

## TABLE OF CONTENTS

<b>SUMMARY .....</b>	<b>1</b>
<b>1. INTRODUCTION .....</b>	<b>3</b>
<b>2. THE STUDY AREA .....</b>	<b>5</b>
<b>3. PHYSICAL OCEANOGRAPHY .....</b>	<b>17</b>
<b>4. CONCEPTUAL MODELS OF NUTRIENT POOLS AND FLUXES .....</b>	<b>18</b>
<b>5. METHODS .....</b>	<b>23</b>
5.1 Water Sampling .....	23
5.2 Underwater and Diurnal Light Measurements .....	23
5.3 Zooplankton Sampling .....	23
5.4 Nutrient Subsampling .....	24
5.5 River Sampling .....	24
5.6 Rainwater Sampling .....	25
5.7 Analytical Procedures .....	25
5.8 Primary Production Measurements .....	26
5.9 Frequency and Magnitude of Intrusive Activity off Cairns .....	27
5.10 Sediment Trap Sampling .....	30
5.11 Moored Traps .....	34
5.12 Drifter Traps .....	36
5.13 Carbon and Nitrogen Analyses of Trapped Materials .....	36
5.14 Phosphorus Analyses of Trapped Materials .....	37
<b>6. NUTRIENT STOCKS .....</b>	<b>40</b>
<b>7. TEMPORAL AND SPATIAL VARIABILITY OF NUTRIENT SPECIES     IN THE CAIRNS AND TULLY BOXES .....</b>	<b>60</b>
<b>8. RIVER INPUTS OF NUTRIENTS .....</b>	<b>71</b>
8.1 Longitudinal Variations of Nutrient Concentrations within Catchments .....	80
8.1.1 Herbert River .....	80
8.1.2 Tully River .....	86
8.2 Inter-River Comparisons .....	87
8.3 Estuarine Processes .....	87
8.4 Riverine Nitrogen and Phosphorus Exports to Coastal Waters .....	98
<b>9. RAINFALL INPUTS OF NUTRIENTS .....</b>	<b>100</b>
<b>10. INTRUSIONS FROM THE CORAL SEA .....</b>	<b>107</b>
<b>11. NITROGEN FIXATION BY <i>TRICHODESMIUM</i> .....</b>	<b>114</b>
<b>12. ATMOSPHERIC NITROGEN FIXATION BY REEF COMMUNITIES .....</b>	<b>116</b>
<b>13. SEDIMENTATION OF PARTICULATE MATERIALS AND     NUTRIENTS .....</b>	<b>118</b>
13.1 Moored Traps .....	118

13.2 Lagrangian Drifting Traps.....	127
<b>14. BENTHIC NUTRIENT FLUXES.....</b>	<b>142</b>
<b>15. PHYTOPLANKTON NUTRIENT DEMAND.....</b>	<b>146</b>
<b>16. WATER COLUMN NUTRIENT MINERALIZATION BY ZOOPLANKTON AND MICROBIAL POPULATIONS.....</b>	<b>149</b>
16.1 Macro- and Microzooplankton .....	149
<b>17. MICROBIAL MINERALIZATION.....</b>	<b>155</b>
<b>18. BUDGET SYNTHESIS AND DISCUSSION .....</b>	<b>158</b>
<b>19. THE BALANCE BETWEEN UPTAKE DEMAND AND SOURCES OF NITROGEN AND PHOSPHORUS .....</b>	<b>178</b>
<b>20. SUMMATION .....</b>	<b>179</b>
<b>ACKNOWLEDGEMENTS.....</b>	<b>182</b>
<b>REFERENCES.....</b>	<b>183</b>

## **TABLES**

1. Shelf areas and volumes of water between isobaths on the central Great Barrier Reef shelf .....	7
2. Areas of reefs in the study area and the estimated area of reef flat .....	10
3. Mean annual discharges and ranges for rivers flowing into the Cairns and Tully boxes.....	13
4. Acronyms and symbols for nutrient species used in this report.....	18
5. Summary statistics for dissolved and particulate water column nutrient concentrations in the Cairns box for the summer (October - April) season.....	41
6. Summary statistics for dissolved and particulate water column nutrient concentrations in the Cairns box for the winter (May - September) season .....	42
7. Summary statistics for dissolved and particulate water column nutrient concentrations in the Tully box for the summer (October - April) season .....	43
8. Summary statistics for dissolved and particulate water column nutrient concentrations in the Tully box for the winter (May - September) season.....	44
9. Distribution of shelf nutrient stocks within long-shelf depth bands in the Cairns box during summer (October - April).....	51
10. Distribution of shelf nutrient stocks within long-shelf depth bands in the Cairns box during winter (May - September) .....	52

