Chapter 2

Identification of ecological assets, pressures and threats

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Contents

Executive summary

The aquatic ecosystems of the Northern Tropical Rivers catchments are still relatively intact and, for this reason, represent an internationally significant asset. Whilst we know much about the aquatic ecosystems, particularly for specific areas (eg. Alligator Rivers Region, Ord River, Daly River), much knowledge still remains unknown and/or unquantified for most of the region. An increasing interest in agricultural and water resource development and expansion in Northern Australia has, however, drawn attention to the identification and need to ensure the maintenance of the ecological (and socio-cultural) assets and associated values of these river systems. Whilst efforts are underway to acquire new knowledge, it is also necessary to summarise existing knowledge.

This chapter deals with what is currently known about the aquatic ecological assets of, and pressures and their associated threats to, the Northern Tropical Rivers study area, and in more detail, the (focus) catchments of the Daly (Northern Territory), Fitzroy (Western Australia) and Flinders Rivers (Queensland). It represents a compilation of the existing information, rather than an analysis of risk or impact; the latter aspect is dealt with in Chapters 3 and 4. This chapter focused on addressing two key questions:

i. What do we currently know about the region's aquatic ecosystems?
ii. What are the pressures and threats most likely affecting the region's aquatic ecosystems at present and into the future?

Descriptions of the aquatic ecological assets focus on the: waterways; wetlands; riparian vegetation; groundwater dependent ecosystems; aquatic biodiversity; and rare, threatened and listed aquatic communities and species, at the Northern Tropical Rivers and focus catchment scales. Where appropriate key values of these assets are discussed also and, where possible, linkages are drawn between ecological and socio-cultural assets and values.

Although the Northern Tropical Rivers study area is much more pristine than elsewhere in Australia and most regions of the world, many of the region's catchments have already been substantially modified by human activities (pressures). The pressures that are considered in this chapter are: horticulture; crop production; pastoralism; urban development; tourism and recreational/customary harvest; mining; and climate change. Associated with these pressures are a range of potential threats that may impact on aquatic ecosystems and the following are considered in this chapter: groundwater extraction; surface water extraction; water impoundment; altered fire regime; land clearance/loss of native vegetation cover; introduced invasive flora; introduced invasive fauna; and contamination.

Where possible, the spatial extent of the assets, pressures and threats is estimated and mapped noting, however, that such information in general is limited. To link the threats to the aquatic ecological assets (and values), asset-threat matrices are constructed with accompanying narrative that depict the potential current and emerging/future threats to the regions' assets. Emerging/future threats are based on projected scenarios of natural resource development. The matrices are considered 'first pass' conceptual models that lead to the detailed assessments undertaken in Chapters 3 and 4.

Whilst documenting a vast amount of literature, this chapter also identifies many gaps in information and knowledge on the biophysical attributes of the aquatic ecosystems. Paramount amongst these are: regional biodiversity, including general species distributional information, relationships between species and habitats, and the extent of endemism; surface water – groundwater interactions; distribution and functions of riparian vegetation; water quality; and the role of riverine freshwater discharge for estuarine and coastal marine productivity. However, there are many deficiencies and limitations in the spatial data for biophysical attributes and these are elaborated upon in Chapter 3.

2.1 Introduction

This chapter represents an initial step in the problem formulation/hazard identification phase of the risk assessments in Chapters 3 and 4. It is presented separately so that readers can refer more easily to the general descriptions of the key assets and threats of the study areas.

Within the scope of the assessments as defined in Chapter 1, data collation focused on the key assets, pressures and threats for the areas of interest. Thus, the aim of this phase was to identify and describe: (i) the key assets (mostly ecological, but capturing a number of overlapping values of socio-cultural and economic importance) and threats to the aquatic ecosystems at the study area and focus catchment scale; and (ii) the interactions between the ecological assets and threats (ie. an initial matrix/description of how the threats might impact on the assets and how the threats themselves might affect each other). Some of the assets data were derived from Sub-project 1 (*Inventory and mapping*), although the majority, as well as all the threats data, were collated as part of this project. Identification of assets and threats within the focus catchments was undertaken through a combination of reviews of existing reports and management plans, and subsequent consultations with stakeholders to check and verify the information. Both spatial and non-spatial data related to assets and threats were collated, and all spatial data have been linked to the inventory GIS developed through Sub-project 1.

