic matter

Salinity/Temperature depth profiles were measured using either a Yellow Springs Instrument Salinity/Conductivity/Temperature meter or an Applied Microsystems Ltd. Aquamate 1000 CTD data logger. The latter instrument was also used for measurements of salinity/depth profiles at each of the Sea Carousel stations.

Secchi Disk depths were measured using a 20 cm dia Secchi Disk. The disk was lowered into the water until it was no longer visible and then retrieved until it reappeared. The Secchi Disk depth was then recorded as the average of the depth of disappearance and reappearance.

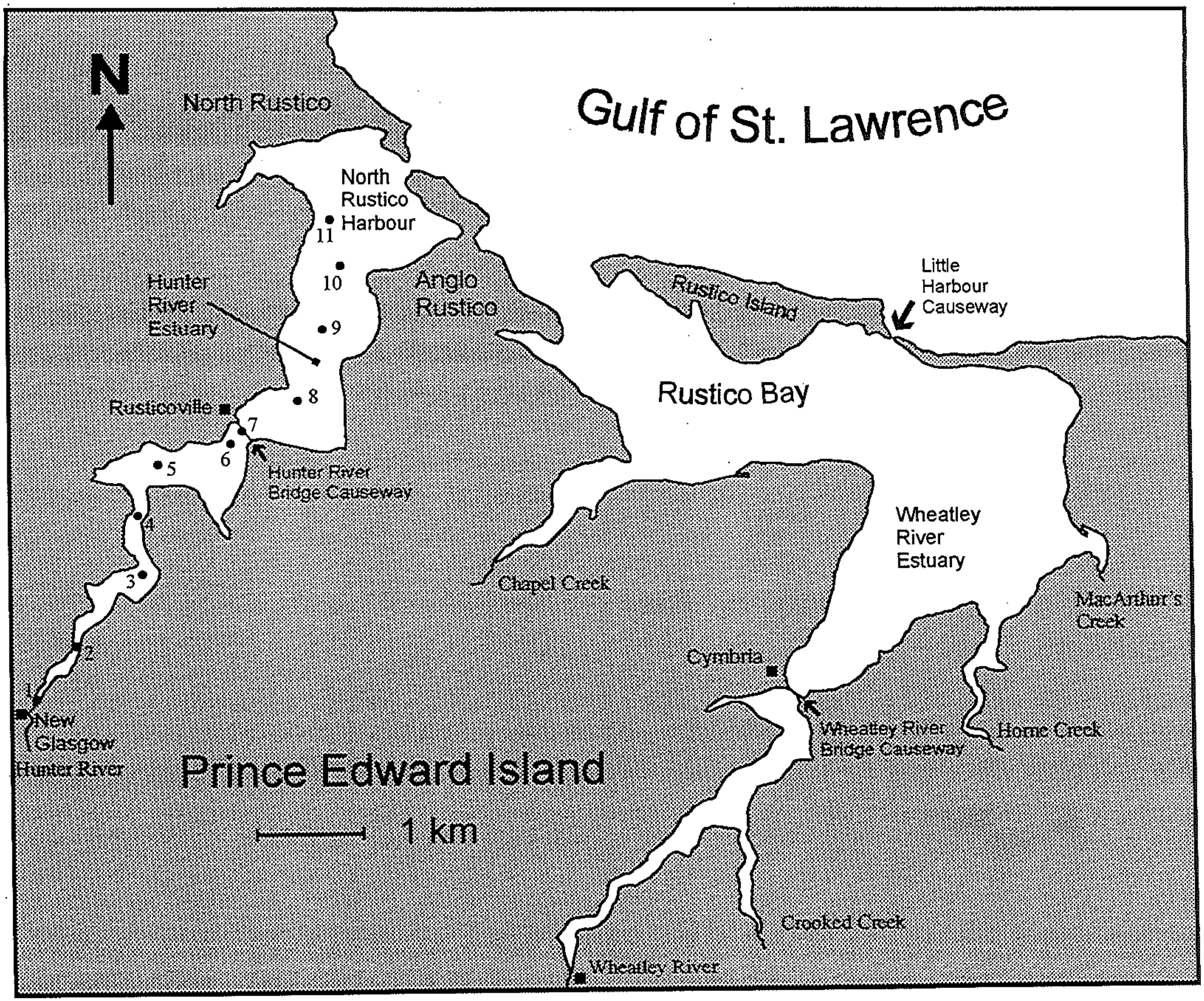

Figure 3.1 Locations of water quality stations for Hunter River transect carried out on 28 July 1997.

Water samples for determination of dissolved oxygen concentration were collected using a Van Dorn water sampler. Samples were collected at mid-depth if the water column was unstratified, and just below the surface and above the bottom if the water column was stratified. The water samples were transferred into 300 ml BOD bottles and fixed immediately after collection. Dissolved oxygen concentration was determined using the Winkler technique. All titrations were carried out the same day as sample collection. Percent dissolved oxygen saturation was calculated according to the algorithm described in Eaton et al. (1995).

Measurements of total suspended particulate matter were made by filtering up to 1 litre of water through a pre-combusted Watman GF/C glass fibre filter and oven drying the filter at 60-70 °C to a constant dry weight. Suspended particulate organic matter was determined after combustion of the filters at 500 °C for 3 hr and reweighing the filters. Suspended particulate organic matter was determined as the difference between total particulate matter and particulate inorganic matter.

All nutrient (total phosphorus, total nitrogen, nitrate and ammonia) and chlorophyll *a* analyses were carried out by the Water Resources Division of the PEI Department of Fisheries and Environment.

3.2. Benthic Nutrient Flux

Application of the various proposed remediation options could potentially lead to areas of the seabed being transformed from depositional to erosional environments. It was therefore considered important to collect information on the nutrient content of sediments for use in model simulations carried out to provide some indication of the potential input of nutrients to the water column as a result of sediment resuspension. This was accomplished by collecting water quality samples from the Sea Carousel during each deployment. Figure 3.5 shows the location of each Sea Carousel deployment.

The water quality samples were collected by pumping water from within the Sea Carousel at the stage of the deployment when sediments were observed to just begin being resuspended. The samples were later analysed for nutrient content (total phosphorus, total nitrogen, nitrate and ammonium). The nutrient analyses were carried out by the Water Resources Division of the PEI Department of Fisheries and Environment.

3.3. Sediment Organic Content

Sediment organic content was measured at each Sea Carousel station. This information was considered important for determining the potential decrease in dissolved oxygen levels that could result from biological and chemical degradation of sediment organic matter if it were resuspended into the water column. Sediment samples were collected with a Van Veen grab and each grab subsampled in triplicate by collecting the

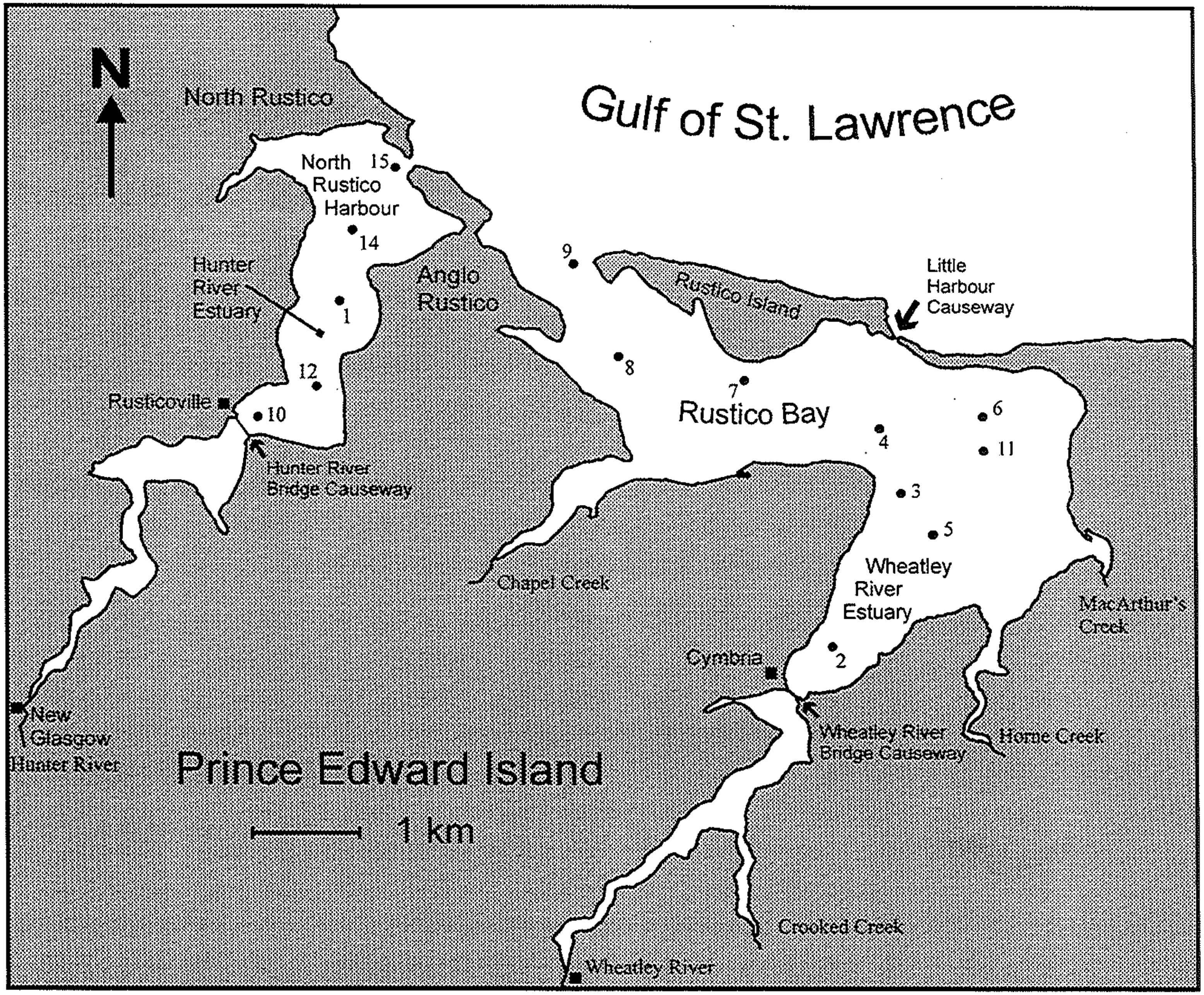

Figure 3.5. Locations of Sea Carousel stations.

upper 1 mm of sediment using a small core sampler. Samples were kept frozen until analysis. Sediment organic content was determined by drying the sample to a constant dry weight at 70 °C and then combusting the sample for 4 hr at 500 °C to remove all organic material. The organic content was determined as the difference between dry weight and combusted weight.

3.4. Salinity/Temperature Time Series

Time series of salinity and temperature were collected at three sites within the Bay to provide some indication of the amounts of river and sea water in Rustico Bay and its variation over the tidal cycle. Two of the sites were located within the Hunter River system, one during 15-17 July at 46° 26.23' N, 63° 18.07'W and one during 22 July -1 August at 46° 25.91'N, 63° 19.03'W. The third site was located within the Wheatley River system during 17-21 July at 46° 24.96'N, 63° 14.18'W. The location of each deployment is shown in Figure 3.6. The time series data were collected with an Applied Microsystems Ltd. Model 2000 EMP CTD data logger that was moored to maintain data sensors one meter above the seabed..

3.5. Flushing Rates

Flushing rates were calculated for the Bay as it presently exists and the value compared to flushing rates calculated on the basis of changes that would occur as a result of each of the proposed remediation alternatives. Since there was little indication of any significant water column stratification within the Bay, flushing rates were calculated using the simple classical tidal prism method (Kennish 1986). The following formula was used:

$$T = (V + P) / P$$ where,

T = Flushing time in tidal cycles

V = Low tide volume

P = Intertidal volume

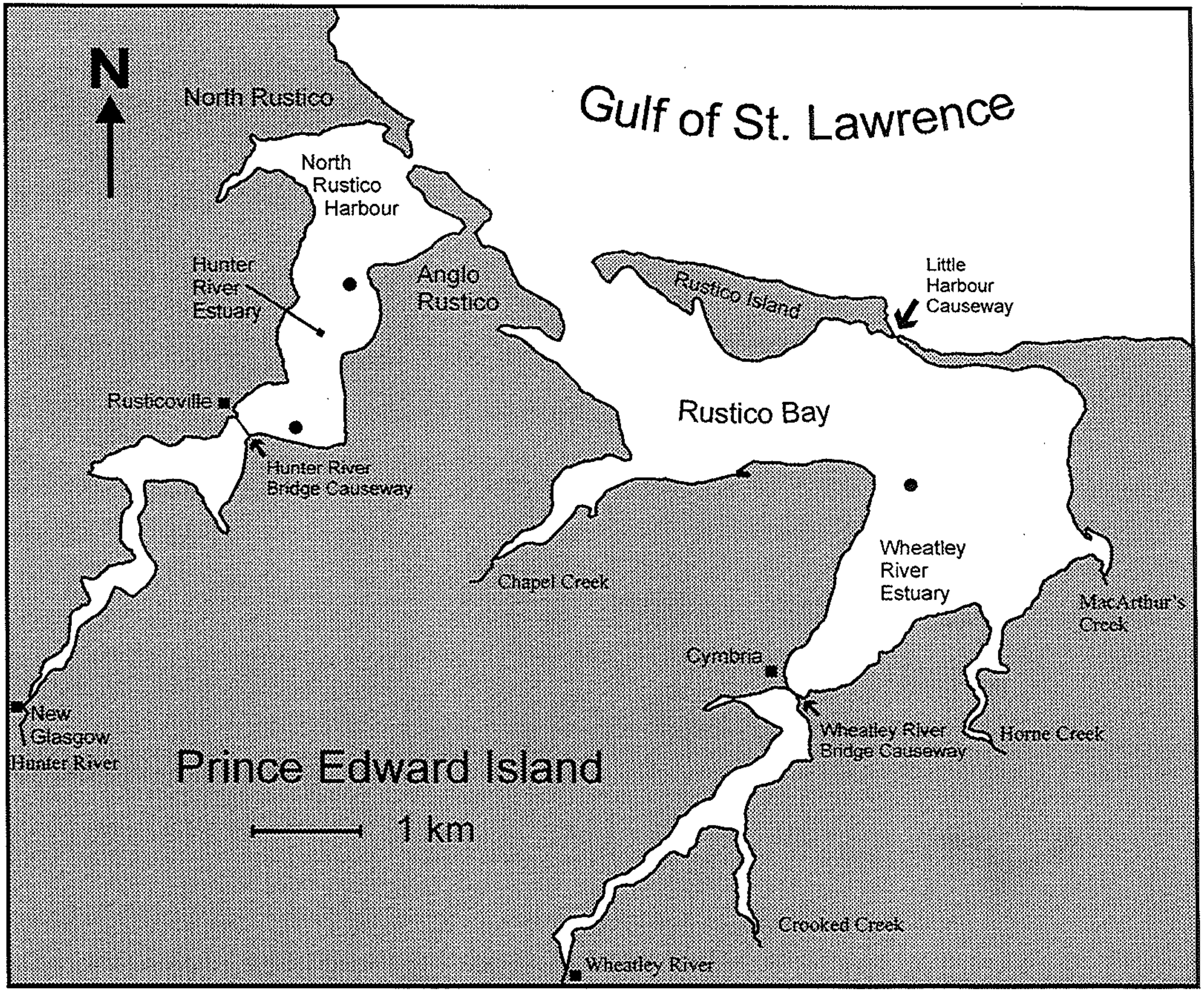

Figure 3.6. Locations of EMP2000 CTD moorings for collection of salinity/temperature time series data.

