

**Investigation of Mangrove Dieback  
in the  
Pioneer River Estuary, Mackay**



**A. Kirkwood and R. Dowling  
August 2002**



# **Investigation of Mangrove Dieback Pioneer River Estuary, Mackay**

**A. Kirkwood Botanist  
and  
R. Dowling Principal Botanist**

**Queensland Herbarium  
Environmental Protection Agency**

**A report prepared for the Sugar Research Development  
Corporation  
August 2002**

**Project EPA001**

Funding for this activity was provided by the sugar industry and the Commonwealth Government through SRDC, and is gratefully acknowledged. The Environmental Protection Agency is not a partner, joint venturer, employee or agent of SRDC and has no authority to legally bind SRDC, in any publication of substantive details or results of this Project.



COVER PICTURE: Mangrove dieback northern bank Pioneer River adjacent to Riverside Drive, North Mackay

## Executive Summary

This report discusses the results of an investigation to establish a potential cause of the mangrove dieback that has occurred within the Pioneer River estuary and Bassett Basin, Mackay, Central Queensland from 1998 to 2001. Only one mangrove species, *Avicennia marina*, is apparently affected by dieback within this area. The principal objective of this study was to assess the hypothesis that a flood event and subsequent deposition of mud and silt in the mangrove communities was a likely cause of the dieback. This report refutes the argument that the most likely cause of the dieback is herbicide (diuron and ametryn) use within the Pioneer River catchment.

Observations of mangrove communities in the Pioneer River estuary made by one of the authors in 2001 indicated that large amounts of mud and silt had been deposited in the estuary and had buried *Avicennia marina* pneumatophores in dieback areas. Burial of pneumatophores is a commonly reported cause of *Avicennia* spp. dieback in other parts of Australia and overseas.

Recent and historical aerial photographs of the Pioneer River estuary were examined to determine the temporal and spatial extent of the current mangrove dieback and any past dieback events within the estuary. The current dieback event appears to have commenced no earlier than June 1998 and was clearly visible in November 1999 photographs. Other historical cases of mangrove dieback in the estuary have been documented.

Flood records from 1884 to 2000 at Mackay were examined and found to correlate with the onset of the present dieback event. As a result of this analysis, an unseasonal flood event in August 1998 was deemed to be a likely cause of the current dieback. Rainfall and stream height data for 1998, especially for August of that year, were analysed to determine the source of these floodwaters. Intense rainfall had occurred across the whole catchment over a three day period in late August 1998, resulting in high river flows across the catchment and within the Pioneer River estuary.

Examination of aerial photographs of the Brisbane River, Queensland, revealed that a major flood in 1974 had caused similar mangrove dieback in that river, most likely by depositing mud and silt in the mangrove communities.

To determine if recent or historical land clearing in the Pioneer River catchment may have contributed to or added to the severity of dieback in the Pioneer River estuary, the extent of land clearing from 1947 to 1999 within the catchment was mapped. The majority of clearing within the Pioneer River catchment occurred prior to 1947 and relatively little clearing has occurred since then.

Other cases of mangrove dieback and clearing have occurred in the Pioneer River estuary in the past and the mangrove communities have recovered. There appears to be no reason why recovery from dieback in this instance will be any different. Indeed there is evidence of seedling recolonisation by *Avicennia marina* to support this assessment.

Because of the high probability that there is no difference in diuron concentrations between Bucasia/Eimeo (non-dieback) and Barnes Creek (dieback) and the fact that mangrove dieback was not observed at Bucasia/Eimeo Creeks, it cannot be concluded that herbicides are the cause of dieback

## Table of Contents

|       |                                                                                       |    |
|-------|---------------------------------------------------------------------------------------|----|
| 1     | <b>Introduction and Background</b> .....                                              | 1  |
| 1.1   | <i>Nature and extent of mangrove dieback in the Mackay region</i> .....               | 1  |
| 1.1.1 | <i>Mangrove monitoring at Barnes Creek</i> .....                                      | 1  |
| 1.1.2 | <i>Preliminary investigation into the mangrove dieback in the Mackay region</i> ..... | 1  |
| 1.2   | <i>Objectives of this study</i> .....                                                 | 4  |
| 2     | <b>Study Area</b> .....                                                               | 5  |
| 2.1   | <i>Climate and streamflow hydrology</i> .....                                         | 7  |
| 2.2   | <i>Tides</i> .....                                                                    | 7  |
| 2.3   | <i>Mangroves</i> .....                                                                | 7  |
| 2.4   | <i>Land use</i> .....                                                                 | 8  |
| 3     | <b>Methods</b> .....                                                                  | 10 |
| 3.1   | <i>Field observations</i> .....                                                       | 10 |
| 3.2   | <i>Recent and historical changes in mangroves</i> .....                               | 10 |
| 3.2.1 | <i>Mapping the current dieback</i> .....                                              | 10 |
| 3.2.2 | <i>Examining past change</i> .....                                                    | 11 |
| 3.3   | <i>Pioneer River floods</i> .....                                                     | 12 |
| 3.4   | <i>Pioneer River catchment rainfall in August 1998</i> .....                          | 12 |
| 3.5   | <i>Pioneer River and tributary stream flows in 1998</i> .....                         | 12 |
| 3.6   | <i>Brisbane River mangrove communities before and after 1974</i> .....                | 14 |
| 3.7   | <i>Land use change</i> .....                                                          | 16 |
| 3.8   | <i>Changes in herbaceous cover in the catchment</i> .....                             | 16 |
| 4     | <b>Results</b> .....                                                                  | 17 |
| 4.1   | <i>Field observations</i> .....                                                       | 17 |
| 4.2   | <i>Recent and historical changes in mangroves in the Pioneer River estuary</i> .....  | 19 |
| 4.2.1 | <i>Recent mangrove dieback</i> .....                                                  | 19 |
| 4.2.2 | <i>Historical changes</i> .....                                                       | 22 |
| 4.3   | <i>Pioneer River floods</i> .....                                                     | 24 |
| 4.4   | <i>Pioneer River catchment rainfall August 1998</i> .....                             | 27 |
| 4.5   | <i>Pioneer River and tributary stream flows in 1998</i> .....                         | 35 |
| 4.6   | <i>Brisbane River mangrove communities before and after 1974</i> .....                | 40 |
| 4.7   | <i>Land use change</i> .....                                                          | 43 |
| 4.8   | <i>Changes in herbaceous cover in the catchment</i> .....                             | 43 |
| 5     | <b>Discussion</b> .....                                                               | 45 |
| 5.1   | <i>Burial of mangrove pneumatophores in the Pioneer River estuary</i> .....           | 45 |
| 5.1.1 | <i>The effect of burial of mangrove pneumatophores</i> .....                          | 45 |
| 5.2   | <i>The August 1998 flood as the source of the sediments</i> .....                     | 46 |
| 5.3   | <i>Sedimentation and accretion within the Pioneer River estuary</i> .....             | 46 |
| 5.4   | <i>Land use and erosion in the Pioneer River catchment</i> .....                      | 48 |
| 5.5   | <i>Patterns of change in mangrove communities</i> .....                               | 49 |
| 5.5.1 | <i>Dieback of Brisbane River mangroves following 1974 flood</i> .....                 | 50 |
| 5.5.2 | <i>Mangrove change in the Pioneer River estuary</i> .....                             | 50 |
| 5.4.3 | <i>The uses of diuron in Queensland</i> .....                                         | 51 |
| 5.7   | <i>Long-term prognosis</i> .....                                                      | 52 |
| 6     | <b>Conclusion</b> .....                                                               | 52 |
| 7     | <b>Further Research Needs</b> .....                                                   | 53 |
| 8     | <b>Dissemination of the results</b> .....                                             | 53 |
| 9     | <b>Acknowledgments</b> .....                                                          | 54 |
| 10    | <b>References</b> .....                                                               | 55 |
| 11    | <b>Appendix A</b> .....                                                               | 68 |

## List of figures

|                                                                                                                                                                                                           |    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| <b>Figure 1</b> Map of eastern Queensland, showing the location of the Pioneer and Brisbane River catchments and major cities. ....                                                                       | 6  |
| <b>Figure 2</b> Map of the Mackay region, showing estuaries surveyed for mangrove dieback by Duke et al. (2001) and the mangroves mapped by Finglas et al. (1995).....                                    | 9  |
| <b>Figure 3</b> The Pioneer River catchment, showing locations of rain and stream gauge stations.....                                                                                                     | 13 |
| <b>Figure 4</b> The reaches of the Brisbane River examined for mangrove dieback in 1973 and 1979 aerial photographs.....                                                                                  | 15 |
| <b>Figure 5</b> Mangrove dieback adjacent to Macalister Street, Mackay before substrate removal by the Queensland Fire Service.....                                                                       | 17 |
| <b>Figure 6</b> Officers of the Queensland Fire Service washing sediment away from dieback affected mangroves adjacent to Macalister Street, Mackay .....                                                 | 18 |
| <b>Figure 7</b> Mangrove substrate adjacent to Macalister Street, Mackay. ....                                                                                                                            | 18 |
| <b>Figure 8</b> Mangrove dieback on the northern bank of the Pioneer River adjacent to Riverside Drive, North Mackay.....                                                                                 | 19 |
| <b>Figure 9</b> The Pioneer River Estuary in 1999 with areas of mangrove dieback visible on the aerial photographs marked in red. ....                                                                    | 21 |
| <b>Figure 10</b> Sandfly Creek and area northeast of Town Beach in 1986, 1990, 1991 and 1998 .....                                                                                                        | 22 |
| <b>Figure 11</b> Changes in mangrove distribution in the Pioneer River estuary between 1953 and 1993. ....                                                                                                | 23 |
| <b>Figure 12</b> The height of floods recorded at Mackay between 1900 and 2000. ....                                                                                                                      | 25 |
| <b>Figure 13</b> The height of floods recorded at Mackay between 1900 and 2000 and the year in which they occurred.....                                                                                   | 26 |
| <b>Figure 14</b> Average monthly rainfall and total monthly rainfall in 1998 at Dalrymple Heights, Finch Hatton Post Office, Mackay Meteorological Office, Mirani and Te Kowai Experimental Station. .... | 28 |
| <b>Figure 15</b> Total rainfall between 28 <sup>th</sup> and 30 <sup>th</sup> August 1998 for selected rain gauge stations in the Pioneer River catchment and at Homebush.....                            | 29 |
| <b>Figure 16a</b> Daily rainfall in 1998 at Dalrymple Heights, Finch Hatton Post Office and Finch Hatton Standalone rainfall stations in the Pioneer River catchment.....                                 | 30 |
| <b>Figure 16b</b> Daily rainfall in 1998 at Hannavale Alert, Mackay Alert and Mackay Meteorological Office rainfall stations in the Pioneer River catchment. ....                                         | 31 |
| <b>Figure 16c</b> Daily rainfall in 1998 at Mirani, Mirani Weir Tailwater and Plevna Alert rainfall stations in the Pioneer River catchment.....                                                          | 32 |
| <b>Figure 16d</b> Daily rainfall in 1998 at Sarich's Alert, Teemburra Creek Dam and Teemburra Creek Dam Catchment rainfall stations in the Pioneer River catchment. ....                                  | 33 |
| <b>Figure 17</b> Daily rainfall in 1998 at Te Kowai Experimental Station rainfall station in the Pioneer River catchment and Sandy Creek at Homebush in the Plane Creek Catchment Area.....               | 34 |
| <b>Figure 18a</b> Maximum daily stream gauge heights in 1998 at Black's Creek and Cattle Creek stream gauge stations in the Pioneer River catchment.....                                                  | 35 |

|                                                                                                                                                                                                  |    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| <b>Figure 18b</b> Maximum daily stream gauge heights in 1998 at Finch Hatton Creek Dam Site, Mirani Weir Tailwater and Sarich's Alert stream gauge stations in the Pioneer River catchment. .... | 36 |
| <b>Figure 18c</b> Maximum daily stream gauge heights in 1998 at Teemburra Creek Dam and Teemburra Creek Dam Tailwater guage stations in the Pioneer River Catchment.....                         | 37 |
| <b>Figure 19</b> Maximum daily gauge heights in 1998 at Sandy Creek at Homebush.....                                                                                                             | 38 |
| <b>Figure 20</b> Predicted tidal data for Mackay Outer Harbour and actual stream gauge recordings at Mackay Alert between 19 <sup>th</sup> August and 1 <sup>st</sup> September 1998.....        | 39 |
| <b>Figure 21</b> The Brisbane River at Long Pocket Reach in 1973 and 1979 .....                                                                                                                  | 40 |
| <b>Figure 22</b> The Brisbane River at Long Pocket, Indooroopilly Island and Indooroopilly in 1973 and 1979. ....                                                                                | 41 |
| <b>Figure 23</b> The Brisbane River at Sherwood Reach and Chelmer Reach and Fig Tree Pocket in 1973 and 1979 .....                                                                               | 42 |
| <b>Figure 24</b> Cleared land in the Pioneer River catchment in 1947, 1995, 1997 and 1999.....                                                                                                   | 44 |
| <b>Figure 25</b> Comparison of the concentrations of herbicide found in mangrove sediment by Duke et al. (2001).....                                                                             | 50 |

#### **List of Tables**

|                                                                                                                                                           |    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| <b>Table 1</b> ‘Cause assessment table’ for mangrove dieback in the Mackay region resulting from the Preliminary Investigation into Mangrove Dieback..... | 3  |
| <b>Table 2</b> Aerial photographs of the Pioneer River estuary examined for mangrove dieback. ....                                                        | 11 |
| <b>Table 3</b> Aerial photographs of the Brisbane River examined for mangrove dieback.....                                                                | 14 |
| <b>Table 4</b> Aerial photographs of the Pioneer River catchment which were used for mapping land use change .....                                        | 16 |
| <b>Table 5</b> Flood classifications for three stream gauge stations in the Pioneer River Catchment. ....                                                 | 40 |
| <b>Table 6</b> The proportion of cleared to uncleared land in the Pioneer River catchment between 1947 and 1999. ....                                     | 43 |

# 1 Introduction and Background

## 1.1 *Nature and extent of mangrove dieback in the Mackay region*

Dieback of mangroves in the Mackay region has reputedly been occurring since 1998. However, the precise date when dieback commenced is unknown. Detailed observations were first made in March 2000 (Duke et al. 2001). Mangrove dieback was then reported as being most severe in, but not restricted to, the Pioneer River estuary and the associated Bassett Basin. Nearby river systems and estuaries also reputedly affected include Leila/Reliance Creeks, Bucasia/Eimeo Creeks, McCreadys Creek, Bakers Creek, Sandringham Bay and Sandy/Alligator Creeks (Duke et al. 2001). The extent and severity of the dieback have caused concern among community groups and other stakeholders in the Mackay region.

Within the Pioneer River estuary only one mangrove species, *Avicennia marina* (grey mangrove), is affected by dieback (Duke et al. 2001; McKillup and Melzer 1999; McKillup and McKillup 2000a, 2000b, 2001a, 2001b; Dowling, personal observation). Although dieback of another mangrove species, *Ceriops* sp., was noted in the nearby Constant Creek and Sandy/Alligator Creek estuaries, it appears to be unrelated to the dieback of *Avicennia marina* in the Mackay region (Duke et al. 2001; R. Dowling, personal observation).

### 1.1.1 *Mangrove monitoring at Barnes Creek*

A monitoring study of the mangrove communities along Barnes Creek was initiated in November 1999 to detect possible impacts caused by the construction or operation of the proposed East West Connector Road running along the northern edge of the intertidal zone at Barnes Creek (McKillup and Melzer 1999). McKillup and McKillup (2000a) noted that some *Avicennia marina* trees had died between November 1999 and December 2000. Further sampling in December 2000, May 2001 and December 2001 did not detect any more dead *Avicennia marina* trees. The mortality of trees did not appear to be age related because a wide range of tree sizes was affected (McKillup and McKillup 2000b, 2001a, 2001b).

### 1.1.2 *Preliminary investigation into the mangrove dieback in the Mackay region*

In March 2000, Dr Norman Duke wrote to the Queensland Department of Primary Industries and the Environmental Protection Agency regarding the dieback of mangroves in the Pioneer River estuary (Appendix 1 in Duke et al. 2001). A preliminary investigation into the dieback and the probable causes commenced in June 2000 (Duke et al. 2001). In that investigation's report, Duke et al. stated "the extent and severity of dieback in the Pioneer River estuary was considered the worst ever recorded where the cause was both unintentional and unknown". Duke stated that the "dieback was species-specific, apparently affecting only the common mangrove, *Avicennia marina*" (Duke et al. 2001, p. 55).

Duke et al.'s 2001 assessment of the extent of mangrove dieback was based on aerial surveys of estuaries in the Mackay region, not on aerial photography. Six estuaries were surveyed, namely Leila/Reliance Creeks, Bucasia/Eimeo Creeks, McCreadys Creek, Pioneer River and Bassett Basin, Bakers Creek, Sandringham Bay and Sandy/Alligator Creeks. Dieback was recorded as occurring in all estuaries surveyed except for

Bucasia/Eimeo Creeks. Dieback was reported as being most severe in the Pioneer River estuary, particularly in Bassett Basin and around Barnes Creek. Duke et al. stated that at least 86%, or 6.6 km<sup>2</sup>, of mangrove forests in the Pioneer estuary were affected by dieback, with around 22% being severely damaged. Severe dieback was defined as “larger patches of dead trees, greater than 20-30 adjacent individuals, or, areas with greater than 30% dead *Avicennia marina* trees”. Moderate dieback was defined as scattered dead and sick trees (less than 30% of *A. marina* dead) amongst healthy *A. marina* trees (Duke et al. 2001 p. 18, 20).

Duke et al.’s conclusions regarding the likely cause of the dieback were based on observations and samples taken from sites in the Pioneer River and Bucasia/Eimeo Creek estuaries. Their measurements and observations included measurement of mangrove health and plant photosynthesis, analysis of leaf chlorophyll, nitrogen, carbon and major elements; analysis of nutrients in water and the level of heavy metals and herbicides within the sediment (Duke et al. 2001). The number of plots used for observation or measurement or sampling varied according to the type of observation or analysis. The number of plots ranged from 3-15 in the Pioneer River estuary and 1-6 in the Bucasia/Eimeo Creeks estuary (Duke et al. 2001).

The preliminary investigation into mangrove dieback in the Pioneer River estuary considered twelve possible causes of the dieback and concluded that herbicides, specifically ametryn and diuron, were the most likely cause (Duke et al. 2001; Table 1). This conclusion was based primarily on the fact that herbicides (ametryn and diuron) were detected in mangrove sediments at concentrations reputedly toxic to seagrasses. Duke et al. dismissed the deposition of silt or changes in hydrology as a likely cause of the dieback.

**Table 1.** ‘Cause assessment table’ for mangrove dieback in the Mackay region resulting from the Preliminary Investigation into Mangrove Dieback. Possible causes are ranked with the most likely shown at the bottom of the table. After Duke et al. (2001).

| <b>Possible causes of dieback</b>                                                 | <b>Aspects of the preliminary investigation</b> |                |                      |
|-----------------------------------------------------------------------------------|-------------------------------------------------|----------------|----------------------|
|                                                                                   | Supportive evidence                             | Spatial extent | Current ground truth |
| Physical damage by humans                                                         | Unlikely                                        | Unlikely       | Unlikely             |
| Violent storm                                                                     | Unlikely                                        | Unlikely       | Unlikely             |
| Pathogens (Phytophthora/Halophytophthora)                                         | Unlikely                                        | Unlikely       | Unlikely             |
| Herbivory and foliage loss                                                        | Unlikely                                        | Unlikely       | Unlikely             |
| Oil spill                                                                         | Unlikely                                        | Unlikely       | Unlikely             |
| Atmospheric-borne pollutants                                                      | Unlikely                                        | Unlikely       | Unlikely             |
| Acid-sulphate soils (mangrove burial)                                             | Possible                                        | Unlikely       | Unlikely             |
| Changes in hydrology (flushing, erosion, or deposition of sediment)               | Unlikely                                        | Unlikely       | Unlikely             |
| Heavy metals                                                                      | Possible                                        | Unlikely       | Unlikely             |
| Changes in salinity as a result of fluctuations in rainfall and climatic patterns | Possible                                        | Possible       | Unlikely             |
| Excess nutrients from fertilisers and sewerage                                    | Possible                                        | Possible       | Unlikely             |
| Toxic chemicals (eg herbicides, algicides and insecticides)                       | Possible                                        | Possible       | Possible             |



In early July and again in late August 2001 one of the authors (Dowling) visited the Mackay region to observe the extent and nature of the mangrove dieback. These field observations indicated that the reported dieback was most severe in the Pioneer River estuary and Bassett Basin with small areas of dieback within Sandringham Bay. Areas of dieback noted in Leila Creek, Bucasia/Eimeo Creek, McCreadys Creek and Bakers Creek occurred in locations where they would normally be expected as a of mangrove community development. As such, they were not considered by the authors to be associated with the dieback that was occurring in the Pioneer River estuary. At that time, it was noted that dieback in the Pioneer River estuary occurred in areas lower on the tidal plane and that areas higher on the tidal plane or towards the tidal limits appeared to be unaffected.

It was also observed that there was a layer of mud and silt over much of the lower estuarine area and few or no pneumatophores of *Avicennia marina* protruding from the soil surface in the mangrove communities affected by dieback as would normally be expected. Where trees were still alive, only partially affected by dieback, or were reshooting, living pneumatophores (breathing roots) were present around these trees. In general these pneumatophores were to be found close to the base of the trees. Those observations, together with the results of the preliminary investigation (Duke et al. 2001) and the Barnes Creek monitoring study (McKillup and Melzer 1999, McKillup and McKillup 2000a, 2000b, 2001a, 2001b), raised a number of questions regarding the possible cause of the dieback of *Avicennia marina* within the Mackay region.

