## 2. CATCHMENT ACTIVITIES POTENTIALLY AFFECTING DUGONG PROTECTION AREAS

Land use changes in the GBR Catchment are significant to the water quality status in the GBR. The land use activities in the GBR Catchment determine the quality of the terrestrial runoff that influences the water quality in the DPAs.

### 2.1 Changes in Land Use

Land within the 17 major river catchments adjacent to the GBR has been extensively modified since European settlement. Land clearing, removal of wetlands and riparian vegetation zones, grazing and cultivation have all occurred to enable the development of agriculture, mining and urban centres within each of the catchments to a greater or lesser extent. Only very small areas of the catchments adjoining the DPAs are considered to be pristine lands. In the Herbert and Haughton River catchments (Central Section of the GBRMP) approximately 10% of the catchment area is pristine lands whereas in the Kolan River catchment (Mackay/ Capricorn Section of the GBRMP) there is no pristine land (Rayment & Neil 1997).

Land clearing during the past 130 years has resulted in loss of rainforest in coastal lowlands (Johnson et al. 1998) and on the ranges and tablelands (Gardiner et al. 1988), loss of coastal wetland forest (Johnson et al. 1998), and extensive loss of open woodland. Forest and woodland clearance in Queensland has been quantified from satellite imagery (Graetz et al. 1995). In the Herbert River catchment *Melaleuca* wetlands have been reduced in area from 30 000 hectares in pre-European times to less than 5000 hectares in 1996, while in the lower Johnstone River catchment a 78% loss occurred between 1951 and 1992. In the Fitzroy River catchment, during the Brigalow (*Acacia harpophylla*) woodland clearance schemes (1950 to 1975) approximately 4 million hectares of Brigalow woodland were cleared for conversion to grasslands for cattle grazing. The National Greenhouse Gas Inventory Committee Report (1999) estimated that in the period between 1988 and 1998 approximately 3 million hectares of land would have been cleared in Queensland. Most of this clearing is now occurring on marginal agricultural land, particularly in central Queensland, where soil fertility is considered to be inadequate for agricultural purposes. In recent reports summarising the status and quality of freshwater streams in Queensland catchments, the loss and disturbance of riparian vegetation zones in agricultural areas is emphasised, primarily because it causes increased erosion and enhanced turbidity in stream waters (Moller 1996; Johnson 1997; Russell & Hales 1994, 1997; Russell et al. 1996a, b).

Use statistics and usage trends for the GBR Catchment have been quantified by Gilbert et al. (in press). Of the catchments flowing into the GBR the primary land use is cattle grazing for beef production, which occupies 77% of the total catchment area. In 1996 there were approximately 4.9 million beef cattle grazing in the GBR Catchment with the highest stock numbers recorded in the Fitzroy River catchment (Gilbert et al. in press). Other land uses, namely cropping (mainly of sugarcane) and urban/residential development, each occupy approximately 3% of the total catchment area.

The largest crop grown on the GBR Catchment is sugarcane which is primarily grown in lowland coastal areas. The catchment area used for sugarcane cropping has increased steadily over the last 100 years with 390 000 hectares being cultivated for sugarcane by 1997 (Figure 2). Sugarcane cropping requires the application of fertiliser which has resulted in a rapid increase in total fertiliser application since 1950 (Pulsford 1996).

The estimated human population in the GBR Catchment is steadily increasing, by 1995 it was 1.2 million. This population growth has been associated with an increasing

demand on land for urban development. Other significant land uses, in specific catchments, include mining (coal and metalliferous) and cotton cropping, however, these land uses occupy only a small area of land relative to the total GBR Catchment. Industries such as aquaculture, cotton (mostly on the Fitzroy catchment) and horticulture (particularly bananas) are presently expanding and consequently fertiliser application associated with these uses is increasing in the GBR Catchment. For example, in the Tully River catchment the area under sugarcane has doubled and fertiliser nitrogen use has increased by 130% (Mitchell et al. 2001).