11.	Distribution of shelf nutrient stocks within long-shelf depth bands in the Tully box during summer (October - April) .....	53
12.	Distribution of shelf nutrient stocks within long-shelf depth bands in the Tully box during winter (May - September) .....	54
13.	Calculated stocks of nutrients per metre of coastline within the Cairns box during summer.....	55
14.	Calculated stocks of nutrients per metre of coastline within the Cairns box during winter .....	55
15.	Calculated stocks of nutrients per metre of coastline within the Tully box during summer.....	56
16.	Calculated stocks of nutrients per metre of coastline within the Tully box during winter .....	56
17.	Locations of longshore transect stations between Cape Tribulation and Green Island .....	60
18.	Overall station means and standard errors for water column variables measured at transect stations between Cape Tribulation and Cape Grafton .....	68
19.	Summary of ANOVAs for significance of variability related to cruises and stations on the transect between Cape Tribulation and Green Island .....	69
20.	River sampling sites, sampling frequencies and analyses carried out .....	71
21.	Summary statistics for concentrations of dissolved nutrients and particulate matter measured contemporaneously at three sites in the Herbert River.....	86
22.	Summary statistics for four water quality constituents sampled contemporaneously in eight north Queensland rivers between 1989 and 1991 .....	87
23.	Estimated nitrogen and phosphorus inputs from gauged rivers discharging into the Cairns and Tully boxes.....	99
24.	Dissolved nutrients in rainfall collected at sites throughout the GBR and western Coral Sea .....	106
25.	Empirical relationships derived for estimating volumes of Subtropical Lower Water and stocks of nitrate and phosphate intruded onto the shelf in the Cairns and Tully boxes from measured near-bottom shelfbreak water temperatures .....	109
26.	Estimates of gross and net nitrogen and phosphorus inputs to outer-shelf waters of the Cairns and Tully boxes from intrusions during the summers of 1989-90, 1990-91 and 1991-92 .....	113
27.	Preliminary estimates of nitrogen fixation by <i>Trichodesmium</i> in the Cairns and Tully boxes.....	115

28.	Mean daily deposition rates of carbon, nitrogen and phosphorus on a cross-shelf transect seaward of the Family Islands .....	123
29.	Estimated annual organic nutrient sedimentation rates in the Cairns and Tully boxes.....	141
30.	Daily benthic nutrient excretion rates used to estimate benthic nutrient recycling.....	142
31.	Estimated annual shelf-scale benthic nutrient fluxes for the Cairns and Tully boxes.....	143
32.	Water column primary production rates off Cairns during November-December 1990.....	148
33.	Summary statistics for depth-averaged zooplankton biomass in the Cairns and Tully boxes .....	150
34.	Summary statistics for areal zooplankton standing crop in the Cairns and Tully boxes.....	151
35.	Estimates of water column nitrogen and phosphorus mineralization by macro- and microzooplankton in the Cairns box .....	153
36.	Estimates of water column nitrogen and phosphorus mineralization by macro- and microzooplankton in the Tully box .....	154
37.	Estimates of water column nitrogen mineralization by heterotrophic microbes in the Cairns and Tully boxes.....	155
38.	Estimates of mean seasonal replacement times (days) for water column stocks of ammonium, DIN, DON and PON in the Cairns and Tully boxes based on <i>in situ</i> mineralization rates of Hopkinson et al. (1987) .....	157
39.	Calculated water column stocks of biogeochemically active nitrogen and phosphorus in the Cairns and Tully boxes and estimated annual fluxes of nitrogen and phosphorus through major sources and sinks and within major water column recycling pools.....	161

## FIGURES

1.	The central Great Barrier Reef and the shelf boxes covered for budgeting purposes .....	6
2.	Top: Reef area < 2 m deep estimated from satellite imagery in relation to total reef area for 209 reefs throughout the GBR. Middle: Area of reefs classified as hard substrate < 2 m deep in relation to total classified reef area. Bottom: Area of reefs classified as sand < 5 m deep in relation to total classified reef area.....	8
3.	Top: The proportion of reef area classified as hard substrate < 2 m deep in relation to total classified reef area. Bottom: The proportion of reef area classified as sand < 5 m deep in relation to total classified reef area.....	9