Four general questions relating to the cause of the mangrove dieback were raised from reading the report by Duke et al.:

1. Why was *A. marina* the only species affected out of the approximately twenty mangrove species that are known to occur in the Mackay region?
2. Why are some *A. marina* plants affected and not others?
3. Why is mangrove dieback in the Pioneer River occurring only in the estuary and lower reaches and not in the upper reaches of the river where the effect of chemicals on mangroves, *A. marina* in particular, could be expected to be more marked or pronounced due to their proximity to the likely source of these chemicals?
4. If herbicides (ametryn and diuron) are responsible, why are similar outbreaks of dieback not occurring in other estuaries in Queensland in which *A. marina* is growing and in which sugar cane is grown within the catchment and where ametryn and diuron are used for weed control?

Four further questions were raised following observations of the mangrove dieback areas made by one of the authors (Dowling).

1. Why were groups of plants affected in some areas but adjacent plants not affected or only partly affected?
2. Why were no or few pneumatophores of *A. marina* observed within the affected mangrove communities or around the base of affected trees where they would normally be expected to be observed?
3. Why was there an obvious layer of relatively unconsolidated mud over much of the lower tidal plane of the lower Pioneer River estuary and the Bassett Basin?
4. Why were *A. marina* plants occurring higher on the tidal plane apparently unaffected by dieback whereas those lower on the tidal plane were, in general, severely affected?

Clearly, as a possible cause of the dieback, the presence of herbicides alone in the estuarine sediments does not adequately answer the above questions.

The current study proposes an alternative cause of the mangrove dieback at Mackay that attempts to answer these questions. Based on the evidence presented by Duke et al. (2001) and observations of the dieback areas made by one of the authors (Dowling), the burial of mangrove pneumatophores by sediment is proposed as an alternative and more likely cause of the dieback. This report proposes that an unseasonal flood event in late August 1998 and the subsequent deposition of silt within the Pioneer River estuary and Bassett Basin were primarily responsible for the dieback.

### ***1.2 Objectives of this study***

The principal objective of this study was to assess the hypothesis that a flood event and the subsequent deposition of silt were a likely cause of the mangrove dieback currently being experienced around Mackay, and in particular in the Pioneer River estuary.

To assess the above hypothesis and achieve the principal objective, specific goals were developed.

They were:

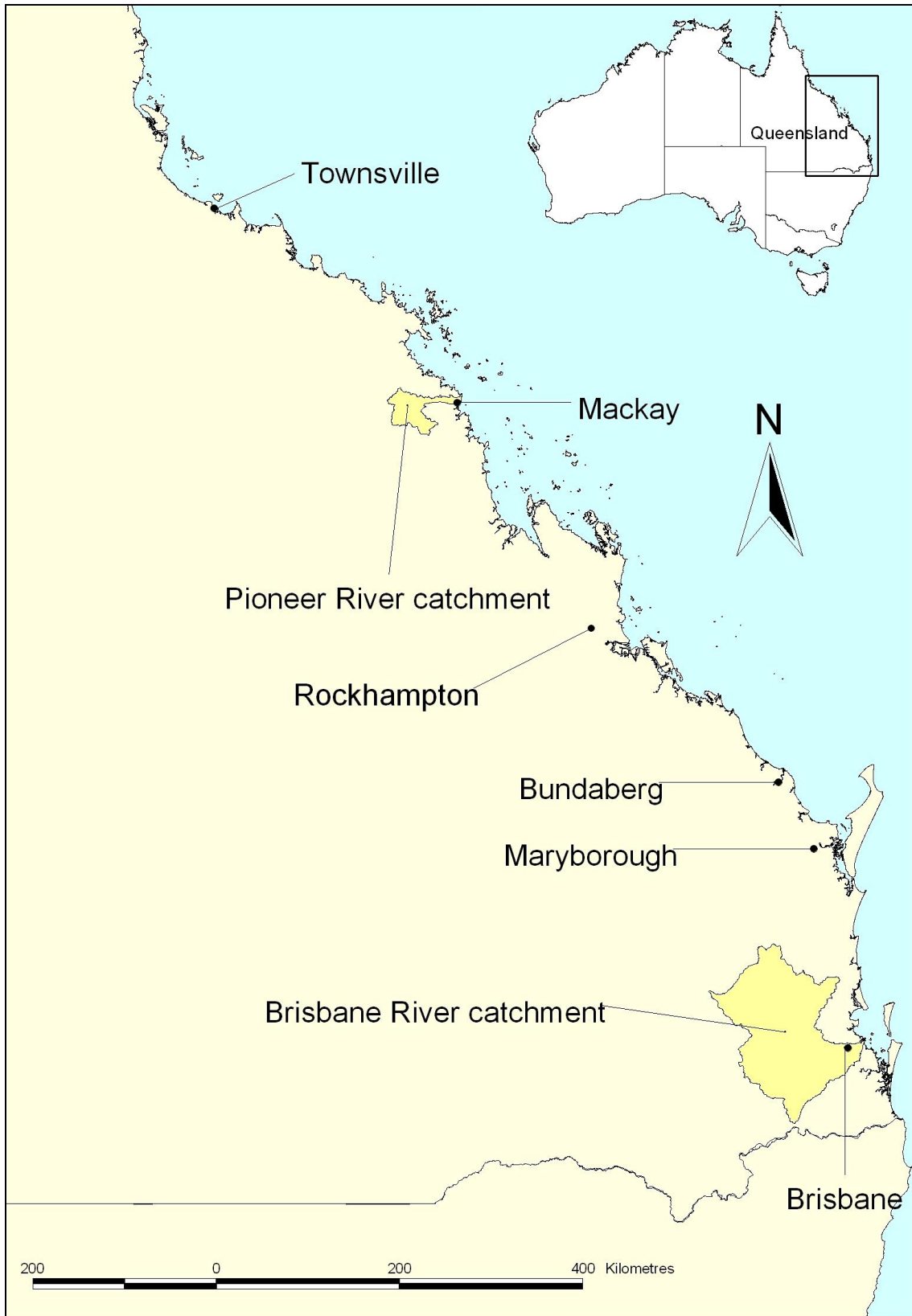
- To determine the extent of the current dieback within the mangrove communities
- To establish whether or not mangrove dieback in the Pioneer River estuary correlated with available rainfall, tidal and climatic data
- To determine if flood events in the past have resulted in mangrove dieback in the Pioneer River estuary
- To determine if mangrove dieback events have occurred in the past following floods in other estuaries in Queensland
- To determine if recent or historical vegetation clearance in the Pioneer River catchment may have contributed to or added to the severity of mangrove dieback

## **2 Study Area**

This study was focused on the Pioneer River catchment which is located on the Central Queensland Coast, Australia, because of (i) the severity of mangrove dieback in the Pioneer River estuary and (ii) the availability and quality of data that are available for the Pioneer River as compared to adjacent creeks and streams.

The Pioneer River catchment occupies approximately 1584 km<sup>2</sup>, and extends approximately 75 km inland from the coast at Mackay in Central Queensland (Fig. 1). The catchment area is characterised by a single estuary. It thereby differs from the adjacent Plane Creek and O'Connell River catchment areas which are drained by multiple smaller streams and estuaries. Natural flow regimes in the Pioneer catchment have been altered by the construction of impoundments such as Dumbelton Weir, Kinchant Dam and Teemburra Dam. Additionally flood mitigation works in the lower estuary have altered tidal flows and inundation patterns.

The City of Mackay is located adjacent to the Pioneer River estuary which includes the main channel of the Pioneer River and the associated Bassett Basin. The Bassett Basin is a large body of water that is protected from waves and wind action by the coastal dunes to the east (Gourlay and Hacker 1986). "It is not part of the main river channel and normally only tidal creeks, including Barnes and Vines Creeks, drain into it. The Bassett Basin receives most of its freshwater flow from Gooseponds Creek rather than the Pioneer River, except during floods (Anon. 2001a). During major and medium floods, the Pioneer River overflows into Barnes Creek (Gourlay and Hacker 1986). The tidal limit in the Pioneer River occurs at Dumbleton Rocks (Anon. 2001a), which are approximately 16 km upstream from the mouth.



**Figure 1.** Map of eastern Queensland, showing the location of the Pioneer and Brisbane River catchments and major cities.

## 2.1 *Climate and streamflow hydrology*

The Pioneer River catchment is situated between latitudes 21°00' and 21°25' South. The area overlaps two Köppen climatic classification categories, *A<sub>w</sub>* (Mackay – Whitsunday Coast) and *C<sub>w</sub>* (inland) (Sturman and Tapper 1996). Both categories are characterised by dry winters, but the former has mean temperatures of the coolest month greater than 18°C, while the latter has mean temperature of the coolest month between 18°C and -3°C. Mean temperatures of the warmest month in both categories exceed 22°C. Mean daily minimum temperatures at Mackay range from 12.8° to 23.4°C, and mean daily maxima from 21.2° to 29.8°C.

The Mackay region has a tropical climate, with most rain falling between the months of December and March, and the least in August and September. Mean annual rainfall for the whole Pioneer River catchment is 1385 mm (Anon. 2001b) but this varies considerably from year to year. Annual rainfall at Mackay ranged from 631 mm in 1923 to 3455 mm in 1958 (Gourlay and Hacker 1986). Similarly, there is significant variation in annual rainfall throughout the catchment, ranging from less than 1000 mm at the eastern end of the catchment to more than 2200 mm at Dalrymple Heights in the Headwaters of Cattle Creek (Gourlay and Hacker 1986). Mean annual rainfall at Mackay (Te Kowai Experimental Station) between 1889 and 2001 was 1686 mm (Bureau of Meteorology<sup>1</sup>).

The Pioneer River is essentially perennial flowing, although it has been reported to cease flowing during extreme drought (Gourlay and Hacker 1986). The tributary streams that arise in high rainfall areas such as the Clarke Range are perennial or near perennial flowing, but other streams in the catchment flow intermittently. Streamflow regimes in the catchment are strongly seasonal, with most flow in summer. Floods in the Pioneer River generally occur in the wet season (December to April) and account for most of the annual discharge of the Pioneer River (Brizga et al. 2001).

## 2.2 *Tides*

The coastline in the Mackay region has one of the highest tidal ranges for the east coast of Australia (Easton 1970). The coastline adjacent to the Pioneer River catchment has a tidal range in excess of 6 m. As a consequence, the Pioneer River estuary is subject to strong tidal currents that cause considerable reworking of the estuarine sediments (Gourlay and Hacker 1986).

## 2.3 *Mangroves*

The total area of mangroves in the Pioneer River estuary in 1993 was approximately 619 hectares (based on 1993 maps by Finglas et al. 1995). Smaller sized areas of mangrove communities were located in the adjacent estuaries of Bakers Creek (447 ha), and Bucasia/Eimeo/McCreadys Creeks (585 ha) (Finglas et al. 1995).

There are 20 species of mangrove recorded for the area between Shoal Point and Hay Point in central Queensland, which occur in 12 community types (Finglas et al. 1995) (Fig. 2). The three most common community types in this area are *Ceriops tagal* (1153 ha), *Rhizophora stylosa* (886 ha) and *Avicennia marina* dominated communities (709 ha) (Finglas et al. 1995).

---

<sup>1</sup> Digital data supplied by Bureau of Meteorology

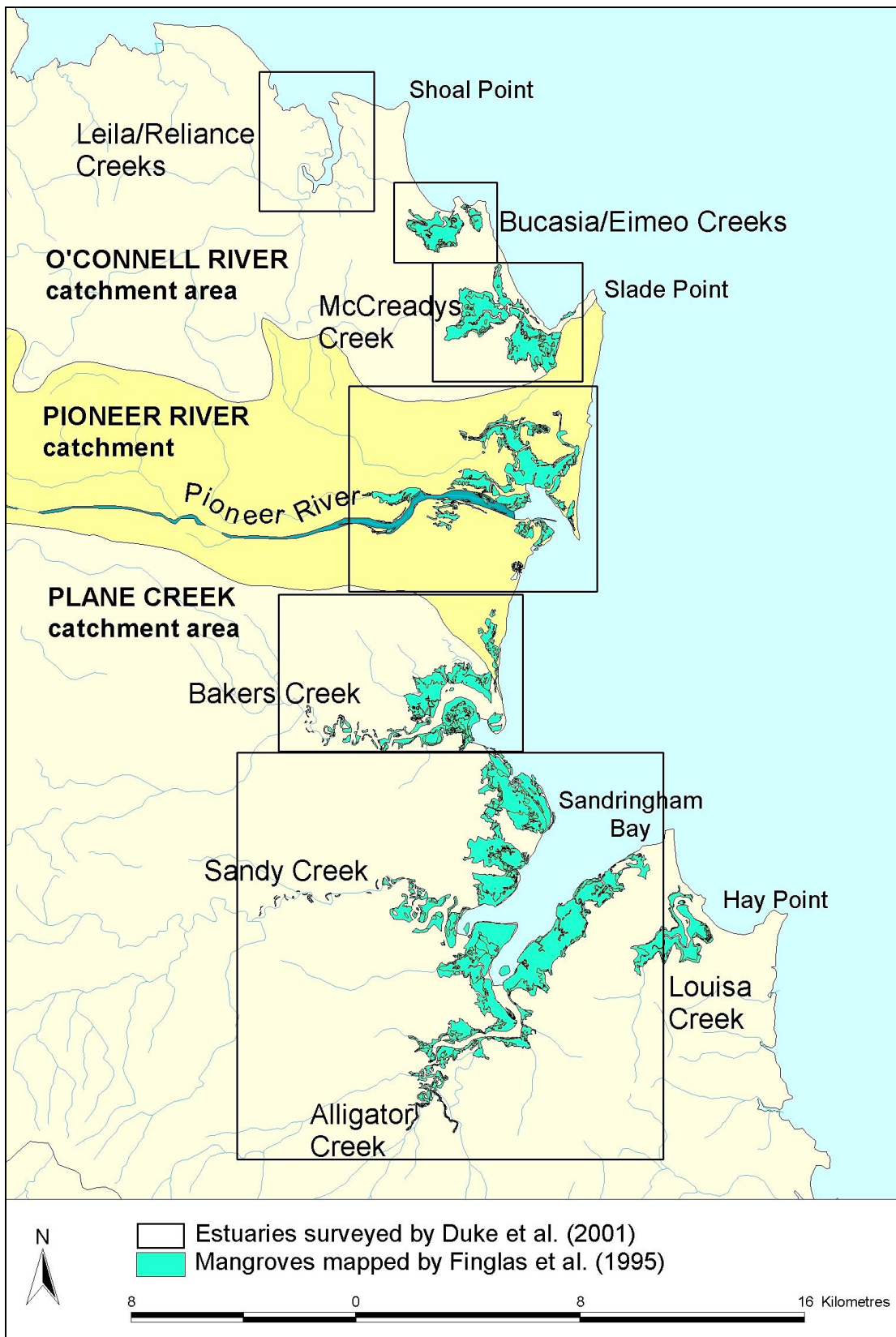


The most common mangrove community in the Pioneer River estuary is an *Avicennia marina* dominated community, which in 1993, comprised 42% (or approximately 257 hectares) of the total area of mangrove communities in this area (Finglas et al. 1995). *Rhizophora stylosa* and *Ceriops tagal* dominated communities were also extensive, occupying about 18% (114 ha) and 13% (81 ha) of the area of the estuary respectively. Of the 12 intertidal community types defined by Finglas et al. (1995), 11 are represented in the Pioneer River estuary, with only the *Bruguiera parviflora* dominated community absent.

*Avicennia marina* occurs as two subspecies in the Mackay region, *Avicennia marina* subsp. *eucalyptifolia* and *A. marina* subsp. *australasica*. The *Avicennia marina* dominated communities are very diverse and occur in all types of intertidal environment. The canopy is 2 to 6 metres high, with emergents extending to 7 metres, and can be either open or closed (foliage projective cover can be less than or more than 50%). This community type only rarely occurs as a monospecific stand, the canopy often being mixed with *Rhizophora stylosa*, when fringing waterways, or occasionally with *Excoecaria agallocha* and *Ceriops tagal* (Finglas et al. 1995).

#### **2.4 Land use**

Land use in the Pioneer River catchment is predominantly for cattle grazing, which utilises approximately 74% of the total land area. Other agricultural uses include cropping (mainly sugar cane), orchards, market gardening and horticulture. Thirty percent of the catchment is cleared, mostly on the plains, and remnant forest occurs mostly in the mountainous areas that are unsuitable for cultivation. Sugar cane production utilises most of the cleared land (63%), or 19% of the total catchment area (Anon. 2001b).



**Figure 2.** Map of the Mackay region, showing estuaries surveyed for mangrove dieback by Duke et al. (2001) and the mangroves mapped by Finglas et al. (1995).

## 3 Methods

### 3.1 Field observations

One of the authors (Dowling) visited the Mackay region in early July and late August 2001. Mangrove dieback was observed to be occurring at a number of locations within the Pioneer River estuary as well as in adjacent estuaries. These field observations, which consisted of point locations and transects through the dieback areas, found that the reported dieback was most extensive within the Pioneer River estuary and Bassett Basin with smaller areas adjacent to the southern mouth of Sandringham Bay. The most severe areas of dieback were to be found along the edges of stream banks downstream of the Ron Cam Bridge on the Pioneer River and along the edges of Barnes Creek, Vines Creek and Bassett Basin. Less severe dieback was also noted mainly within the mangroves along Barnes Creek, Vines Creek and within Bassett Basin. The only species apparently affected was *Avicennia marina*. Other areas of dieback that were noted within the Mackay region were in locations where dieback would normally be expected as part of the natural development of mangrove communities. As such, they were not considered by the authors to be associated with dieback occurring in the Pioneer River estuary.

It was noted that most of the mangrove dieback areas occurred on the low to mid-tidal plane. Mangroves in areas towards the upper tidal limits appeared to be unaffected. A thick layer of mud was noted to cover much of the sediments in which mangroves occurred in the area downstream of the Hospital Bridge. In addition, there was a conspicuous absence or unusually low occurrence of *A. marina* pneumatophores protruding above the substrate in the dieback-affected mangrove communities. However, it was noted that live pneumatophores were present around trees that were either still alive, only partially affected by dieback or were reshooting. In general, these pneumatophores were to be found close to the base of the trees.

To determine whether the pneumatophores had been buried by mud or had merely rotted away after the death of the trees (and were therefore not present), the Queensland Fire Service was requested to wash the mud and silt away from around the base of dead *A. marina* trees. This was undertaken on 30<sup>th</sup> August 2001 in an area of mangroves to the east of the convict built pathway that leads from the end of Macalister St., Mackay to the Pioneer River. This area is marked in the report by Duke et al. (2001) as an area of severe mangrove dieback. Due to limitations on the use of the Queensland Fire Service Officers for this purpose it was only possible to wash the mud and silt away at one location.

### 3.2 Recent and historical changes in mangroves

#### 3.2.1 Mapping the current dieback

Aerial photographs of the Pioneer River estuary were examined for two reasons. Firstly, to provide information on the progress of the mangrove dieback on a temporal basis, and secondly, to confirm that aerial photography could be used to identify areas or incidence of mangrove dieback that may have occurred in the past.

Aerial photographs of the Mackay region, provided by the Mackay Sugar Cooperative which overflies the sugar cane lands on a regular basis, were examined to determine the extent and temporal variation of the current mangrove dieback event. Aerial

photographs taken in November 1999 at 1: 30 000 scale, were examined and compared to photographs of the same area taken in October 1996 at 1: 25 000 scale. Aerial photographs taken in December 1998 at 1: 30 000 scale were also examined but these photographs did not cover the whole area of the estuary only covering as far east as the Forgan Bridge.

Mangrove dieback was clearly visible in the November 1999 aerial photographs but was not visible in the earlier 1996 or 1998 photographs. The location of areas of mangrove dieback that were visible in the November 1999 aerial photographs were recorded on transparent overlay film. The aerial photographs were scanned and geo-referenced, using control points visible on the aerial photographs which corresponded with points on the Digital Cadastral Database (DCDB). The photograph images were then used as a background layer over which the areas of dieback were digitised on-screen using MapInfo.

### 3.2.2 Examining past change

After confirming that mangrove dieback was discernable on aerial photographs, historical aerial photographs were examined for changes in mangrove distribution over time to determine past dieback events. Aerial photography of the Pioneer River estuary between 1947 and 1998 was obtained from Natural Resources and Mines (Queensland) (NR&M) and examined (Table 2). Aerial photography of the Mackay region after 1998 was not available from NR&M.

To determine the location and extent of changes in mangrove distribution between 1953 and 1993, maps of mangrove communities in the Pioneer River estuary in 1953 and 1993 (Finglas et al. 1995) were used. To verify that the 1993 maps adequately described the distribution and extent of mangrove communities in the Pioneer River estuary in 2000 (the year that Duke et al. undertook their survey), the GIS coverages created by Finglas et al. (1995) were obtained and compared to recent Landsat satellite images and registered aerial photographs of the area using MapInfo.

**Table 2.** Aerial photographs of the Pioneer River estuary examined for mangrove dieback.

| Year | Name of Photography                             | Runs        |
|------|-------------------------------------------------|-------------|
| 1947 | Mackay 47 Program Aerial Photography            | 3a, 4       |
| 1953 | Mackay 53 Program Aerial Photography            | 11          |
| 1962 | Mackay 62 Program Aerial Photography            | 5           |
| 1972 | Mackay 72 Program Aerial Photography            | 5           |
| 1976 | Mackay 76 Program Aerial Photography            | 4           |
| 1977 | Mackay 77 Project Aerial Photography            | 4           |
| 1982 | Mackay 82 Program Aerial Photography            | 4           |
| 1986 | Mackay 86 Program Aerial Photography            | 4           |
| 1991 | Mackay 91 Program Aerial Photography            | 4, 5        |
| 1993 | Mackay Study Area 93 Project Aerial Photography | 16, 17, 17a |
| 1996 | Pioneer River 96 Project Aerial Photography     | 17a         |
| 1998 | Mackay 98 Program Aerial Photography            | 4, 5        |

### ***3.3 Pioneer River floods***

The peak height of floods which occurred at Mackay between 1884 and 2000 were obtained from NR&M and analysed to determine the frequency of recorded floods and the frequency of floods for each month of the year.