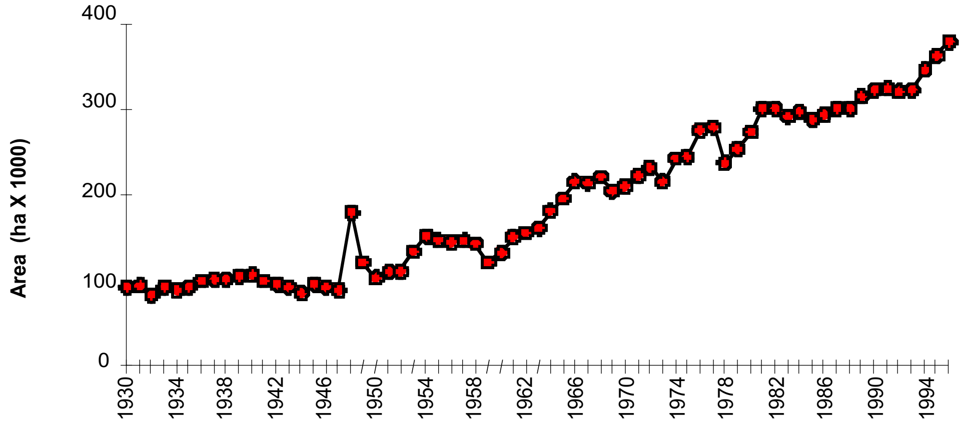


**Figure 2**. Increase in land area used for sugar cultivation from 1930 to 1996 (Gilbert et al. in press)

### 2.2 Terrestrial Runoff

Terrestrial runoff is considered one of the most significant anthropogenic impacts on the water quality of the GBRWHA because it carries sediments, nutrients, heavy metals and other contaminants, acid sulfate soil leachate and litter. There has been an ongoing and often controversial discussion on the biological and physical impacts of terrestrial runoff on the health of the GBR (e.g. Bell 1991; Bell & Gabric 1991; Kinsey 1991; Walker 1991; Baldwin 1992; Brodie 1995; Larcombe & Woolfe 1999). However, there is now agreement that "there is significant risk that terrestrial runoff is currently or may in future damage areas of high exposure along the tropical and central Queensland coasts of the GBRWHA" and that "there is a continued urgency to work towards a reduction in the runoff of sediments, nutrients, herbicides and other pollutants into the Great Barrier Reef Marine Park World Heritage Area." (statement by the CRC Reef Research Centre, December 2001).

The main sources of terrestrial runoff to the GBR are via point sources and river discharge.

### 2.2.1 Point Sources

Point source discharges include sewage outfalls, discharge from aquaculture operations and industrial effluent.

Sewage discharges contribute only a few per cent of the 'new' nutrients to the coastal waters of the GBR (Figure 3) however they can be significant on a local scale (Brodie 1995). A majority of the large coastal cities and most of the smaller coastal settlements adjacent to the GBRWHA, have secondary treatment sewage systems. Many of these treatment plants use a proportion of the effluent for land irrigation and several have sewage outfalls, as point-source discharges, either into coastal streams or directly into the GBRWHA. The operation of treatment plants (greater than 21 equivalent persons capacity) is regulated by the Queensland *Environmental Protection Act 1994*. Problems may arise from these point-source discharges, particularly in dry season conditions, where discharge into a stream may constitute the total stream flow. Under these conditions eutrophication, algal blooms and anoxia in the vicinity of the point-source discharge may result. In some areas with significant urban populations septic systems are still in operation, for example, most of the Magnetic Island and Mission Beach residential areas. Plans to upgrade the sewage systems in these communities are being investigated.

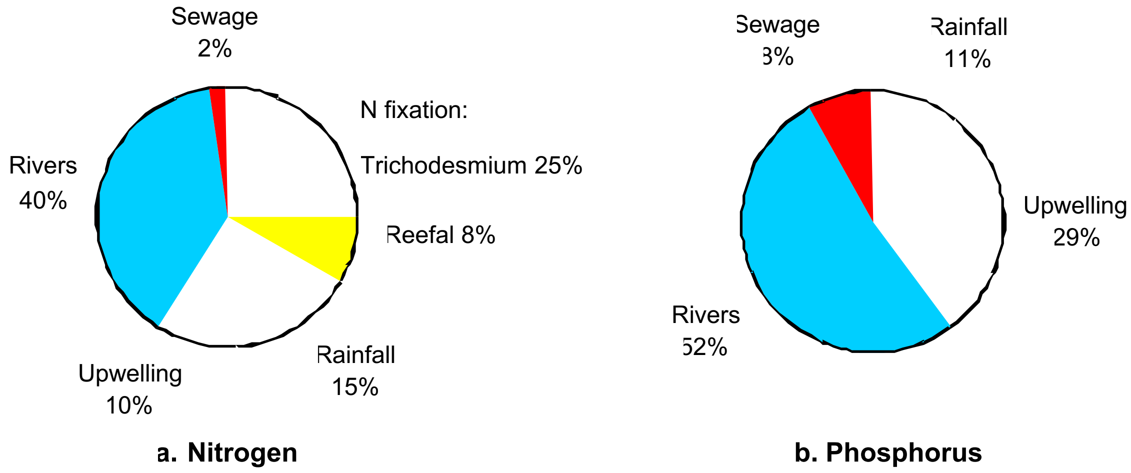


**Figure 3**. Sources of new nitrogen and phosphorus to the Great Barrier Reef shelf waters (Source: Furnas et al. 1995).