4. Results

4.1. Salinity/Temperature Time Series

The results of the salinity/temperature time series are presented Figures 4.1 and 4.2. At the Hunter River site, salinity varied between about 23 and 27 ppt over the tidal cycle. Salinity at the Wheatley River site was slightly higher and exhibited much less variation over a tidal cycle. At both sites there was little indication that river inputs had a great influence on salinity. (Surface seawater salinity measured in the Gulf of St. Lawrence about 10 km offshore of North Rustico on 1 August 1997 was 27.3 ppt).

4.2 Salinity/Temperature Depth Profiles

The salinity/temperature depth profiles taken at each of the Sea Carousel stations (Figure 4.3) also indicated water in the Bay to consist largely of seawater. Except for a very thin layer of freshwater in the upper few cm of the water column, there was never any indication of significant water column stratification within the Bay below either the Hunter or Wheatley River Bridges. It should be noted, however, that the period during which the data was collected was unusually dry. Total precipitation during the month of July amounted to only 17.0 mm, which is considerably below the ten year monthly mean of 81.6 mm for July (Environment Canada weather records for Charlottetown Airport). It is possible that salinity stratification within the Bay may be more pronounced during periods of higher river flow.

Above the bridges there is an increasing trend for the water column to become stratified as one moves further up the river (Figure 4.4), presumably as a result of the reduced amount of tidal energy and mixing above the bridges. Most of the stratification is a result of salinity differences as opposed to temperature differences.

4.3. Secchi Disk Depths

Secchi Disk depths provide an indication of water clarity. Low Secchi Disk depths are usually a result of either high algal concentrations or high suspended sediment concentrations. Figure 4.5 illustrates the variation in Secchi Disk depths along each of the water quality transects and Figure 4.6 shows the Secchi Disk depth recorded for each Sea Carousel station, all of which were located within the Bay below the Bridges.

The Wheatley River transects all showed an increase in Secchi Disk depth from the head of the River to the mouth of the Bay. Secchi Disk depths above the Wheatley River Bridge were always less than 1 m while those above the Bridge were always greater than 1 m. Within the outer parts of the Bay of the Wheatley estuary, Secchi Disk depths were often greater than 2.0 m. The data base for the Hunter River estuary is not as extensive as that for the Wheatley and there is no clear relationship between Secchi Disk depth and

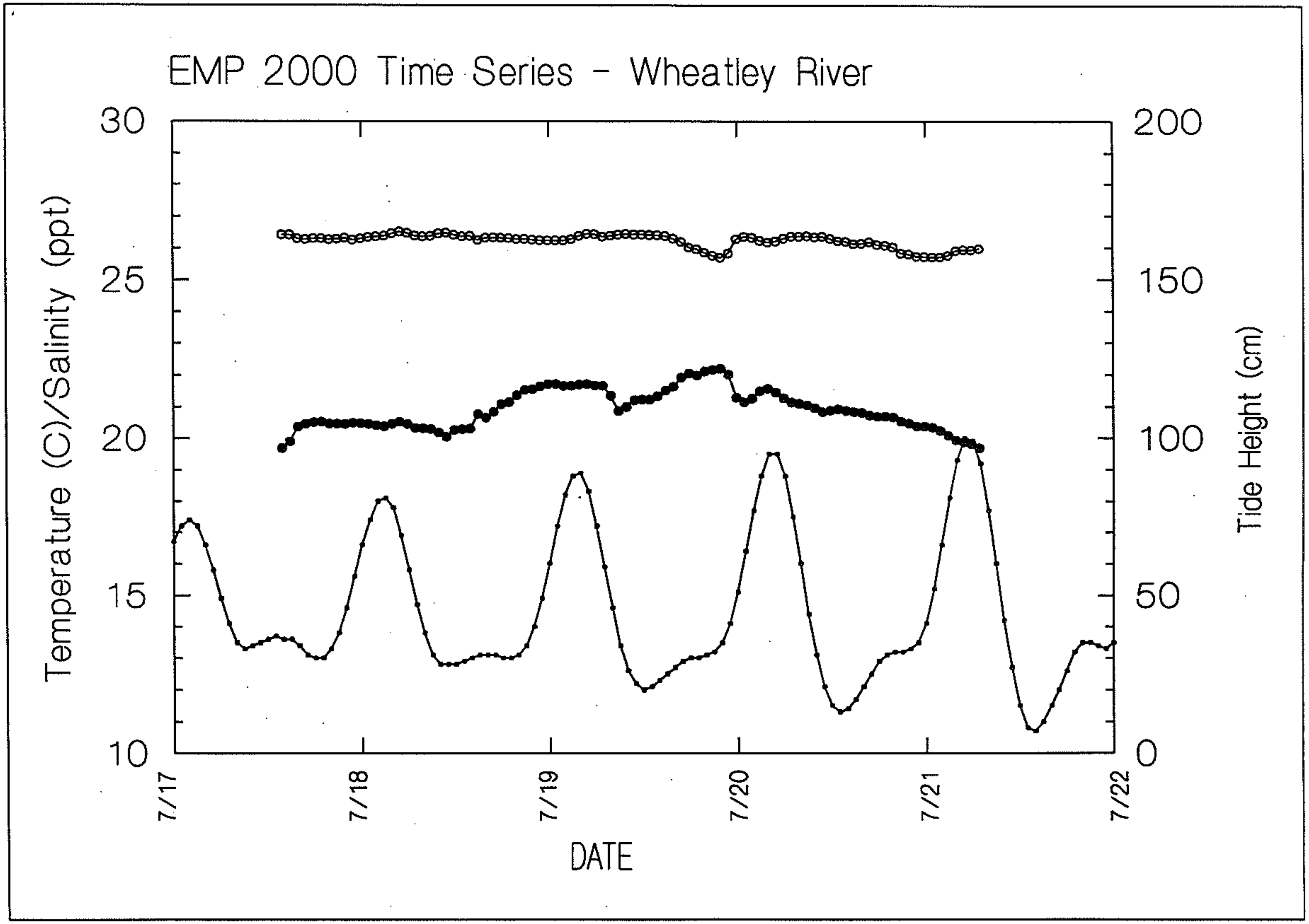

Figure 4.1. Time series of salinity (o), temperature (•) and tide height (•) at the Wheatley River station.

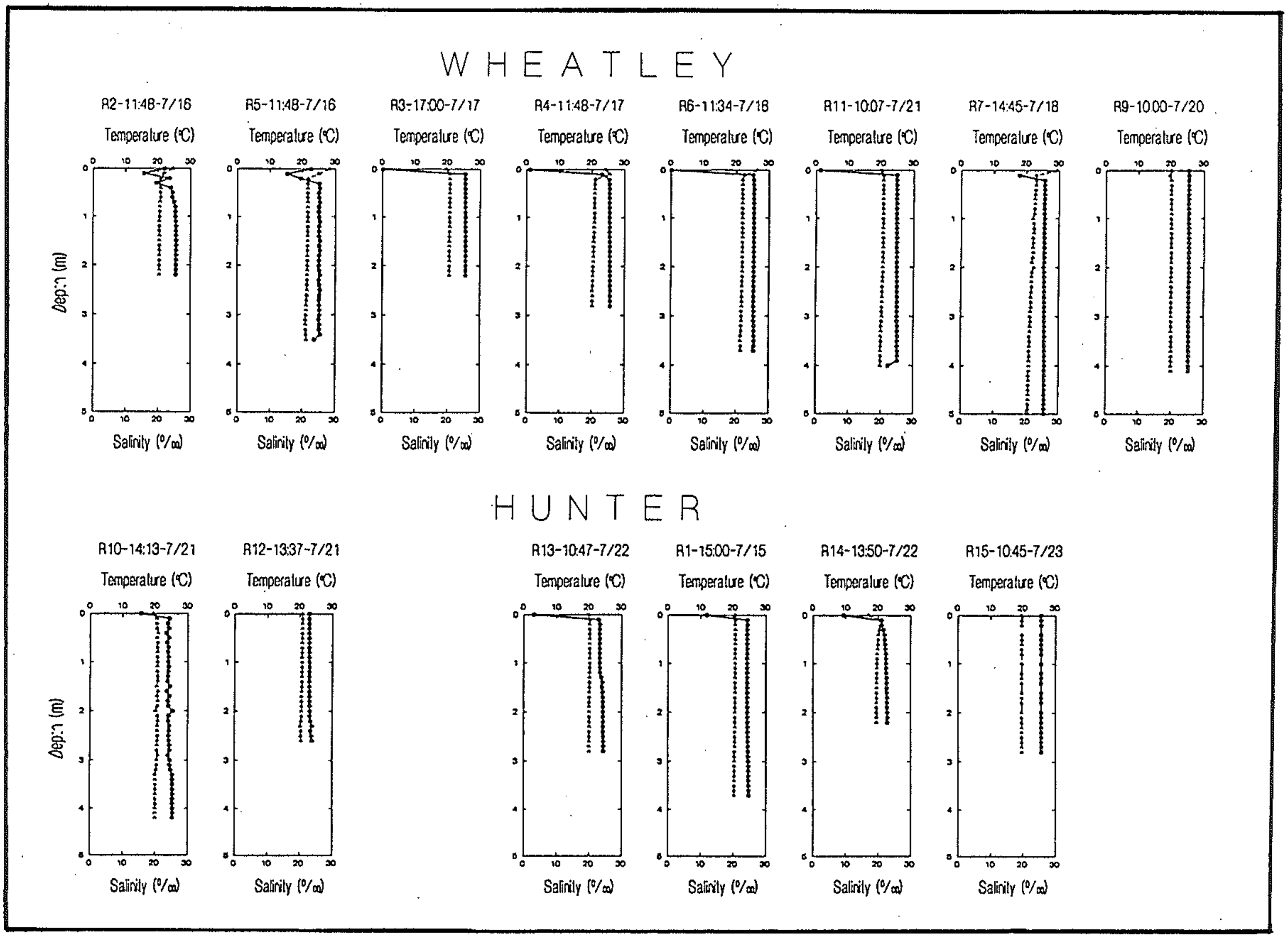

Figure 4.3. Salinity(∘)/temperature (▿) depth profiles at each Sea Carousel station.

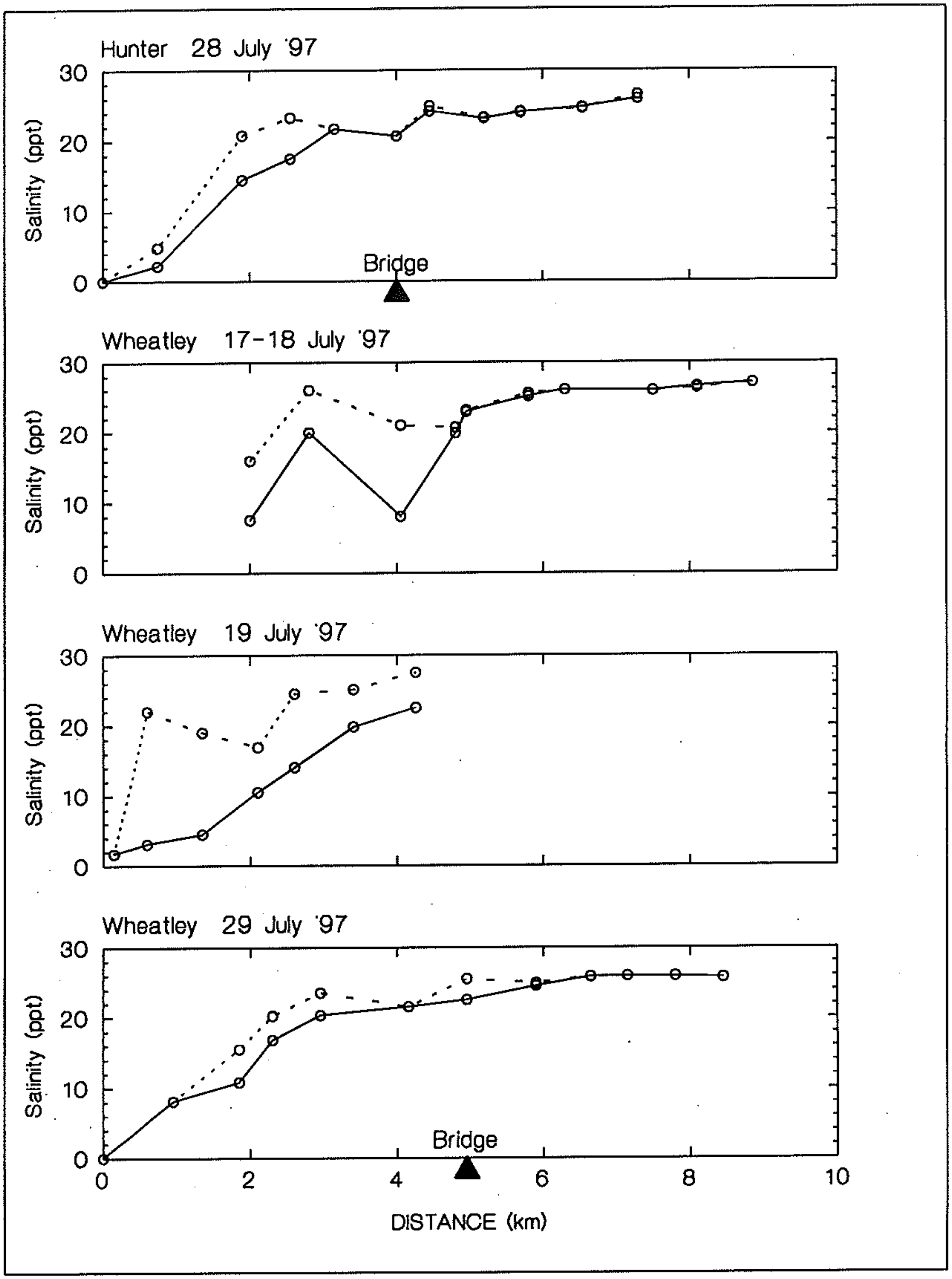

Figure 4.4. Salinity variation between surface (—) and bottom (----) water along each of the Hunter and Wheatley transects.

