3. METHODOLOGY

3.1 Flood Plume Monitoring Program

Studies of Queensland rivers and their plumes in flood conditions are made difficult by access roads becoming untrafficable, rough seas associated with cyclonic winds, dangerous wind conditions for sampling and the difficult logistics of sampling with minimal preparation time. These difficulties partly explain the small number of studies of water quality conditions in plumes. The Great Barrier Reef Marine Park Authority, in conjunction with other agencies, manages a multi-institutional research effort to collect quantitative information on the composition and spatial dynamics of flood plumes. The sampling methodology was initially designed to sample flood events and at this stage seven GBR cyclones and their associated floodwaters have been mapped and sampled for water quality data between 1991 and 1999. Data from this flood monitoring program describes the water quality conditions of plumes and the movement, distribution and composition of these flood plumes.

Sampling methodology is highly dependent on the particular event, where it is, where it floods and how fast the plume moves offshore. In setting up this flood program, sampling has been ad hoc and updated as different techniques and strategies in sampling of the flood plumes have evolved. Differences in sampling strategies for each plume is a consequence of the difficulties associated with sampling under extreme weather conditions and the unpredictable spatial and temporal nature of tropical cyclones. The nature of this study means that sampling must be undertaken in less than ideal conditions.

Water samples were taken in cyclonic flood plumes over a period of three to five days. The main objective of the sampling was to take water samples of the initial intrusion of the freshwater plume to inshore waters and to identify concentration gradients of water quality parameters (salinity, temperature, dissolved inorganic, organic and particulate nutrients, suspended solids and chlorophyll *a*). Salinity and temperature depth profiles were recorded.

This flood sampling program has an evolving, flexible design, and will continue to change as more information becomes available following each new flood event. The current design will contribute to a more complete database of flood plume characteristics. Eventually it may be possible to link land use and catchment characteristics with the composition of the plume and to estimate the short and long term effects of flood water impingement on reef biota.

3.2 Aerial Mapping and Distribution of Flood Plumes

Over the monsoonal season, weather reports were monitored closely and all low pressure rain depressions monitored. The onset of a rain depression /cyclone was the catalyst for a rapid sampling plan to be activated. As soon as logistically possible after the onset of flooding, mapping of the flood plume, and sampling of water quality parameters commenced. Aerial surveillance was used to define the geographical limits of the plume and in some instances, movement of the plume over a period of days.

Flood plumes associated with cyclone Joy (1991), cyclone Sadie (1994), cyclone Violet (1995), cyclone Ethel (1996), cyclone Justin (1997), cyclone Sid (1998) and cyclone Rona (1999) were mapped on flights along and outwards from the coast. Plumes are readily observable as brown turbid water masses contrasting with cleaner seawater (figure 9). The locations of the plume fronts were fixed with geographic positioning systems (GPS) and loaded into a

geographic information system (GIS) where the approximate spatial extent of the flood waters is presented.

3.3 Long term Patterns of Cyclones and Rainfall

Climate conditions and seasonal variation is controlled by sea-surface temperature, sea-level pressure, surface winds, tropical cyclones and rainfall and river flow for adjacent areas (Lough 1994). Frequency of cyclones and plumes are related to the wet and dry seasonal pattern, which is in turn controlled by the El Ninõ/Southern Oscillation (ENSO). For Queensland, the associations between rainfall and ENSO vary with season, region and through time. Generally, times of 'weak' Southern Oscillations are known to be of less variable rainfall in Queensland and also times of weaker associations between Queensland rainfall and other climatic variables (Puotinen et al. 1993; Lough 1992). During times of strong development of the Southern Oscillation, rainfall variations show a greater amount of co-variation in space and within the monsoon season than at times of weak Southern Oscillation development. The shift of the summer monsoon circulation away from the north-eastern Australia during ENSO years also dramatically impacts tropical cyclone activity along the GBR. During an ENSO year, the number of tropical cyclones drops to two with about 2.5 tropical cyclone days. This relates to years, such as late 1991–1994, where there was very little rainfall and no real plume development. During anti-ENSO years the level of tropical cyclone activity increases, with, on average, about 7.5 tropical cyclones and 8.5 tropical cyclone days in the region of the GBR (Lough 1994).

Figure 9. Observable plume in aerial flyover. Edge of plume defined by series of latitudinal and longitudinal points (Russell-Mulgrave River plume)

3.4 Water Sampling

Water samples were collected from multiple sites within the flood plume. Location of samples were dependent on which rivers were flooding and the areal extent of the plume

but generally samples were collected in a series of transects heading out from the river mouth, with additional samples taken in between river mouths if more than one river was in flood. Transects and station locations are shown in figures 11–19. Time of sampling was also dependent on the type of event and how quickly boats were mobilised. The majority of samples were collected inside the visible area of the plume, though some samples were taken outside the edge of the plume for comparison. Range of analyses and the parameters measured in the plumes are presented in table 3. Depth, number and location of samples were dependent on the extent and area of the flood plume.