Aquaculture of saltwater prawns is a small but expanding industry along the coast adjacent to the GBRWHA. Wastewater from prawn ponds is periodically released into coastal streams or potentially, directly into the GBRWHA, and may be a considerable local source of nutrients (Macintosh & Phillips 1992). Such point-source discharges are high in nutrients, suspended solids, algae and bacteria and thus have potential impacts on the GBRWHA. Again such point-source discharges are regulated under the Queensland *Environmental Protection Act 1994* through a licensing system however compliance is self-regulated by individual prawn farms once a license is obtained. More recently, regulations have been introduced under Section 66(2)(e) of the *Great Barrier Reef Marine Park Act 1975* that regulate discharge of aquaculture waste from the coastal boundary of the GBRMP to 5 km inland from the highest astronomical tide. The *Great Barrier Reef Marine Park (Aquaculture) Regulations 2000* came into effect in February 2000 to manage aquaculture waste discharge immediately adjacent to the coast and the estuaries of the GBRWHA. These Regulations allow for accreditation of the Queensland assessment and approval processes when these processes adequately address the Commonwealth assessment and approval requirements, which aim to minimise impacts on marine ecosystems. At present, Queensland is encouraging new prawn farms to minimise the volume of discharge and to install biofiltration systems to reduce the concentration of contaminants in their

wastewater by filtering the discharge water through beds of bivalves (e.g. oysters and mussels) or algae, or through mangroves. Currently, publications from a number of research projects addressing the environmental impacts of prawn farm effluents are in preparation (M. Burford, CSIRO Marine Research, pers. comm.).

The major industrial sites on the coast adjacent to the GBR are concentrated near Gladstone and Townsville. Only a few of these sites discharge wastewater into coastal streams or directly into the GBRWHA. These discharges are regulated under the Queensland *Environmental Protection Act 1994*. Recently developed industrial sites are encouraged to have no ocean wastewater discharge, for example, the Korea Zinc smelter in Townsville.

### 2.2.2 River Discharge

River discharges make a substantial contribution to the inputs of 'new' nutrients (N and P) to the shelf ecosystems of the GBR (Figure 3). The actual river flows in all catchments adjacent to the GBR are highly variable, both between and within years. Discharge in both wet and dry river systems is dominated by large flood events associated with tropical cyclones and monsoonal rainfall (Mitchell & Furnas 1997; Mitchell et al. 1996). While the large 'dry' catchments of the Burdekin and Fitzroy Rivers have the greatest average flows, significant flood events only occur episodically at intervals ranging between several years and a decade. Limited information suggests that area-specific erosion is higher in the 'wet' catchments of the central GBR (16 to 19°S), but overall sediment and nutrient inputs are dominated by the large dry catchments as a consequence of their larger average water flows.

The coastal region adjoining the DPAs is divided into a number of wet and dry tropical catchments. Most catchments are small (< 10 000 $km^2$), but the Burdekin (133 000 $km^2$) and Fitzroy River catchments (143 000 $km^2$) are among the largest in Australia. Estimates of the long-term average volume of water discharged annually into the whole of the GBRWHA by rivers range from 40 $km^3$ (Furnas & Mitchell 1997) to 84 $km^3$ (Wasson 1997).

Approximately 37 % of this discharge originates from the Burdekin and Fitzroy Rivers and 30% originates from the relatively small rivers in the Wet Tropics region (16°S to 19°S).

How far terrestrial runoff is transported in river discharge depends on the velocity of the waterway, the size of the transported material and whether or not the material is dissolved or in suspension. While sand and silt sized sediment fractions may be re-deposited within the catchments during low flow events, most of the fine clay fraction is transported downstream to the river mouth (Arakel et al. 1989). During major flood events associated with tropical cyclones, the sediment re-deposited in the streams may be resuspended and transported downstream. These major events are responsible for almost all the transport of material from catchments to the inner lagoon (Cosser 1989; Furnas & Mitchell 1991; Hunter 1997; Bramley & Johnson 1996; Mitchell et al. 1997). Intense rainfall associated with tropical cyclones causes massive river flows and flood plumes, which intrude into the GBR lagoon (Figure 4).