4.	Locations of hydrographic stations used to develop the nutrient budget.....	11
5.	Locations of transect stations in the Cairns box resampled ten times between February 1989 and July 1991 .....	12
6.	Major rivers discharging into or adjacent to the Cairns and Tully boxes.....	14
7.	Top: Zones (shaded boxes) where free-drifting sediment traps were deployed in the Cairns box between May 1990 and July 1991. Bottom: Transect sites off the Family Islands where moored sediment traps were deployed between September 1988 and August 1989.....	15
8.	Location of stations where water column primary production measurements were made between January 1983 and December 1990 .....	16
9.	Schematic depiction of the water column nitrogen budget.....	19
10.	Schematic depiction of the water column phosphorus budget.....	20
11.	Carbon and nitrogen as a percentage of dry weight for zooplankton samples net collected in the Great Barrier Reef between 1983 and 1992.....	22
12.	Bottom: Cross-shelf section through a cold-water intrusion into Palm Passage during January 1983. Top: The same intrusion event masked with the bathymetry down the central axis of Grafton Passage .....	28
13.	Temperature-salinity plots for water masses in Palm Passage on three occasions during the summer of 1983 .....	29
14.	Representative seasonal temperature-salinity relationships from a station in the East Australian Current, immediately seaward of Palm Passage .....	31
15.	Mean cross-shelf bathymetric profiles for the Cairns and Tully boxes in comparison to the cross-shelf bathymetry down the central axis of Palm Passage.....	32
16.	Temperature-inorganic nutrient relationships from stations in the East Australian Current during 1983.....	33
17.	Moored sediment trap array used to collect sedimenting carbon, nitrogen and phosphorus in the Cairns and Tully boxes.....	35
18.	Free-drifting sediment trap array used to collect sedimenting carbon, nitrogen and phosphorus in the Cairns box .....	38
19.	Comparisons between calculated sedimentation fluxes of particulate carbon, nitrogen and phosphorus using drifting and moored sediment traps in simultaneous deployments at the same site.....	39
20.	Cross-shelf gradients and seasonal changes in depth-weighted mean water column concentrations of ammonium, nitrite and nitrate in the Cairns and Tully boxes .....	45
21.	Cross-shelf gradients and seasonal changes in depth-weighted mean water column concentrations of DON, PN and silicate in the Cairns and Tully Boxes .....	46

22.	Cross-shelf gradients and seasonal changes in depth-weighted mean water column concentrations of phosphate, DOP and PP in the Cairns and Tully Boxes....	47
23.	Cross-shelf gradients and seasonal changes in depth-weighted mean water column concentrations of chlorophyll <i>a</i> , phaeophytin and suspended solids in the Cairns and Tully boxes .....	48
24.	Relationships between depth-weighted mean water column stocks of PN and PP and stocks of chlorophyll <i>a</i> in waters of the Cairns and Tully boxes.....	57
25.	Relationships between depth-weighted mean water column stocks of PN and PP and stocks of suspended solids in waters of the Cairns and Tully boxes .....	58
26.	Relationships between depth-weighted mean water column stocks of PN and PP in the Cairns and Tully boxes.....	59
27.	Depth-weighted mean water column concentrations of ammonium and nitrite along a transect between Cape Tribulation and Green Island, sampled ten times between February 1989 and July 1991 .....	62
28.	Depth-weighted mean water column concentrations of nitrate and dissolved organic nitrogen along a transect between Cape Tribulation and Green Island, sampled ten times between February 1989 and July 1991.....	63
29.	Depth-weighted mean water column concentrations of phosphate and dissolved organic phosphorus along a transect between Cape Tribulation and Green Island, sampled ten times between February 1989 and July 1991.....	64
30.	Depth-weighted mean water column concentrations of particulate nitrogen and particulate phosphorus along a transect between Cape Tribulation and Green Island, sampled ten times between February 1989 and July 1991 .....	65
31.	Depth-weighted mean water column concentrations of silicate and suspended solids along a transect between Cape Tribulation and Green Island, sampled ten times between February 1989 and July 1991 .....	66
32.	Depth-weighted mean water column concentrations of chlorophyll and phaeophytin along a transect between Cape Tribulation and Green Island, sampled ten times between February 1989 and July 1991 .....	67
33.	Cruise means for depth-weighted mean water column concentration of nitrogen species, phosphorus species and silicate and pigments on the 11 station Cairns box transect .....	70
34.	Temporal changes in concentrations of dissolved inorganic nitrogen, dissolved organic nitrogen and particulate nitrogen in the lower South Johnstone River during 1990 and 1991 in relation to the temporal pattern of discharge at South Johnstone.....	73
35.	Temporal changes in concentrations of dissolved inorganic phosphorus, dissolved organic phosphorus and particulate phosphorus in the lower South Johnstone River during 1990 and 1991 and their relation to discharge measured at South Johnstone.....	74

