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River flood plumes in the Great Barrier Reef Lagoon

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Introduction

A small body of observations made over the last 80 years is available to gain some understanding of the dispersion of river discharge in the Great Barrier Reef (GBR) lagoon and thus assist in predicting the fate of material carried in the discharge.

The larger dry-catchment coastal Queensland rivers such as the Burdekin and Fitzroy have extreme flow patterns with average intervals between major flows of several years. The 'wet tropics' rivers, on the other hand, although also displaying highly event driven discharge display a more even discharge pattern with one or more major flows almost every year (Mitchell et al, 1996). This is a consequence of their location in the relatively reliable monsoon rainfall 'wet tropics' coastal region.

Particulate and most dissolved nutrient concentrations in river waters discharging into the GBR reach peak values during flood events (Mitchell et al., 1996). Flooding rivers push normal estuarine mixing, biological and geochemical processes out over the GBR shelf in discharge plumes. Concentrations and forms of particulate matter and nutrients in flood plumes reflect the concentrations in the source waters, the extent of mixing with shelf waters and biological processes occurring over time in river plumes. The largest proportion of the annual discharge of sediments and nutrients from rivers into the GBR occurs during large flood events (eg. Furnas et al., 1995; Mitchell et al., 1996). It is important to understand how extreme water quality conditions associated with floods influence sediment deposition, lagoonal water quality and effects on benthos in the GBR.

Observed Plumes

Early observations of the presence of flood plumes in the GBR lagoon around Low Isles in February 1929, were made by Orr (1933) who noted that the adjacent Daintree River was in flood. Widespread loss of coral cover associated with the major floods of January, 1918 (the 'Mackay' cyclone) in the Whitsundays area was reported by Rainford (1925) and Hedley (1925). Anecdotal accounts of fresh water at the surface 8 miles offshore were also recorded. The probable effects of wind direction on plume dispersion was noted at this time.

The Burdekin and Fitzroy Rivers are the two largest catchments draining into the GBR. Annual discharge from these rivers varies considerably from year to year, with major flood events separated by drier periods with little river flow which often last many years. During major floods in the Burdekin and Fitzroy Rivers, high discharge rates persist for several weeks. Plumes extend for several hundreds of kilometres away from the river mouth (Wolanski and Van Senden, 1983; O'Neill et al, 1992) and low salinity water masses can be identified for several weeks. The buoyancy of low salinity water and geostrophic forces are major factors controlling the movement of flood waters on the shelf (Wolanski and Jones, 1981) but wind forcing of surface water may be an important factor during moderate and strong winds (Brodie and Furnas, 1996).

In the major flood events of 1979-80 and 1980-81 in the Burdekin and northern rivers, low salinity waters were tracked along the central GBR shelf between the Burdekin River mouth and Cairns, 350 km to the north, and as much as 40 km away from the coast (Wolanski and

Jones, 1981; Wolanski and Van Senden, 1983). However, for the most part low salinity flood waters remained close to the coast, well away from outer shelf reefs. Significant interactions between plume water and offshore reefs only occurred north of Hinchinbrook Island (18°S), by which time, significant salinity alterations had occurred in the river water. High suspended sediment loads were restricted to the coast, with most particulate matter apparently deposited in areas where the salinity was < 10 (Wolanski and Jones, 1981).

High dissolved nutrient concentrations have been measured off Townsville and in Bowling Green Bay, up to 50 km north of the Burdekin River mouth, for periods of two or more weeks during the 1977-78 wet season (Revelante and Gilmartin, 1982) and following cyclone Charlie in 1988 (Liston, 1990). Phytoplankton and zooplankton populations also developed a pronounced bloom in response to the available nutrients following these events.

Cyclone Joy (1990-91) produced significant floods in most rivers between the Barron and the Fitzroy, those in the Burdekin and Fitzroy lasting for a number of weeks. Off Townsville, low-salinity water (22) was observed 25 km offshore. The frontal zone between low salinity plume water and low nutrient shelf waters was accompanied by enhanced phytoplankton concentrations and local increases in larval fish populations (McKinnon and Thorrold, 1993).