Ecological assets and threats information for the whole of the study area was drawn largely from regional NRM reporting processes, but also from broad scale national datasets, existing national scale reporting efforts and published research papers. Ecological assets and threats information for the focus catchments was drawn from the national scale sources and published research papers where relevant, but largely from more detailed, finer scale datasets held by the relevant government jurisdictions and other organisations (eg. local research institutions, non-government organisations – NGOs, NRM bodies). The data sources are detailed in the sections below.

Where detailed synthesis information already existed in published reports (eg. NRM Plans), no attempt was made to duplicate the information in this report. Instead, summaries have been provided where possible, with the subsequent focus being on the conceptual model development and risk analysis components of the study. For more detailed information we refer the reader to the NRM reports and additional references cited throughout this report.

2.2 Northern Tropical Rivers

The Northern Tropical Rivers study area comprises 51 river/drainage basins across Queensland, Northern Territory and Western Australia, from Broome in the west to Cape York in the east (see Figure 1.2). The region's river systems are unique and comprise one of the last great river networks in relatively pristine condition in the world today, representing an internationally significant asset (Australian Tropical Rivers Group 2004). Within the region, however, there are also rivers that have been substantially modified by agricultural, urban and industrial development, such as the Ord (WA), Flinders (Qld), Leichhardt (Qld) and Darwin/Finniss River catchments (NT). In recent years (ie. the past 5–10 years), attention has been drawn to the ecological and socio-cultural assets (and associated values) of these river systems, in most part because of the increased interest in agricultural and water resource development and expansion in Northern Australia. Hamilton & Gehrke (2005) provided an excellent and concise overview of the characteristics of Australia's tropical rivers, whilst the

TRIAP Sub-project 1 report by Lukacs & Finlayson (2008) provides more detail on specific biophysical attributes. Thus, the biophysical nature of the rivers is not described in detail here.

2.2.1 Ecological Assets

Most efforts to characterise the status of aquatic ecosystems across this vast geographical area have been made as part of national scale activities (eg. Ball et al 2001; Norris et al 2001; Stein et al 2002; Kingsford et al 2005; Beeton et al 2006; Blanch 2006). In most cases, national scale activities cannot provide the necessary resolution or coverage to adequately describe the key ecological assets and values of the tropical rivers for regional or catchment-based risk assessments, and the concomitant management of issues that potentially threaten them.

Fewer studies have concentrated solely on the Northern Tropical Rivers study area. Finlayson et al (1997) provided a short review of the management issues for wetlands across the wet-dry tropics of Northern Australia, overviewing the knowledge of wetland characteristics and distribution, and key wetlands management issues including pressures and threats. The tropical rivers data audit (NGIS Australia 2004) compiled spatial datasets from across the region but did not focus on describing the ecological assets and their status. Finally, Gehrke et al (2004) provided a short synthesis of the existing scientific knowledge of Australia's tropical river systems, and identified critical knowledge gaps for future research attention. However, as the report was the result of a multi-stakeholder public forum, it did not provide a review of existing reports/information.

Reports focused at the jurisdictional scale have been undertaken (eg. State/Territory State of the Environment reports), and are useful in identifying key ecological assets and threats across the Northern Tropical Rivers study area. At a greater level of detail the Northern Tropical Rivers study area's five Natural Resource Management (NRM) bodies provide good regional-scale information on assets and threats. For the most part, it was the reporting efforts of NRM regional and State/Territory jurisdictional scales that were used in this study to identify the key ecological assets and threats of the aquatic ecosystems of the tropical rivers region. In addition, information collated for TRIAP Sub-project 1 by Lukacs & Finlayson (2008) was used to further describe some of the key assets. Additional information on the potential effects of key pressures and associated threats was gained from peer-reviewed publications.