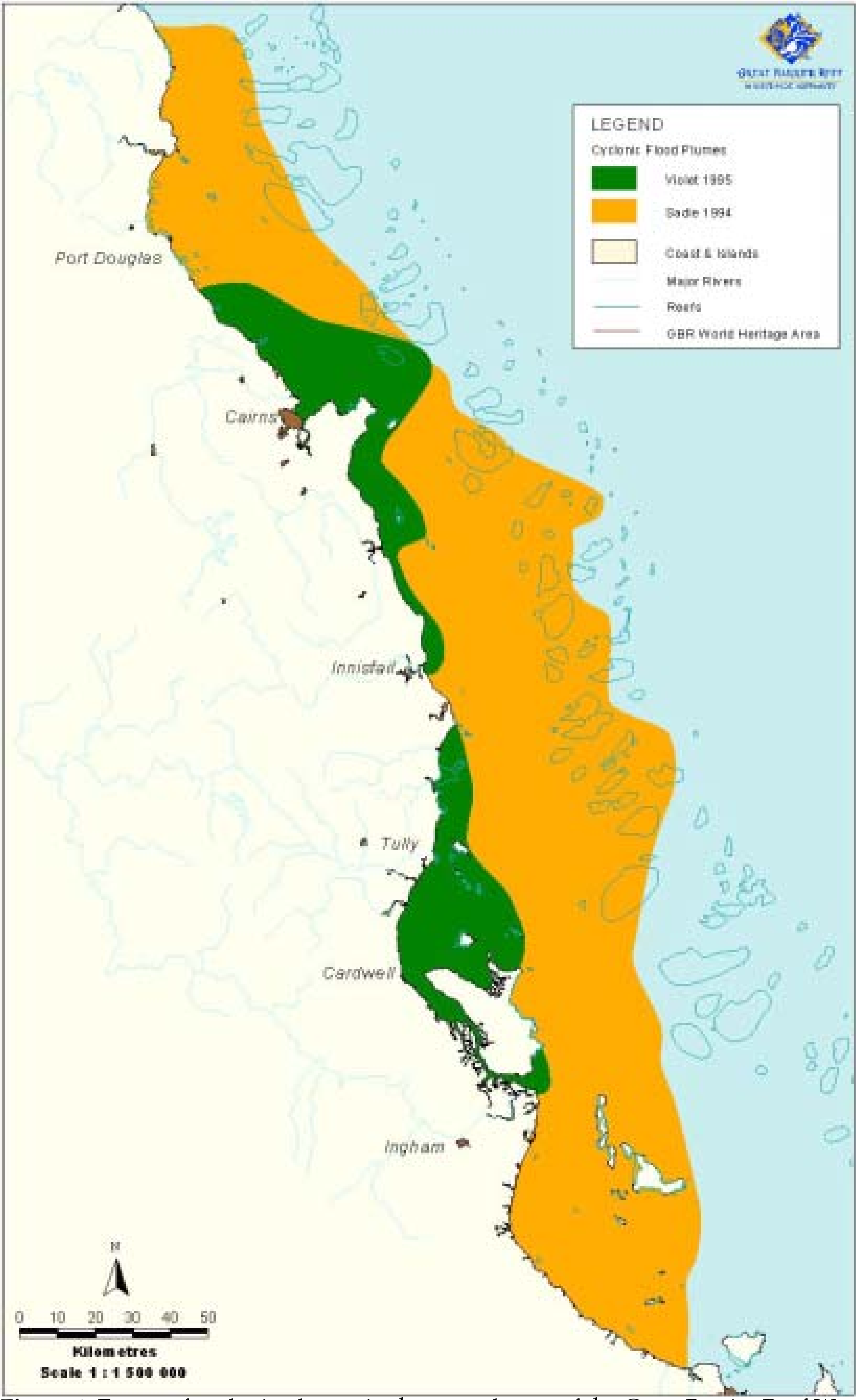


**Figure 4.** Extent of cyclonic plumes in the coastal zone of the Great Barrier Reef World Heritage Area

### *2.2.3 Cyclonic Flood Plumes*

The buoyancy of low salinity water and geostrophic forces are major factors controlling the movement of flood waters on the GBR shelf (Wolanski & Jones 1981; Wolanski 1994; Wolanski & King 1997), but wind-forcing of surface water may be an important factor during moderate and strong winds (Brodie & Furnas 1996). As a result the direct effects on GBR ecosystems are primarily concentrated close to the coast. For example, the flood plume following cyclone Violet was restricted to a shallow, nearshore band by strong south-east tradewinds whereas in the relatively calm conditions following cyclone Sadie, the flood plume extended seaward over much of the continental shelf (Figure 4).

The annual discharge from the Burdekin and Fitzroy Rivers varies considerably from year to year. Major flood events are separated by drier periods, often of many years, with little river flow. During major floods, high discharge rates persist for several weeks. Flood plumes extend for several hundreds of kilometres away from the river mouth (Wolanski & Van Senden 1983; O'Neill et al. 1992) and low salinity water masses can be identified for several weeks along the coast.

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 & Jones 1981; Wolanski & Van Senden 1983). Mostly, however, the low salinity flood waters remained close to the coast, well away from outer shelf reefs. High suspended sediment loads were restricted to the coast, with most fine particulate matter settling out of the water column at salinities < 10 ppt, near the river mouth (Wolanski & Jones 1981).

Most of the sediment transported by river systems is deposited within 10 km of the coast. In particular, the northward facing embayments, trap large amounts of sediment (Johnson et al. 1997; Woolfe & Larcombe 1998). Isotopic and geochemical markers indicate that the bulk of terrestrial organic matter discharged from rivers is deposited in coastal sediments (Gagan et al. 1987; Risk et al. 1994; Currie & Johns 1989; Pailles et al. 1993; Walker & Brunskill 1997a, b). Only small amounts of terrestrial sediments appear to reach the outer shelf reefs, primarily during major cyclonic floods when river plumes can cover extensive areas of the shelf (Brodie & Furnas 1996; Devlin et al. 2002), and mid- and outer-shelf reef sediments contain very low proportions of siliceous, terrestrially derived sediments (Okubo & Woolfe 1995).