### ***3.4 Pioneer River catchment rainfall in August 1998***

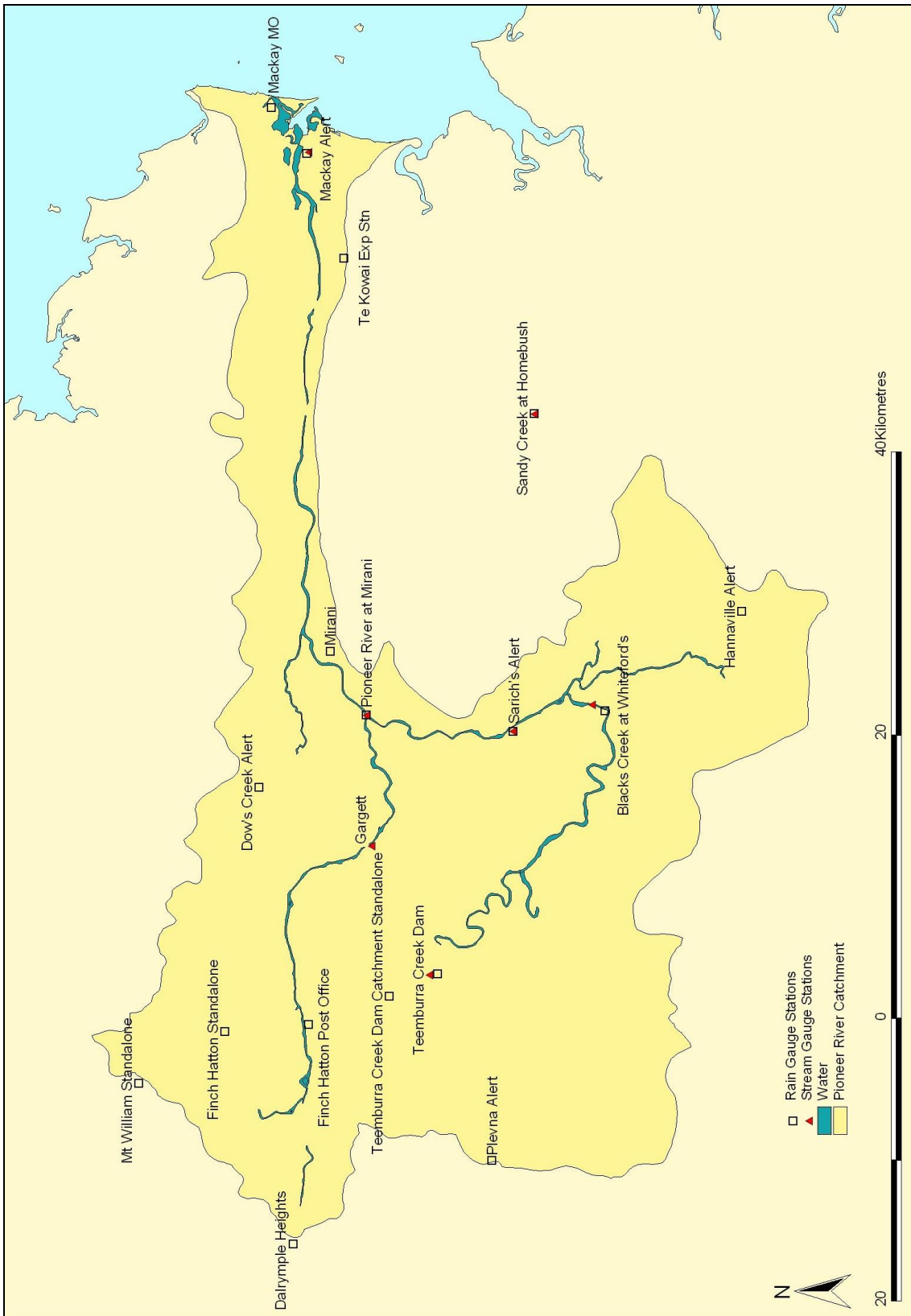
To determine the spatial and temporal distribution of rainfall across the Pioneer River catchment in 1998, daily rainfall data at rain gauge stations in the catchment were obtained from the Bureau of Meteorology (BOM) and Natural Resources and Mines (NR&M). Average monthly rainfall data for five stations in the catchment were also provided by BOM. The location of the rain gauge stations for which data were obtained is shown in Figure 3. Monthly rainfall data were calculated from the daily rainfall data for 1998 and compared with the average monthly data for the sites where they were available. To compare rainfall in the Pioneer River and Plane Creek catchment areas, daily rainfall data for Homebush were obtained.

### ***3.5 Pioneer River and tributary stream flows in 1998***

To determine the variation in stream flows across the Pioneer River catchment area in 1998, daily maximum stream heights for seven stream gauge stations in the catchment were obtained from NR&M. The location of the stream gauge stations for which data were obtained is shown in Figure 3. To compare stream flows in the Pioneer River and Plane Creek catchment areas, maximum daily stream heights at Sandy Creek (at Homebush) were also obtained. In 1998, this was the only stream gauge for which data were available in the Plane Creek catchment area.

To determine the height, time and duration of flood events in the Pioneer River at Mackay in 1998, continuous stream height data for the Mackay Alert stream gauge (situated adjacent to the Mackay Business District) were obtained from the Pioneer River Improvement Trust. Because the Pioneer River at Mackay Alert is tidally affected, the predicted tide height (for Mackay Outer Harbour) and recorded stream height at Mackay Alert were compared. Predicted tide height data in digital format for Mackay Outer Harbour in 1998 were obtained from the Queensland Department of Transport.





**Figure 3.** The Pioneer River catchment showing locations of rain and stream gauge stations.

### 3.6 *Brisbane River mangrove communities before and after 1974*

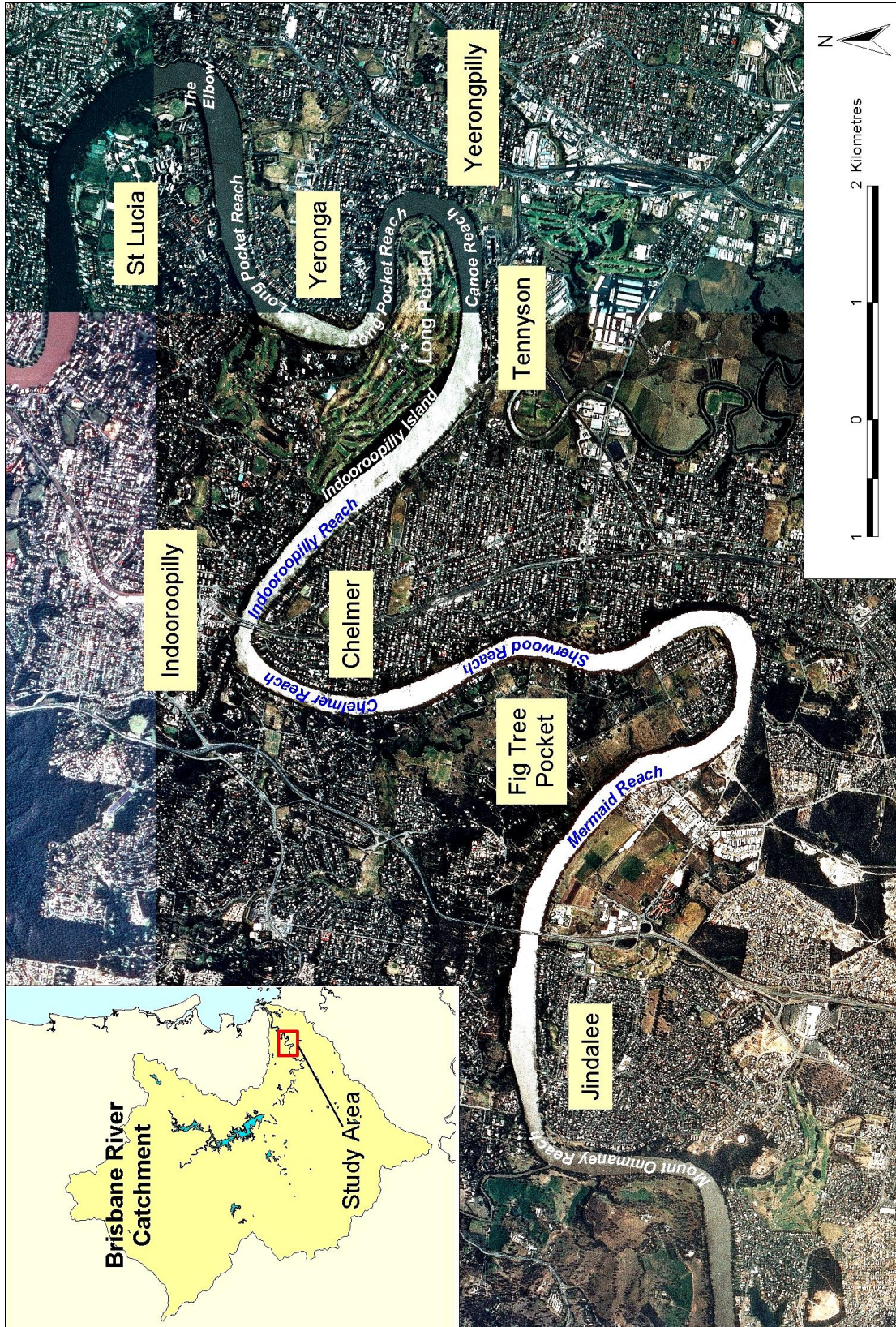
To determine if flood events have caused mangrove dieback in other Queensland rivers, comparable data from the Brisbane River was collated and examined. Aerial photographs and flood data for the Brisbane River are readily available because the capital city of Queensland, Brisbane, is located on the river close to the mouth. In January 1974, a major flood affected Brisbane and inundated much of the city. For this reason, aerial photographs of the Brisbane River were examined for mangrove dieback. Whilst the Brisbane River is tidally affected upstream beyond the Bremer River Junction, salt water intrusion probably only occurs as far upstream as Wacol as indicated by the presence of salt tolerant riparian vegetation (R. Dowling, personal observation).

Aerial photographs of the Brisbane River before and after the January 1974 flood were examined for signs of mangrove dieback (Table 3). Fringing mangrove communities in 1973 photographs at 1: 25 000 scale and 1979 photographs at 1: 25 000 scale were compared. Mangroves were examined along the length of the river between St Lucia and Jindalee (Fig. 4). Downstream of St Lucia examination of aerial photographs showed that few, if any, mangroves existed in 1973.

**Table 3.** Aerial photographs of the Brisbane River examined for mangrove dieback.

| <b>Year</b> | <b>Name of Photography</b>         | <b>Runs</b> |
|-------------|------------------------------------|-------------|
| 1973        | Brisbane River Harbours and Marine | 2           |
| 1979        | Ipswich                            | 1, 2        |





**Figure 4.** The reaches of the Brisbane River examined for mangrove dieback in 1973 and 1979 aerial photographs. (Derived from orthophotos supplied by NR&M)



### 3.7 *Land use change*

To determine recent patterns and extent of vegetation clearing on land in the Pioneer River catchment, maps and data documenting the extent of cleared land in the catchment at different dates were compared. Data on historical land clearing in the Pioneer River catchment was interpreted from the earliest available aerial photography (1947) of the area. However, in the southern parts of the catchment, the earliest available aerial photographs were from 1953 and 1957 (Table 4).

**Table 4.** Aerial photographs of the Pioneer River catchment which were used for mapping land use change.

| Year | Name of Photography                                | Flight Runs    | No. of Photographs |
|------|----------------------------------------------------|----------------|--------------------|
| 1947 | Mackay 47 Program Aerial Photography               | 3, 3a, 4, 5, 6 | 61                 |
| 1953 | Mt Britton-Hillalong 53 Program Aerial Photography | 15, 16, 17, 18 | 3                  |
| 1953 | Stockton-Mirani 53 Program Aerial Photography      | 14             | 7                  |
| 1957 | Mt Britton 57 Program Aerial Photography           | 1, 2           | 5                  |

Areas of cleared land were plotted on translucent drafting film overlaid on the aerial photographs. Vegetation was regarded as cleared if the canopy cover was less than 50% or less. A problem occurred when two of the flight runs diverged causing the photography from these runs to be non-overlapping. In this situation (limited to only a few photographs and a small area), the gap between the runs was mapped from later photographs, and it was assumed that this represented the situation in the earlier 1947 photographs. Control points were plotted on the overlays for the purpose of geo-referencing the maps. The overlay control points matched identifiable points located on 1997 Landsat TM satellite imagery and the DCDB for the area. Other features such as roads and streams were plotted for the purpose of evaluating the accuracy of the control points following geo-referencing.

The cleared land data was digitised by scanning the overlay maps, geo-referencing the resulting digital image using MapInfo and digitising the image on-screen. The accuracy of this process was evaluated by comparing the location of plotted roads and streams with satellite imagery and the DCDB.

To determine changes in the amount of cleared land over time, the Regional Ecosystem (RE) coverages produced by the Queensland Herbarium for 1995, 1997 and 1999 were compared with the 1947 coverage.

### 3.8 *Changes in herbaceous cover in the catchment*

To determine the temporal patterns of herbaceous cover in the Pioneer River catchment over the course of a year, CSIRO Land and Water were consulted. Specific information on herbaceous cover was not available for any land uses other than for sugar cane cropping. The Mackay Cane Production and Productivity Board provided data on the area of fallow land and the area of the crop as plant cane in 1998.

## 4 Results

### 4.1 Field observations

Removal of sedimentary mud by the Queensland Fire Service on the in an area adjacent to Macalister St, Mackay, showed that there were intact, but dead, pneumatophores present under the mud surface (Fig. 5,6,7). At this location the depth of the mud above the tops of the pneumatophores varied from 5 to 10cm.

Mud was also washed away from reshooting and living mangroves and this indicated that the pneumatophores present around the base of these trees were living and functional. This could be discerned by the numerous white fine roots present in the root mass and from around the base of the pneumatophores where these attached to the main root system.

Observations in the field also showed that pneumatophores were to be found around the base of live and reshooting trees. In general, where mangroves were still alive, they occurred on points that were comparatively higher on the tidal plane or in areas where fresh mud deposits were not evident (Fig. 8). This could be discerned from the drainage pattern and micro-relief of the sites examined. Such patterns were also noticeable at other areas in the Pioneer River estuary and the Bassett Basin that were examined.



**Figure 5.** Mangrove dieback adjacent to Macalister Street, Mackay, before sediment removal by the Queensland Fire Service. Note lack of pneumatophores above the substrate around dead trees.





**Figure 6.** Officers of the Queensland Fire Service washing sediment away from dieback affected mangroves adjacent to Macalister Street, Mackay 30<sup>th</sup> August 2001.



**Figure 7.** Mangrove substrate adjacent to Macalister Street, Mackay, showing live pneumatophores protruding above the substrate adjacent to a live *Avicennia marina* tree (yellow arrow). Note the absence of pneumatophores around the dead tree in upper left (red arrow).





**Figure 8.** Mangrove dieback on the northern bank of the Pioneer River adjacent to Riverside Drive, North Mackay. Live *Avicennia marina* trees are growing on a mound (indicated by arrow), the elevation of which is higher on the tidal plane than the substrate of the adjacent dead trees.

## 4.2 Recent and historical changes in mangroves in the Pioneer River estuary

### 4.2.1 Recent mangrove dieback

Neither dead mangrove trees nor mangrove dieback were obvious in the June 1998 or earlier photographs of the Pioneer River estuary. The current episode of mangrove dieback in the Pioneer River estuary was clearly visible in November 1999 photography. Dead and live *Avicennia marina* trees could be distinguished by the colour and density of their canopy. Dead trees were noticeable but difficult to distinguish in the January 2001 photographs because of the larger scale (1: 50 000) of the photographs, which made it difficult to distinguish individual dead trees. Such evidence indicates that the dieback probably commenced late in 1998 or early 1999.

The distribution and extent of mangroves in the Pioneer River estuary observed in 2000 were well represented by the 1993 maps of mangrove distribution made by Finglas et al. (1995). The total area of mangroves in the Pioneer River estuary is 6.19 km<sup>2</sup> (Finglas et al. 1995).

The extent of mangrove dieback observable in the November 1999 photography is shown in Figure 9. All the areas observed fall within the area of dieback as mapped in Duke et al. (2001). The area of dieback visible in November 1999 aerial photographs was considerably smaller in extent than that mapped by Duke et al. in June 2000 (Duke et al. 2001). Some areas of dieback mapped by Duke et al. in the upper part of Barnes Creek were not obvious in the November 1999 photographs. Suitable aerial photographs of the Pioneer River estuary after November 1999 were unavailable so it was not possible to map the current extent of dieback using aerial photography. In addition,

field observations by one of the authors (Dowling) in August 2001 indicate that the distribution and extent (if not the severity) of mangrove dieback as described by Duke et al. in 2001 is accurate.

However, the actual area of dieback-affected mangrove communities has probably been over-estimated. Duke et al. estimated that 6.6 km<sup>2</sup> of the mangrove forests in the Pioneer River estuary were affected by dieback, but previously stated that the total area of mangroves in the Mackay region in 1998 was only around 6.29 km<sup>2</sup> (Duke et al. 2001 p. 14, 30).

Duke et al. (2001) reported surveying approximately 53 km<sup>2</sup> of mangrove forests between Leila/Reliance Creeks and Sandy/Alligator Creeks. This may also be an overestimation as the area of mangrove forest between Bucasia/Eimeo Creeks and Sandy/Alligator Creeks was previously estimated as 32.2 km<sup>2</sup> (Finglas et al. 1995) and this figure was verified using GIS. The areas covered by both these surveys are shown in figure 2.





**Figure 9.** The Pioneer River estuary in 1999, with areas of mangrove dieback visible on the aerial photographs marked in red. (Compiled from aerial photographs supplied by Mackay Sugar).

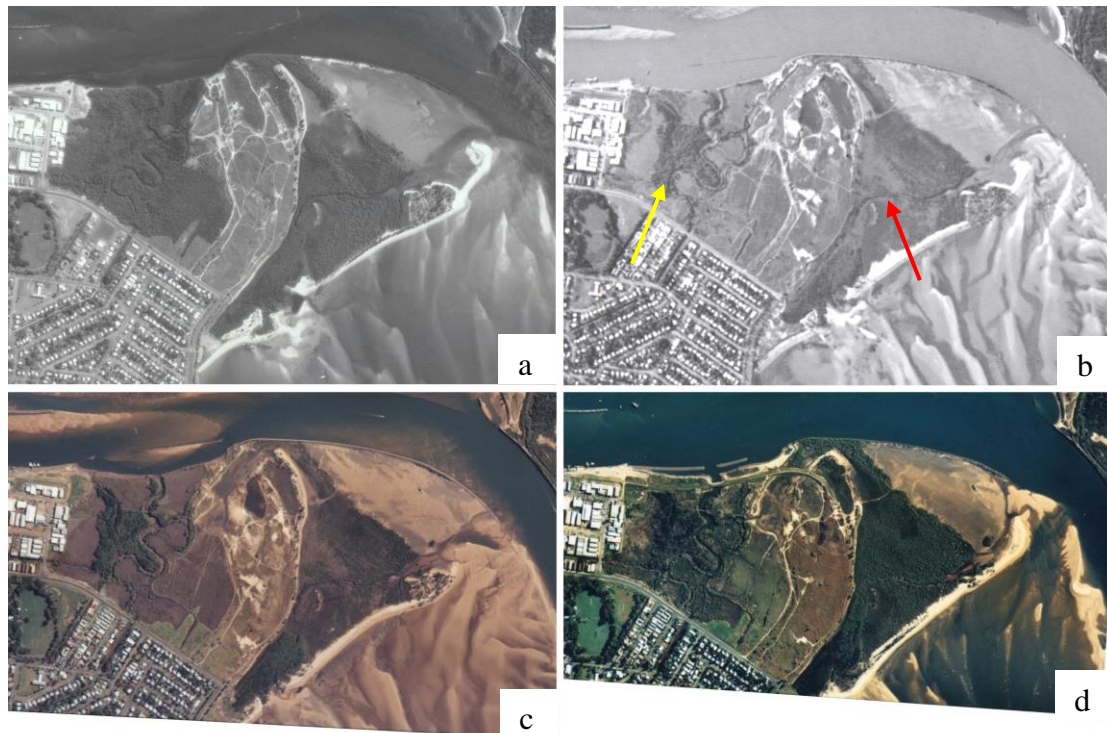


#### 4.2.2 Historical changes

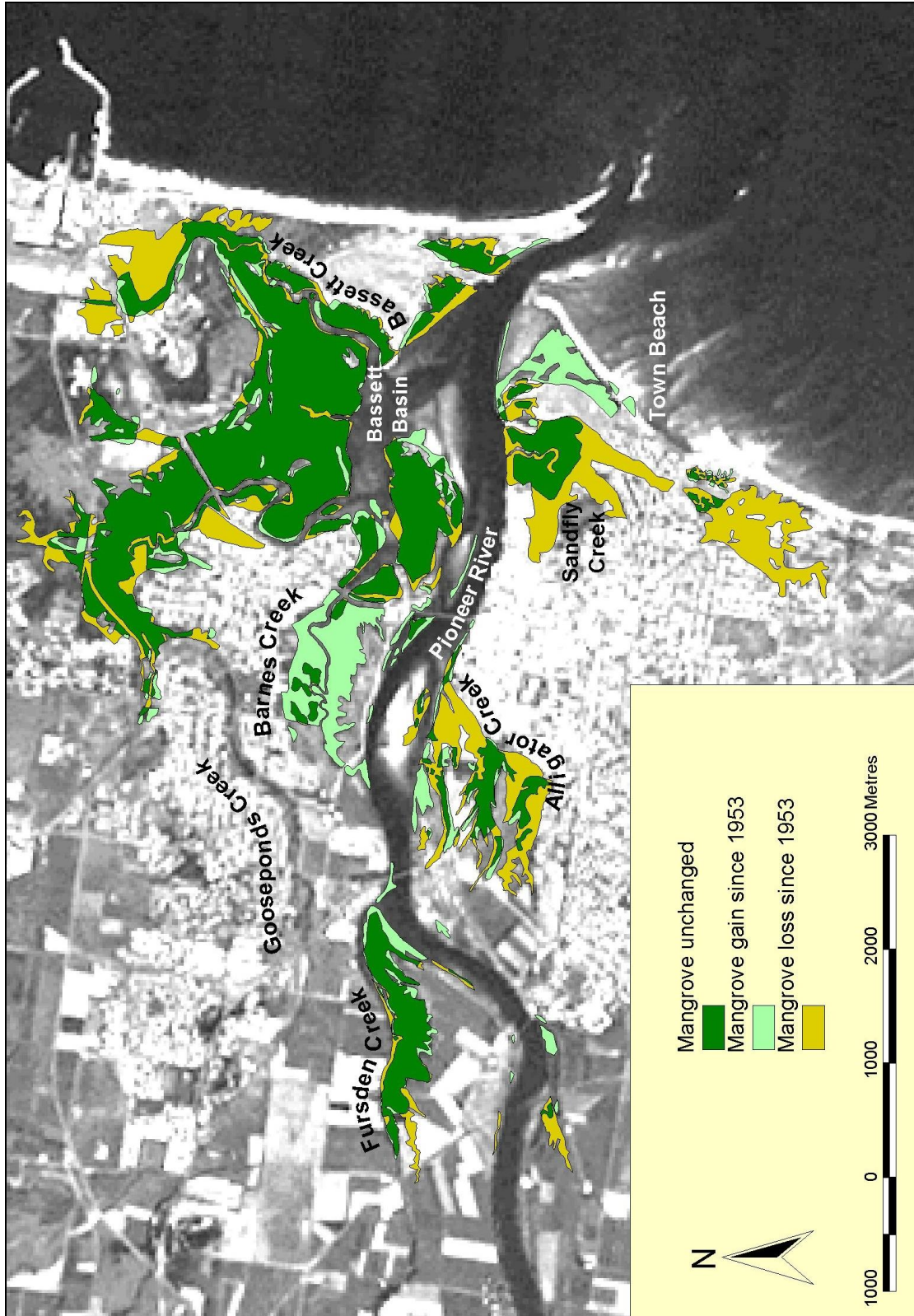
The distribution and extent of mangrove communities in the Pioneer River estuary changed considerably between 1953 and 1995 resulting in a net loss of mangroves (Finglas et al. 1995). The principal losses occurred around Sandfly Creek, Alligator Creek, northeast of the airport, and northeast of Mt Bassett. The principal net gains in mangroves occurred in the areas around Barnes Creek and northeast of Town Beach (Fig. 11) (Finglas et al. 1995).