The major aquatic ecological assets identified for the Northern Tropical Rivers study area are summarised in Table 2.1 and described in more detail below. Although the assets are discussed separately, there is a strong interdependence between them. Water provides the major connection between the uplands, savanna lowlands, coastal plains, wetlands and offshore habitats of a catchment, and each of these also acts as a receiving environment for changes occurring elsewhere in the catchment (Cape York Interim Advisory Group 2004).

Waterways

Based on the 1:2 500 000 drainage dataset produced by Geoscience Australia, being the scale at which the Tropical Rivers Region study area geomorphic and hydrological classifications were undertaken by Saynor et al (2008) and Moliere (2008), respectively, there is approximately 62 500 km of riverine length across the Northern Tropical Rivers study area, as depicted in Figure 2.1a. These waterways are considered to be mostly unmodified compared with systems elsewhere in Australia (Stein et al 2002; Gehrke et al 2004; Woinarski et al 2007). Consequently, the vast majority of Australia's "Undisturbed Rivers" (formerly referred to as "Wild Rivers") occur in Northern Australia, as depicted in Figure 2.1b (Stein et al 2002;

NGIS 2004). The undisturbed physical context and ecological intactness represents an important attraction to tourists and the wider community.

Table 2.1 List of aquatic ecological assets for the Northern Tropical Rivers study area that were considered in this study, as reported through the Natural Resource Management Planning process[1].

Asset	Details (including components, values, functions, etc..)
Waterways	Includes all channel reaches (including estuary), and associated values/functions/ecosystem services such as water supply, water availability, streamflow, water/nutrient supply (to estuaries) and habitat/refugia/nursery.
Wetlands	Includes all non-channel surface water bodies, such as springs, swamps, floodplains, salt marshes, mud flats, and associated values/functions/ecosystem services such as erosion control, flood regulation, habitat/refugia/nursery, water treatment/purification, water/nutrient supply (to estuaries), Internationally and Nationally important wetlands.
Riparian vegetation	Includes all habitats that adjoin or directly influence waterways and streams, and their associated functions/ecosystem services such as bank stabilisation, water filtration, stream flow attenuation, provision of energy sources and habitat for many semi-aquatic and terrestrial plants and animals.
Groundwater dependent ecosystems	Includes all aspects of waterways, wetlands and riparian vegetation, as well as groundwater ecosystems (although groundwater ecosystems are not considered in detail in this study).
Biodiversity	Includes significant levels of species diversity and endemism for macroinvertebrates, freshwater fish, amphibians, aquatic/semi-aquatic reptiles or waterbirds, in either a national or international context.
Rare, Threatened and Listed communities and species	Includes Threatened Ecological Communities and Threatened or Migratory species listed under the EPBC Act and other State/Territory legislation

[1] NRM references: *WA (Kimberley)* – RNRMCG (2004), IKNRMG (2004); *NT (Top End)* – Landcare Council of the Northern Territory (2005); *Qld (Gulf of Carpentaria and Western Cape York)* – Southern Gulf Catchments (2005a), McDonald & Dawson (2004), Cape York Interim Advisory Group (2004).

The majority of rivers are seasonal or ephemeral, with only a handful having a consistent base flow throughout the year. These include the Daly River (NW NT), Roper River (NE NT) and Gregory River (Southern Gulf of Carpentaria, Qld) (Blanch et al 2005; Landcare Council of the Northern Territory 2005; Southern Gulf Catchments 2005a). The lower reaches of the Ord River also maintain year-round flow, but this is as a result of water releases from upstream dams for hydroelectric power generation and irrigation return flows (IKNRMG 2004).

During the dry season seasonal rivers are reduced to dry channels with disconnected remnant billabongs/pools (Storrs & Finlayson 1997; Southern Gulf Catchments 2005a). These riverine waterholes are extremely important as dry season refugia, supporting aquatic and terrestrial life until the wet season. Overall, however, the ecological processes that occur in these waterbodies, and the role they play in sustaining the communities, are not well understood.