Early observations of the presence of flood plumes in the GBR lagoon around Low Isles in 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 1918 (the 'Mackay' cyclone) in the Whitsundays area was reported by Rainford (1925) and Hedley (1925).

### *2.2.4 Other Sources - Water Dynamics and Sediment Resuspension*

The volume of the GBR lagoon, from the coast to the 100 metre isobath on the edge of the continental shelf, is approximately 8000 $km^3$. Water in the GBR lagoon typically has a salinity of 34 to 36 ppt (Furnas & Brodie 1996; Andrews 1983), except during monsoonal rainfall periods when salinity close to the coast may range from 28 to 33 ppt for long periods, and in major river plumes when salinity may range from 2 to 30 ppt (Brodie & Furnas 1996; Devlin et al. 2001).
Water circulation within the GBR lagoon is largely driven by tides and the dominant south east tradewinds (Wolanski 1994). Exchanges of water between the GBR lagoon and the Coral Sea occur through tidal exchange and episodic upwelling of Coral Sea water along the edge of the continental shelf (Furnas & Mitchell 1997; Wolanski 1994). Vertical mixing induced by wave action, currents and the reef matrix keep the water

column well mixed. The general water flow on the outer GBR, south of 16°S, is to the south. Inshore, where the effects of the south-east trade winds predominate, average water flow is to the north (Wolanski & King 1997). Generally, a significant barrier exists between mixing of inshore and offshore GBR waters due to the current regimes (King 1995). This hinders the movement of materials, including contaminants, from inshore to the mid-shelf area and from the Coral Sea to the inshore reefs. Flushing of the GBR lagoon is limited by the enclosure formed by the main reef. Residence times of water in the inner lagoon, while not precisely known, may be prolonged (Wolanski 1994). Suspended solids, and potentially nutrients and other contaminants may remain in the inner lagoon, that is to the 20 metre isobath, for periods of weeks to months due to recycling and resuspension processes (Wolanski 1994; Furnas et al. 1995).

It is assumed that suspended particles carried by terrestrial runoff are not transported beyond the inner lagoon (Currie & John 1989; Larcombe & Woolfe 1999). Suspended solids stay in the inner lagoon for prolonged periods due to wind-driven resuspension in the shallow waters of the inner shelf (Wolanski 1994; Larcombe et al. 1995). Suspended sediment concentrations of up to 50 mg/l in the upper water column and 200 mg/l near the bottom are common in areas such as Cleveland and Halifax Bays under windy conditions (Larcombe et al. 1995). Additional particles that are rich in organic material are formed during mixing processes in estuaries by aggregation and microbial colonisation of fine particles (Ayukai & Wolanski 1997; Wolanski et al. 1997), and by planktonic biomass. During resuspension, significant amounts of nutrients are released from the sediments and the sediment porewater (Ullman & Sandstrom 1987; Chongprasith 1992). Nutrient release from suspended sediments during storm events stimulates phytoplankton growth during subsequent days (Walker & O'Donnell 1981) when chlorophyll *a* concentrations may reach 1.5 $\mu$g/l compared to background concentrations of 0.4 $\mu$g/l. The concentration of phytoplankton, measured as chlorophyll *a* concentration, is used as an integrative parameter to monitor nutrient concentrations in the GBRWHA (Brodie et al. 1997; Steven et al. 1998). In cyclonic wind conditions large masses of sediment are resuspended and moved (Gagan et al. 1987; Gagan et al. 1990). After a cyclone, the nutrients released by resuspension stimulated a phytoplankton bloom in southern GBR shelf waters with chlorophyll *a* concentrations reaching 18 $\mu$g/l (Furnas 1989).

Sediment resuspension and the coastal northward current flow are the principal mechanism for the northward and shoreward transport of sediments along the GBR (Orpin & Ridd 1996). These mechanisms concentrate materials, such as suspended solids, nutrients, and associated contaminants in the inner lagoon.

During low flow conditions, either during the dry season or caused by flow restriction from dams, weirs, etc., very little material is transported out of the rivers. This may occasionally lead to pollutant concentration problems in sheltered bays and inlets, which are not flushed out. Generally, however, the discharge into the sea is event driven and largely dependent on large flood events during the summer (Bramley & Johnson 1996; Mitchell et al. 1997).

## 2.3 Constituents of Terrestrial Runoff

The main constituents of concern in terrestrial runoff include nutrients and sediment, heavy metals and other contaminants, freshwater, and highly acidic water and litter.

### *2.3.1 Nutrients and Sediment*

The GBR is characterised by low nutrient concentrations so GBR ecosystems naturally derive most of their nutrient supply from internal recycling processes (Furnas et al. 1995). 'New' nutrients are introduced into the GBR lagoon by river discharge and

point sources (section 2.2). Rain, upwelling of the Coral Sea and nitrogen fixation by cyanobacteria are natural sources of 'new' nutrients (Furnas et al. 1995).