Following major flooding in the Fitzroy River catchment (Brodie and Mitchell, 1992; Preker, 1992), low salinity plume water was observed offshore for a period of 3 weeks (O'Neill et al, 1992). Low salinity water (down to 8) caused significant coral mortality (Van Woesik, 1991) to the fringing coral reefs around the Keppel Islands. In the Capricorn-Bunker group of reefs, more than 200 km north of the river mouth, salinities as low as 28 were recorded and some damage to corals was observed. Winds appeared to be a major factor influencing the movement of the plume on the shelf. During the first two weeks of the flood, fresh southeasterly winds prevailed and the plume was held close to the coast and moved to the north. In the third week of the flood, the winds weakened and shifted to the north. During this period, large lobes of the plume broke away ('calving') and moved southeast toward and into the Capricorn-Bunker area.

Short-lived river plumes from the numerous small north Queensland rivers have been observed during and after cyclonic floods at a number of mid- and outer shelf locations. Following cyclone Dominic (1981), Davies and Hughes (1983) observed abrupt changes in current and suspended particle loads at Boulder Reef, a mid-shelf reef near Cooktown, which they ascribed to flooding in the nearby Endeavour River. Suspended particulate concentrations reaching the reef peaked at ca. 200 mg l⁻¹. Aerial observations carried out immediately following cyclones Winifred (1986; M. Jones, L. Zann, pers. comm. and available photographs), Sadie (1994) (Brodie and Baer, 1995), Violet (1995) (Steven et al, 1996) and Ethel (1996) have identified, and in recent cases mapped, turbid river plumes in the GBR lagoon. During cyclones Sadie and Violet, discharges from a number of small rivers and streams (in particular the Herbert, Tully, Johnstone, Russel-Mulgrave, Barron, Mossman and Daintree) merged into a broad plume (Figure 1) which covered substantial areas on the inner- and mid-shelf. In all cases, the short period of direct impingement upon outer-shelf reefs reflected the brief duration of high flow in these catchments (Mitchell et al, 1996).

Recognisable distributions of flood plumes in the central GBR appear to be directly related to winds over the shelf. Under relatively calm conditions following cyclone Sadie, the merged plume extended seaward over much of the shelf. In contrast, the Violet plume was restricted to a shallow, nearshore band by stronger SE tradewinds following the cyclone (Figure 1).

The three cyclones, Winifred, Sadie and Violet, while producing roughly equivalent catchment rainfall and river discharge, had distinctly different paths (Figure 2). As a result significantly different plume and lagoon disturbance patterns occurred.

Cyclone Winifred originated in the Coral Sea and crossed the coast near Innisfail (Figure 2) on 1 February 1986 (Dutton, 1986). The category 3 cyclone caused substantial waves in the GBR lagoon and the resuspension of lagoon-floor sediments to a depth of 60 mm in waters up to 25 m deep (Gagan et al., 1990). It was concluded from this event that wave resuspension could be a major agent of moving terrestrial sediments across the GBR shelf but that river plumes from the wet tropics rivers were unlikely to ever reach the mid- and outer-shelf reefs of the GBR in this region (Gagan et al., 1987). Large river flows resulted from the associated rain on the catchments but the extent of the visible muddy river plumes were difficult to determine in the presence of wave-resuspended sediment in the lagoon. Lagoonal resuspension and river plume input of nutrients caused a phytoplankton bloom, dominated by diatoms, in the lagoon off the Johnstone River 1-3 days after the passage of the cyclone (Furnas, 1989).