The Northern Tropical Rivers comprise a range of geomorphic types, ranging from bedrock-confined channels through alluvial plains to estuarine reaches (Saynor et al 2008). On a state-by-state basis, Queensland rivers are dominated by undulating alluvial plains, NT rivers by bedrock confined/bedrock channels, and WA rivers by bedrock channel and level or rolling plains (Saynor et al 2008). Many of the rivers have long tidal reaches. In the Top End (ie. the northern part of the NT), tidal influences and associated estuarine habitats can extend as far as 80–100 km upstream (Storrs & Finlayson 1997).

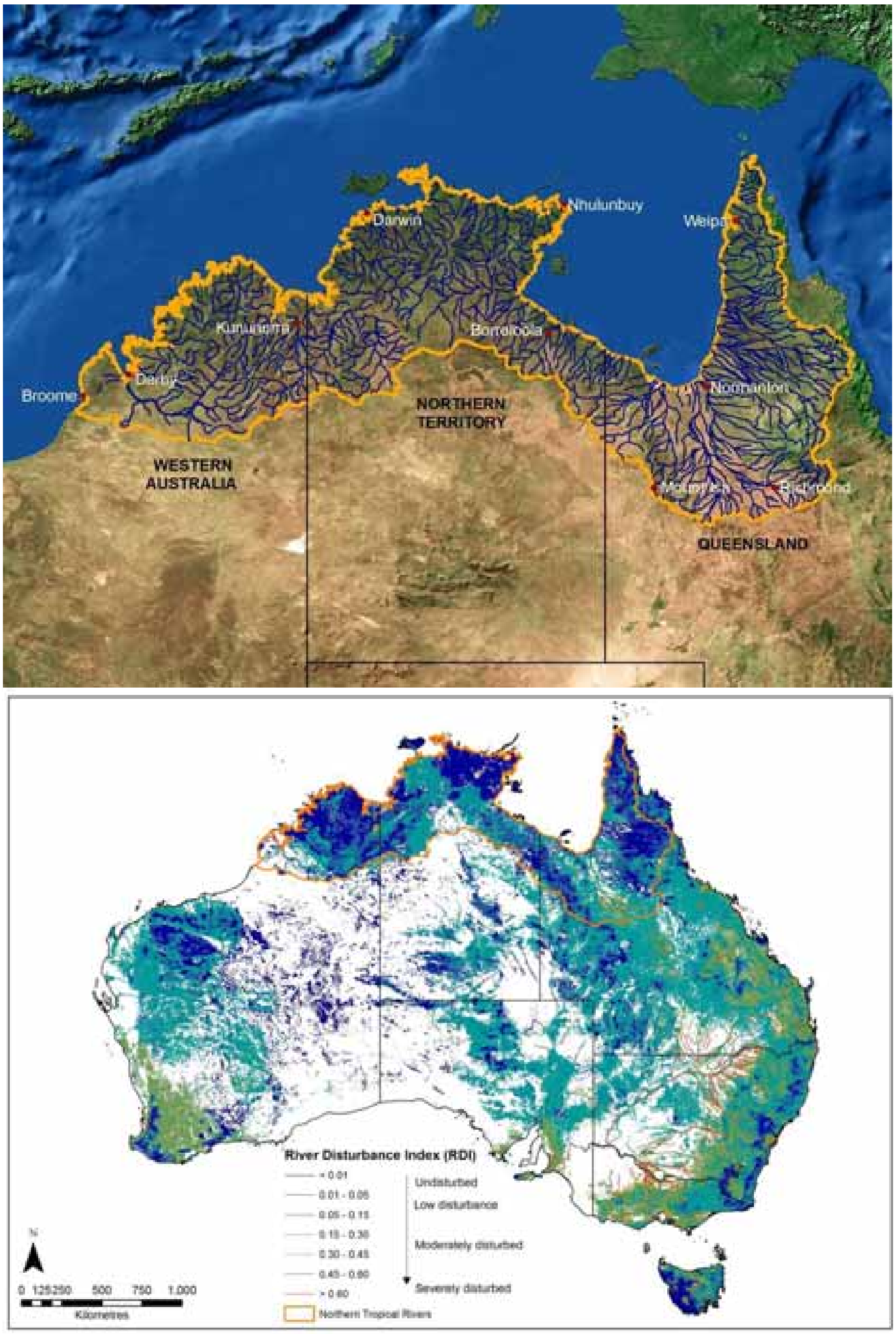


Figure 2.1 A. The waterways of the Northern Tropical Rivers study area (Data source: GEODATA TOPO 2.5M (2003) – Drainage layer); and B. River Disturbance Index for Australia showing the extent of Undisturbed Rivers in the study area relative to the rest of Australia (Data source: updated version of continental analysis by Stein et al (2002)).

The rivers are also extremely important in supporting production across the region, most notably the rich fisheries in the coastal regions, including the Northern Prawn Fishery and barramundi and mud crab fisheries. There is a strong relationship between river flow and catch from these fisheries (Robins et al 2005). However, this relationship has only been well characterised or quantified for some species and a few river catchments, and more knowledge is required on the linkage between the freshwater and marine ecosystems. The flow-fish relationship is dealt with in detail in Chapter 4 (Section 4.3).

Wetlands

The wetlands of the Northern Tropical Rivers are considered amongst the most important in Australia and are very significant in a world context. They are important as permanent, temporary or refugia habitat (eg. for feeding, breeding, roosting, sheltering) for local and migratory waterbirds as well as many other aquatic species. They support a high biodiversity (Driscoll 1994; Storrs & Finlayson 1997; McDonald & Dawson 2004; Southern Gulf Catchments 2005a) and provide numerous additional functions and services including flood control/prevention, groundwater recharge, erosion control, water purification and food supply (De Groot et al 2008).