36.	Scatter plots showing relationships between measured water column concentrations of individual nutrient species and the contemporaneous discharge rate of the South Johnstone River as measured at South Johnstone .....	75
37.	Temporal changes in concentrations of dissolved silicate in the lower South Johnstone River during 1990 and 1991 and their relation to discharge measured at South Johnstone.....	76
38.	Top: Relative contributions of dissolved and particulate nitrogen species to total water-borne nitrogen concentrations and fluxes in the South Johnstone River. Middle: Cumulative export of dissolved and particulate nitrogen from the South Johnstone River. Bottom: Cumulative export of total nitrogen from the South Johnstone River in relation to discharge measured at South Johnstone .....	78
39.	Top: Relative contributions of dissolved and particulate phosphorus species to total water-borne phosphorus concentrations and fluxes in the South Johnstone River. Middle: Cumulative export of dissolved and particulate phosphorus from the South Johnstone River. Bottom: Cumulative export of total phosphorus from the South Johnstone River in relation to discharge measured at South Johnstone.....	79
40.	Temporal and longitudinal changes in concentrations of water-borne dissolved and particulate nitrogen in the Herbert River (1990-1992).....	81
41.	Temporal and longitudinal changes in concentrations of water-borne dissolved and particulate phosphorus in the Herbert River (1990-1992).....	82
42.	Temporal and longitudinal changes in concentrations of water-borne chlorophyll, dissolved silicate and suspended solids in the Herbert River (1990-1992) .....	83
43.	Functional relationships between particulate nitrogen, particulate phosphorus and suspended solids concentrations at three sites in the Herbert River.....	85
44.	Temporal and longitudinal changes in concentrations of water-borne nitrogen in relation to daily flow in the Tully River (1988-1992) at sites near the Koombooloomba Dam and the Bruce Highway bridge.....	89
45.	Temporal and longitudinal changes in concentrations of water-borne phosphorus in relation to daily flow in the Tully River (1988-1992) at sites near the Koombooloomba Dam and the Bruce Highway bridge.....	90
46.	Concentrations of particulate phosphorus measured contemporaneously at lower catchment sites under low-flow conditions in eight north Queensland rivers between 1989 and 1992 .....	91
47.	Concentrations of phosphate measured contemporaneously at lower catchment sites under low-flow conditions in eight north Queensland rivers between 1989 and 1992 .....	92
48.	Concentrations of nitrate measured contemporaneously at lower catchment sites under low-flow conditions in eight north Queensland rivers between 1989 and 1992.....	93

49.	Concentrations of suspended solids measured contemporaneously at lower catchment sites under low-flow conditions in eight north Queensland rivers between 1989 and 1992 .....	94
50.	Longitudinal, cross-axial and vertical variability in total dissolved nitrogen and total dissolved phosphorus concentrations in the estuarine section of the Murray River .....	95
51.	Longitudinal, cross-axial and vertical variability in nitrate and phosphate concentrations in the estuarine section of the Murray River.....	96
52.	Longitudinal, cross-axial and vertical variability in ammonium and silicate concentrations in the estuarine section of the Murray River.....	97
53.	Mean monthly rainfall measured at Green Island (1949-1990) and Fitzroy Island (1962-1990).....	101
54.	Frequency distributions of measured ammonium and silicate concentrations in rainwater collected at AIMS and in the western Coral Sea (GBR included) .....	102
55.	Frequency distributions of measured nitrate and nitrite concentrations in rainwater collected at AIMS and in the western Coral Sea (GBR included) .....	103
56.	Frequency distributions of dissolved inorganic nitrogen and phosphate concentrations in rainwater collected at AIMS and in the western Coral Sea (GBR included) .....	104
57.	Frequency distribution of DIN/DIP ratios in rainwater collected at AIMS and in the western Coral Sea (GBR included) .....	105
58.	Calculated volumes of undiluted Subtropical Lower Water per linear metre of shelf in the Cairns and Tully boxes in relation to (Top) calculated bottom water temperature at 58 m near Euston Reef and (Bottom) the calculated near-surface to bottom temperature difference at the shelfbreak near Euston Reef. ....	108
59.	Calculated volumes percentages of undiluted Subtropical Lower Water per linear metre of shelf in the Cairns and Tully boxes in relation to (Top) calculated bottom water temperature at 58 m near Euston Reef and (Bottom) the calculated near-surface to bottom temperature difference at the shelfbreak near Euston Reef. ....	109
60.	Calculated net charges in nitrogen (Top) and phosphorus (Bottom) stocks per linear metre of shelf in the Cairns and Tully boxes in relation to calculated shelfbreak bottom water temperatures near Euston Reef.....	111
61.	Near-bottom shelfbreak water temperatures recorded near Euston Reef (58 m depth) near the seaward end of Grafton Passage .....	112
62.	Near-bottom shelfbreak water temperatures recorded near Norman Reef (58 m depth) near the seaward end of Trinity Opening .....	112
63.	Seasonal and day-to-day variability in gross sedimentation measured with moored sediment traps on a cross-shelf transect seaward of the Family Islands .....	119