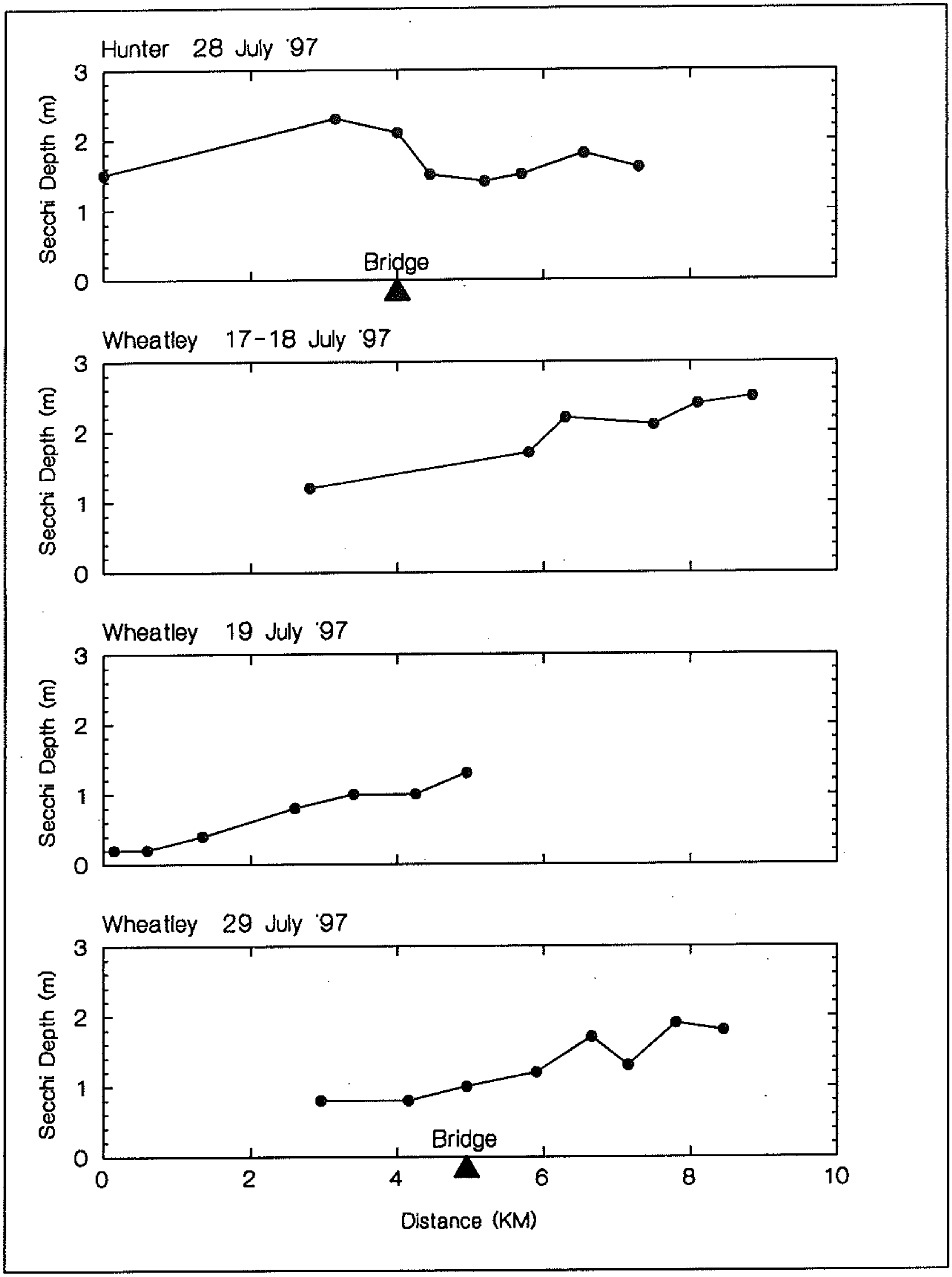

Figure 4.5. Secchi Disk depths along each of the Hunter and Wheatley transects.

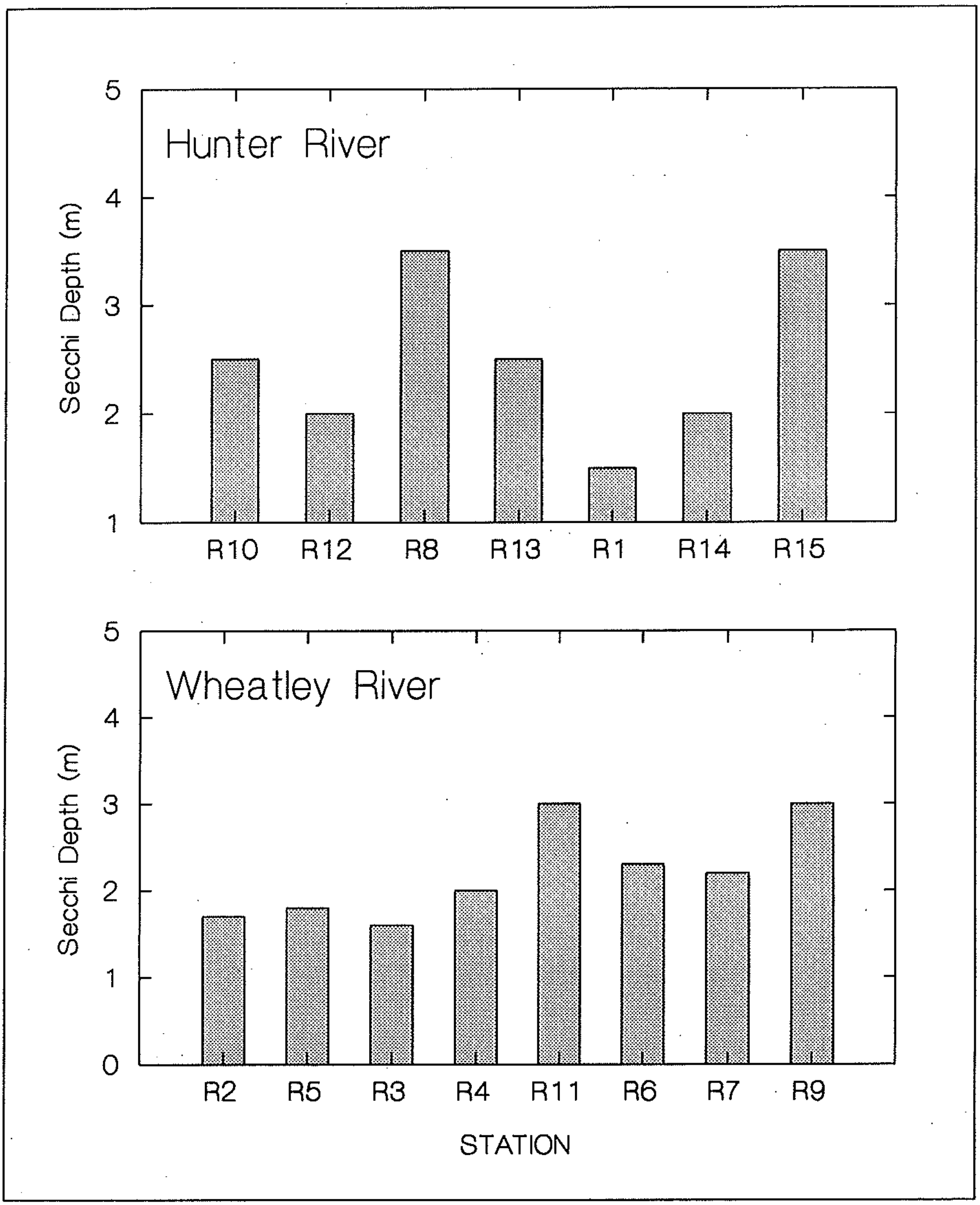

Figure 4.6. Secchi Disk depths at each of the Sea Carousel stations.

distance along the river. Within the Bay, Secchi Disk depths were generally lower in the Hunter than the Wheatley estuary and seldom exceeded 2 m.

Table 4.1 lists the suspended sediment concentration, chlorophyll *a* concentration, and Secchi Disk depth at each station of the water quality transects and Figure 4.7 shows the relationship between Secchi Disk depth , chlorophyll *a* and suspended sediment concentration. Within the upper parts of the river, Secchi Disk depths appear to be largely determined by suspended sediment concentration as opposed to chlorophyll *a* concentration.

4.4. Dissolved Oxygen

Dissolved oxygen concentration and percent saturation of dissolved oxygen are the two parameters often considered to be most indicative of water quality problems related to eutrophication of an aquatic ecosystem. Most aquatic organisms can not survive in environments where dissolved oxygen values fall below about the 50 percent saturation level.

Figures 4.8 and 4.9 show the variation in dissolved oxygen and percent saturation measured along each water quality transect. Within the Bay, levels of dissolved oxygen were in all cases quite high often exceeding 100 percent saturation. Within the Hunter estuary, there was little indication of depressed dissolved oxygen levels either above or below the Bridge. Within the Wheatley estuary above the Bridge, however, dissolved oxygen levels were often below the 50 percent saturation value and, in some cases, particularly for bottom water, no dissolved oxygen was present. These depressed concentrations, however, were not observed during every transect suggesting that there is a periodic intrusion of water containing higher dissolved oxygen levels. The positive relationship between dissolved oxygen concentration and tide height at the time the measurements were taken (Figure 4.10) indicates this is most likely a result of tidal flushing.

4.5. Chlorophyll *a*

Chlorophyll *a* is an indirect measure of the amount of algal material present in the water column. The concentration of chlorophyll *a* was characteristically much higher in the River portion of both estuaries as compared to the Bay portion (Figure 4.11). Levels above the Bridges were often exceptionally high, at times exceeding 50 μg/l, but there was considerable variation in the trend observed from the upper to lower reaches. This suggests that the distribution of chlorophyll *a* is quite patchy and probably influenced by numerous factors such as turbidity in the upper reaches and dilution by sea water in the lower reaches. The level of chlorophyll *a* below the Bridges was generally much less in both estuaries seldom exceeding 10 μg/l.

Table 4.1. SPM, Secchi Disk depth and Chlorophyll *a* concentration at each station of the water quality transects.