Based on the flats, lake, mangroves, pondage area, rapid area, reservoirs and watercourse polygon attributes for the 1:250 000 GEODATA TOPO Series 3 (Geoscience Australia; ie. the "Waterbodies" GIS) Topographic Map GIS data, wetlands across the Northern Tropical Rivers cover approximately 76 000 km^2 (Figure 2.2a). While this estimation method may seem particularly coarse, Lowry & Finlayson (2004) found the previous Series 2 release of this dataset to consistently be the most reliable representation (of 10 datasets evaluated) of both multiple and specific wetlands classes across Northern Australia.

Across the region, there are a total of five wetlands of International Importance (ie. Ramsar listed sites; Figure 2.2b) and 70 wetlands of National Importance (ie. Directory of Important Wetlands in Australia sites; Figure 2.2c). These cover an area of approximately 26 438 km^2, representing approximately 2.2% of the entire Northern Tropical Rivers study area. Of the five Ramsar sites, three are in WA (Lake Argyle and Lake Kununurra, Ord River Floodplain, Roebuck Bay) and two are in the NT (Cobourg Peninsula, Kakadu). Of the 70 nationally important wetlands, 17 are in WA, 21 in NT and 32 in Qld (Table 2.2). It should be noted that many of the wetlands of National Importance would also satisfy criteria for designation as Ramsar sites (Halse & Jaensch 1998; Chatto 2006).

The Kimberley wetlands include inland and coastal systems comprising mound springs, swamps, marshes, lagoons, permanent lakes, seasonal and ephemeral pools, claypans, mudflats and seasonally inundated floodplains (Vernes 2007). The Kimberley region is home to the only substantial riverine floodplains in WA (Lane et al 2001).

Wetlands in the Top End region include semi-permanent or permanent waterholes in gorge or escarpment systems, spring systems in rainforest areas, seasonal freshwater lakes and swamps on extensive seasonally inundated floodplains, and a few permanent lakes and swamps along the northern coast (Storrs & Finlayson 1997; Landcare Council of the Northern Territory 2005).

Natural wetlands and lakes in the southern Gulf region form mainly in low-lying floodplains and in coastal areas along the shores of the Gulf. They include mangroves, salt marshes and coastal or near-coastal freshwater wetlands. There are also deep permanent waterholes in the drainage system of the Northwest Highlands, most notably those at Lawn Hill Creek, in the Gregory River catchment (Southern Gulf Catchments 2005a).