In the central GBR it is estimated that terrestrial runoff of nutrients provides approximately 41% of the 'new' nitrogen (N) and 60% of the 'new' phosphorus (P) inputs to shelf waters from external sources (Figure 3, Furnas et al. 1995). These terrestrial nutrient inputs enter the shallow coastal areas of the GBR lagoon that comprise only a small percentage (< 10%) of the total GBR shelf area and water volume. Consequently, any changes in water quality caused by terrestrial activities will be most apparent in the coastal areas of the GBR lagoon.

The findings of several nutrient (N and P) monitoring programs in the GBR region over the past 20 years provide a good overview of the ambient nutrient concentrations in the GBR lagoon (Bellamy et al. 1982; Furnas & Mitchell 1984a, b; Furnas et al. 1988, 1990, 1995). Minimum concentrations of almost all measured nutrient species are observed in the Far Northern Section of the GBRMP. This Section is adjacent to the north-east Cape York catchment, an area predominantly used for cattle grazing at low-stocking rates that remains relatively undisturbed (DPI 1993a). Elevated concentrations of a number of nutrient species are found in the Torres Strait, the Cairns Section and the Central Section of the GBRMP.

The water quality of the shelf area adjacent to Cairns and Innisfail (Cairns Section) has been studied intensively and local cross-shelf gradients in nutrient concentrations are evident (Furnas et al. 1995; Furnas & Brodie 1996; Furnas & Mitchell 1997). In general the data indicate that in the absence of local river runoff, the very low dissolved nutrient conditions which prevail in mid-shelf and lagoonal waters of the GBR are also characteristic of shallow nearshore waters. However, particulate nutrient concentrations are consistently higher inshore (Furnas et al. 1995, 1997); particulate nitrogen (N) and particulate phosphorus (P) are approximately 30–50% and 70% higher respectively (Furnas et al. 1997).

Dissolved nutrient concentrations from inshore waters, in the absence of local river runoff, range from non-detectable to 2 µM for dissolved inorganic nitrogen (DIN) and from non-detectable to 0.2 µM for phosphate (Furnas et al. 1995; Furnas & Brodie 1996; Devlin et al. 1997; Schaffelke et al. in press).

Sediment and nutrient runoff from the coastal catchments of Queensland have been estimated using existing data and catchment models (Moss et al. 1992; Neil & Yu 1996; Rayment & Neil 1997). The most current and sophisticated modelling effort has been completed within the National Land and Water Resource Audit (NLWRA) by CSIRO Land & Water (NLWRA, unpub. Data; methodology in Prosser et al. 2001). According to these latest estimates 12 million tonnes of sediment, 47 thousand tonnes of nitrogen and 10 thousand tonnes of phosphorus are exported to the inner GBR lagoon via river discharge annually. Even though there are large differences between the catchment models employed (Wasson 1997) all estimates indicate an increase in terrestrial nutrient and sediment delivery to the GBR of at least four-fold since European settlement. A river monitoring program, presently being conducted by the Australian Institute of Marine Science (M. Furnas, AIMS, pers. comm.) will supply data for improved ground-truthing of the nutrient export estimates.

Cattle grazing is the largest contributor of nutrients and sediments to terrestrial runoff (Figure 5). Even when there is minimal runoff from grazing lands they lose significant amounts of sediment and associated nutrients in comparison with natural or plantation forests and woodlands. Average soil erosion rates for Queensland grazing lands range from 0 to 4 t $ha^{-1}$ $yr^{-1}$ (Elliott et al. 1996). The principal cause for nutrient losses is the clearing of vegetation and overgrazing, which in turn leads to the loss of nutrients naturally present in the soil (Prove & Hicks 1991). This is significant as

extensive removal of grass and vegetation cover occurs in grazing lands particularly during extended drought periods.

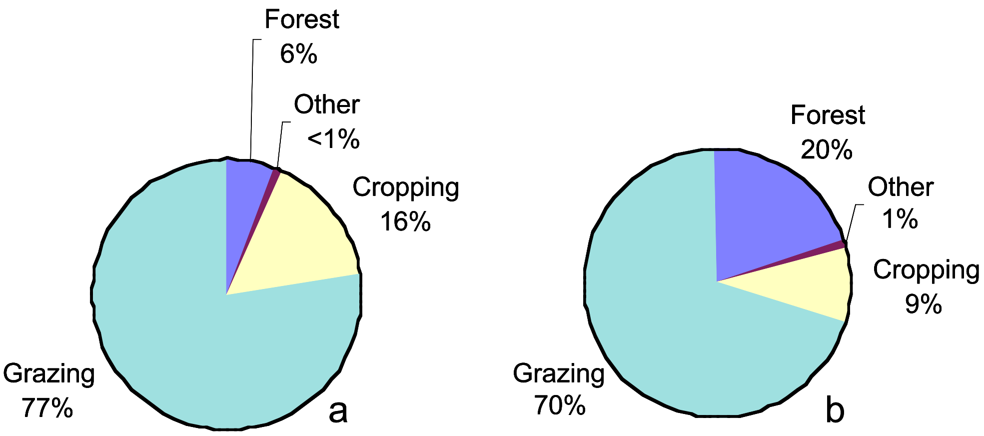


**Figure 5**. Contribution of different land uses to a) nutrients and b) sediments in terrestrial runoff. *(Sources: a) Moss et al. 1992, b) NLWRA and CSIRO Land & Water, unpub. Data; methodology in Prosser et al. 2001).*