Site	Transect	Station #	Date	Time	Total Particulate Matter (mg/l)	Particulate Organic Matter (mg/l)	Particulate Inorganic Matter (mg/l)	% Organic Particulate Matter	Secchi Depth (m)	Chlorophyll a (ug/l)
Hunter	A	1	280797	11.33	36.12	7.91	28.20	21.91	1.5	6.0
Hunter	A	2	280797	11.58	119.19	28.38	90.81	23.81	.	47.9
Hunter	A	3	280797	12.08	13.45	3.15	10.30	23.42	.	8.2
Hunter	A	4	280797	12.42	9.24	3.31	5.93	35.82	.	9.5
Hunter	A	5	280797	12.58	6.52	3.03	3.48	46.51	2.3	4.1
Hunter	A	6	280797	12.83	3.82	1.76	2.06	46.15	2.1	4.3
Hunter	A	7	280797	13.66	9.14	2.52	6.62	27.54	1.5	8.4
Hunter	A	8	280797	13.90	5.17	2.65	2.52	51.28	1.4	5.5
Hunter	A	9	280797	15.08	5.10	2.04	3.06	40.00	1.5	4.7
Hunter	A	10	280797	14.25	5.62	2.47	3.15	43.90	1.8	3.6
Hunter	A	11	280797	14.58	17.86	4.15	13.71	23.24	1.6	4.5
Wheatley	A	1	170797	13.50	4.84	1.83	3.01	37.78	.	2.0
Wheatley	A	2	170797	13.72	62.00	34.67	27.33	55.91	1.2	132.0
Wheatley	A	3	170797	14.12	5.34	2.51	2.83	47.06	.	4.2
Wheatley	A	4	170797	14.33	4.89	2.23	2.66	45.65	.	9.3
Wheatley	A	5	180797	15.23	5.91	3.23	2.69	54.55	.	8.9
Wheatley	A	6	180797	15.57	6.40	2.17	4.23	33.93	1.7	4.7
Wheatley	A	7	180797	15.75	5.19	1.95	3.24	37.50	2.2	2.0
Wheatley	A	8	180797	16.00	4.55	1.72	2.83	37.78	2.1	1.5
Wheatley	A	9	180797	16.20	8.49	2.47	6.02	29.11	2.4	2.0
Wheatley	A	10	180797	16.47	5.19	2.22	2.96	42.86	2.5	2.4
Wheatley	B	1	190797	13.75	48.93	7.86	41.07	16.06	0.2	5.9
Wheatley	B	2	190797	14.00	113.50	17.75	95.75	15.64	0.2	2.2
Wheatley	B	3	190797	14.50	19.71	4.71	15.00	23.91	0.4	3.7
Wheatley	B	4	190797	14.93	9.80	4.12	5.69	42.00	.	3.3
Wheatley	B	5	190797	15.25	28.36	13.28	15.08	46.82	0.8	6.4
Wheatley	B	6	190797	15.48	7.41	3.97	3.45	53.49	1	11.9
Wheatley	B	7	190797	15.67	13.60	5.40	8.20	39.71	1	18.6
Wheatley	B	8	190797	15.70	7.65	3.92	3.73	51.28	1.3	17.5
Wheatley	C	0	290997	16.30	8.20	3.20	5.00	39.02	.	3.3
Wheatley	C	1	290997	11.50	9.20	3.60	5.60	39.13	.	20.6
Wheatley	C	2	290997	11.92	11.00	6.40	4.60	58.18	.	33.5
Wheatley	C	3	290997	12.25	9.00	4.00	5.00	44.44	.	44.0
Wheatley	C	4	290997	12.50	10.60	6.60	4.00	62.26	0.8	1.3
Wheatley	C	5	290997	12.80	11.20	8.00	3.20	71.43	0.7	70.6
Wheatley	C	6	290997	12.07	11.60	6.80	4.80	58.62	0.8	65.2
Wheatley	C	7	290997	14.75	5.60	2.80	2.80	50.00	1	14.9
Wheatley	C	8	290997	15.05	8.40	3.20	5.20	38.10	1.2	12.7
Wheatley	C	9	290997	15.20	8.80	3.00	5.80	34.09	1.7	1.9
Wheatley	C	10	290997	15.42	8.60	2.80	5.80	32.56	1.3	3.9
Wheatley	C	11	290997	15.55	9.20	2.80	6.40	30.43	1.9	3.4
Wheatley	C	12	290997	15.73	6.00	2.00	4.00	33.33	1.8	.

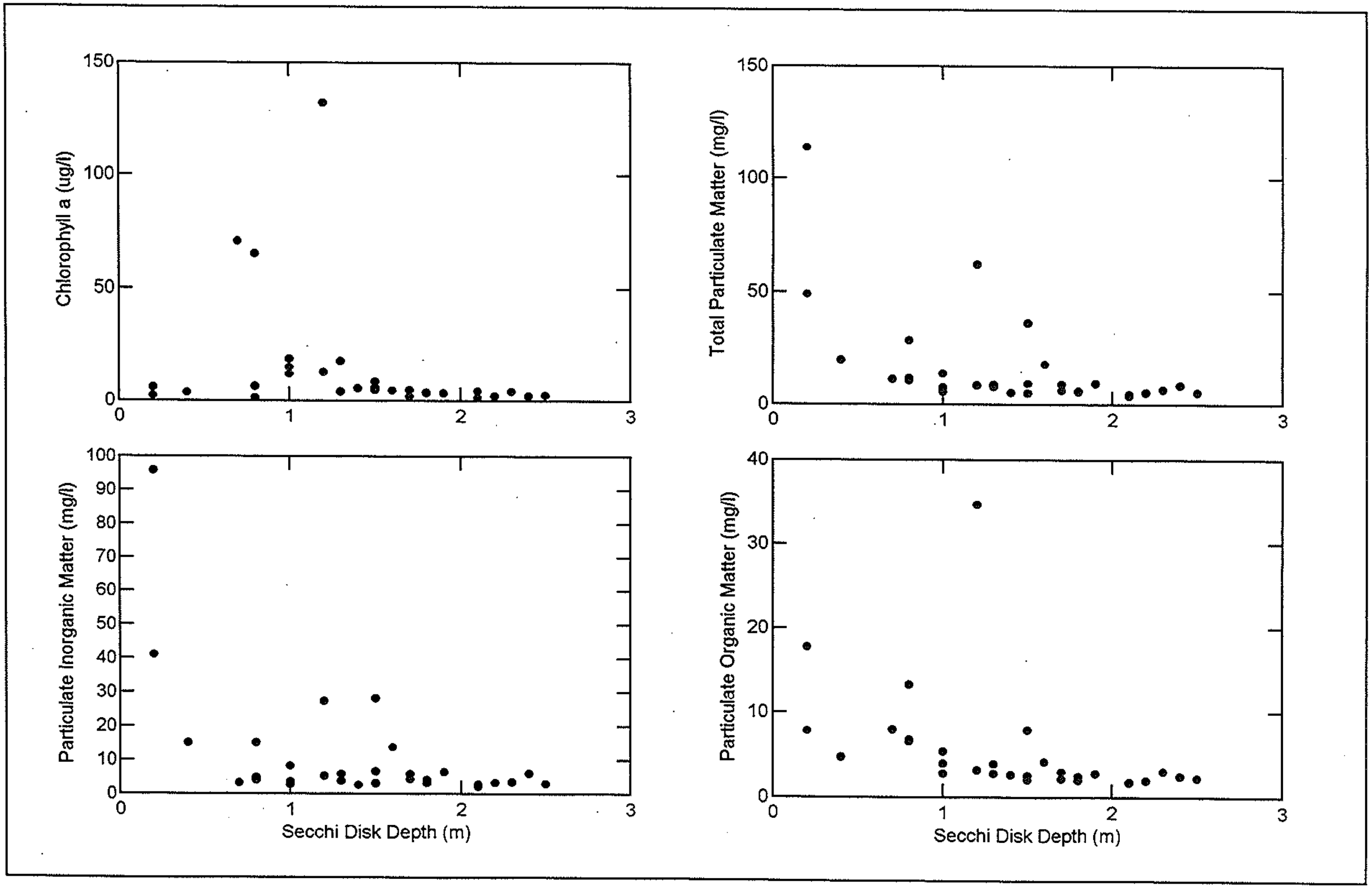

Figure 4.7. Relationship between Secchi Disk depth, chlorophyll *a* and various forms of suspended particulate matter.

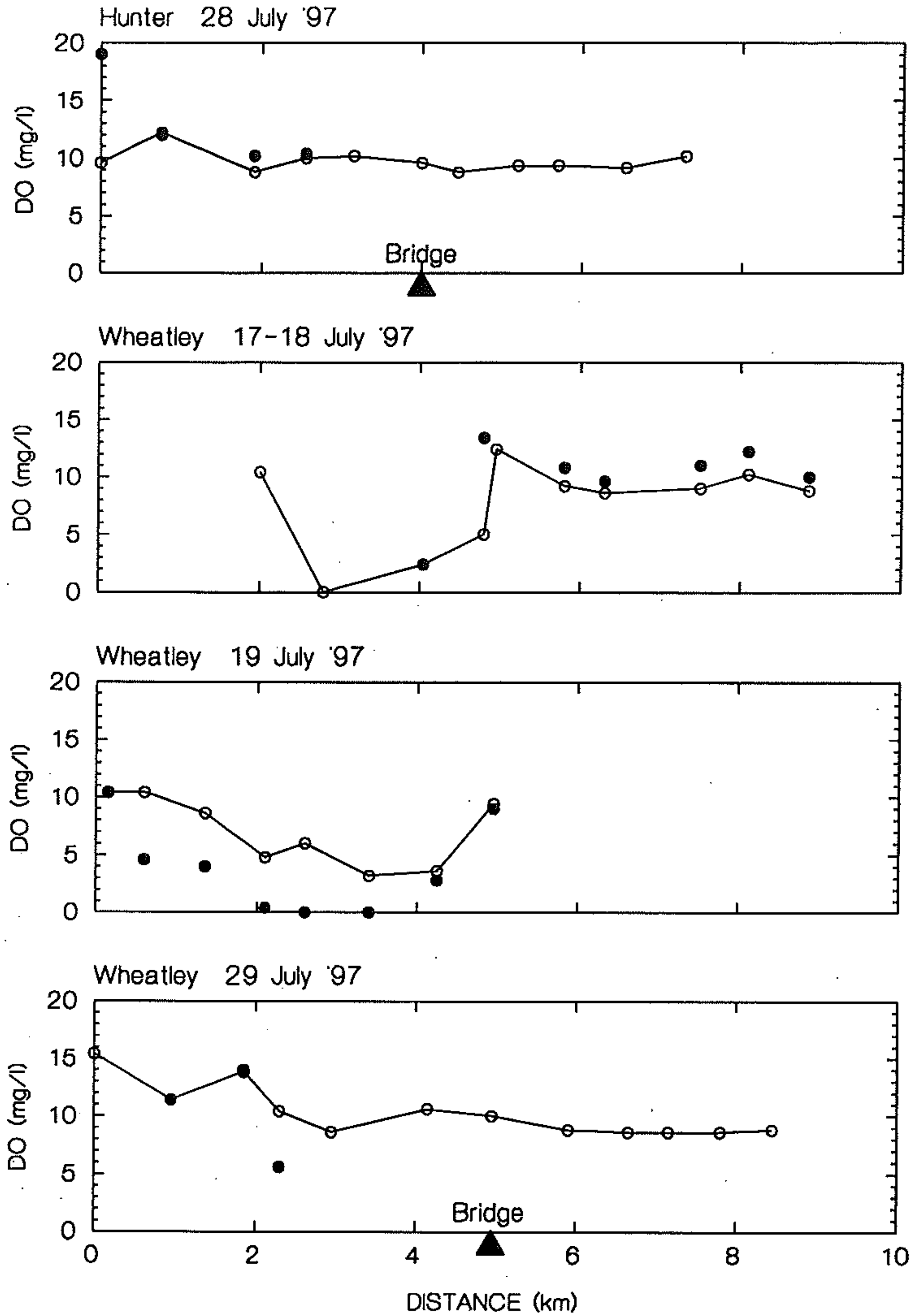

Figure 4.8. Dissolved oxygen concentration (o surface, • bottom) along each of the Hunter and Wheatley transects.

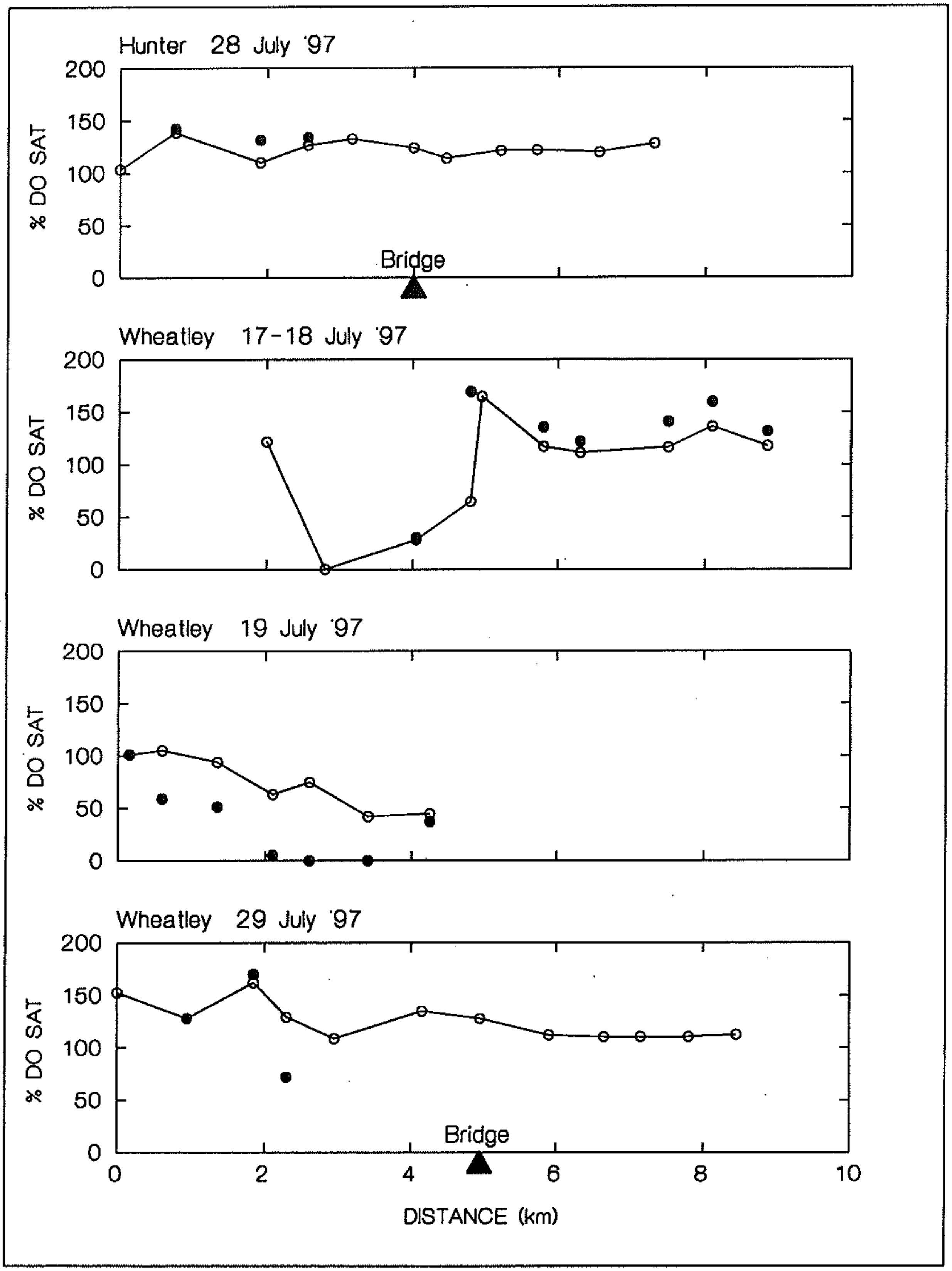

Figure 4.9. Percent dissolved oxygen saturation (o surface, • bottom) along each of the Hunter and Wheatley transects.