Cyclone Sadie originated in the Gulf of Carpentaria and after crossing the coast moved inland in a southerly direction parallel to the east coast (Figure 2). Short period but intense rainfall resulted on coastal catchments with the major flows on the North and South Johnstone Rivers on 31 January 1994. Winds offshore were slight and, with no turbidity from lagoonal resuspension, river plumes in the period 31 January to 4 February were easily mappable (Figure 1). The plume from the Johnstone River merged with plumes originating from rivers from the Black River in the south to the Daintree in the north forming a continuous plume in this area on 3 February. The combined plume reached the outer-shelf near Noreaster Reef. The plume was short-lived with little evidence of it in the water column by 6 February (Devlin et al, 1995).

Cyclone Violet originated in the Coral Sea and moved south parallel to but at some distance from the coast, and finally dissipating in NSW waters (Figure 2). Heavy rainfall, similar to that observed in Cyclone Sadie, occurred in a period of a few days after 22 February 1995 on catchments between Townsville and Cooktown. Winds offshore were moderate (10-15 kt) south-easterlies producing some resuspension in shallow inshore waters. However the river plumes were clearly able to be distinguished by aerial survey and mapped in the week following the event (Figure 1). Plumes in this event also merged into a combined plume from the Herbert to the Daintree but the combined plume was far less extensive in area than for Sadie. The plume was not detected more than 25 km from the coast and did not approach the mid-shelf in any sector (Steven et al, 1996).

With similar rainfall and discharge the contrast between plume behaviour in Sadie and Violet is striking. The one contrasting factor was wind conditions and it is thus likely that wind speed and direction play a major role in the control of the areal extent and direction of movement of plumes, confirming previous observations.