Other significant changes in mangrove communities observed were:

- Between 1986 and 1990, a large area of mangroves around Sandfly Creek was cleared as part of a land development project. Later aerial photographs show regrowth of mangroves, including *Avicennia marina*, in this area (Fig. 10 yellow arrow).
- The area to the northeast of Town Beach was colonised by mangroves, predominantly *A. marina*, between 1947 and 1986. A dense stand of mangroves in the area was evident in 1986. Between 1986 and 1990, loss of mangroves occurred, mainly on the western side (Fig. 10 red arrow). Considerable regrowth of mangroves within this area was obvious in 1998 photography, when mangrove cover had returned to previous levels. Some losses had also occurred on the seaward side of these mangrove communities.
- In the Alligator Creek area, mangroves were cleared between 1953 and 1960. Regrowth was obvious until 1977, but later photographs showed these mangroves had been cleared again for development.



**Figure 10.** Sandfly Creek and area northeast of Town Beach in 1986 (a), 1990 (b), 1991 (c), and 1998 (d). (Scanned from aerial photographs supplied by NR&M).

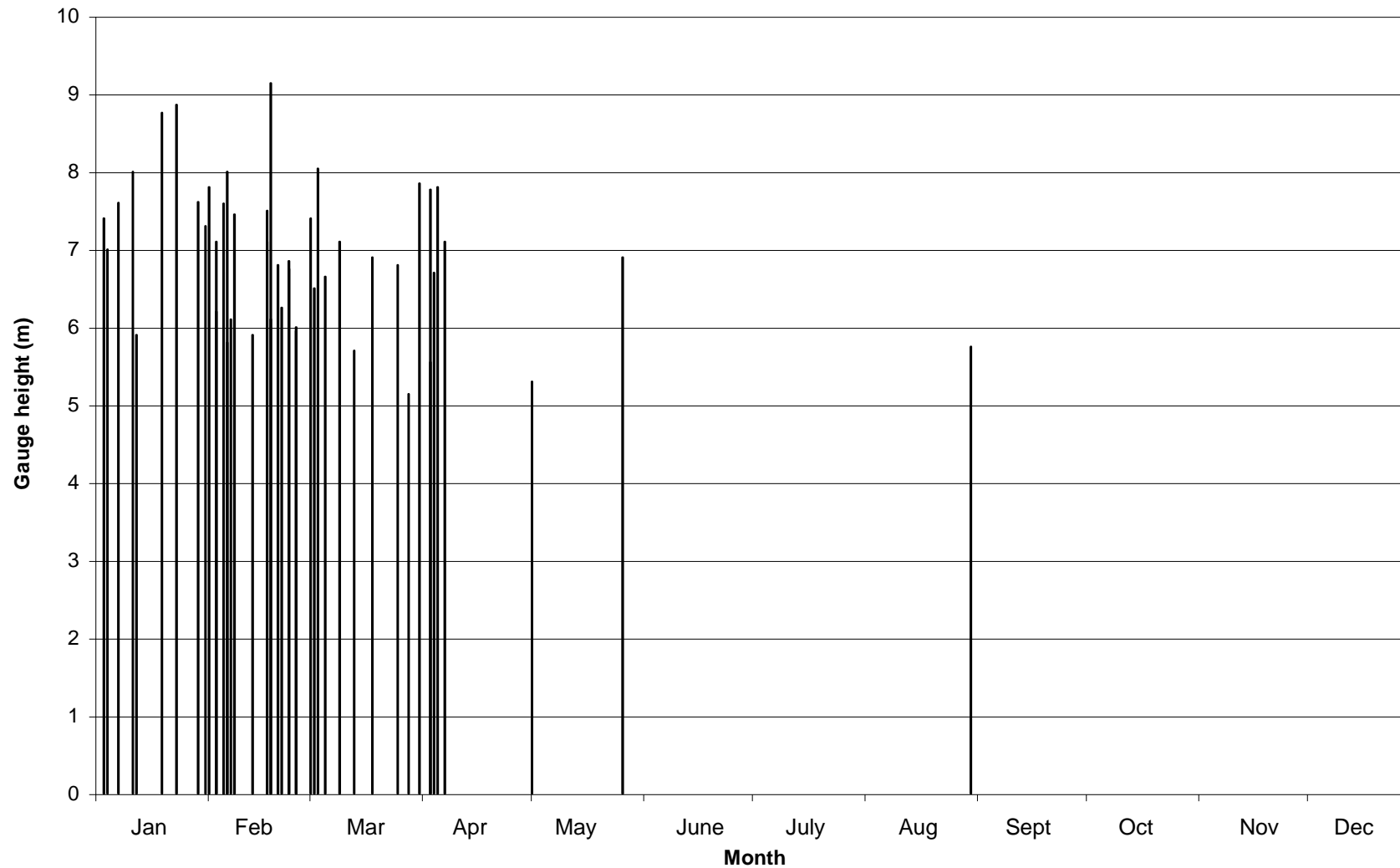


**Figure 11.** Changes in mangrove distribution in the Pioneer River estuary between 1953 and 1993. After Finglas et al. (1995). (Landsat base supplied by NR&M).

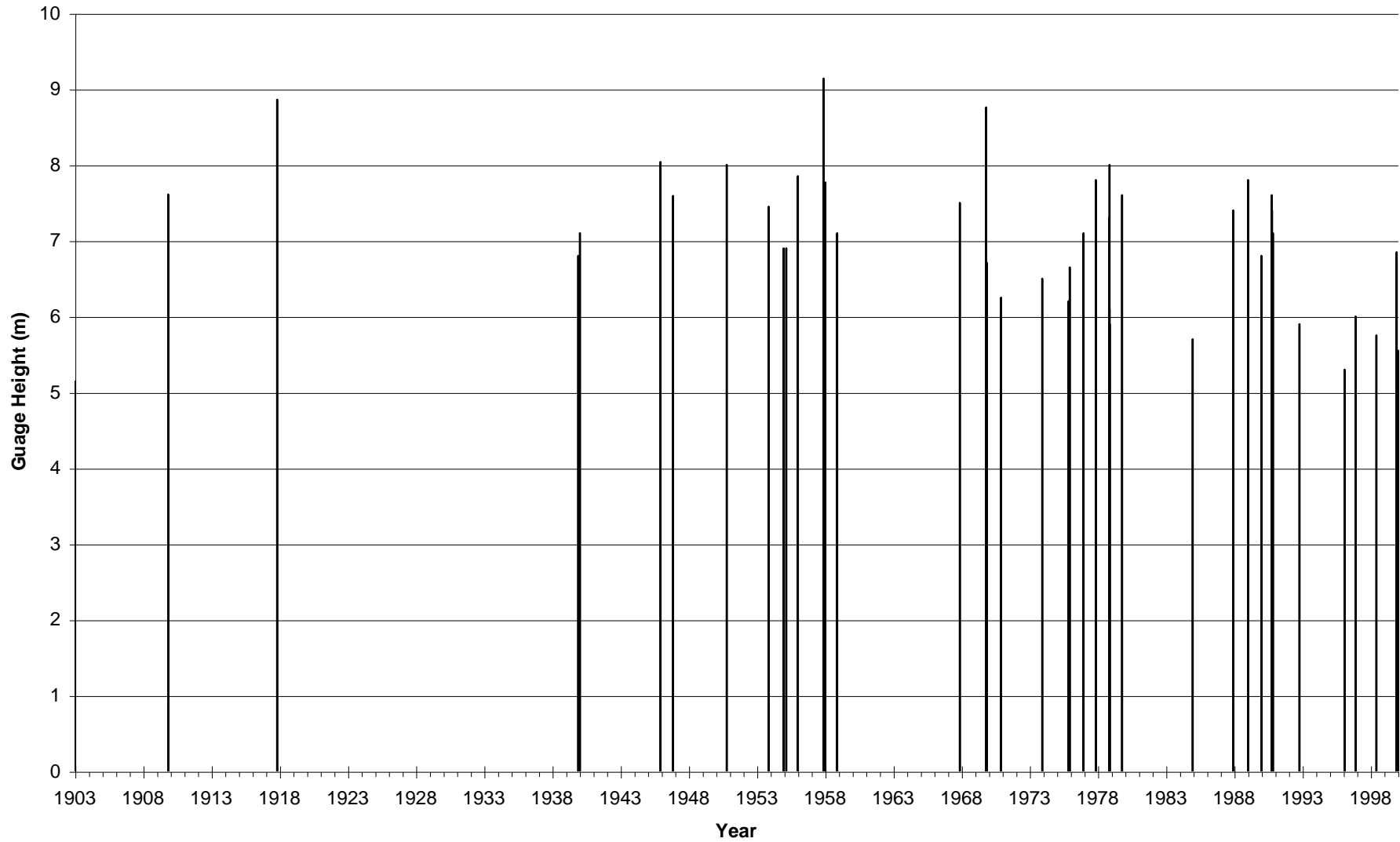
### ***4.3 Pioneer River floods***

Examination of the flood records for Mackay between 1884 and 2000 indicated that the majority of floods in the Pioneer River occur between late December and early April (Fig. 12). The record of peak flood heights obtained from NR&M must be interpreted with caution because of the possibility that some floods, particularly minor floods, were not recorded. Floods occurred with greater frequency in the latter half of this period than in the former half (Fig. 13). Floods occurred, on average, once every 5 years between 1884 and 1950, but at a rate of almost four floods per five-year period between 1950 and 2000. The only flood recorded as occurring between June and November since 1884 occurred in August 1998. No other floods were recorded in 1998.





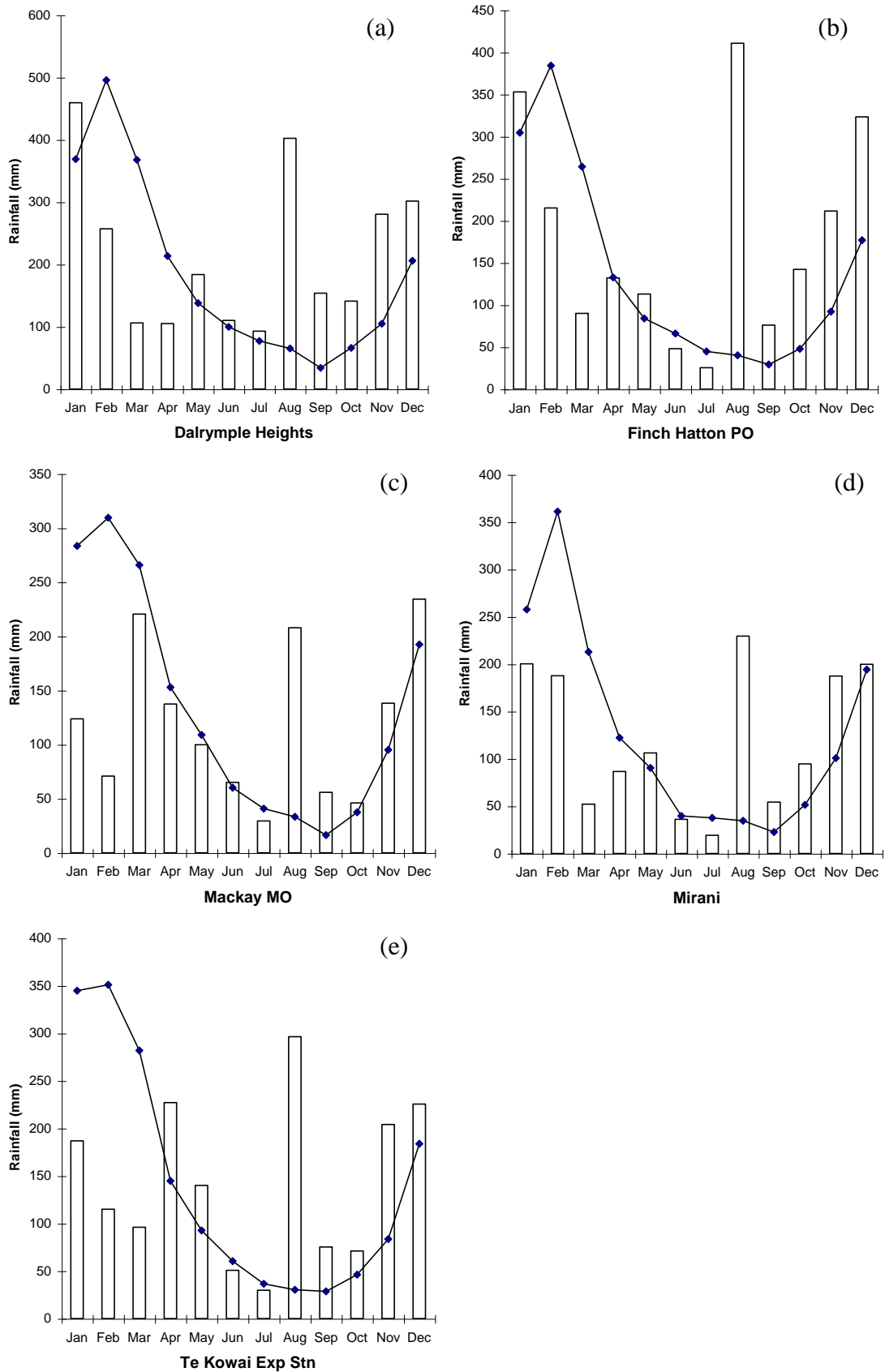
**Figure 12.** The height of floods recorded at Mackay between 1900 and 2000 and the month in which they occurred. Multiple floods in the same month were counted as one event. Other recorded floods occurred in January 1884 (8.3 m) and in February 1884 (7.91 m).



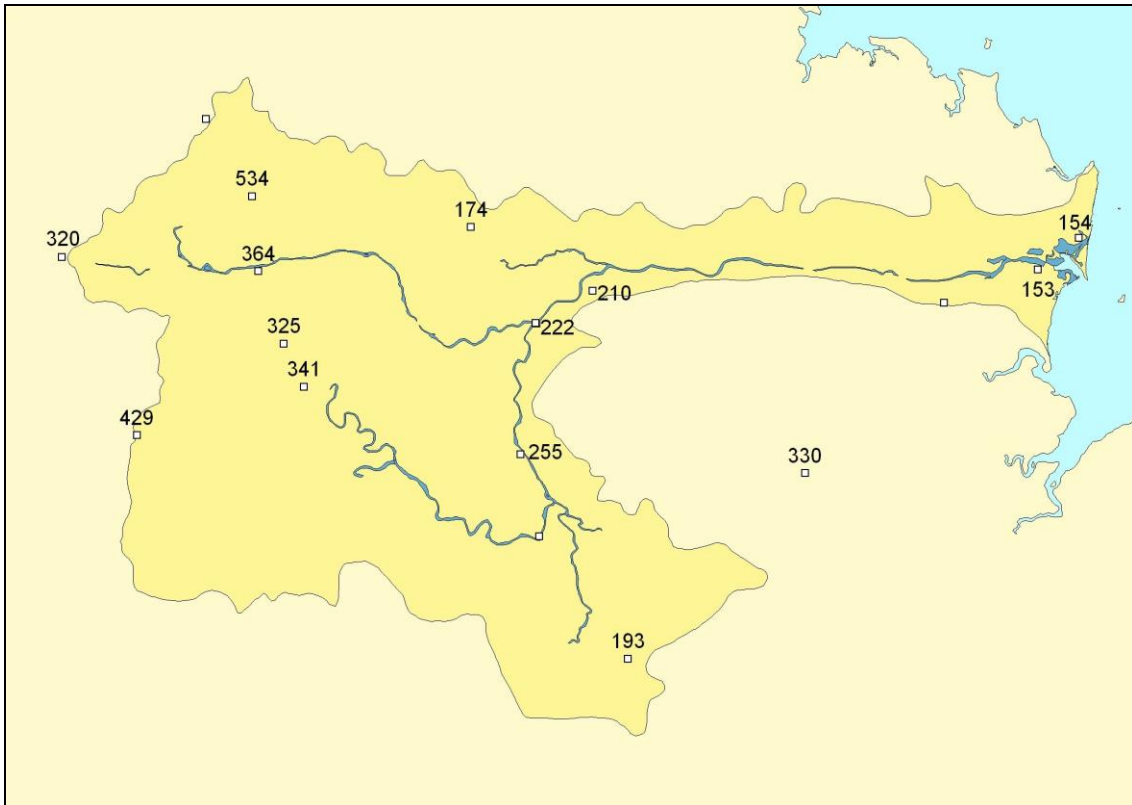
**Figure 13.** The height of floods recorded at Mackay between 1900 and 2000 and the year in which they occurred. Other floods were recorded at Mackay in January 1884 (8.3 m) and in February 1884 (7.91 m).

#### ***4.4 Pioneer River catchment rainfall August 1998***

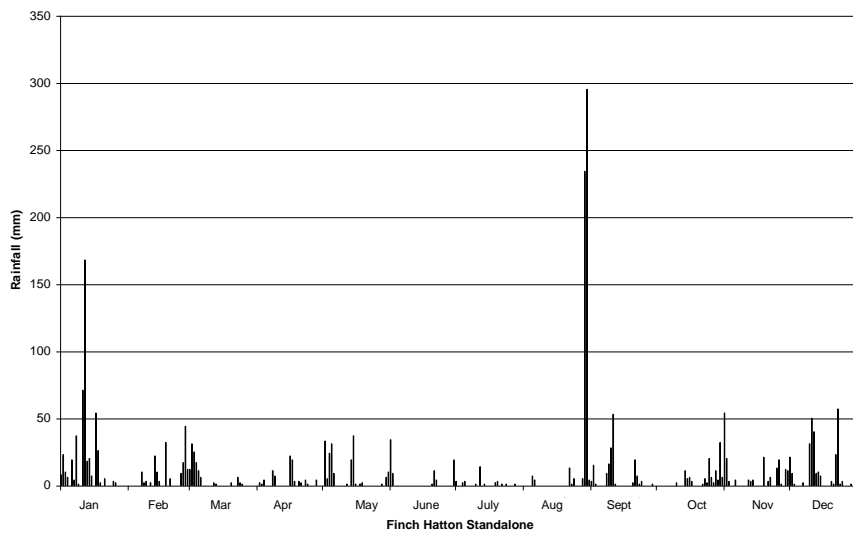
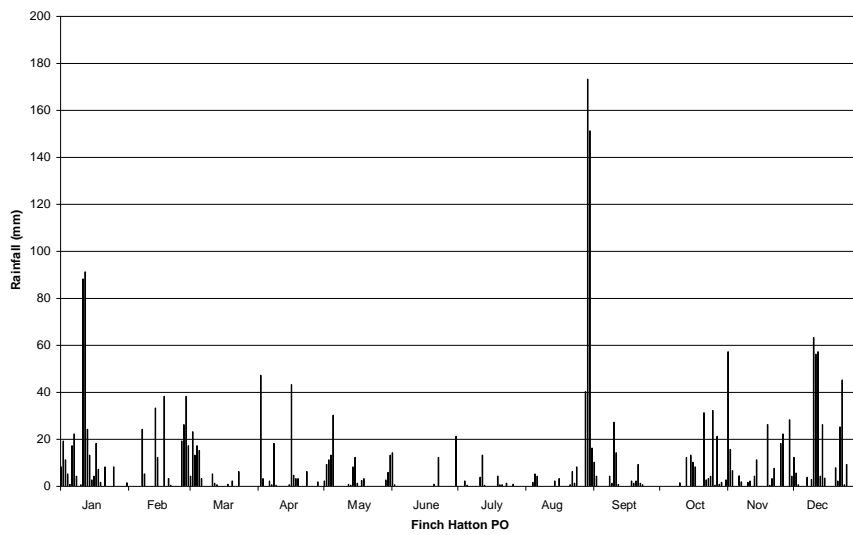
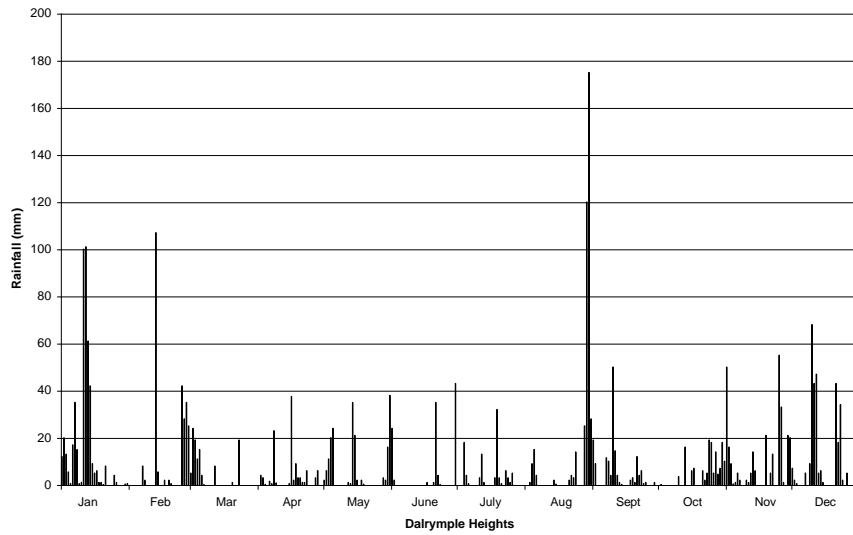
Below average rainfall was recorded across most of the Pioneer River catchment between January and March of 1998 (Fig. 14). Rainfall in August 1998 was between four and eight times higher than the average rainfall for this area in August (Fig. 14). The majority of rain in the Pioneer River catchment in August fell between the 28<sup>th</sup> and 30<sup>th</sup> August. Total rainfall for these three days in the catchment area is shown in Figure 15. During those three days, the highest daily rainfall for the year was recorded at all rain gauge stations across the catchment except for Hannaville Alert where a larger fall had occurred in January (Fig. 16a, Fig. 16b, Fig. 16c, Fig. 16d, Fig.17). The highest daily rainfall of 212 mm was recorded at Plevna Alert on 30<sup>th</sup> August. High rainfall (268 mm) was also recorded at Homebush on Sandy Creek, located in the adjacent Plane Creek catchment area, on the 30<sup>th</sup> August (Fig. 17).