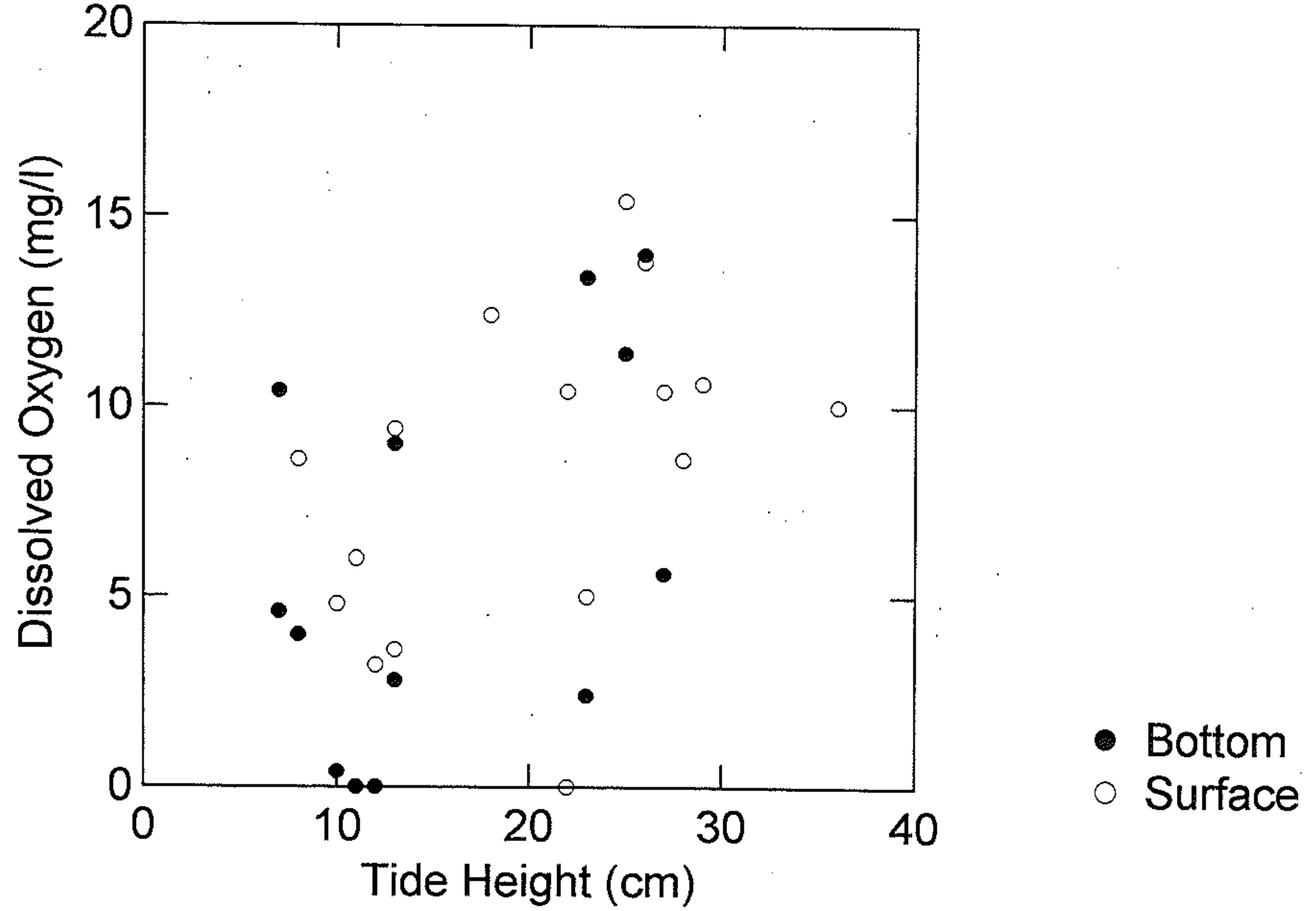

Figure 4.10. Relationship between dissolved oxygen concentration (o surface, • bottom) and tide state (as indicated by tide height) in the Wheatley River estuary.

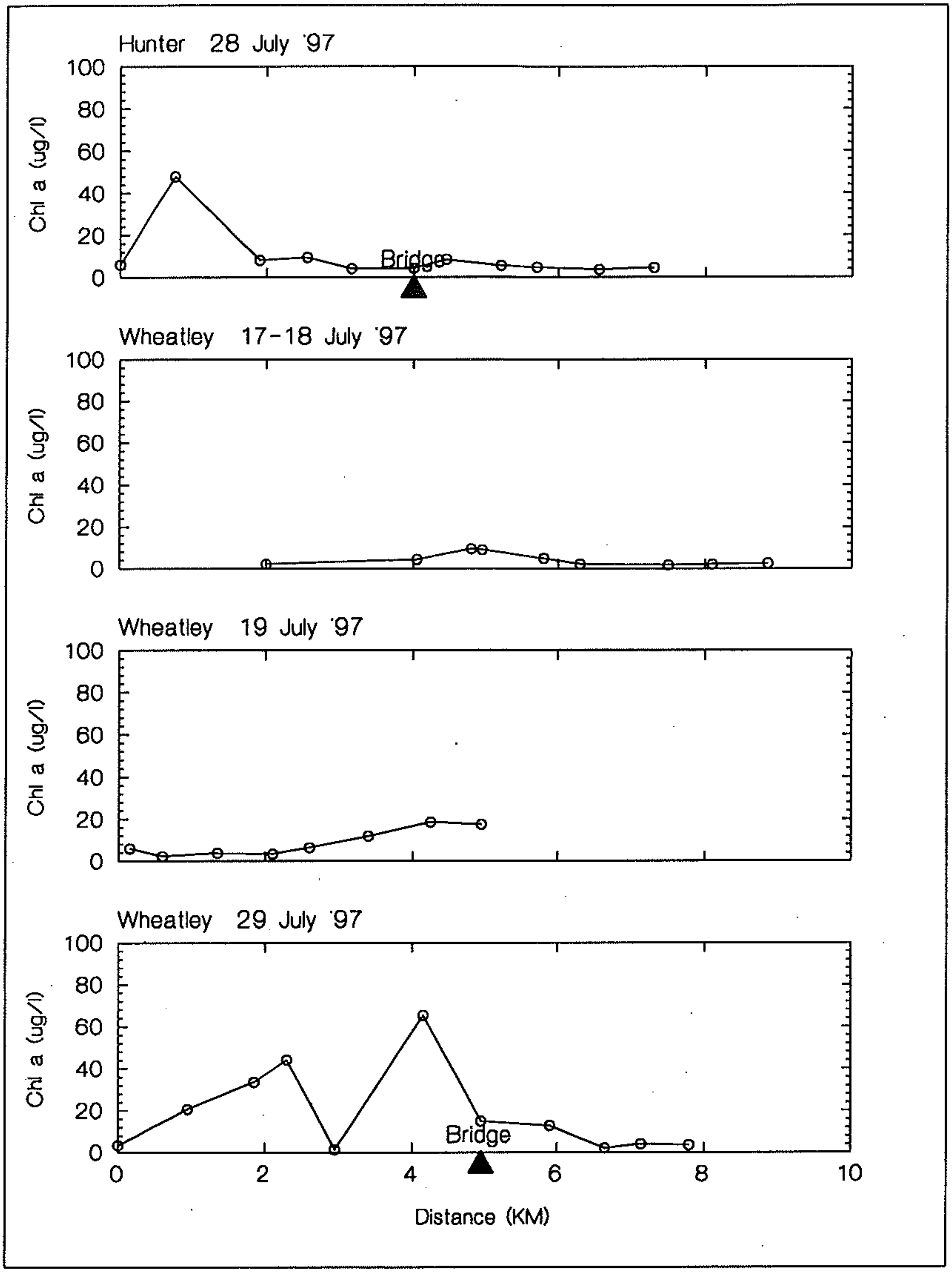

Figure 4.11. Chlorophyll *a* concentrations along each of the Hunter and Wheatley transects.

4.6. Nutrients

The major nutrients responsible for eutrophication and poor water quality of aquatic systems are phosphorus and nitrogen. Phosphorous is considered to be the nutrient most often causing eutrophication of freshwater systems, and nitrogen is considered to be the nutrient most responsible for eutrophication of marine systems. Recent studies, however, have shown that phosphorous may be more important than previously thought in causing eutrophication of marine systems (Howarth 1988). Levels of phosphorous and nitrogen above about 100 μg/l and 1.0 mg/l respectively are considered to be in the range of concentrations that may lead to eutrophication of marine systems.

Both phosphorous and nitrogen can occur in numerous chemical forms. This is particularly true of nitrogen and in this study it was measured as total nitrogen, nitrate and ammonium. Phosphorous was measured as total phosphorous only. Table 4.2 lists the nutrient concentrations found at each station of the water quality transects and Figures 4.12 - 4.15 illustrate the trends in concentration along each transect.

Total phosphorus concentrations were very high in most parts of both estuaries with values often exceeding 100 μg/l. Within the Wheatley estuary concentrations sometimes exceeded 200 μg/l. In both estuaries there was a trend of decreasing total phosphorus concentration toward the mouth of the Bay.

Total nitrogen, nitrate and ammonium concentrations showed the same general trends as that of total phosphorus being highest in the upper reaches of the estuaries and decreasing toward the mouth of the Bay. Nitrogen values were exceptionally high within the upper parts of the Wheatley estuary.

In an attempt to determine whether the estuary was acting conservatively, or as a source or sink, with regard to phosphorus and nitrogen, micronutrient concentration-salinity plots were made for each nutrient. Figure 4.16 illustrates the idealized nutrient-salinity relationships expected under each behaviour when high nutrient river water is mixed with low nutrient sea water. Figure 4.17 illustrates the relationship observed for total nitrogen and total phosphorus for each estuary. Within the entire Hunter estuary and the lower part of the Wheatley estuary, both nitrogen and phosphorus concentrations appear to behave conservatively and be subject to dilution by sea water. The relationship in the upper parts of the Wheatley estuary, however, is much less clear and suggests the nutrient concentrations are controlled by factors other than dilution.

4.7. Benthic Nutrient Flux

The results of measurements of benthic nutrient flux during each Sea Carousel deployment are listed in Table 4.3 along with the erosion threshold for each station. The nutrient flux data are also presented graphically in Figure 4.18 and indicate that the level of nutrient resuspension observed was quite high at some stations. The amount of

Table 4.2. Nutrient concentrations at each station of the water quality transects.

Site	Transect	Station #	Date	Time	Total Nitrogen (mg/l)	Nitrate (mg/l)	Ammonium (ug/l)	Total Phosphorous (ug/l)
Hunter	A	1	280797	11.33	0.7	0.2	0.1	96
Hunter	A	2	280797	11.58	1.6	0.2	0.4	182
Hunter	A	3	280797	12.08	0.5	0.022	0.1	109
Hunter	A	4	280797	12.42	0.8	0.1	0.3	130
Hunter	A	5	280797	12.58	0.6	0.008	0.2	97
Hunter	A	6	280797	12.83	0.6	0.008	0.2	91
Hunter	A	7	280797	13.66	0.7	0.1	0.3	100
Hunter	A	8	280797	13.90	0.5	0.015	0.2	85
Hunter	A	9	280797	15.08	0.6	0.02	0.2	82
Hunter	A	10	280797	14.25	0.4	0.002	0.1	63
Hunter	A	11	280797	14.58	0.7	0.054	0.1	93
Wheatley	A	1	170797	13.50	1.3	1.1	0.1	55
Wheatley	A	2	170797	13.72	2.3	0.1	0.8	222
Wheatley	A	3	170797	14.12	1.6	0.3	0.5	144
Wheatley	A	4	170797	14.33	1.0	0.1	0.3	98
Wheatley	A	5	180797	15.23	0.9	0.1	0.3	126
Wheatley	A	6	180797	15.57	0.6	0.1	0.2	79
Wheatley	A	7	180797	15.75	1.6	0.1	0.1	224
Wheatley	A	8	180797	16.00	0.5	0.03	0.2	78
Wheatley	A	9	180797	16.20	0.5	0.014	0.2	77
Wheatley	A	10	180797	16.47	1.5	0.1	0.1	257
Wheatley	B	1	190797	13.75	1.6	1.2	0.1	118
Wheatley	B	2	190797	14.00	1.4	1.0	0.2	101
Wheatley	B	3	190797	14.50	1.4	1.0	0.2	77
Wheatley	B	4	190797	14.93	1.7	1.0	0.3	131
Wheatley	B	5	190797	15.25	1.3	0.032	0.2	139
Wheatley	B	6	190797	15.48	1.7	0.1	0.6	136
Wheatley	B	7	190797	15.67	1.9	0.1	0.4	127
Wheatley	B	8	190797	15.70	1.2	0.1	0.4	110
Wheatley	C	0	290997	16.30	2.4	2.3	0.1	64
Wheatley	C	1	290997	11.50	1.5	1.0	0.2	80
Wheatley	C	2	290997	11.92	1.4	0.7	0.3	97
Wheatley	C	3	290997	12.25	2.6	0.4	1.0	152
Wheatley	C	4	290997	12.50	1.9	0.2	0.6	151
Wheatley	C	5	290997	12.80	2.0	0.1	0.6	127
Wheatley	C	6	290997	12.07	1.6	0.02	0.4	122
Wheatley	C	7	290997	14.75	0.9	0.016	0.3	104
Wheatley	C	8	290997	15.05	0.7	0.02	0.2	93
Wheatley	C	9	290997	15.20	0.7	0.018	0.1	84
Wheatley	C	10	290997	15.42	0.8	0.012	0.1	86
Wheatley	C	11	290997	15.55	0.5	0.006	0.2	77
Wheatley	C	12	290997	15.73	0.4	0.004	0.1	71