Soil losses as high as 500 t $ha^{-1}$ $yr^{-1}$ have been reported from sugarcane cropping areas (Prove et al. 1995). With the adoption of modern land-management practices, such as trash blanketing and soil conservation plans, this rate has been lowered to about 14 t $ha^{-1}$ $yr^{-1}$ in recent years (Rayment & Neil 1997). However, the amount of land used for sugarcane cultivation in lowland areas continues to expand, primarily into marginal lands, such as wetlands (Zann et al. 1996) and as a result higher rates of downstream soil transport may be expected. The nutrients in runoff from cropping lands are a combination of natural soil nutrients and nutrients added to the soil in fertilisers. Sugarcane cropping utilises the highest proportion of fertiliser in Queensland (Pulsford 1996). Large increases in the use of fertilisers in the last 30 years have occurred in the coastal catchments (Pulsford 1996) and a high proportion (50–70%) of the applied fertiliser is lost to the off-farm environment (Moody et al. 1996; Rayment et al. 1996; Mitchell et al. 2001). Rayment and Neil (1997) compared actual and recommended fertiliser application rates in sugarcane cropping and concluded that more phosphorus fertiliser but, in most cases, less nitrogen fertiliser than recommended is applied. At regional scales, nitrogen losses from fertilised sugarcane growing sub-catchments are detectable in river systems during major flood events (Mitchell et al. 1997; Hunter 1997). Long term sampling of nutrients in the Tully River has shown a near doubling of levels of particulate nitrogen and phosphorus and a small increase in nitrate at a downstream site over the last thirteen years (Mitchell et al. 2001).

### *2.3.2 Heavy Metals*

Heavy metals are naturally found in rocks and soils and can be applied to crops as either essential micronutrients in fertiliser (copper, zinc, iron) or as contaminants in fertilisers (cadmium, lead, mercury). The mean concentrations of the heavy metals arsenic, cadmium, cobalt, copper, chromium, lead, nickel and zinc, were found by Rayment and Neil (1997) to be higher in sugarcane cropping soils than in similar soil types nearby that are without sugarcane.

The major processes for transportation of heavy metals are soil erosion or sediment mobilisation as most heavy metals are bound to soil particles. Agriculture, mining, metal processing, and other industrial processes have the potential to release elevated levels of the toxic heavy metals (primarily arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc), via these processes, into the GBR lagoon. Also of concern is the mobilisation of heavy metals by acid leaching from oxidised acid sulfate soils (ASS) (section 2.3.5). Atmospheric transport of dust is also a possible pathway for heavy metals to be transported to the GBR lagoon (Rayment 1995).

Evidence for elevated metal levels from past mining activity has been found off the Burdekin River in Bowling Green Bay (Walker & Brunskill 1997a, b). Significantly elevated mercury levels (up to 20 $\mu$g/kg) were found in sediment cores and this has been linked to the use of mercury in gold recovery during the peak (1870–1890) of gold mining in Charters Towers, a small town approximately 100 kilometres inland on the Burdekin River. Sediment cores taken in the Hinchinbrook Channel and Missionary Bay show close correlation between elevated mercury levels in marine sediments, and the application of Shirtan mercury as a fungicide on cane land in the Herbert River from 1950 to 1996 (Brunskill et al. unpub. data). Accumulated concentrations of mercury in these soils have almost doubled since 1950. In harbour and port areas, such as those of Townsville and Gladstone, very high concentrations of metals are often found in sediments (Jones & Thomas 1988). This is usually attributed to ore spillage, stormwater runoff and ship building and repair.

Once in the water column, heavy metals may be bioaccumulated by marine organisms (Chester & Murphy 1990; Rainbow 1990). Elevated heavy metal concentrations, particularly of cadmium, have been found in dugong tissues (especially liver and kidney) from the GBR (Denton et al. 1980; Gladstone 1996) and in crustaceans (prawns, crayfish and spanner crabs) from Torres Strait (Evans-Illidge 1997). These are, however, believed to be naturally high and not associated with contamination sources.

### *2.3.3 Other Contaminants*

Organochlorines are carbon-based chemicals compounds containing chlorine. Many of these compounds are artificial and have a wide range of industrial and agricultural applications. They include pesticides and herbicides such as DDT, lindane, diuron and 2,4-D and polychlorinated biphenyls (PCBs). Organochlorine pesticides were widely used in Australia until the use of many were banned in the late 1980s. The main organochlorine pesticide still in use today is the insecticide endosulfan. Polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) form as unwanted by-products of processes such as waste incineration, coal burning, metal smelting, car exhausts, pulp and paper manufacture and sugarcane and trash burning (Anon. 1989; Müller et al. 1996a, b). They also occur as contaminants in a range of herbicides and in polychlorinated benzene (PCB) compounds (Safe & Hutzinger 1989).