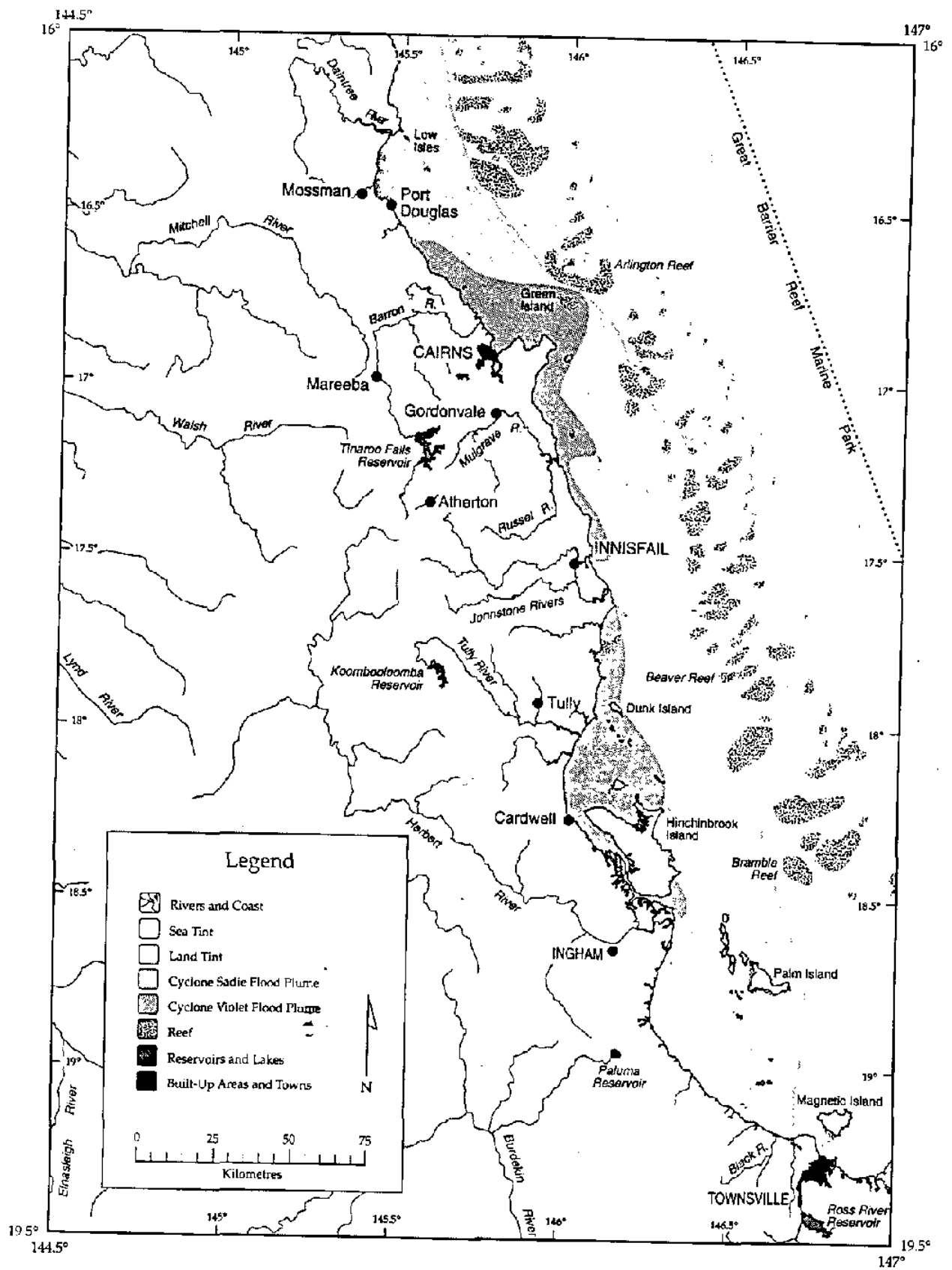


Figure 1. Areal extent of Cyclone Sadie and Violet flood plumes.