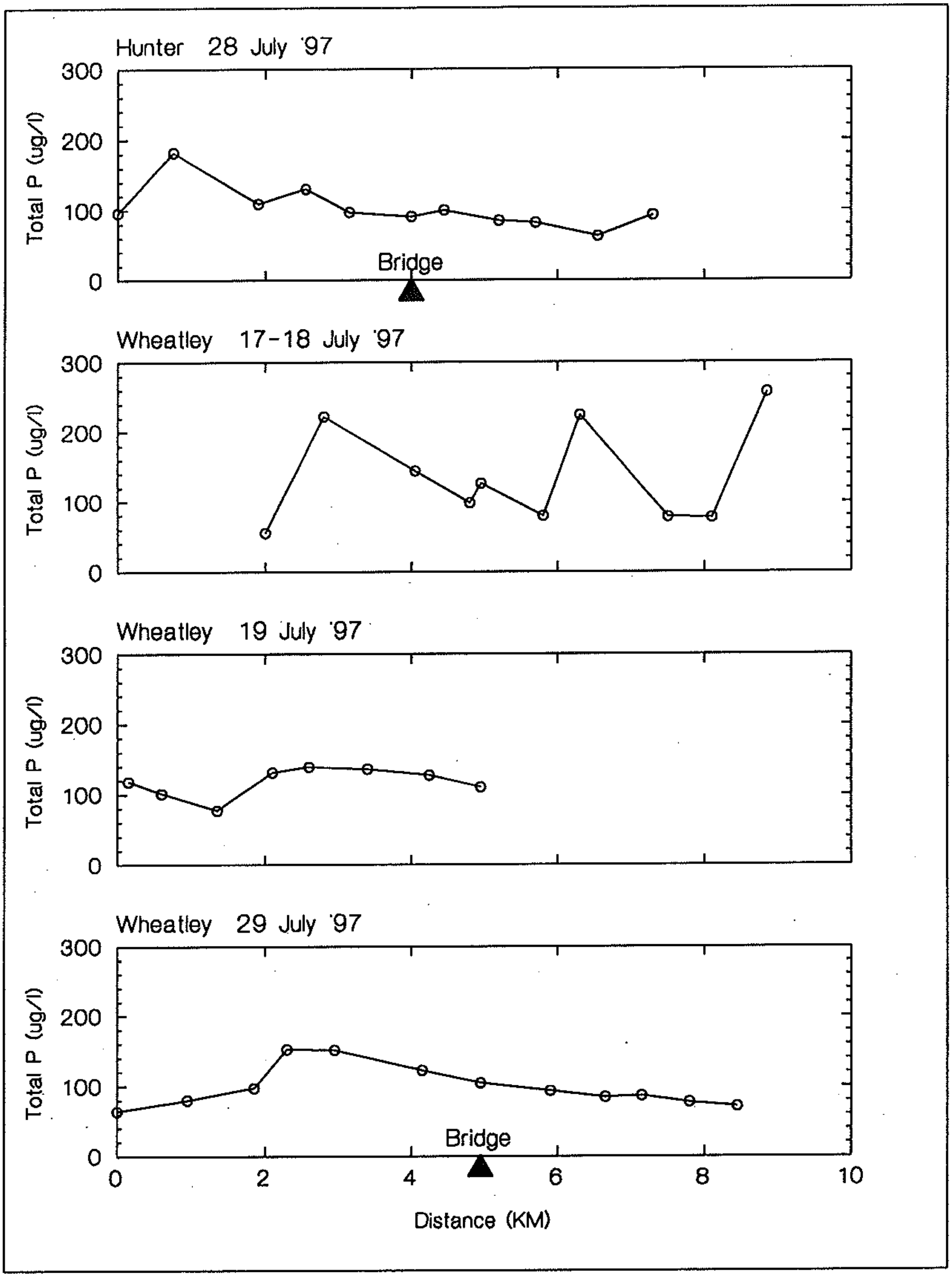

Figure 4.12. Total phosphorus concentrations along each of the Hunter and Wheatley transects.

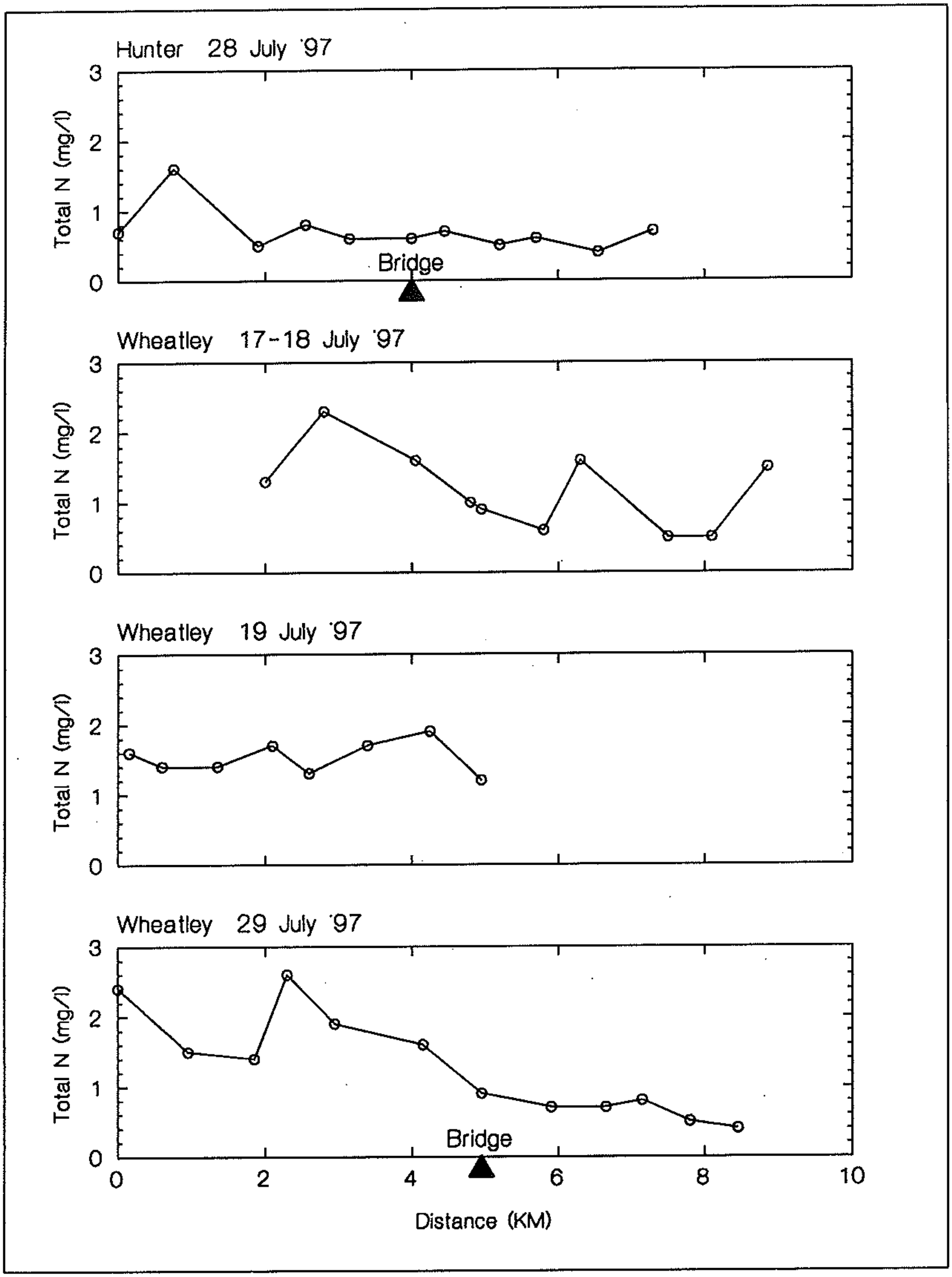

Figure 4.13. Total nitrogen concentrations along each of the Hunter and Wheatley transects.

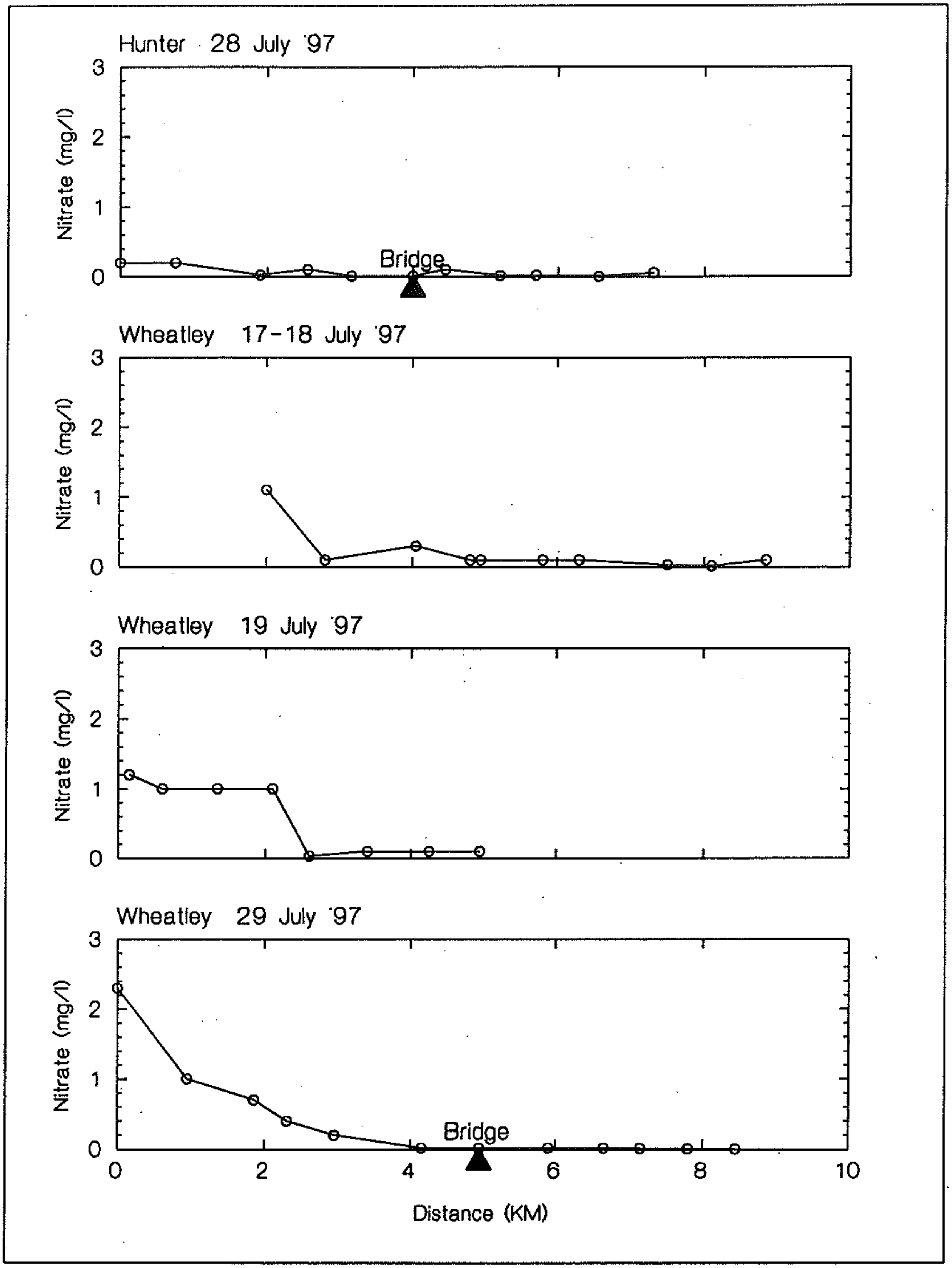

Figure 4.14. Nitrate concentrations along each of the Hunter and Wheatley transects.

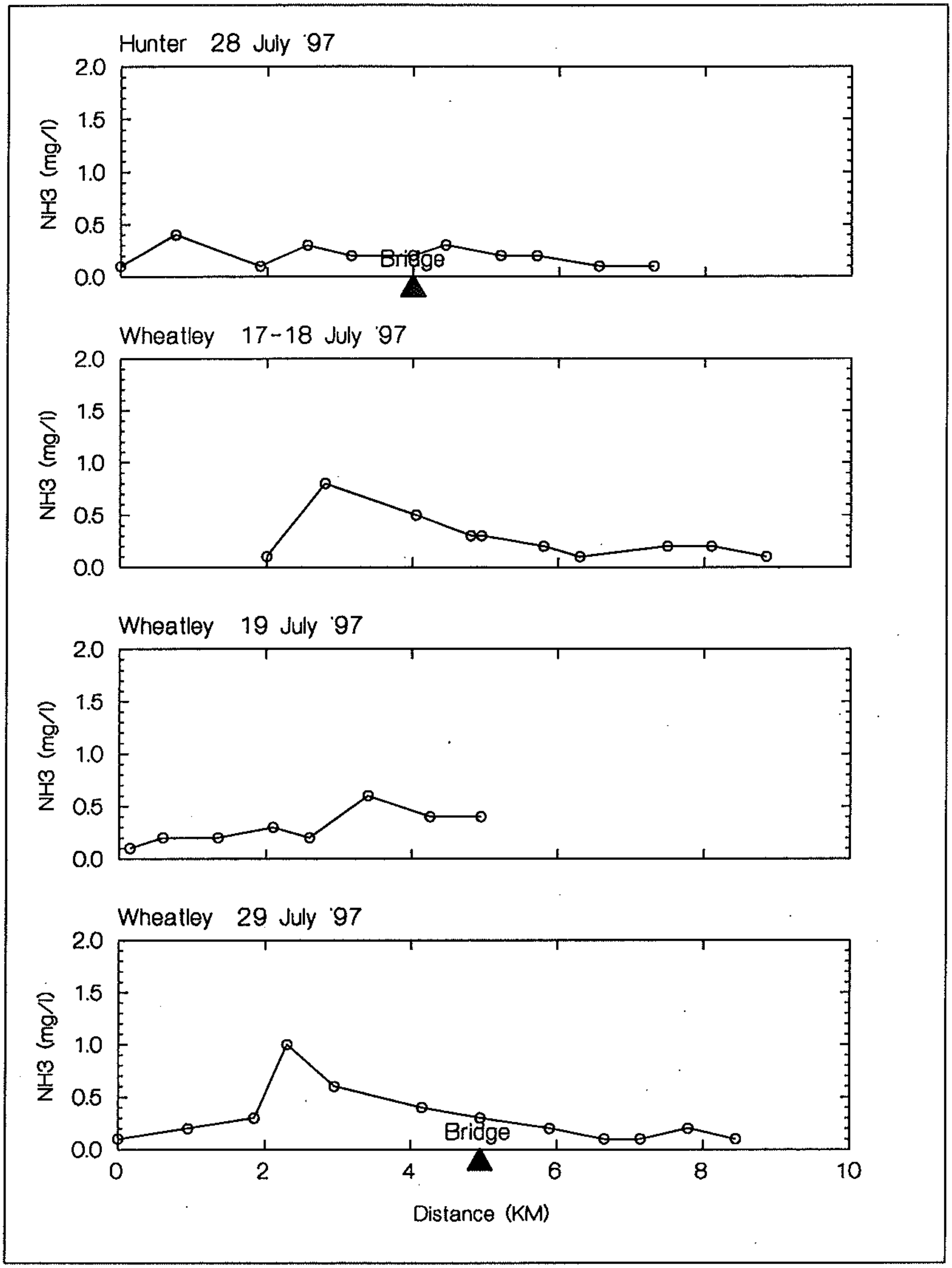

Figure 4.15. Ammonium concentrations along each of the Hunter and Wheatley transects.