The wetlands of the Northern Gulf and Cape York regions include fan aggregations, lakes areas, seasonally inundated swamps, creek and lake aggregations, sedge lands, lagoons, springs and tidal mud flats (Cape York Interim Advisory Group 2004; McDonald & Dawson 2004). They are amongst the largest, richest and most diverse wetlands in Australia (Abrahams et al 1995). Of the various wetlands of national importance, the Archer River/Holroyd River coastal/sub-coastal floodplains and associated diverse wetlands are considered to be the most important dry season refuge on the Cape York Peninsula (Abrahams et al 1995).

A

B

C

Wetland Type	Km²
Lake	1,339
Land Subject To Inundation	44,959
Mangrove	4,837
Marine Swamp	312
Pondage Area	33
Rapid Area	<1
Reservoirs	1,186
Saline Coastal Flat	14,155
Swamp	4,124
Watercourse Area	5,234
Total	**76,180**

Figure 2.2 The wetlands of the Northern Tropical Rivers study area (shown in green): A. all wetlands based on GEODATA TOPO 250K Series 3 (Geoscience Australia) Features (Flats, Lake, Pondage Areas, Mangrove, Rapid Areas, Reservoirs and Watercourse Areas); B. Wetlands of International Importance (Ramsar); and C. Wetlands of National Importance (Directory of Important Wetlands in Australia sites). Note that in Figure 2.2 (c) wetland areas < 100 ha in size have been cartographically exaggerated for representation in the figure.

Table 2.2 Wetlands of National Importance within the Northern Tropical Rivers study area (source: Directory of Important Wetlands in Australia (DIWA) 2007).

Western Australia	Northern Territory	Queensland	Queensland (cont.)
Big Springs	Adelaide River Floodplain System	Archer Bay Aggregation	Port Musgrave Aggregation
Bunda-Bunda Mound Springs	Arafura Swamp	Archer River Aggregation	Skardon River - Cotterell River Aggregation
Camballin Floodplain (Le Livre Swamp System)	Blyth-Cadell Floodplain & Boucaut Bay System	Bluebush Swamp	Smithburne - Gilbert Fan Aggregation
	Borroloola Bluebush	Buffalo Lake Aggregation	Somerset Dunefield Aggregation
Drysdale River	Bradshaw Field Training Area	Bull Lake	Southeast Karumba Plain Aggregation
Geikie Gorge	Cobourg Peninsula System	Dorunda Lakes Area	Southern Gulf Aggregation
Gladstone Lake	Daly River Middle Reaches	Great Barrier Reef Marine Park	Spring Tower Complex
Lake Argyle	Daly-Reynolds Floodplain-Estuary System	Gregory River	Stranded Fish Lake
Lake Kununurra	Finniss Floodplain and Fog Bay Systems	Jardine River Wetlands Aggregation	Thorntonia Aggregation
Mitchell River System	Kakadu National Park	Lake Julius	Undara Lava Tubes
Ord Estuary System	Katherine River Gorge	Lake Moondarra	Wentworth Aggregation
Parry Floodplain	Legune Wetlands	Lawn Hill Gorge	
Prince Regent River System	Limmen Bight (Port Roper) Tidal Wetlands System	Lignum Swamp	
Roebuck Bay	Mary Floodplain System	Macaroni Swamp	
Roebuck Plains System	Mataranka Thermal Pools	Marless Lagoon Aggregation	
Tunnel Creek	Mount Bundey Training Area - Mary River Floodplain	Mitchell River Fan Aggregation	
Willie Creek Wetlands	Moyle Floodplain and Hyland Bay System	Musselbrook Creek Aggregation	
Windjana Gorge	Murgenella-Cooper Floodplain System	Nicholson Delta Aggregation	
	Port Darwin	Northeast Karumba Plain Aggregation	
	Port McArthur Tidal Wetlands System	Northern Holroyd Plain Aggregation	
	Shoal Bay - Micket Creek	Orford Bay-Sharp Point Dunefield Aggregation	