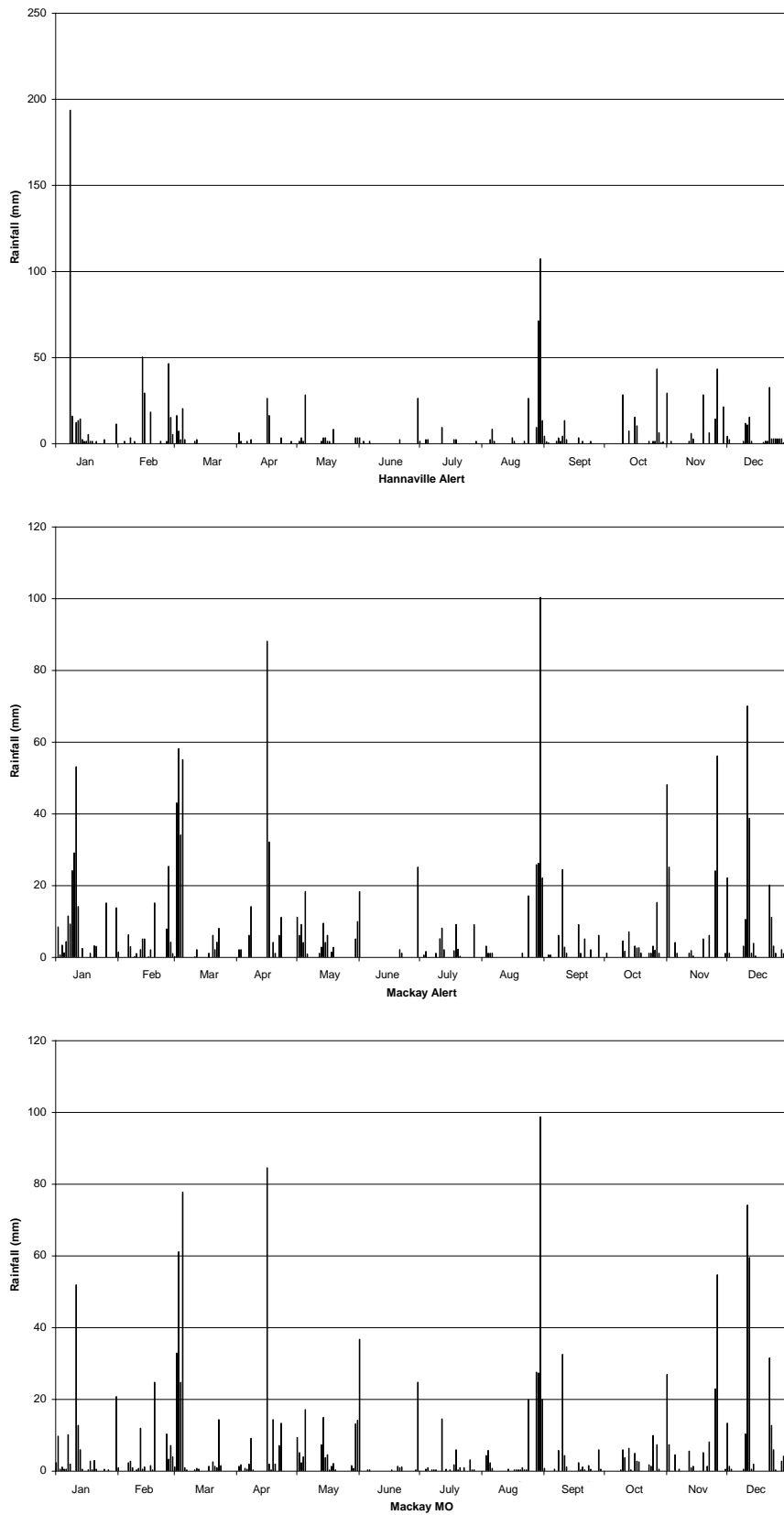
**Figure 14.** Average monthly rainfall (points) and total monthly rainfall in 1998 (columns) at Dalrymple Heights (a), Finch Hatton Post Office (b), Mackay Meteorological Office (c), Mirani (d) and Te Kowai Experimental Station (e).



**Figure 15.** Total rainfall between 28<sup>th</sup> and 30<sup>th</sup> August 1998 for selected rain gauge stations in the Pioneer River catchment and at Homebush.

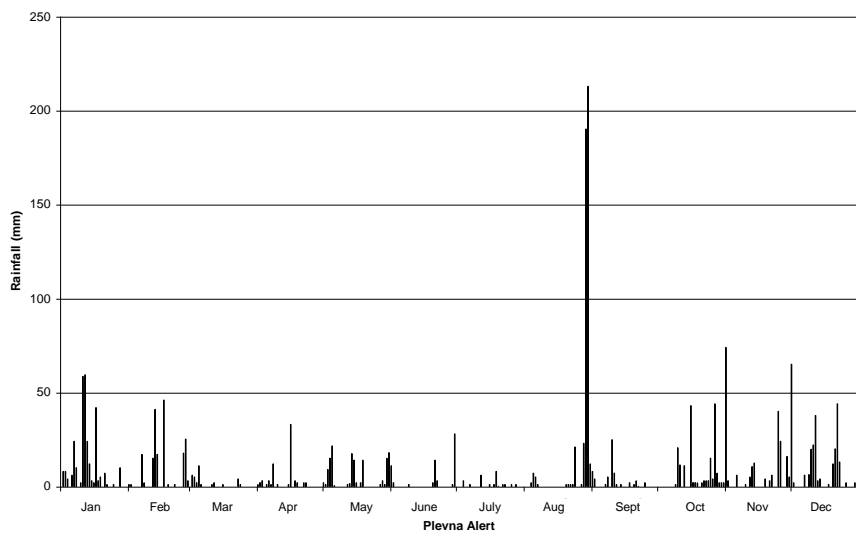
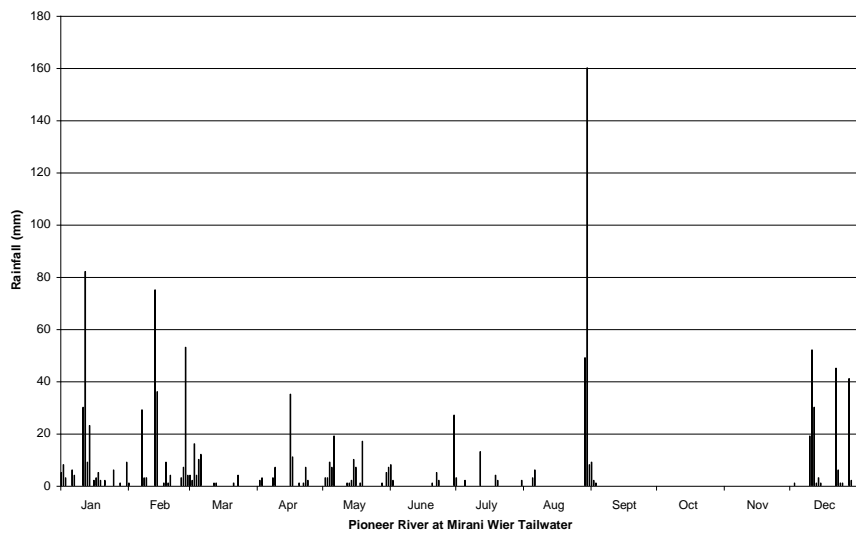
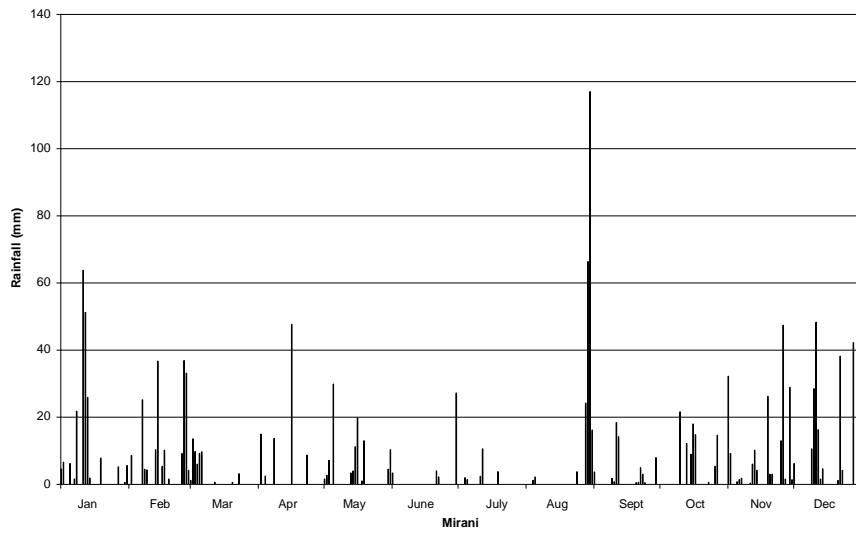


**Figure 16a.** Daily rainfall in 1998 at Dalrymple Heights, Finch Hatton Post Office and Finch Hatton Standalone rainfall stations in the Pioneer River catchment.

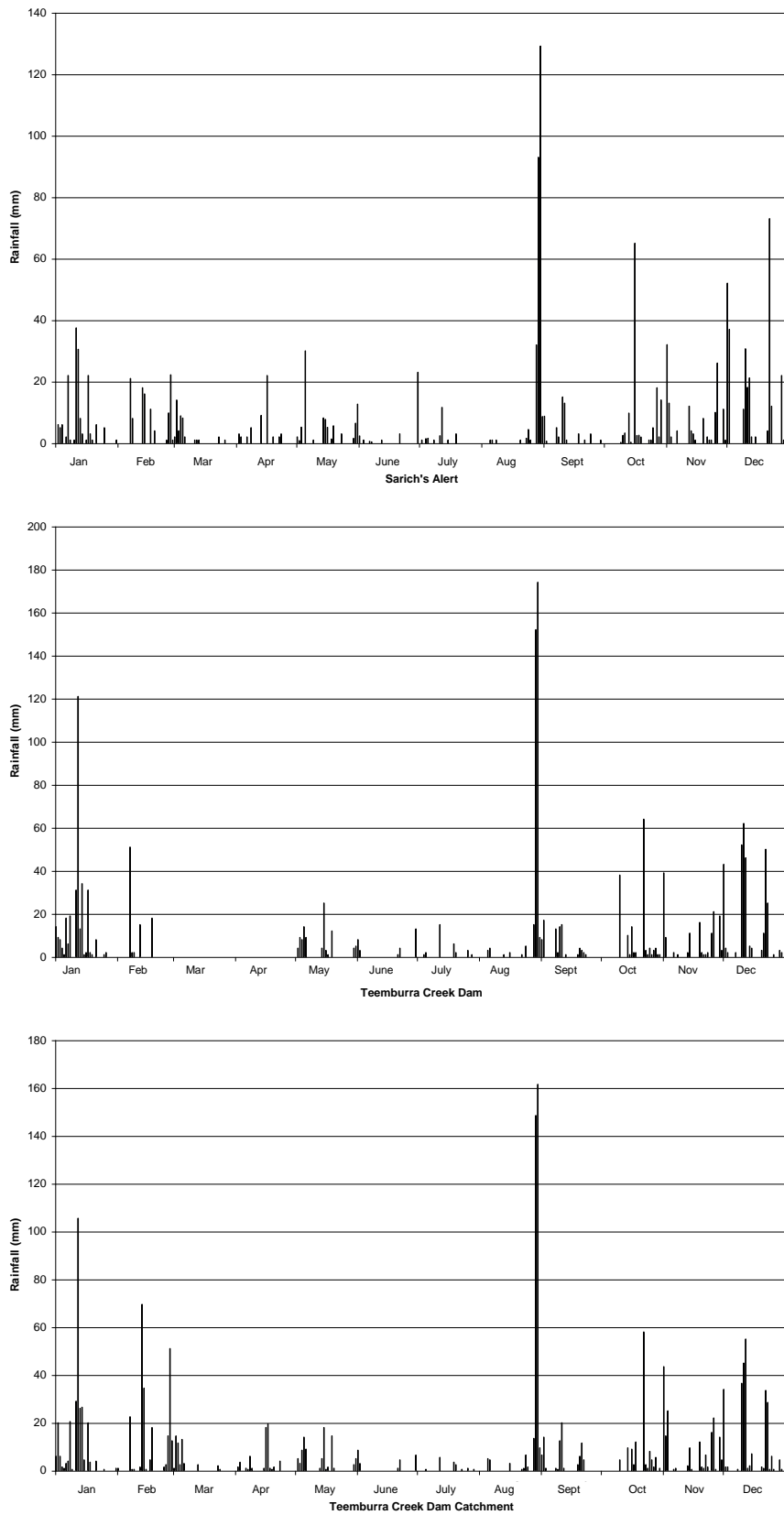


**Figure 16b.** Daily rainfall in 1998 at Hannaville Alert, Mackay Alert and Mackay Meteorological Office rainfall stations in the Pioneer River catchment.

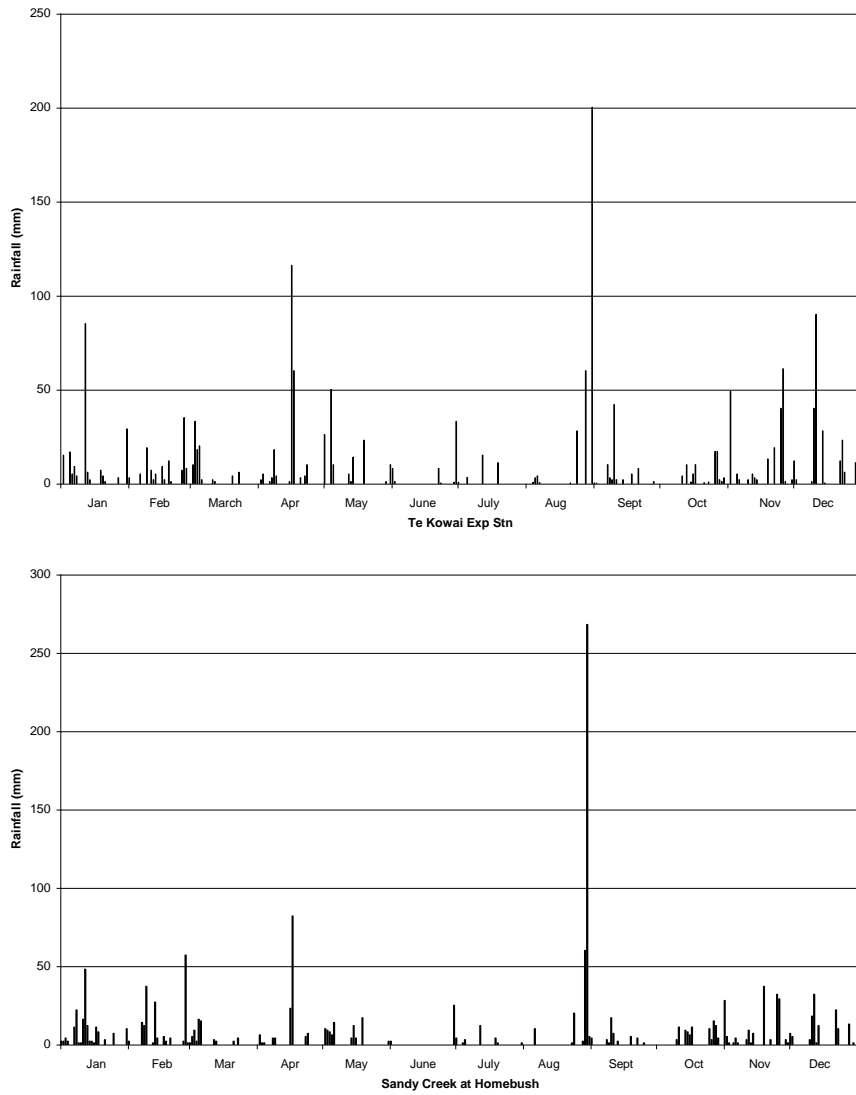




**Figure 16c.** Daily rainfall in 1998 at Mirani, Mirani Weir Tailwater and Plevna Alert rainfall stations in the Pioneer River catchment.



**Figure 16d.** Daily rainfall in 1998 at Sarich's Alert, Teemburra Creek Dam and Teemburra Creek Dam Catchment rainfall stations in the Pioneer River catchment.

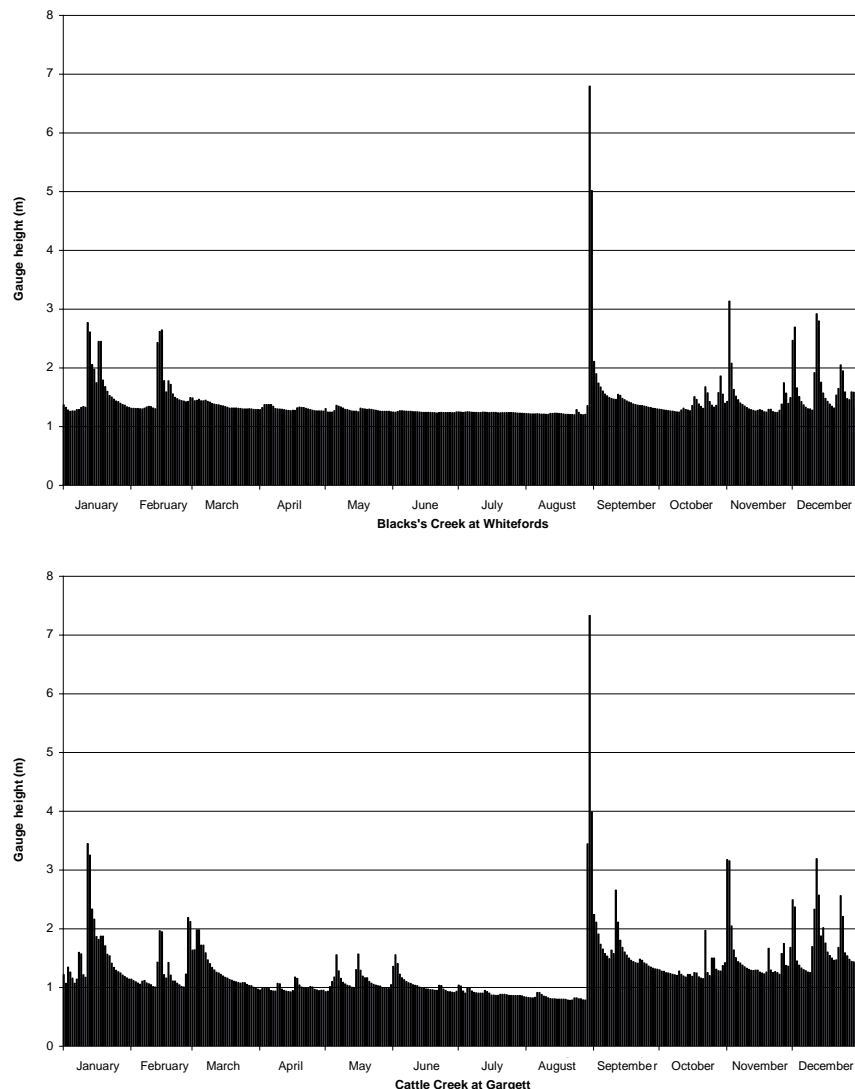


**Figure 17.** Daily rainfall in 1998 at Te Kowai Experimental Station rainfall station in the Pioneer River catchment and Sandy Creek at Homebush in the Plane Creek catchment area.