Organochlorines enter the aquatic environment through terrestrial runoff, urban stormwater runoff, and as aerosols (Clendening et al. 1990). Once in the water column, organochlorines adsorb to fine particulates or are bioaccumulated into lipids in aquatic biota (Olsen et al. 1982). The bioaccumulation of organochlorine pesticides and PCBs has been linked to reproductive and immunological abnormalities in terrestrial bird populations and in marine mammal populations (Boon et al. 1992). Many of these compounds are also assumed to be carcinogens (Richardson 1995). Herbicides have the potential to adversely impact seagrasses (section 3.2). Measurable quantities of the herbicide diuron and of other pesticides have been detected in sediments and seagrass at a number of locations along the GBRWHA coast and in Moreton Bay (Haynes et al. 1999). Pesticide residues were also detected in estuarine sediments and biota along the Queensland coast (Mortimer 2000) and in surface water of streams in the Johnstone River catchment (Hunter et al. 1996). Cavanagh et al. (1999), however, did not detect pesticide residues in coastal sediments in Bowling Green Bay or around Hinchinbrook Island.

High levels of octa-chloro-*p*-dioxin (OCDD) were detected in intertidal and/or estuarine sediments along the Queensland coast between Brisbane and Cardwell although the source of the dioxin has not yet been clearly identified (Müller et al.

1999). The Queensland OCDD levels were higher than levels in areas that are regarded as polluted such as waterways close to urban areas in Europe and the United States.

Polycyclic aromatic hydrocarbons (PAHs) are derived from petroleum products. They are known carcinogens and mutagens (Clark 1992; Benlahcen et al. 1997) that are easily bioaccumulated in some aquatic organisms (Connell 1995) and have been implicated in a wide range of human health effects as well as disease problems in aquatic organisms (Grimmer 1983; Plesha et al. 1988).

### 2.3.4 Freshwater

In Queensland catchments, as in many catchments overseas, the area of land covered with vegetation has been reduced and replaced by consolidated surfaces in urban areas, roads, and drainage schemes that result in higher volumes of water runoff. Conversely, the presence of dams on many GBR rivers may moderate flows and an estimated 13% (8 $km^3$) of the average annual discharge from the GBR Catchment is potentially captured in existing reservoirs (Gilbert et al. in press). The implications of changes in mean freshwater flow and the impacts of river regulation on estuarine and marine habitats are largely unknown (Robertson et al. 1996), however, low salinity events from cyclonic rainfall floods have caused coral reef bleaching and mortality in the GBRWHA (e.g. Berkelmans & Oliver 1999; Hoegh-Guldberg 1999).

### 2.3.5 Acid Sulfate Soils

Acid sulfate soils (ASS) is the common name for soils that contain iron sulphides. ASS are potentially widespread in coastal Queensland especially below 5 AHD; an estimated 2.3 million hectares of coastal lands contain actual or potential ASS (Powell & Ahern 1999). These soils occur naturally in water-logged soils in low-lying coastal areas and are harmless when they remain below the water table. When ASS become exposed to air, by disturbance or drainage, the iron sulphides are oxidised and produce sulphuric acid (White et al. 1996). Acid leaching leads to severe acidification of adjacent waterways (pH as low as 2) as well as the mobilisation of toxic heavy metals (iron and aluminium) naturally present in the soil. The impact on coastal biota and habitats is severe, including fish kills and fish diseases (Sammut & Lines-Kelly 1997).

The more recent identification of the toxic cyanobacterium *Lyngbya majuscula* (forming extensive benthic mats) as the cause of dermatitis in fisherman around northern Deception Bay in south-east Queensland has raised further concerns about the effects of ASS runoff (Dennison et al. 1999a). Blooms of *Lyngbya majuscula* in Queensland coastal waters are triggered by dissolved iron runoff from acid sulfate soils and the leaching of ‘coffee rock’, an organic iron-rich geological deposit formed in vegetated sandy soils (Dennison et al. 1999b) and can cause severe damage to seagrass beds. In addition to the contact dermatitis, *Lyngbya* has been linked to breathing irritation and eye inflammation. Further investigation is required into the occurrence of these blooms in the GBRWHA.

### 2.3.6 Litter

Stormwater discharge, particularly from urban areas, carries quantities of litter into the GBR. Surveys of litter on GBR islands have shown that much of the material is ship-sourced however a significant proportion may come from terrestrial sources (Haynes 1997). As well as aesthetic concerns, litter may be implicated in the entanglement of marine animals such as turtles (Carr 1987), birds (Laist 1987), mammals (Beck & Barros 1991) and fish (Laist 1987).