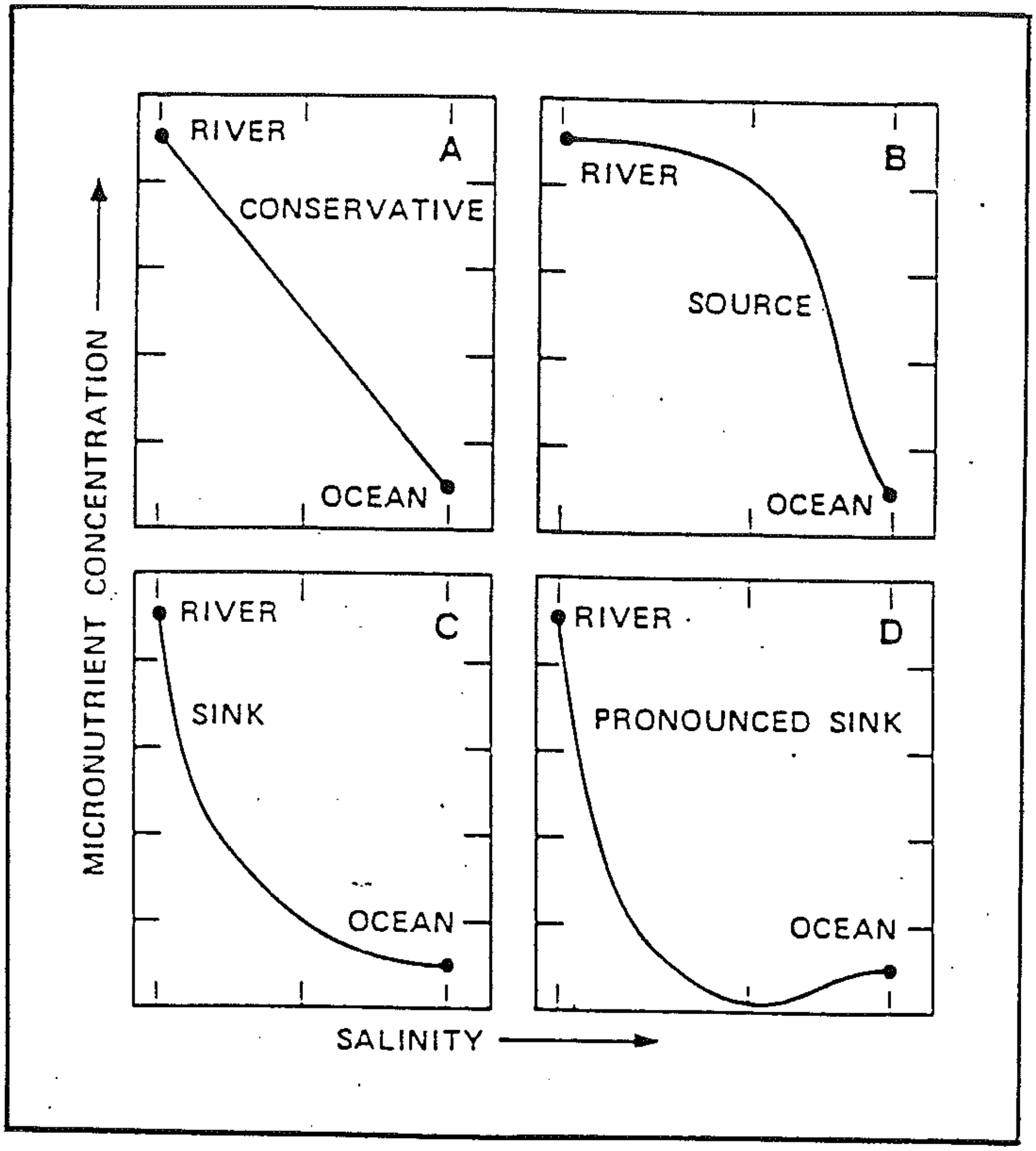

Figure 4.16. Idealized micronutrient-salinity relations for estuaries that behave (A) conservatively, (B) as a source of nutrients, (C) as a sink for nutrients and (D) as a pronounced sink for nutrients (after Peterson et al. 1975).

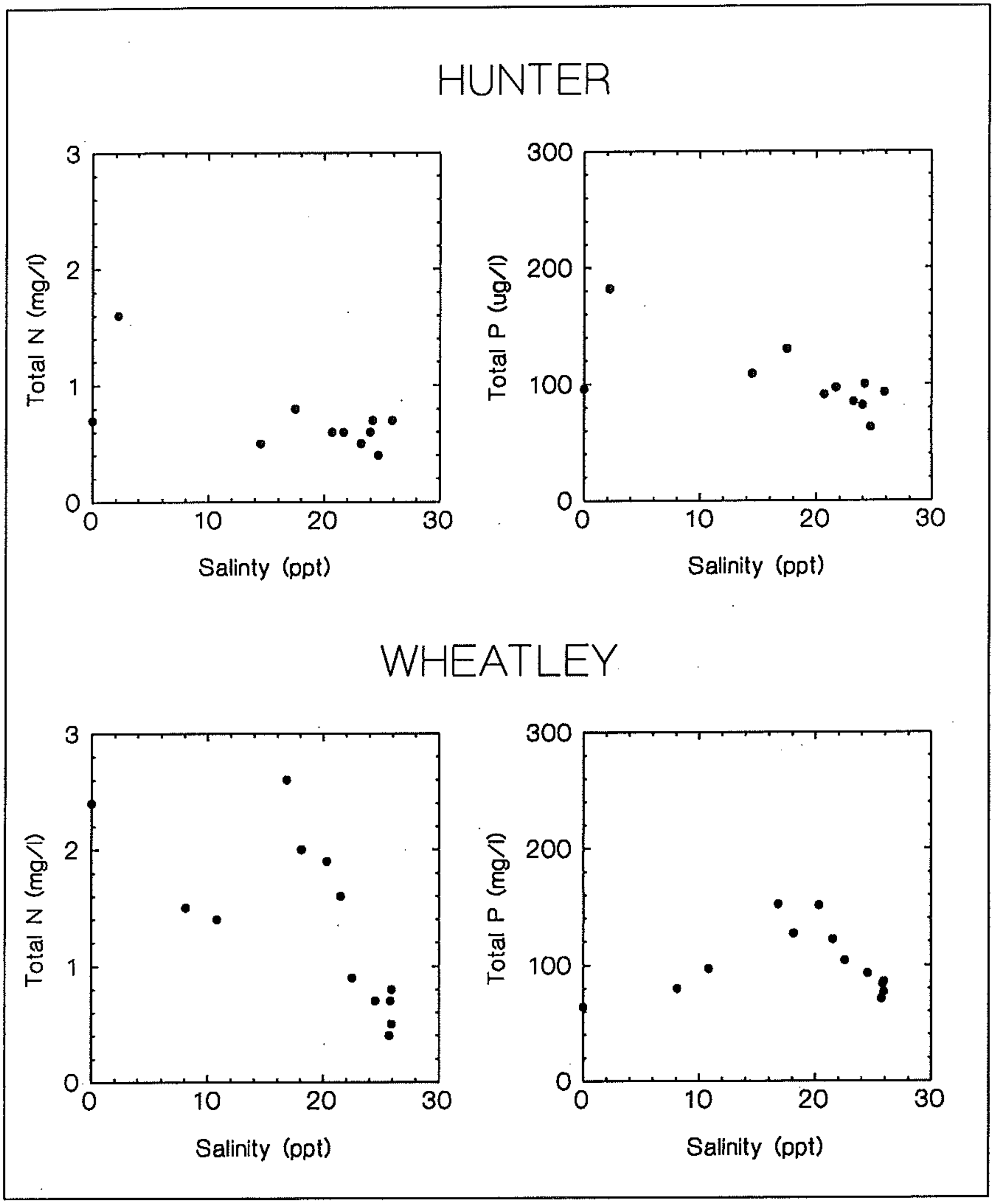

Figure 4.17. Micronutrient-salinity relationships for the Hunter and Wheatley transects.

Table 4.3. Benthic nutrient flux and erosion threshold at each Sea Carousel station.

Site	Station #	Erosion Threshold (Pa)	Total Nitrogen (mg/l)	Ammonium (mg/l)	Nitrate (mg/l)	Total Phosphorous (ug/l)
Hunter	1	0.11	2.70	0.10	0.25	703
Hunter	8	0.51	0.65	0.10	0.08	61
Hunter	10	0.26	1.45	0.15	0.10	319
Hunter	12	0.17	2.40	0.15	0.25	649
Hunter	13	0.40	1.00	0.10	0.05	244
Hunter	14	0.15	1.45	0.10	0.10	407
Hunter	15	0.79	0.50	0.10	0.04	180
Wheatley	2	0.11	4.85	0.10	0.65	628
Wheatley	3	0.21	2.00	0.10	0.15	890
Wheatley	4	0.26	2.25	0.10	0.20	546
Wheatley	5	0.14	2.00	0.10	0.30	623
Wheatley	6	0.22	2.20	0.10	0.10	586
Wheatley	7	0.41	1.50	0.10	0.15	403
Wheatley	9	0.62	0.18	0.15	0.01	38
Wheatley	11	0.17	3.20	0.10	0.20	619

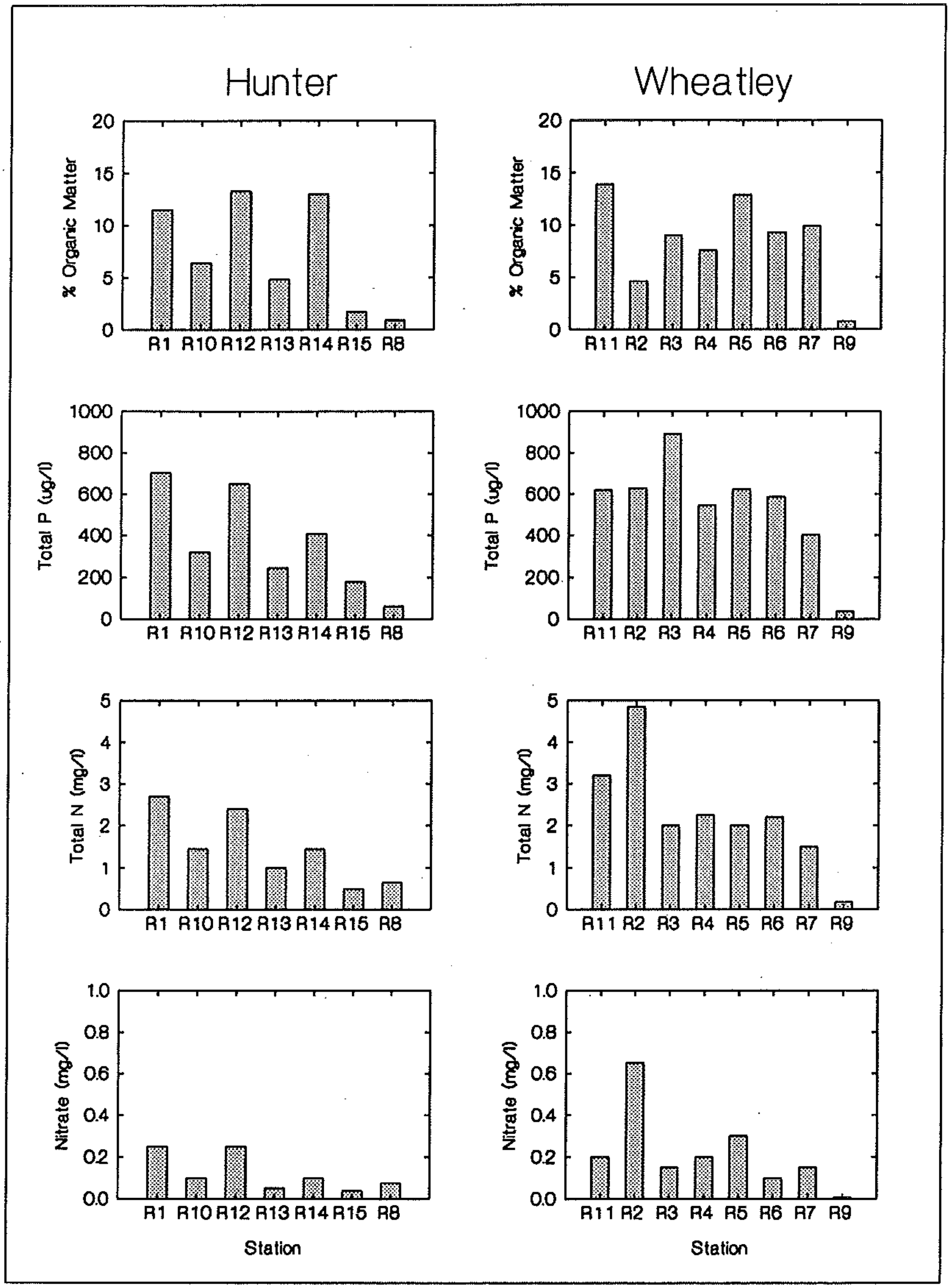

Figure 4.18. Sediment organic content and benthic nutrient flux at each Sea Carousel station.

nutrient resuspended is strongly correlated with the erosion threshold which is in turn strongly related to sediment organic content (Figure 4.19). These relationships indicate that the sediments most susceptible to erosion are also those containing the highest levels of nutrients.