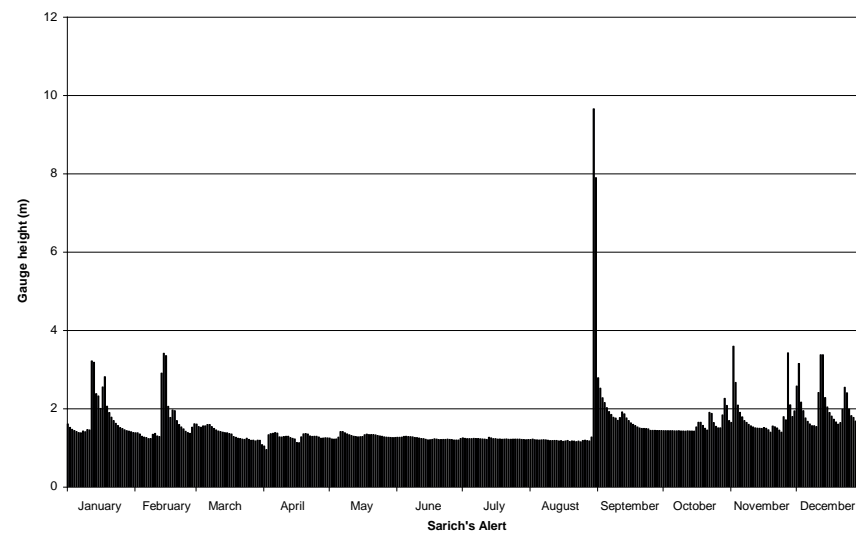
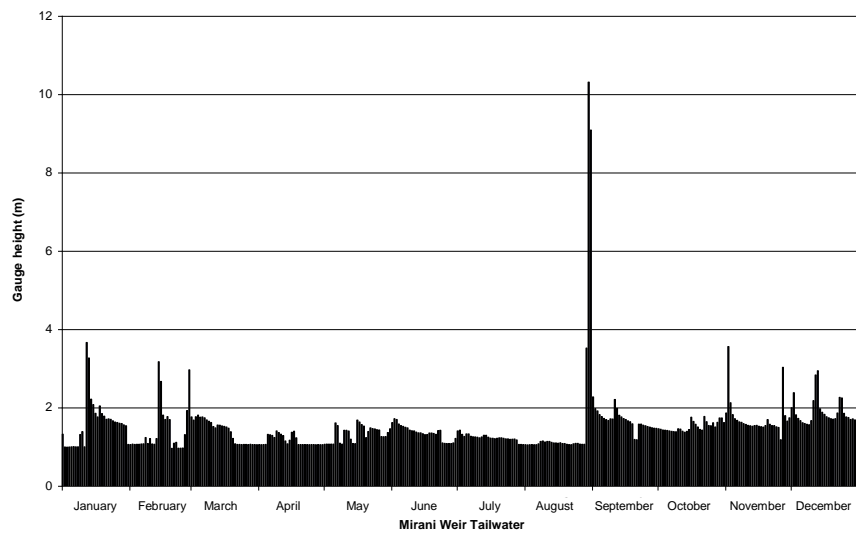
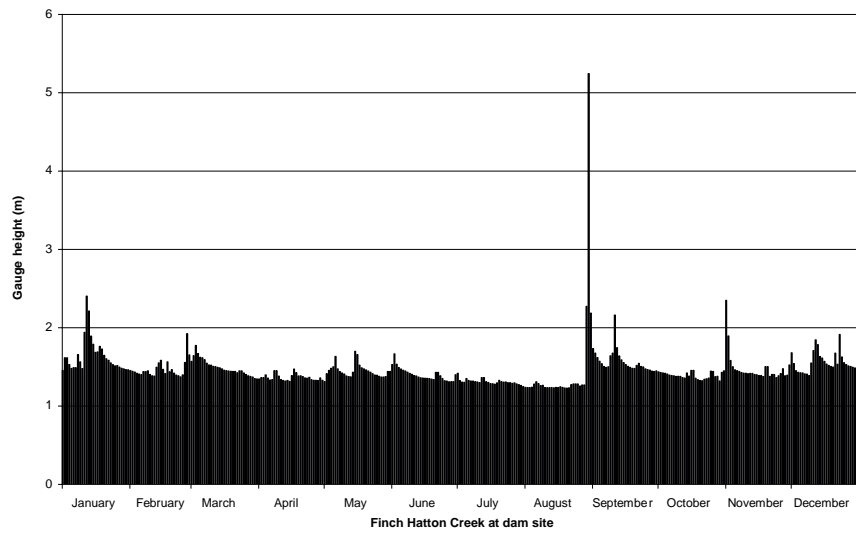
#### 4.5 Pioneer River and tributary stream flows in 1998

Stream heights in 1998 were highest between 28<sup>th</sup> and 30<sup>th</sup> August at all stream gauge stations in the Pioneer River catchment (Fig. 18a, Fig. 18b, Fig. 18c) and also at Homebush on Sandy Creek which drains into Sandringham Bay (Fig. 19).

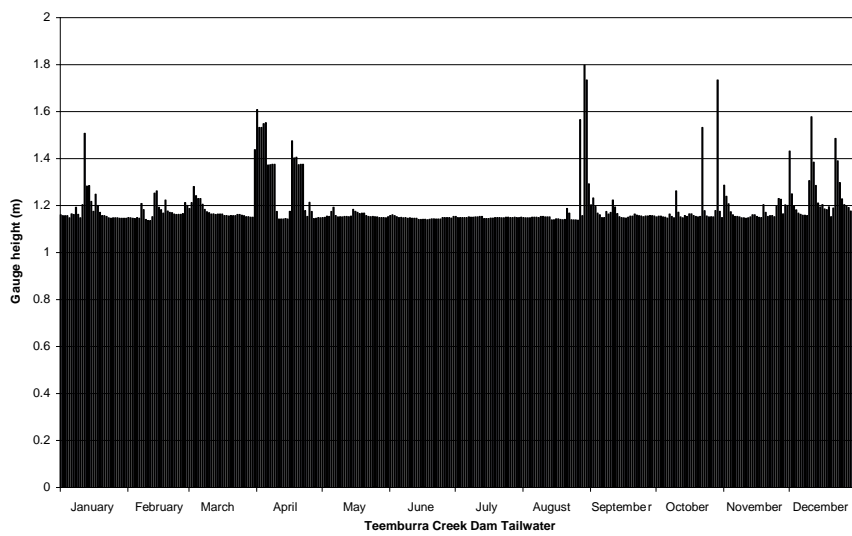
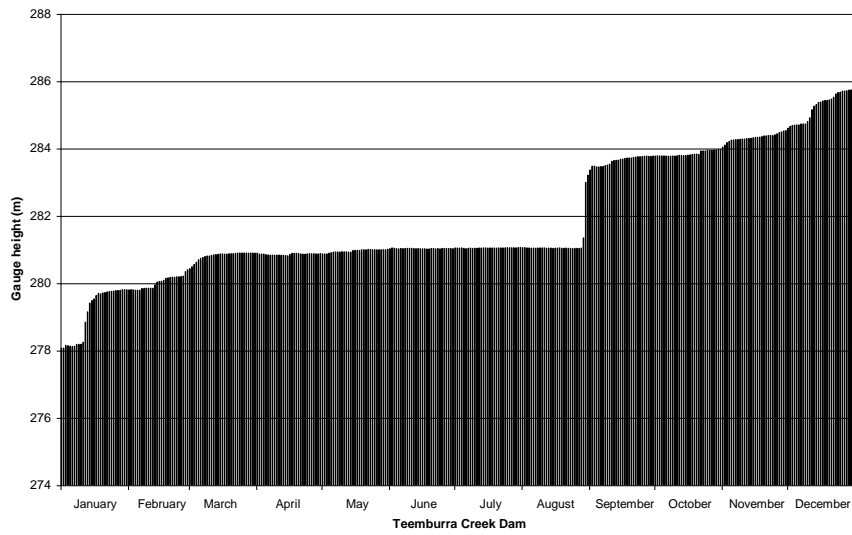
The predicted tide height at Mackay Outer Harbour was found to accurately describe the tidal fluctuations in the stream height at Mackay Alert in non flood times. The stream height at Mackay Alert began to rise above predicted tidal levels on 28<sup>th</sup> August 1998 and did not return to normal levels until the 31<sup>st</sup> August 1998. The maximum height recorded during this time was 5.95 m at 01:38 on 30<sup>th</sup> August 1998. The peak in water levels was relatively short in duration and the river dropped below the level of the predicted high tide height of 3.44 m at 1100 hrs on 30<sup>th</sup> August. The August 1998 flood occurred during a neap tide cycle, a period when the tidal range was at a minimum, ie low tide levels are at their highest and high tide levels are at their lowest in the tidal cycle as compared to other tide cycles (Fig. 20).



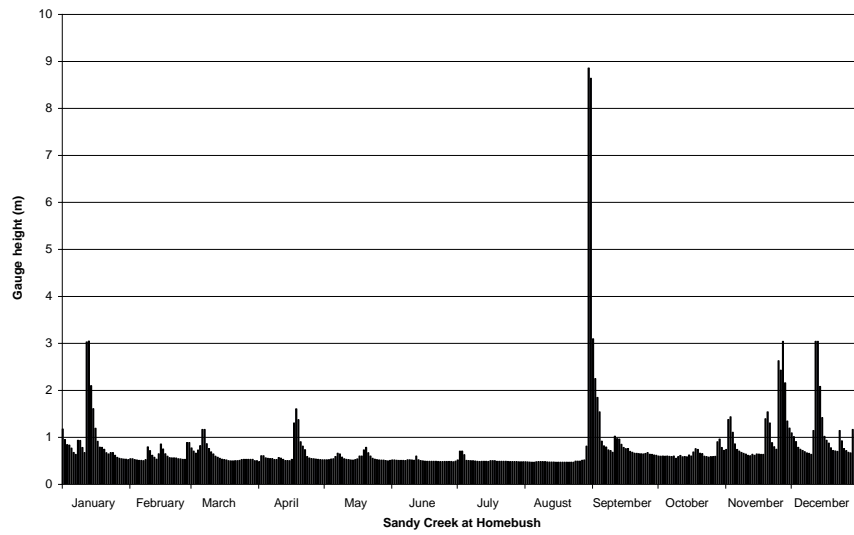
**Figure 18a.** Maximum daily stream gauge heights in 1998 at Black's Creek at Whitefords and Cattle Creek at Gargett gauge stations in the Pioneer River catchment.



**Figure 18b.** Maximum daily stream gauge heights in 1998 at Finch Hatton Creek at Dam Site, Mirani Weir Tailwater and Sarich's Alert gauge stations in the Pioneer River catchment.

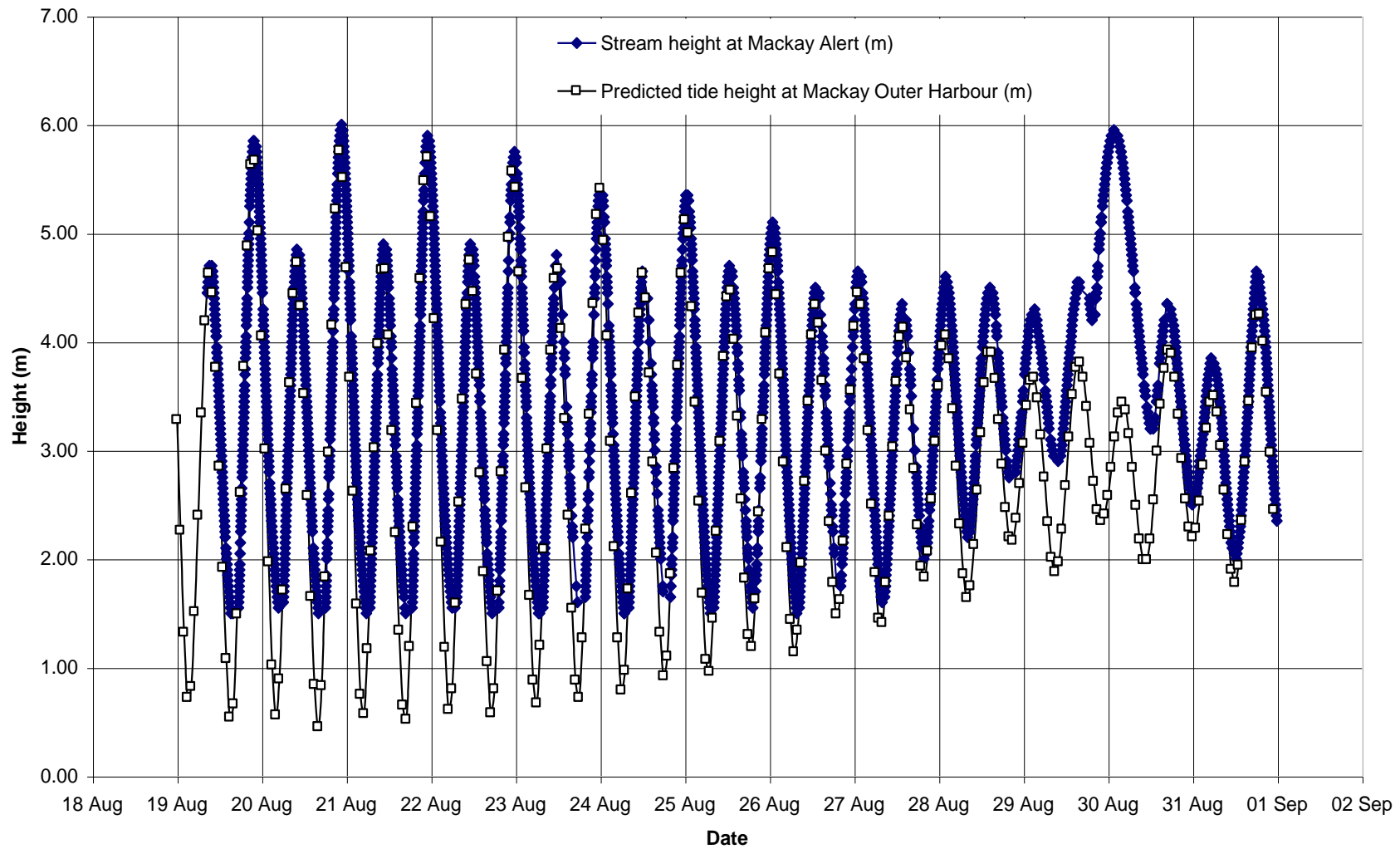


**Figure 18c.** Maximum daily stream gauge heights in 1998 at Teemburra Creek Dam and Teemburra Creek Dam Tailwater gauge stations in the Pioneer River catchment.



**Figure 19.** Maximum daily stream gauge heights in 1998 at Sandy Creek at Homebush in the Plane Creek catchment area.





**Figure 20.** Predicted tidal data for Mackay Outer Harbour and actual stream gauge recordings at Mackay Alert between 19<sup>th</sup> August and 1<sup>st</sup> September 1998.

Floods in the Pioneer River are classified at each stream gauge station according to gauge height. Floods at Mackay are first recorded when the gauge height exceeds 5.0 m and classified as ‘minor’ floods when the gauge height reaches 6.0 m (Table 5). The August 1998 flood was therefore classified as a “below minor” flood in the Pioneer River at Mackay (where the peak height was 5.95 m, Fig. 20), but a “major” flood at Mirani (where the peak height was 10.27 m). The average height of floods over 5.0 m at Mackay is 6.96 m.

**Table 5.** Flood classifications for three stream gauge stations in the Pioneer River Catchment. Information provided by BOM.

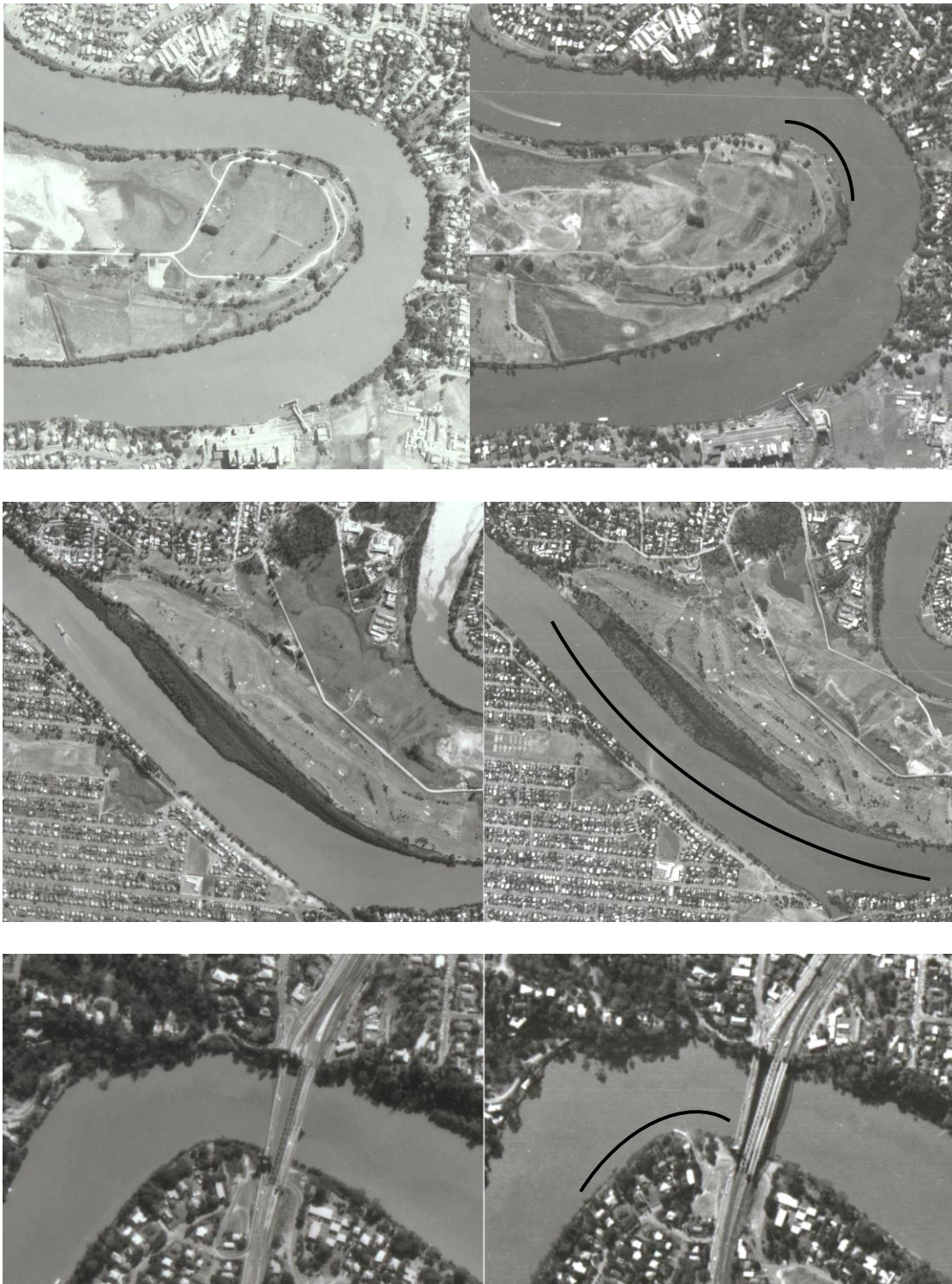
| Stream Gauge Station | First Report Height (m) | Minor Flood Level (m) | Moderate Flood Level (m) | Major Flood Level (m) |
|----------------------|-------------------------|-----------------------|--------------------------|-----------------------|
| Finch Hatton         | 1.5                     | 3                     | 4                        | 5                     |
| Mirani               | 3                       | 6                     | 8                        | 9                     |
| Mackay               | 5                       | 6                     | 6.9                      | 7.3                   |

#### 4.6 Brisbane River mangrove communities before and after 1974

Examination of aerial photographs indicate that between 1973 and 1979, fringing mangrove forests along the Brisbane River between St. Lucia and Jindalee either disappeared or were reduced in extent. This was obvious primarily at inner bank locations, particularly at Long Pocket Reach, Long Pocket, Indooroopilly Island, Indooroopilly, Sherwood Reach, Chelmer Reach and Fig Tree Pocket (Fig. 21, Fig.22, Fig. 23).



**Figure 21.** The Brisbane River at Long Pocket Reach in 1973 (left) and 1979 (right). The black line indicates areas of the river bank at Yeronga where mangroves disappeared or were reduced in extent between the two dates. (Aerial photographs supplied by NR&M).



**Figure 22.** The Brisbane river at Long Pocket (top) Indooroopilly Island (centre) and Indooroopilly (bottom) in 1973 (left) and 1979 (right). Black lines indicate areas along the river bank where mangrove communities disappeared or were reduced in extent between the two dates. (Aerial photographs supplied by NR&M).





**Figure 23.** The Brisbane River at Sherwood Reach and Chelmer Reach (top) and Fig Tree Pocket (bottom) in 1973 (left) and 1979 (right). Black lines indicate areas along the river bank where mangrove communities disappeared or were reduced in extent between the two dates. (Aerial photographs supplied by NR&M).

#### 4.7 Land use change

Most vegetation clearing in the Pioneer River catchment took place prior to 1947 (Table 6). In the 1943 to 1957 period, the Pioneer River catchment plains were extensively cleared, from the coast to the Cattle Creek and Finch Hatton Creek valleys in the upper catchment. In the narrow eastern part of the catchment (between Mirani and the coast), almost all the land except the more mountainous regions to the north, was cleared by 1947.