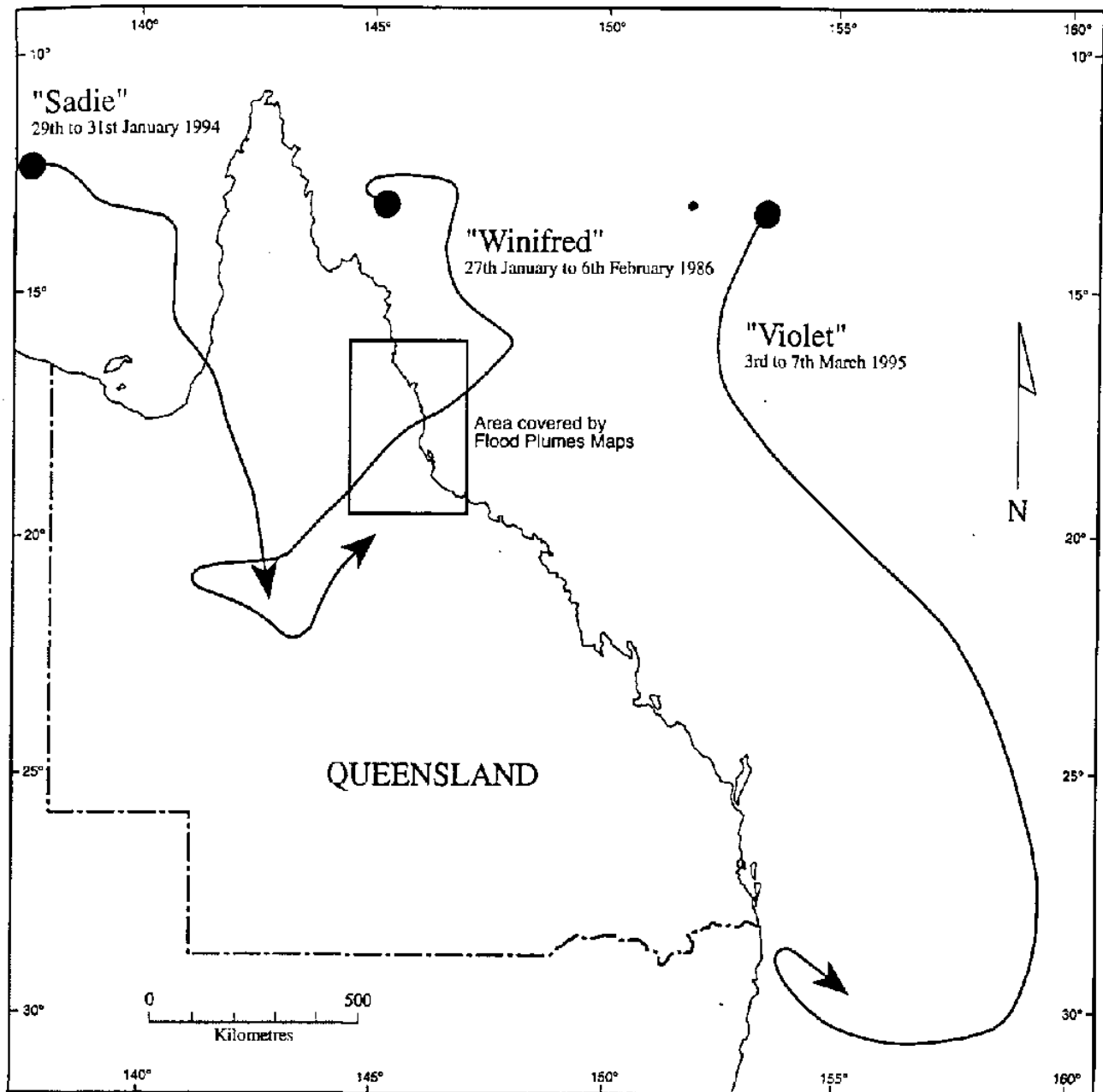


Figure 2. Tracks of cyclones Winifred, Sadie and Violet.

Effects

Terrestrial runoff supplies a significant proportion of the nutrients and fine sediments entering sections of the GBR shelf (Furnas et al, 1995). However opinions differ as to how much and in what form materials running off the land actually affect lagoon benthos. Seagrass and corals living along the coast have recruited, grown, and evolved in the presence of freshwater, terrestrial nutrient, and sediment inputs. The ability of individual corals to deal with sediments (and likely nutrients) is recognized, but varies between species (eg. Stafford-Smith and Ormond, 1992). We know unambiguously that extended periods of freshwater inundation can damage reefs and kill corals (eg. Van Woessik, 1991; Jokiel et al., 1993). Similarly large areas of seagrass in Harvey Bay (southern Queensland) were killed by flood plumes from the Mary River and Koolan Creek in 1992 (Preen, 1993). Over longer periods, high sediment and nutrient loads are also known to smother or otherwise affect

coastal reefs (eg. Smith et al., 1981 for nutrients; Rogers, 1990 for sediment). Sediment and nutrient fluxes from Queensland rivers associated with land use changes in the catchments are believed to have risen fourfold over the last 100 years (Moss et al, 1992). It is still unresolved whether this increase is impinging on inshore systems during flooding events, or is having a long-term effect on GBR benthos.

Summary

Plumes arising from major flooding of rivers discharging into the GBR lagoon most often remain near the coast but may occasionally reach the mid-shelf of the GBR. Geostrophic forces and wind appear to be the major determinants on the direction of plume travel and extent of dispersion. The effects on GBR benthos of increased sediment and nutrient loads in river discharge since European settlement and modification of catchment land-use is not yet resolved.