Evaluation of the potential for nutrients contained within sediments to be resuspended as a result of the proposed remediation alternatives, and therefore contribute to potential eutrophication problems, was carried out by comparing the bed shear stresses predicted by the sedimentological model (Amos et al. 1998) to the erosion thresholds measured by the Sea Carousel deployments. None of the proposed remediation alternatives examined are expected to result in erosion thresholds above that required to resuspend nutrients in those areas where sediment and nutrient contents are great. It is therefore unlikely that water quality will be affected by resuspension of sediment organics and nutrients for any of the proposed remediation alternatives.

4.8 Flushing Times

The only remediation option that would result in any real change in the tidal prism within the Bay is the Three Phase Proposal (Baird and Associates, 1998). Although some of the other proposed remediation measures may alter water current velocities and directions, it is unlikely that these alterations would have any impact on water quality since there is no evidence that significant stratification, and resulting variations in water quality, exists within the Bay.

Table 4.4 lists the volumes of water in the Hunter and Wheatley estuaries under present conditions and what is predicted after implementation of the Three Phase option. Also listed are the resulting changes in flushing times. In all cases the differences in flushing times are very small and it is unlikely that there would any significant change in water quality as a result of implementing the Three Phase Proposal.

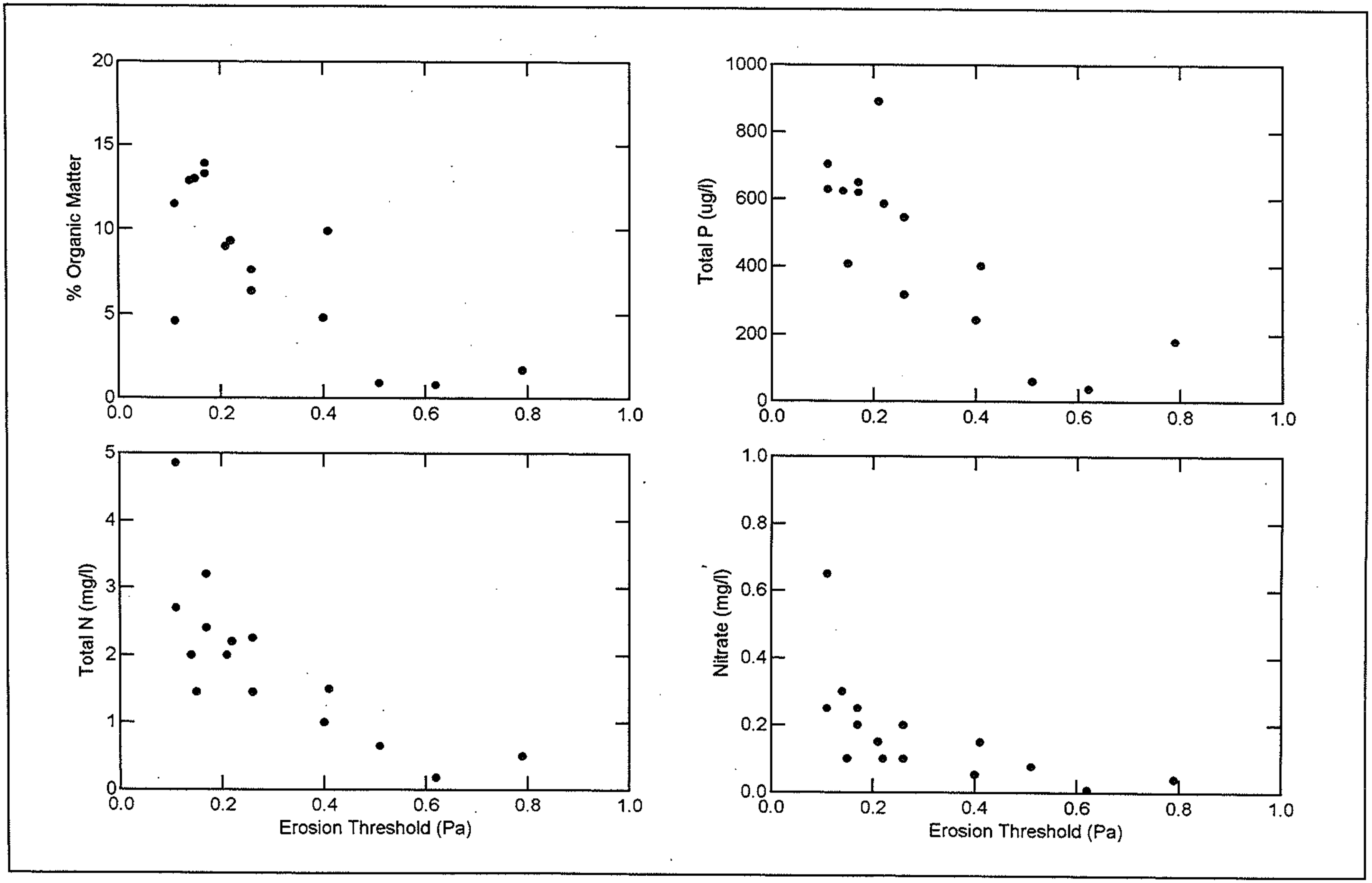

Figure 4.19. Relationship of sediment organic content and sediment nutrient flux to erosion threshold.

Table 4.4. Estuarine volumes, tidal prism volumes and flushing times for existing conditions and for the Three Phase remediation option.

	Low Tide Volume (10^6 m^3)	**High Tide Volume** (10^6 m^3)	**Tidal Prism Volume** (10^6 m^3)	**Flushing Time** (days)
Hunter Estuary:				
Existing	7.24	12.70	5.46	2.26
III Phase Option	7.44	12.99	5.55	2.27
% Change	2.8	2.3	1.6	0.44
Wheatley Estuary:				
Existing	22.07	36.78	14.71	2.38
III Phase Option	22.14	36.74	14.60	2.44
% Change	0.3	- 0.1	- 0.7	2.52

5. Discussion

Water quality in aquatic systems is often classified as being either oligotrophic, mesotrophic or eutrophic. Oligotrophic systems are relatively unproductive and lack either high concentrations of algae or consistently low dissolved oxygen concentrations. Mesotrophic systems are moderately productive and have periodic blooms of algae and may periodically exhibit depressed levels of dissolved oxygen. Eutrophic systems are characterised as having high algal growth and prolonged periods of low dissolved oxygen levels. The present status of the Hunter and Wheatley estuaries can be evaluated according to a recently prepared set of guidelines that have been applied to over 120 North American estuaries by the U.S. National Oceanic and Atmospheric Administration as part of a national estuarine eutrophication survey (NOAA 1997). Table 5.1 presents the guidelines and the corresponding values for the Hunter and Wheatley estuaries for the areas both below and above the bridges at the upper end of Rustico Bay.

According to these criteria, the Wheatley estuary above the Wheatley River Bridge would be considered eutrophic, and the area below mesotrophic. By the same criteria, the Hunter estuary would be classified as mesotrophic both above and below the bridge. This indicates that water quality in the Bay is not presently seriously degraded and that the most serious water quality problems are in the upper portion of the Wheatley River.

There is little evidence to suggest that water quality within the estuary is influenced by the Little Harbour Causeway as a result of a reduction in tidal flushing. The hydrodynamic model simulations indicated that there would be only minor changes in the volume of the tidal prisms, and therefore flushing rates, in either the Hunter or Wheatley estuaries as a result of removal of the Little Harbour Causeway.

There is also little evidence to indicate that either the Wheatley River or Hunter River Bridge Causeways is limiting flushing and thereby reducing water quality in the upper part of the Rivers. Field measurements of tide heights on either side of both bridge causeways revealed that that the phase lag between tide heights on either side of the causeways were very small, on the order of a few minutes at most, indicating that the bridge causeways have little influence on tidal flushing (Williamson 1998).

The differences in water quality between the upper and lower portions of the Wheatley estuary are probably more a result of differences in the types of biological communities present as opposed to differences in flushing characteristics. The upper portion of the estuary is shallow, generally less than one meter in depth. As a result, sufficient light penetrates to the bottom which, when combined with the high nutrient inputs, provides optimum conditions for the growth of macroscopic attached algae, particularly sea lettuce (*Ulva lactuca*), which was observed to be present in very high densities in all of the shallower areas of the estuary. Since these algae are attached to the bottom, they are not subject to being flushed from the estuary and essentially act as nutrient traps. In addition, as the macroscopic algae grow and die they continually increase the organic load of bottom sediments and lower portion of the water column This eventually leads to oxygen depletion and the production of toxic decomposition products.

The biological community of the lower portion of the estuary, where water depth is greater and there is insufficient light for photosynthesis on the bottom, is characterised by planktonic organisms. Planktonic algae are small in size and remain suspended in the water column. As a result, they do not act as nutrient traps since the nutrients they accumulate are subject to being flushed out of the system.

Based on the results of the field studies and model simulations carried out, it appears unlikely that any of the proposed remediation options, including those involving the removal of Little Harbour Causeway, will result in significant changes in water quality in either the Hunter or Wheatley estuaries. Remediation of existing water quality problems in these systems should focus on reduction of nutrient inputs into the rivers.

The present data base on water quality in Rustico Bay is very limited, particularly with respect to seasonal variations, and would not allow a reliable pre and post comparison of water quality to be carried out if this were required. It is therefore recommended that a monitoring program be designed to obtain a more comprehensive data base on water quality in the Hunter and Wheatley estuaries. This monitoring should be carried out prior to, during and after initiation of any of the proposed remediation options. This is necessary not only to validate the conclusions presented in this study, but to ensure that any potential negative impacts, particularly with respect to mussel aquaculture operations, are detected at an early stage. The parameters that should be considered for monitoring include: salinity, temperature, suspended sediment concentrations (both organic and inorganic) and chlorophyll *a*. Periodic measurements of dissolved oxygen and nutrients (phosphorous and nitrogen) should also be considered for inclusion in the monitoring program.

Table 5.1. Some guidelines for assessing nitrogen, phosphorus and chlorophyll *a* concentrations and Secchi Disk depth as they apply to the potential for causing or indicating eutrophication of estuarine systems and corresponding values for the Hunter and Wheatley estuaries.

	LOW (oligotrophic)	MEDIUM (mesotrophic)	HIGH (eutrophic)	Wheatley (above bridge)	Wheatley (below bridge)	Hunter (above bridge)	Hunter (below bridge)
Dissolved Nitrogen (mg/l)	≥ 0 < 0.1	≥ 0.1 < 1.0	≥ 1.0	0.91	0.19	0.33	0.22
Dissolved Phosphorus (μg/l)	≥ 0 < 10	≥ 10 < 100	≥ 100	59	56	61	42
Chlorophyll *a* (μg/l)	< 5	≥ 5 < 20	≥ 20	20	4	15	5
Secchi Disk Depth (m)	≥ 3	≥ 1 < 3	< 1	0.8	1.9	1.9	1.6

Note: The values of dissolved nitrogen for the Hunter and Wheatley estuaries were calculated as the sum of nitrate and ammonia. The values of dissolved phosphorus were calculated on the assumption that they equal to one-half total phosphorus.

6. Conclusions

a. Serious degradation of water quality, as evidenced by low dissolved oxygen levels, within the Rustico Bay system is limited to the area of the Wheatley estuary above the Wheatley River Bridge Causeway,

b. Water quality in the Hunter estuary and the lower portion of the Wheatley estuary is not seriously degraded,

c. Water quality in the Rustico Bay system does not appear to be significantly influenced by the presence of either Little Harbour Causeway or the Hunter and Wheatley River Bridge Causeways,

d. None of the proposed remediation options is expected to result in significant resuspension of existing sediment nutrients and organics and it is unlikely that this would be a major concern in terms of impacting water quality,

e. There is little evidence that any of the proposed remediation options for improving navigation into North Rustico Harbour will have a significant impact on water quality within the Rustico Bay system,

f. Remediation of water quality problems in the Rustico Bay system should focus on developing and implementing land use practices that minimise nutrient inputs to the Hunter and Wheatley Rivers,

g. In order to further validate the conclusions reached, as well as detect any potential impacts that may not have been adequately considered in this study, it is recommended that a water quality monitoring program be designed and carried out prior to, during and after implementation of any of the proposed remediation options.

7. Acknowledgements

distance along the river. Within the Bay, Secchi Disk depths were generally lower in the Hunter than the Wheatley

The competent help of the crew of the Mosey Boy, Neil Gallant, Brent Jarvis and Robert Gallant, is gratefully acknowledged as is the help provided to us by numerous local community members, particularly James Gallant and Ted Gamauf. Tracy Horseman, Jamie Gibson and Graham Daborn of the Acadia Centre for Estuarine Research aided in field work, sample processing and data analyses. The nutrient analyses were carried out by the Water Resources Division of the PEI Department of Fisheries and Environment as an in-kind contribution and we are grateful to Clair Murphy and Bruce Raymond of that Department for their support in arranging for this. They were also helpful in providing weather records and information on hydrology of the Rustico Bay watershed. Richard Gallant and Dale Small of the PEI Department of Fisheries and Environment provided information on shellfish aquaculture activities in Rustico Bay.

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