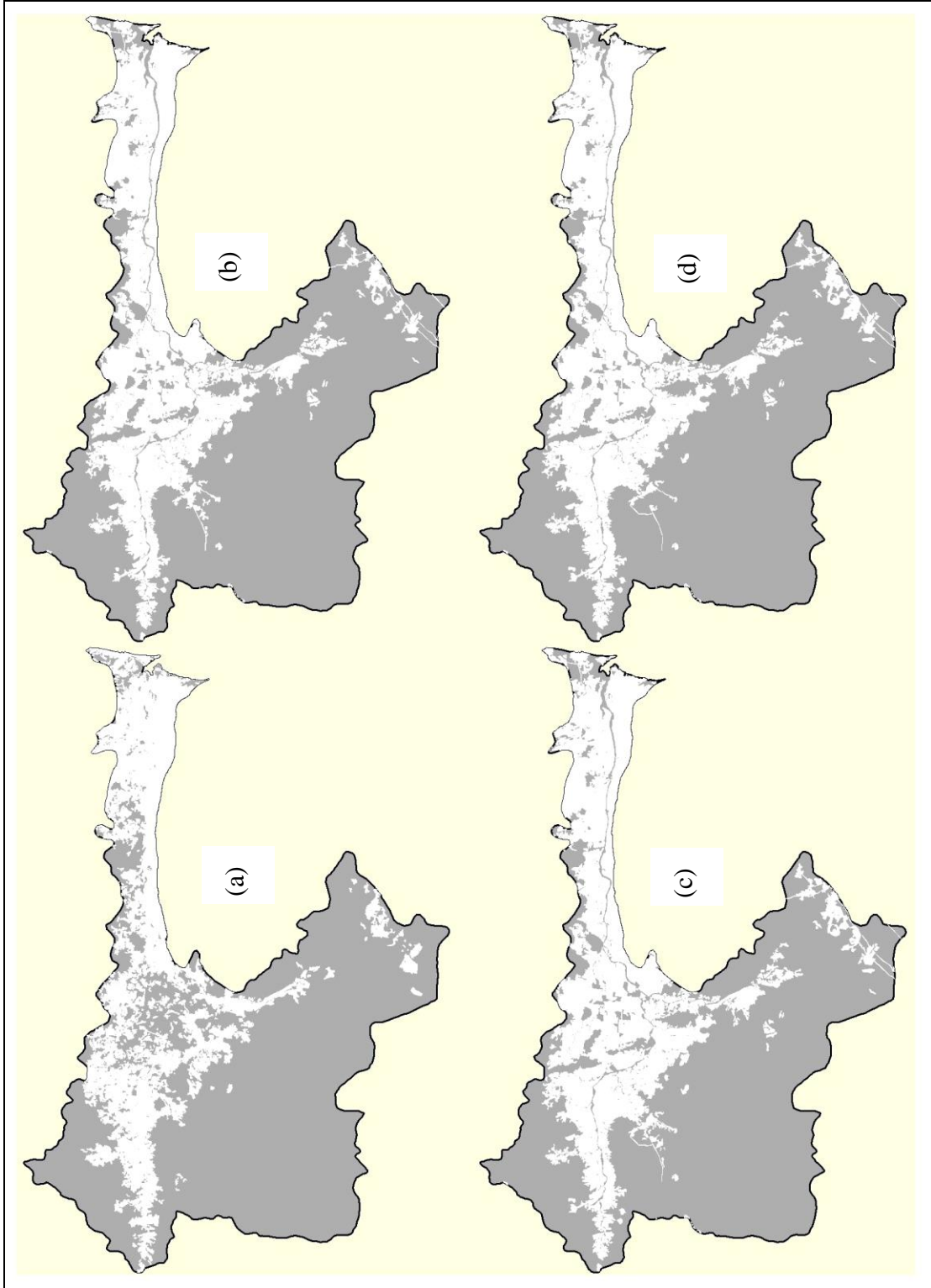
**Table 6.** The proportion of cleared to uncleared land in the Pioneer River catchment between 1947 and 1999.

| Year       | Percentage of catchment cleared |
|------------|---------------------------------|
| 1947/53/57 | 26.1                            |
| 1995       | 32.2                            |
| 1997       | 32.6                            |
| 1999       | 32.7                            |

Relatively little clearing has taken place in the catchment since 1947. Clearing that has taken place since then has mainly occurred on the flatter country rather than the steeper hills and foot slopes. The majority of this clearing has occurred in the western part of the catchment, particularly south of Pinnacle and in the area west of Mirani bounded by Cattle Creek, Middle Plain Range and McGregor Creek (Fig. 24). No analysis was undertaken of the changes in land use over time within the catchment and whether this may be affecting silt loads within the Pioneer River. Such an analysis was beyond the scope of this study.

#### 4.8 Changes in herbaceous cover in the catchment

The density of herbaceous cover in the Pioneer River catchment is strongly seasonal. Herbaceous cover is densest in the wet season (December – May) and thinnest from August to November (H. Lu, personal communication). Specific information on herbaceous cover was not available for any land uses other than sugar cane cropping. Sugar cane cropping, like all other land uses, renders the land susceptible to erosion during periods of low levels of plant cover. This includes times when the land is fallow or under plant cane. While the amount of fallow land remains constant at approximately 8% throughout most of the year, the area of plant cane cropping varies. Because planting only commences in March and concludes in August/September, cane land susceptible to erosion during the wet season (December to March) is primarily fallow land. In August 1998, approximately 1.72% of the district was under plant cane (A. Royal, pers. comm.). At other times of the year, especially at harvest, while the vegetative cover (cane) is removed the ground surface is covered with green blanket trash as a result of harvesting.



**Figure 24.** Cleared land in the Pioneer River catchment in 1947 (a), 1995 (b), 1997 (c) and 1999 (d). Grey areas represent vegetated land, white areas represent cleared land.



## 5 Discussion

Mangroves can be adversely affected or killed by a range of natural, anthropogenic or human-induced causes. These include impoundment, oil pollution, severe hailstorms, reclamation (for agricultural and residential development), siltation, drought, felling of trees, erosion, frost damage, leaf blight, insect damage and cattle grazing (West et al. 1983; Quinn and Beumer 1984, Turner and Lewis 1997; Edyvane et al. 1994; Duke et al. 1997; Wardrop et al. 1998; Houston 1999).

The preliminary investigation into mangrove dieback in the Mackay region by Duke et al. (2001) concluded that the most likely cause of this dieback was herbicide (ametryn and diuron) runoff from surrounding cane lands. They regarded all other possible causes as unlikely based on evidence they found, the spatial extent of the dieback and their ground-truthing (Table 1).

The Duke report is deficient in that it a) used an inadequate sampling strategy, b) incorrectly assigned diuron toxicity to *Avicennia marina* and applied incorrect application rates of diuron used in the Mackay district.

### 5.1 *Burial of mangrove pneumatophores in the Pioneer River estuary*

Observations made by one of the authors (Dowling) in August 2001 indicated that unusually large amounts of mud and silt had been deposited over much of the banks of Pioneer River estuary. Specifically, a layer of mud was observed to cover the lower estuarine sediments and intact, but dead, mangrove pneumatophores were observed under the mud and silt surface in an area of mangrove dieback which the Queensland Fire Service washed away. For these and other reasons, the authors of this study regard the burial of mangrove pneumatophores by mud and silt as a likely cause of the mangrove dieback in the Pioneer River estuary.

#### 5.1.1 *The effect of burial of mangrove pneumatophores*

Burial or permanent immersion of mangrove roots is a commonly reported cause of mangrove death, especially of plants of *Avicennia* sp., in Australia and overseas. A range of factors such as floods, siltation, land reclamation, deposition of dredge spoil and storms may cause burial (Ellison 1998). Mangrove pneumatophores do not have to be completely buried before stress in the plant occurs. Partial burial of pneumatophores has caused stress and death in plants in mangrove communities in Gladstone and Point Samson, Queensland, Australia (Ellison 1998); Mud Island, Moreton Bay, Queensland, Australia (Allingham and Neil 1995) and Singapore (Lee et al. 1996).

*Avicennia marina* is the only mangrove species in the Mackay region to have pneumatophores, an adaptation of the root system to life growing in anaerobic sediments. Sediments low in oxygen are frequently found in the inundated intertidal zones in which mangroves live. Other species of mangroves have other adaptations, such as the lenticels on the lower stems and prop roots of *Rhizophora stylosa*, which are used to obtain oxygen when they are exposed at low tides. Pneumatophores, which are peg-like and contain a spongy material, allow the roots to 'breathe' at low tide and to absorb oxygen for use by the submerged root system at high tide. Covering these pneumatophores by either silt or water inhibits the supply of oxygen to the root system.

*Avicennia* plants, because of their reliance on pneumatophores, are particularly sensitive to these pneumatophores being buried by sediment or inundated for extended periods.

Because of the regularity of tidal flows and the height on the tidal plane that mangroves occur, their pneumatophores are exposed to the air for considerably more than half the tidal cycle in every twelve hours. There are normally two tidal cycles every 24 hours. Depending on their position and the nature of a particular tide (ie. neap or spring) the period of pneumatophore exposure can regularly extend for up to 24 hours and even days or several weeks at a time. Therefore, there is no need for the storage capacity of oxygen within the pneumatophores to be large as they are normally regularly exposed to the air. Consequently any interruption to the exposure of the pneumatophores to the air, such as prolonged inundation by water or covering by anaerobic substrates, can very rapidly have serious and fatal consequences (Ellison 1998). Partial burial may also cause stress or death in mangrove communities by preventing or limiting exposure to the air. Any such stress could also be expected to result in a drop in photosynthetic activity as was noted by Duke et al. (2001).

### ***5.2 The August 1998 flood as the source of the sediments***

Floods are considered the most likely agent of sediment deposition and burial of mangrove pneumatophores in the Pioneer River estuary for two reasons. Firstly, the superficial sediments are almost entirely terrigenous (derived from the land) rather than biogenic, as in some other Australian estuaries (Gourlay and Hacker 1986). Sediment in its estuary is largely supplied by the Pioneer River, particularly in times of flood when large volumes of sediment are brought down to the estuary both as suspended load and as bed load (Gourlay and Hacker 1986).

Secondly, comparison of the date of onset of the current mangrove dieback event, as derived from aerial photographs, with the flood records for Mackay indicate that the most likely flood that deposited the large amounts of sediments occurred in August 1998. Examination of aerial photographs of the Pioneer River estuary indicated that dieback of mangroves appears to have commenced after June 1998, not earlier as suggested by some Mackay community groups. An aerial photograph taken in March 1998 of mangrove communities around Bassett Basin appears to be the only evidence of dieback occurring at this time (Duke et al. 2001 p. 31). However this photograph is of poor quality and colour balance, making it difficult to compare with the photograph of the same area taken in June 2000. We do not regard the March 1998 photograph as convincing evidence of dieback occurring at that time.

### ***5.3 Sedimentation and accretion within the Pioneer River estuary***

There are three main types of sediment deposition in the Pioneer River estuary. Deposition from suspended sediment loads and bed loads occurs mainly during floods, as mentioned above. The reworking, transport and deposition of suspended sediments by tides may also occur throughout the year. It is important to note that these processes may act to varying degrees in different parts of the estuary and affect the amount or type of sediment accretion at any location. The dynamics of the Pioneer River estuary have also been modified by dam construction and flood mitigation levees.

During floods, the deposition of sediment within the estuary is extremely complex and is controlled by the rate and duration of the flood flow and by its interaction with the tide cycle. "If the tide is high, deposition of bed load material takes place within the estuary but, if the tide is low, material is carried through the estuary out to the bar"

(Gourlay and Hacker 1986 p.142). On the other hand, much of the suspended load is carried out to sea during large floods. During minor floods, however, the suspended sediment load may be deposited within the estuary, where flocculation of the clay and silt particles by salt water and their subsequent deposition as mud and silt layers may occur (Gourlay and Hacker 1986 p.142).

Thus, even minor floods in the Pioneer River, such as that which occurred in August 1998, have the capacity to contribute to sediment accretion in the estuary. Gourlay and Hacker (1986) described a visit made to the Pioneer River estuary after a “minor flow” in June 1980. Their observation that “almost all the estuarine sediments were covered by a thin layer of mud” matches observations of the estuary made by one of the authors of this study (Dowling) in August 2001, except in that the deposition of sediments observed in August 2001 appears to have been greater than that noted by Gourlay and Hacker (1986).

Deposition of bed load material in the Pioneer River estuary can vary spatially. For example, flood deposits in the Cremorne/Mangrove Island area occur in the form of flood splay deposits of bed load sediments which are very variable in thickness. Thus, although there may be considerable deposition in one locality, another only a few metres away may have even undergone significant erosion (Gourlay and Hacker 1986). This spatial variation in the deposition of sediments in the Pioneer River estuary may explain why mangroves in some areas of the estuary were severely affected while nearby plants were unaffected.

Finally, there is also deposition of fine material within the estuary that is transported by tidal action from exposed areas into low energy environments where mangroves are prolific. In fact, “The mangroves themselves encourage the siltation process further as they provide excellent sediment traps” (Gourlay and Hacker p. 143). Such siltation has occurred at Mangrove Island, Barnes Creek and behind the new beach ridge south of the river mouth and northeast of Town Beach (Gourlay and Hacker 1986). *Avicennia marina* is a pioneering species and often traps silt to provide sediment for secondary succession.

Bassett Basin is being infilled with sediments brought in by fluvial and tidal action together with wind-blown material from the coastal dunes north of East Point (Gourlay and Hacker p. 143). “There has been a general increase in ground level in the Cremorne and Barnes Creek area during the [20<sup>th</sup>] century” (Gourlay and Hacker 1986 p. 111). Comparison of the early surveys of Bassett Basin (1886-1903) with photogrammetric maps prepared from aerial photographs (1953, 1962, 1972 and 1977) has shown that, overtime, Bassett Basin has decreased in size (Gourlay and Hacker 1986). On the other hand Mangrove Island has increased in extent and the mangroves on the northern edge of Bassett Basin have encroached southwards. “The construction of the north wall across the southern margin of Bassett Basin must have restricted the tidal circulation and accelerated accretion in the area. The construction of the wall would have provided a sediment trap for material brought down Barnes and Vines Creeks during times of flood flows, as well as for material brought in by tidal action” (Gourlay and Hacker 1986 p. 113).

#### **5.4 Land use and erosion in the Pioneer River catchment**

Though this is the first recorded instance of dieback occurring in the Pioneer River estuary, floods are relatively common events. If a flood did cause the recent mangrove dieback then it must be asked “Why doesn’t mangrove dieback usually occur after all such events”? In answer to this question, we propose that the August 1998 flood transported larger quantities of sediment into the Pioneer River estuary than would normally have occurred in floods of that size. There are two possible reasons for this.

Firstly, if the area of land susceptible to erosion in the Pioneer River catchment today is greater than that in the past, then larger amounts of sediment could be eroded during periods of heavy rainfall and transported to the estuary by floodwaters. Because cleared land is generally more susceptible to erosion than vegetated land, any recent increase in the area of cleared land in the Pioneer River catchment is likely to result in an increase in sediment loads in the Pioneer River. One of the objectives of this study was to determine recent and historical patterns of land clearing in the Pioneer River catchment. The results show that most of the catchment was cleared prior to 1947 and relatively little clearing has occurred in recent years. Thus, it is reasonable to assume that land clearing in the catchment since 1947 because of its relatively limited extent has not caused a marked increase in sediment loads in the Pioneer River since 1947 though no figures are available to verify this. Improved land use practices within the catchment in recent years, such as green trash blanketing, should also have resulted in a reduction in sediment loads in the Pioneer River.

Secondly, if the erosion potential of land in the Pioneer River catchment is greater at some times of the year than at other times, then larger amounts of sediment would be eroded during periods of heavy rainfall at those times and transported to the estuary by floodwaters. Crop canopy cover, surface cover, surface roughness and organic material below the surface are important factors influencing land erosion potential. Herbaceous ground cover (both natural vegetation and crops) often varies seasonally in Australia (Lu 2001). In the Mackay region, herbaceous cover is greater in the wet season (December–May) than in drier times of the year (June–November). August is the time of the year when sugar cane lands are most vulnerable to erosion due to ploughing for fallow and plant cane. Therefore, given all other factors (including rainfall intensity) remaining the same, erosion potential in the Mackay region is probably greater between the months of August and November than it is between December and May (H.Lu, pers. comm.).

Most floods in the Pioneer River occur in the wet season, from December to May, when the amount of herbaceous plant cover in the catchment is usually at its highest. The August 1998 flood was the first flood recorded in the August-September period since 1884 and occurred after a particularly dry summer. For these reasons, it is likely that the intense rainfall in the Pioneer River catchment in late August 1998 resulted in greater erosion and a heavier than normal sediment load in the rivers and streams draining the catchment than would normally have occurred during a similar flood episode at a different time of the year.

Until relatively recently, mangrove communities were considered to be wastelands and mosquito and sandfly infested swamps and therefore of little value. Their habitats were considered best utilised by infilling and the communities destroyed (Lugo and Snedaker 1974). As such, it is likely that little consideration or comment would have been made

in the past of cases of mangrove death or dieback within the Pioneer River estuary. Similarly there are no known reports of dieback of mangroves in the Brisbane River after the 1974 flood. Cases of mangrove dieback may have occurred in the Pioneer River estuary or other estuaries in Queensland in the past but gone unreported. In recent years, however, increasing environmental awareness of the ecological role of mangroves as a habitat for fish has changed public awareness and perceptions of mangrove communities which are now in consequence more valued by society. In addition, they are now protected in Queensland under the *Fisheries Act 1994* and have a status akin to National Parks. As such, any disturbance of mangrove communities is noted by the community and reported to the Queensland Boating and Fisheries and Boating Patrol and acted upon.

### **5.5 Patterns of change in mangrove communities**

Siltation and sedimentation in mangrove communities and estuaries are natural and normal processes. The Pioneer River estuary and associated mangrove communities are no exception. Recent monitoring of mangroves in Barnes Creek indicates that sediment is steadily accreting in the area (McKillup and McKillup 2001b). The monitoring of substratum height at 9 sites in Barnes Creek between November 1999 and December 2001 showed an increase in elevation of about 0.5 cm per year (McKillup and McKillup 2001b). This change is comparable to past measures of deposition in the upper Barnes Creek area of 0.5 m in 50 years (or 1 cm per year). Deposition in the Cremorne/Mangrove Island area has been more rapid, up to 0.9 m over 60 years and possibly 2 m over 120 years in some places (Gourlay and Hacker 1986).

A review of the natural rates of sedimentation at eight locations throughout the world (Ellison 1998) found that most accretion was at rates of less than 0.5 cm per year with a maximum around 1.0 cm per year. In the siltation or sedimentation process the slow accretion of mud fosters serial changes in mangrove ecosystems characterised by slow replacement of mangrove species (Lugo and Snedaker 1974). For example, sedimentation in Singapore mangrove communities induced natural succession from an *Avicennia* sp. dominated community to *Rhizophora* spp. dominated community (Lee et al. 1996). McKillup and McKillup (2001b) speculated that the dieback of mangroves in the Barnes Creek area of the Pioneer River estuary could be indicative of a trend toward a altitudinally higher, more “freshwater” or “riverine” community. Similarly, McKillup and McKillup (2000a, 2001b) suggested that an increase in substratum altitude could explain the colonisation of lower more saline areas such as the banks of Barnes Creek by *A. marina*.

While the slow accretion of sediment can induce gradual changes in the composition of mangrove communities, extremely rapid or acute sedimentation, such as may have occurred in 1998 in the Pioneer River estuary, can cause mass mortality in mangrove communities (Lugo and Snedaker 1974, Ellison 1998). The subsequent colonisation of affected areas by mangroves depends on a range of factors, including the input of propagules into the site and any changes to the environmental conditions of the site. Sedimentation can directly affect two important factors that determine the distribution and zonation of mangrove species, micro-elevation and the frequency of inundation (Ellison 1998). If sedimentation reduces the inundation frequency of an area, that area may become unsuitable for the persistence of the original species and be colonised by a species better adapted to the changed conditions (Lugo and Snedaker 1974).



Ellison (1998) reported natural regeneration of *Avicennia marina* occurring at Doughty Creek, Bowen, Queensland, despite deposition of approximately 12 cm of sediment because the new altitude was still within the normal inundation regime for this species. Similarly, Watson (1928) described the re-colonisation of the shores of the Brisbane River by *Avicennia* following floods.

#### 5.5.1 Dieback of Brisbane River mangroves following 1974 flood

Comparison of mangrove communities in aerial photographs of the Brisbane River before and after the January 1974 flood supports the hypothesis that deposition of sediment on these mangrove communities by floods can cause mangrove dieback. Alternative explanations for the disappearance or reduction of mangrove communities in the Brisbane River with time include: (i) deliberate removal of trees, and (ii) their washing away by floodwaters. However, the extent and distribution of current mangrove loss does not support either of these explanations. Firstly, mangrove loss was obvious in a number of separate areas, suggesting that systematic clearing was not the cause. Secondly, mangrove loss was evident only on inner banks (sites of low flow rates and sediment deposition) while communities on the outer banks (sites with high flow rates and sediment erosion) appeared unchanged, indicating that mangrove trees had not been washed away by floodwaters. The conclusion is also supported by past observations of mangrove dieback in the Brisbane River. Possibly the earliest reported case of Australian mangrove dieback is of *Avicennia officinalis* (now known as *A. marina*) dieback in the Brisbane River. Watson (1928) concluded that the cause of this dieback was burial of the pneumatophores by silt deposited during a small flood. Watson also described how “dead trees were in many cases standing alongside trees in robust growth.” “Trees which had all or portion of their roots [pneumatophores] exposed to the air were quite unaffected” (Watson 1928).

#### 5.5.2 Mangrove change in the Pioneer River estuary

The distribution and extent of mangrove communities in the Pioneer River estuary changed between 1947 and 1998, resulting in a net loss of 21% of the area covered by these communities (Finglas et al. 1995). Losses of mangroves in the Pioneer River estuary occurred for a variety of reasons. In some areas, mangroves were cleared for flood mitigation purposes. For example, in 1958 mangroves were cleared in the Alligator Creek area to improve outflow of water and reduce flood levels (Gourlay and Hacker 1986). Considerable regrowth subsequently occurred and the area had a dense stand of mangroves by 1976 (Gourlay and Hacker 1986). Mangroves were also lost to large-scale land development such as construction of the harbour, urban subdivision for housing and shopping centres (Finglas et al. 1995). For example the area around Alligator Creek was cleared of mangroves for the construction of Canelands Shopping centre in 1978 (Gourlay and Hacker 1986).