64.	Seasonal and day-to-day variability in gross organic carbon sedimentation measured with moored sediment traps on a cross-shelf transect seaward of the Family Islands.....	120
65.	Seasonal and day-to-day variability in gross organic nitrogen sedimentation measured with moored sediment traps on a cross-shelf transect seaward of the Family Islands.....	121
66.	Seasonal and day-to-day variability in gross particulate phosphorus sedimentation measured with moored sediment traps on a cross-shelf transect seaward of the Family Islands.....	122
67.	Seasonal and day-to-day variability in the percentage of the integrated water column stock of particulate nitrogen collected by moored sediment traps deployed on a cross-shelf transect seaward of the Family Islands .....	125
68.	Seasonal and day-to-day variability in the percentage of the integrated water column stock of particulate phosphorus collected by moored sediment traps deployed on a cross-shelf transect seaward of the Family Islands .....	126
69.	N/P ratios (atoms) of particulate material collected by moored sediment traps on a cross-shelf transect seaward of the Family Islands .....	128
70.	C/P ratios (atoms) of particulate material collected by moored sediment traps on a cross-shelf transect seaward of the Family Islands .....	129
71.	Scatter plots showing relationships between carbon, nitrogen and phosphorus in material collected by moored sediment traps off the Family Islands .....	130
72.	Top: Gross sedimentation fluxes measured in nearshore waters of the Cairns box with free drifting sediment traps. Bottom: Calculated percentages of the water column stock of suspended particulates sedimenting daily .....	131
73.	Top: Gross sedimentation fluxes of particulate organic carbon in nearshore waters of the Cairns box with free drifting sediment traps. Bottom: Gross sedimentation fluxes of particulate organic carbon in mid- and outer-shelf waters of the Cairns box .....	132
74.	Top: Particulate nitrogen sedimentation fluxes measured in nearshore waters of the Cairns box with free drifting sediment traps. Bottom: Calculated percentages of the water column stock of particulate nitrogen sedimenting daily.....	133
75.	Top: Particulate phosphorus sedimentation fluxes measured in nearshore waters of the Cairns box with free drifting sediment traps. Bottom: Calculated percentages of the water column stock of particulate phosphorus sedimenting daily .....	134
76.	Day-to-day and between-cruise variability in atomic ratios between carbon, nitrogen and phosphorus in material collected by free-drifting sediment traps in nearshore waters of the Cairns box.....	135
77.	Top: Gross sedimentation fluxes measured in mid- and outer-shelf waters of the Cairns box with free-drifting sediment traps. Bottom: Calculated percentages	

	of the water column stock of suspended particulates sedimenting daily .....	137
78.	Top: Particulate nitrogen sedimentation fluxes measured in mid- and outer-shelf waters of the Cairns box with free-drifting sediment traps. Bottom: Calculated percentages of the water column stock of particulate nitrogen sedimenting daily....	138
79.	Top: Particulate phosphorus sedimentation fluxes measured in mid- and outer-shelf waters of the Cairns box with free-drifting sediment traps. Bottom: Calculated percentages of the water column stock of particulate phosphorus sedimenting daily.....	139
80.	Day-to-day and between-cruise variability in atomic ratios between carbon, nitrogen and phosphorus in material collected by free-drifting sediment traps in mid- and outer-shelf waters of the Cairns box .....	140
81.	Calculated annual inputs of nitrogen and phosphorus to the Cairns box.....	159
82.	Calculated annual inputs of nitrogen and phosphorus to the Tully box .....	160
83.	Calculated stocks of nitrogen and phosphorus in the Cairns box in relation to system-scale input, export and recycling fluxes where they could be measured or estimated .....	162
84.	Calculated stocks of nitrogen and phosphorus in the Tully box in relation to system-scale input, export and recycling fluxes where they could be measured or estimated .....	163