Table 3. Sampling strategies of each plume event

CYCLONE	Joy	Sadie	Violet	Ethel	Justin	Sid	Rona
Salinity	profile	profile	profile	profile	profile	profile	profile
Temperature	profile	profile	profile	profile	profile	profile	profile
Water samples	profile	profile	profile	surface	surface	surface	surface
Water analyses							
DIN	√	√	√	√	√	√	√
DIP	√	√	√	√	√	√	√
DON	√	√	√	√	√	√	√
PN	√		√	√	√	√	√
PP	√		√	√	√	√	√
SS	√	√	√	√		√	√
Chl *a* Phaeo	√	√	√	√	√	√	√

Note: 'profile' denotes where samples were taken through the water column and 'surface' denotes where samples where taken within the first 0.5 m of the water surface. √ denotes that the analysis was done for that parameter.

Surface samples were collected at 0.5 m below the surface, with either a reversing thermometer Niskin bottle or a rinsed clean sampling container with temperature measured by thermometer. Samples taken at depth were collected with Niskin bottles. Salinity and temperature profiles were measured at all sites with a YSI salinity meter. Secchi disk clarity was determined at each station.

Water samples for nutrient and chlorophyll analysis were collected, filtered and stored for further analysis. Volumes filtered for all analyses were dependent on the turbidity of the water. Subsamples were filtered through GF/F (glass fibre) filters for chlorophyll and phaeophytin, the filter and retained algal cells were wrapped in aluminium foil and frozen. The second subsample was filtered through pre-weighed 0.45 µm membrane filters for suspended solids. The third subsample was filtered through pre-combusted GF/F for particulate nutrient analysis, wrapped in aluminium foil and frozen.

Dissolved nutrient samples were collected using sterile 50 ml syringes, pre-rinsed three times with the seawater to be sampled. A 0.45 µm disposable membrane filter was then fitted to the syringe and a 10 ml sample collected in tubes pre-rinsed in filtered water. Tubes

were placed upright in tube holders, which were then stored either on ice in an insulated container or in a freezer dependent on the sampling vessel. Further samples were taken in tubes for silicate analysis and stored at room temperature. Samples were analysed for dissolved inorganic nutrients (NH_4, NO_2, NO_3, $NO_2 + NO_3$, PO_4 and Si) and Total Dissolved Nitrogen and Phosphorus (TDN, TDP).

3.5 Analytical Methods

Dissolved inorganic nutrient concentrations were determined by standard procedures (Ryle et al. 1982) implemented on a Skalar 20/40 autoanalyser, with baselines run against artificial seawater. Immediately prior to analysis, the frozen samples were thawed to room temperature. Dissolved organic nitrogen (DON) and phosphorus (DOP) concentrations were calculated by difference after seven hours oxidation of the samples with high intensity UV light (Walsh 1989) and measurement of the total dissolved nitrogen or phosphorus.

Particulate nitrogen concentrations of the particulate matter collected on the GF/F filters were determined by high temperature combustion using an ANTEK Model 707 Nitrogen Analyser. The filters were freeze dried before analysis. Following primary (650^{o}C) and secondary combustion (1050^{o}C), the nitrogen oxides produced were quantified by chemiluminescence.

Particulate phosphorus was determined colorimetrically (Parsons et al. 1984) following acid-persulfate digestion of the organic matter retained on the glass fibre filters. Acid-wash glass mini-scintillation vials were used as reaction vessels. Filters were placed in the vials with 5 ml of 5% w/v potassium persulfate and refluxed to dryness on an aluminium block heater using acid-washed marbles as stoppers for the vials. Following digestion, 5 ml of deionized water was added to each vial and the filter and salt residue resuspended and pulverized to dissolve all soluble material. The residue in the vials was compressed by centrifugation and the inorganic P determined colorimetrically in aliquots of supernatant. Inorganic and organic P standards were run with the batch of samples.

Chlorophyll *a* and phaeophytin concentrations were determined by fluorescence following maceration of algal cells and pigment extraction in acetone (Parsons et al. 1984). A *Turner 10-005R* fluorometer was used for analysis and was periodically calibrated against diluted chlorophyll extracts prepared from log-phase diatom cultures (Jeffery & Humphrey 1975). Blanks were also run routinely over the analysis period (Devlin & Lourey 1996).

Suspended solids concentrations were determined gravimetrically from the difference between loaded and unloaded membrane filter weights after drying the filters overnight at 60^{o}C. Wet filter salt blanks were subtracted from the resulting weight.