Mangroves have also colonised further areas in the Pioneer River estuary since 1947. For example, substantial expansion of mangrove communities has occurred in an area of approximately 100 ha on the intertidal flats around Barnes Creek. These mangroves were not present in the area in 1948 as indicated by Duke et al. 2001, p. 13. In 1947, the area was dominated by saltmarsh, but today an *Avicennia marina* dominated community is the predominant community type on this land (Gourlay and Hacker 1986, Finglas et al. 1995). Gourlay and Hacker (1986) speculated on the cause of this change, suggesting that salinities in the area were reduced during the wet years of the 1950s which allowed mangroves to colonise the area. They stated that “Once established, the shade of the trees prevented further desiccation and its accompanying high salinity, thus encouraging the further growth of the mangroves. The causeways for road and railway would provide and additional sediment trap in times of flood and possibly protection to

small mangroves from the damaging effects of fast moving water. It is also possible that the causeways have reduced the extent of the area that dries out at low tide, hence further reducing the high salinities of the area [that favour saltmarsh communities]”

Accretion of silt and sand favoured colonisation by mangroves and establishment of mangrove communities in the area northeast of Town Beach between 1953 and 1986 (Gourlay and Hacker 1986). The cause of the loss of these mangroves between 1986 and 1990 is unknown. While dead mangrove trees were not observed in the older aerial photographs of this area, the cause appears unlikely to be deliberate clearing because of the location of the mangroves that were lost. The deposition of excess sediment from nearby development may have caused the dieback. Some losses also occurred on the seaward side of these mangrove communities, probably as a result of wave action scouring the substrate and reworking of the sandy sediments on which they were growing. Considerable regrowth of the mangroves in this area has occurred since 1990.

### ***5.6 The uses of diuron in Queensland***

Diuron is used as a herbicide in a large variety of situations in Australia such as crops, roadside and railway weed control as well as an anti-fouling agent on vessels. Duke et al. (2001) argue that in the Mackay region “the sugar cane industry is the only user of diuron and ametryn over such a wide extent in the region which correlates with the distribution of mangrove dieback” (p. 58). However, there are problems with this association of diuron usage by the sugar industry with areas of mangrove dieback.

In terms of the proportion of the catchment utilised for cane cropping, the Pioneer River catchment is the second largest producer of cane in Queensland (Appendix A; Hamilton and Haydon 1996). Not surprisingly then, the annual amount of diuron applied in the Pioneer River catchment is relatively high (Appendix A). Duke et al. (2001) claim that the rates of application of diuron in the three catchments where mangrove dieback is occurring (O’Connell River, Pioneer River and Plane Creek) are the highest of those reported for sugar cane areas from northern Queensland to NSW. Duke et al. calculated the diuron application rate by dividing the amount of diuron applied to the catchment by the area of mangrove communities in the catchment. This is not an appropriate measure. The way to calculate the diuron application rate for an area is to divide the amount of diuron applied by the area it was applied to. When application rates of diuron in the Pioneer River catchment (in terms of kg of active ingredient applied per km<sup>2</sup> of sugar cane land) are calculated this way they are comparable with those of the adjacent O’Connell and Plane Creek catchments, but less than for those of the Mary, Maroochy and Noosa River catchments (Appendix A). If diuron was the primary cause of the mangrove dieback in the Mackay region (as stated by Duke et al. 2001), then it would be expected that dieback would also be occurring within the Mary, Maroochy and Noosa River estuaries. To date, there have been no reports of mangrove dieback occurring within these estuaries.

### 5.7 Long-term prognosis

What is the long-term prognosis for the health of mangrove ecosystems in the Pioneer River estuary? Duke et al. stated that “the long term prognosis for affected mangrove areas is not good” based on “preliminary observations of insufficient recruitment of seedlings” (Duke et al. 2001 p. 10). Furthermore, Duke et al. warned that without recruitment of mangroves, the dieback would result in “permanent loss of significant mangrove habitat in the region” (Duke et al. 2001 p. 4). These warnings seem particularly severe considering that 94% of the mangrove dieback they observed was classed as ‘moderate’, and that “in many cases, the species [*A. marina*] did not occur as monotypic stands, but as individual trees amongst other species” (Duke et al. 2001 p. 29).

Concerns raised by Duke et al. (2001) that dieback of mangroves in the Pioneer River estuary will result in erosion of the sediment and permanent habitat loss appear to be unfounded and not supported by available evidence. Severe mangrove dieback and mangrove clearing have occurred in the Pioneer River estuary in the past, specifically in areas northeast of Town Beach and around Alligator Creek. In both areas, mangrove communities have recovered within ten years. Duke et al. stated that “without successful re-colonisation, affected sites will become unstable, and mudbanks eroded dispersing sediments downstream” (Duke et al. 2001 p. 10). Duke et al. appear to suggest that accretion of sediment only exists because mangroves keep the sediment in place. However, contrary to common belief, the presence of mangroves does not cause accretion of sediment in estuaries, but can accelerate the process after establishing communities in areas of natural sediment deposition (Steers 1977, Thom 1967).

The long-term prognosis for the Pioneer River estuary mangrove communities depends mainly on what caused the 1998 mangrove dieback. Our study suggests that the most likely cause of this dieback was an unseasonal flood that deposited an unusually large amount of sediment in the mangrove communities in the estuary. There are many recorded instances of the response of mangrove communities to burial by sediment. Mangrove clearing and dieback have occurred in the Pioneer River estuary in the past and the mangrove communities have recovered with time. It can therefore be reasonably assumed that mangroves (either *Avicennia marina* or some other species) will recolonise those areas within the estuary that have been subject to mangrove dieback since 1998.

## 6 Conclusion

Herbicides, as proposed by Duke et al. (2001), are not the most likely cause of the current mangrove dieback in the Pioneer River estuary for two main reasons. Firstly, there are insufficient data available to demonstrate higher herbicide concentrations in dieback areas than in non-dieback areas. Secondly, the concentrations at which herbicides were recorded are comparatively very low so there is no evidence to indicate that these concentrations were sufficient to kill mangroves.

Although herbicides at the concentrations recorded have been shown to affect seagrasses physiologically, the biological differences between seagrasses and mangroves are so great that it seems unreasonable to expect mangroves to exhibit the same physiological response as seagrasses to herbicides.

Burial (or partial burial) of mangrove pneumatophores is a more plausible explanation of the mangrove dieback in question. This explanation is supported by a wide range of evidence including observations made by one of the authors (R.Dowling) of buried pneumatophores in the Pioneer River estuary; observations of sediment accretion in the Pioneer River estuary, rainfall patterns in 1998 resulting in an unseasonal flood in August of that year, estimates that dieback commenced no earlier than June 1998; the recording of other cases of burial of pneumatophores inducing mangrove dieback throughout the world; a similar case of burial *Avicennia marina* pneumatophores inducing mangrove dieback following a flood in the Brisbane River in 1974 and the species-specific nature of the dieback. This explanation is probably also applicable to other mangrove dieback areas in the Mackay region. Intense rain in late August 1998 was not restricted to the Pioneer River catchment. Records show that heavy rainfall and high stream heights also occurred at Homebush on Sandy Creek in the adjacent Plane Creek catchment area where mangrove dieback was also observed.

There are many recorded instances of recovery of mangrove communities following dieback caused by burial throughout Australia and the world. Mangrove clearing and dieback have occurred in the Pioneer River estuary in the past and the mangrove communities concerned have recovered. There appears to be no reason why recovery from this dieback event will be any different.

## **7 Further Research Needs**

To determine the source of the sediments that appear to be responsible for the dieback, studies need to be undertaken into the amount of runoff and silt loads that are generated from each of the different land uses within the Pioneer River catchment. Such a study should enable figures to be generated on the silt load within the Pioneer River that each land use produces. Such data would enable appropriate management strategies to be implemented within each of the different land use categories to mitigate problems associated with any future unseasonal runoff events.

In addition studies need to be undertaken on the movement and fate of diuron and other herbicides used in the Pioneer River catchment. Specifically these studies need to focus on (i) the fate of these chemicals in estuarine sediments and (ii) the likelihood or potential of these herbicides to effect the growth and health of mangroves. Currently there is little or no available data on these effects.

## **8 Dissemination of the results**

It is intended publish this report in sufficient quantities to make it readily available to stakeholders and interested parties. In addition it is intended to present the results at workshops to held in Brisbane and Mackay to ensure the results and conclusions are presented to as wide an audience as possible.

## 9 Acknowledgments

The following people provided information, advice or assistance in the compilation and writing of this report. Their help is greatly appreciated.

Alan Royal, Mackay Cane Production and Productivity Board  
Bill Discher, Pioneer River Improvement Trust  
Casey Van Mollunbrook Queensland Fire Service, Mackay  
Dr Gordon Guymmer., Director, Botanical Services, Environmental Protection Agency  
Hua Lu, CSIRO Land and Water  
Ian White, Natural Resources and Mines (Queensland)  
Dr Jennifer Marohasy, Environmental Manager Canegrowers  
Dr John Beumer, Queensland Fisheries Service, Department of Primary Industries  
John Broadbent, Queensland Department of Transport  
John Markley, Mackay Sugar Co-operative (Cane Supply)  
Dr John Neldner, Senior Principal Botanist, Environmental Protection Agency  
Lawrie Patterson, Natural Resources and Mines (Queensland)  
Lawrie Wade, District Manager, Environmental Protection Agency, Mackay  
Matt Ryan, Great Barrier Reef Marine Park Authority (GBRMPA)  
Peter Baddiley, Supervising Engineer Hydrology, Bureau of Meteorology  
Peter Kelly, Natural Resources and Mines (Queensland)  
Rod Henderson, Senior Principal Botanist, Environmental Protection Agency  
Dr Samma Low Choy, Environmental Modeller, Environmental Protection Agency  
Dr Stephen McKillup, University of Central Queensland  
Terry Hughes, Climate and Consultancy Section, Bureau of Meteorology  
Tim Mulherin, State Member for Mackay

The Sugar Research Development Corporation (SRDC) provided funding for this project



## 10 References

- Anon. (2001a) *Draft Pioneer Valley Water Resource Plan: Current Environmental Conditions and Impacts of existing water resource development*. Department of Natural Resources and Mines, Brisbane.
- Anon. (2001b) *Great Barrier Reef catchment water quality action plan. A report to the Ministerial Council on targets for pollutant loads*. Great Barrier Reef Marine Park Authority, Townsville.
- Allingham, D. P. and Neil, D. T. (1995) The supratidal deposits and effects of coral dredging on mud island, Moreton Bay, Southeast Queensland. *Zeitschrift fur Geomorphologie* 39, 273-292.
- Brizga, S. O., Arthington, A. H., Choy, S., Craigie, N. M., Mackay, S., Poplawski, W., Pusey, B. and Werren, G. (2001) *Pioneer Valley WRP: Current environmental conditions and impacts of existing water resource development*. 2 Volumes. Department of Natural Resources and Mines, Brisbane.
- Cotrim, A.D., Reis, M.F. and Silva, F.T. (1998) Effects of ametryn, diuron and 2,4-D on black oat and radish germination and growth. *9<sup>th</sup> IUPAC International Congress of Pesticide Chemistry*, Abstract, 2C-015
- Duke, N. C., Pinzon, Z. S., and Prada, M. C. (1997) Large scale damage to mangrove forests following two large oil spills in Panama. *Biotropica*, 29: 2-14.
- Duke, N. C., Roelfsema, C., Tracey, D. and Godson, L. (2001) *Preliminary investigations into dieback of mangroves in the Mackay region*. Botany Department, University of Queensland, Brisbane.
- Easton, A. K. (1970) *The tides of the continent of Australia*. Flinders University, Horace Lamb Centre, Adelaide.
- Edyvane, K. S., Morris, K., and Seddon (1994) Monitoring the effects of an oil spill on mangrove, *Avicennia marina*. In O. Bellwood (ed.), *6<sup>th</sup> Pacific Congress on Marine Science and Technology*, PACON '94.
- Ellison, J. C. (1998) Impacts of sediment burial on mangroves. *Marine Pollution Bulletin* 37: 420-426
- Finglas, A. P., Winter, D. and Wild, A. (1995) Current distribution and historical comparisons of intertidal vegetation communities and saltpans in the Mackay region (Shoal Point to Hay Point). June – September 1995. Department of Primary Industries, Fisheries, Mackay.
- Gourlay, M. R. and Hacker, J. L. F. (1986) *Pioneer River Estuary Sedimentation Studies*. Department of Civil Engineering, University of Queensland, Brisbane.

- Hamilton, D. and Haydon, G. (1996) *Pesticides and fertilisers in the Queensland sugar industry – estimates of usage and likely environmental fate*. Department of Primary Industries, Resource management institute, Indooroopilly, Brisbane.
- Houston, W. A. (1999) Severe hail damage to mangroves at Port Curtis, Australia. *Mangroves and Saltmarshes*, 3: 29-40.
- Lee, S. K., Tan, W. H. and Havanond, S. (1996) Regeneration and colonisation of mangrove on clay-filled reclaimed land in Singapore. *Hydrobiologia* 319, 23-35.
- Lu, H., Gallant, J., Prosser, I. P., Moran, C., Priestley, G. (2001) Prediction of sheet and rill erosion over the Australian continent, incorporating monthly soil loss distribution. Technical Report 13/01, CSIRO Land and Water, Canberra. (Unpublished Report).
- Lugo, A E and Snedaker, S C (1974) The ecology of mangroves. *Annual review of ecology and systematics* 5: 39-64
- McKillup, C. and Melzer, A. J. (1999) *Preliminary monitoring of the intertidal community at Barnes Creek, Mackay, November 1999 (Report number 1)*. Faculty of Arts, Health and Sciences, Central Queensland University, Rockhampton.
- McKillup, C. and McKillup, R. V. (2000a) *Monitoring of the intertidal community at Barnes Creek, Mackay, May 2000 (Report number 2)*. Faculty of Arts, Health and Sciences, Central Queensland University, Rockhampton.
- McKillup, C. and McKillup, R. V. (2000b) *Monitoring of the intertidal community at Barnes Creek, Mackay, December 2000 (Report number 3)*. Faculty of Arts, Health and Sciences, Central Queensland University, Rockhampton.
- McKillup, C. and McKillup, R. V. (2001a) *Monitoring of the intertidal community at Barnes Creek, Mackay, May 2001 (Report number 4)*. Faculty of Arts, Health and Sciences, Central Queensland University, Rockhampton.
- McKillup, C. and McKillup, R. V. (2001b) *Monitoring of the intertidal community at Barnes Creek, Mackay, December 2001 (Report number 5)*. Faculty of Arts, Health and Sciences, Central Queensland University, Rockhampton.
- Quinn, R.H. and Beumer, J.P. (1984) *Wallum Creek – a study of the regeneration of mangroves*. pp238-259. Focus on Stradbroke, Boolarong Pubs., Brisbane.
- Steers, J. A. (1977) Physiography. In Chapman, V. J. (ed.), *Ecosystems of the World. I. Wet Coastal Ecosystems*. Elsevier, Amsterdam, pp. 31-60.
- Sturman, A. P. and Tapper, N. J. (1996) *The weather and climate of Australia and New Zealand*. Oxford University Press, Melbourne.
- Thom, B. G. (1967) Mangrove ecology and deltaic geomorphology: Tabasco, Mexico. *Journal of Ecology* 55, 301-343.

- Turner, R. E. and Lewis, R. R. (1997) Hydrological restoration of coastal wetlands. *Wetlands Ecology and Management*, 4: 65-72.
- Wardrop, J. A., Wagstaff, B., Pfennig, P., Leeder, J., and Connoly, R. (1998) *The distribution, persistence and effects of petroleum hydrocarbons in mangroves impacted by the "Era" oil spill (September 1992)*. Environment Protection Authority, South Australian Department of Environment and Natural Resources.
- Watson, C. J. J. (1928) Notes on the Growth of the Grey mangrove (*Avicennia*) in the upper Brisbane River. *The Queensland Naturalist* 6: 83-84
- West, R. J., Thorogood, C. A. and Williams, R. J. (1983) Environmental stress causing mangrove 'dieback' in NSW. *Australian Fisheries* 42: 17-20

- 11. APPENDIX A.** Data for east coast catchments in NSW and Queensland regarding the area of the catchment used for sugar cane cropping, size of catchment, amount of diuron applied to catchment annually, calculations of diuron application rate (kg of diuron applied per km<sup>2</sup> of cane) and diuron applied per square kilometre of catchment (kg ai = kg of active ingredient) (modified and recalculated from Duke et al. 2001).

| Catchment name     | Catchment area (km <sup>2</sup> ) | Cane area (km <sup>2</sup> ) | Proportion of catchment as cane crop (%) | Diuron applied annually (kg ai.y) | Diuron application rate (kg ai.km <sup>-2</sup> .y) | Diuron applied / catchment area (kg ai.km <sup>-2</sup> .y) |
|--------------------|-----------------------------------|------------------------------|------------------------------------------|-----------------------------------|-----------------------------------------------------|-------------------------------------------------------------|
| 1 Daintree         | 1978                              | 32                           | 2                                        | 2378                              | 74.31                                               | 1.20                                                        |
| 2 Mossman          | 417                               | 46                           | 11                                       | 3278                              | 71.26                                               | 7.86                                                        |
| 3 Barron           | 2159                              | 40                           | 2                                        | 835                               | 20.88                                               | 0.39                                                        |
| 4 Mulgrave/Russell | 1723                              | 206                          | 12                                       | 4702                              | 22.83                                               | 2.73                                                        |
| 5 Johnstone        | 2284                              | 252                          | 11                                       | 17353                             | 68.86                                               | 7.60                                                        |
| 6 Tully            | 1596                              | 104                          | 7                                        | 2768                              | 26.62                                               | 1.73                                                        |
| 7 Murray           | 947                               | 44                           | 5                                        | 1252                              | 28.45                                               | 1.32                                                        |
| 8 Herbert          | 10315                             | 464                          | 4                                        | 16618                             | 35.81                                               | 1.61                                                        |
| 9 Black            | 1001                              | 4                            | 0                                        | 100                               | 25.00                                               | 0.10                                                        |
| 10 Ross            | 1579                              | 0                            | 0                                        | 0                                 | -                                                   | -                                                           |
| 11 Haughton        | 3812                              | 281                          | 7                                        | 4123                              | 14.67                                               | 1.08                                                        |
| 12 Burdekin        | 130475                            | 230                          | 0                                        | 4372                              | 19.01                                               | 0.03                                                        |
| 13 Don             | 2752                              | 34                           | 1                                        | 489                               | 14.38                                               | 0.18                                                        |
| 14 Proserpine      | 1994                              | 139                          | 7                                        | 9281                              | 66.77                                               | 4.65                                                        |
| 15 O'Connell       | 2220                              | 229                          | 10                                       | 23896                             | 104.35                                              | 10.76                                                       |
| 16 Pioneer         | 1580                              | 219                          | 14                                       | 23435                             | 107.01                                              | 14.83                                                       |
| 17 Plane           | 2321                              | 448                          | 19                                       | 52079                             | 116.25                                              | 22.44                                                       |
| 18 Styx            | 3129                              | 0                            | 0                                        | 0                                 | -                                                   | -                                                           |
| 19 Shoalwater      | 3782                              | 0                            | 0                                        | 0                                 | -                                                   | -                                                           |
| 20 Water Park      | 1765                              | 0                            | 0                                        | 0                                 | -                                                   | -                                                           |
| 21 Fitzroy         | 145447                            | 0                            | 0                                        | 0                                 | -                                                   | -                                                           |
| 22 Calliope        | 1890                              | 0                            | 0                                        | 0                                 | -                                                   | -                                                           |
| 23 Boyne           | 2484                              | 0                            | 0                                        | 0                                 | -                                                   | -                                                           |
| 24 Baffle          | 4112                              | 13                           | 0                                        | 234                               | 18.00                                               | 0.06                                                        |
| 25 Kolan           | 2823                              | 94                           | 3                                        | 1761                              | 18.73                                               | 0.62                                                        |
| 26 Burnett         | 33323                             | 174                          | 1                                        | 3445                              | 19.80                                               | 0.10                                                        |
| 27 Burrum          | 3118                              | 198                          | 6                                        | 3303                              | 16.68                                               | 1.06                                                        |
| 28 Mary            | 9600                              | 80                           | 1                                        | 9614                              | 120.18                                              | 1.00                                                        |
| 29 Noosa           | 2877                              | 6                            | 0                                        | 938                               | 156.33                                              | 0.33                                                        |
| 30 Maroochy        | 912                               | 60                           | 7                                        | 9828                              | 163.80                                              | 10.78                                                       |
| 31 Pumicestone     | 702                               | 0                            | 0                                        | 0                                 | -                                                   | -                                                           |
| 32 Caboolture      | 462                               | 0                            | 0                                        | 0                                 | -                                                   | -                                                           |
| 33 Pine            | 977                               | 0                            | 0                                        | 0                                 | -                                                   | -                                                           |
| 34 Brisbane        | 13643                             | 0                            | 0                                        | 0                                 | -                                                   | -                                                           |
| 35 Logan-Albert    | 4065                              | 47                           | 1                                        | 766                               | 16.30                                               | 0.19                                                        |
| 36 South Coast     | 6023                              | 0                            | 0                                        | 0                                 | -                                                   | -                                                           |
| 37 Tweed           | 1126                              | 70                           | 6                                        | 979                               | 13.99                                               | 0.87                                                        |
| 38 Brunswick       | 488                               | 18                           | 4                                        | 551                               | 30.61                                               | 1.13                                                        |
| 39 Richmond        | 7000                              | 139                          | 2                                        | 1890                              | 13.60                                               | 0.27                                                        |
| 40 Clarence        | 22220                             | 91                           | 0                                        | 3173                              | 34.87                                               | 0.14                                                        |