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Contents

Foreword 3
Dr. Chris Crossland

Introduction 5

Terrigenous sediment fluxes and the central Great Barrier Reef shelf:
the current state of knowledge 7
P. Larcombe, K.J. Woolfe, N. Amjad, D.J. Barnes, J. Brodie, G.J. Brunskill, S. Bryce, R.M. Carter, A. Costen, K.A.W. Crook, C. Crossland, G.L. Deacon, M.A. Ferland, A. Gorrie, J. Grindrod, D.P. Johnson, C. McIntyre, D.T. Neil, C. Okubo, A.R. Orpin, R.G. Purdon, K. Pye, P.V. Ridd, J. Shulmeister, J. Taylor, G.S. Walker

The distribution of sediments and nutrients throughout the Whitsunday Islands
inner-shelf region, Great Barrier Reef 24
Steve G. Blake

River flood plumes in the Great Barrier Reef lagoon..... 33
Jon Brodie

Sediment transport in the Normanby River estuary,
northern Great Barrier Reef shelf, Australia..... 40
Sonya Bryce, Piers Larcombe & Peter V. Ridd

The late post-glacial sedimentary fill of a tropical embayment:
Cleveland Bay, central Great Barrier Reef shelf 45
Bob Carter & Piers Larcombe

Sedimentary processes at Paluma Shoals, an inner-shelf coral reef 47
Andrew Costen, Piers Larcombe, Richard Purdon & Ken Woolfe

Moss vs Visher: a new view of an old approach to grain size analysis..... 51
Geoff L. Deacon & Keith A. W. Crook

Long-term variations in sediment supply to the NSW shelf 53
Marie A. Ferland & Peter S. Roy

Use of palynology for interpretation of late-Quaternary marine sediments,
anthropogenic influence and climate in northeast Queensland 57
John Grindrod & Peter Kershaw

Review of dredging operations at ports in the Great Barrier Reef region 61
Robert W. Hilliard & Steve Raaymakers

Coral reefs and small islands - implications of more modest climate
and sea-level change predictions 76
David Hopley

1996 Knowledge summary of terrigenous input to the Central Great Barrier Reef..... 86
David Johnson

The influence of sea level and sediment transport on modern and Holocene growth
of the Great Barrier Reef, Australia 91
Piers Larcombe & Ken Woolfe

Seagrass-sediment interactions in the Great Barrier Reef.....	97
<i>Warren John Lee Long and Robert Coles</i>	
Centuries-long records of coral growth: a means to assess human impacts on the GBR.....	101
<i>Janice M. Lough & Dave J. Barnes</i>	
The Holocene sedimentary facies of Cleveland Bay, Townsville, Great Barrier Reef shelf.....	104
<i>Christine McIntyre</i>	
Differences in suspended sediment flux to the GBR shelf between wet and dry catchments of north Queensland.....	108
<i>Alan W. Mitchell & Miles J. Furnas</i>	
Spatial and temporal variation of fluvial sediments in Rockingham Bay, north Queensland.....	116
<i>David T. Neil</i>	
Simple climate-driven models for estimating sediment input to the Great Barrier Reef Lagoon.....	122
<i>David T. Neil & Bofu Yu</i>	
Sediment distribution and transport mechanisms, Burdekin region, central Great Barrier Reef lagoon.....	128
<i>Alan R. Orpin & Peter V. Ridd</i>	
Sand dune development on the Great Barrier Reef coastline.....	144
<i>Kenneth Pye</i>	
Holocene climate change in Queensland: implications for sea-level change and coastal sedimentation.....	151
<i>James Shulmeister</i>	
Sediment input to the Great Barrier Reef lagoon via river discharge - the Barron River.....	152
<i>Jeremy Taylor</i>	
Detection of anthropogenic and natural mercury in sediments from the Great Barrier Reef lagoon.....	155
<i>G. Stewart Walker & Gregg J. Brunskill</i>	
Contrasting sedimentation regimes across Cape York Peninsula.....	160
<i>Ken J. Woolfe, Nuzhat Amjad, Piers Larcombe, Christine M. McIntyre, Per Michaelsen, Alan R. Orpin, & Richard G. Purdon</i>	
A brief field guide to the Burdekin Delta and Cocoa Creek.....	164
<i>Ken J. Woolfe, Piers Larcombe, Peter V. Ridd, Alan R. Orpin, Sonya Bryce & Christine McIntyre</i>	
List of contributors.....	173