Riparian vegetation

Riparian vegetation is broadly defined as that occupying the land that adjoins, or directly influences, a body of water (Price & Lovett 2002). This definition includes floodplains and the areas around wetlands and lakes. Given that wetlands, including floodplains, are considered separately in this study, riparian vegetation here refers to the riparian zones associated with waterways and streams. The riparian habitats of the Northern Tropical Rivers, based on the National Vegetation Information System (NVIS) data derived by the three jurisdictions, are shown in Figure 2.3. Based on these datasets, riparian habitats occupy approximately 119 000 km^2 across the study area. There is some overlap with wetland areas on floodplains where there are riparian vegetation communities (eg. sedgelands, grasslands).

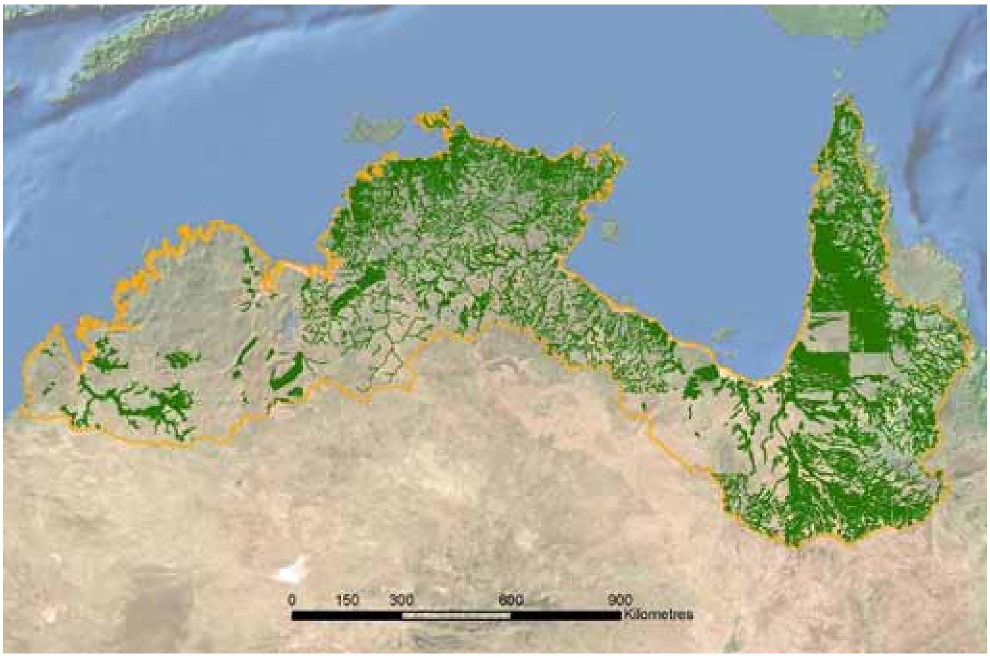


Figure 2.3 Riparian vegetation across the Northern Tropical Rivers study area. (Source: Records deemed to be riparian were extracted from the: Western Australia National Vegetation Information System 2007 [NVIS] data produced by the WA Department of Agriculture and Food; Northern Territory National Vegetation Information System [NVIS] data produced by the NT Department of Natural Resources, Environment and the Arts; and Queensland National Vegetation Information System [NVIS] Version 4 data produced by the Queensland Government)

In Northern Australia, riparian zones make a disproportionately large contribution to the biodiversity and other values of the river and land systems (Dixon et al 2006). They perform a range of functions and provide various ecosystem services. For example, they slow water flow and help stabilise stream banks, provide energy sources and habitat for terrestrial and aquatic plants and animals, and trap and filter sediments, nutrients and other contaminants before surface runoff enters the waterways (Qld Government 2003; Dixon et al 2006; WA SoE 2006).

Mangrove communities represent highly important riparian zones, serving as important habitat, including nursery grounds for many species (Australian State of the Environment Committee 2001). Mangrove species richness in Northern Australia is substantially higher relative to southern Australia (Australian State of the Environment Committee 2001).

Groundwater dependent ecosystems

Groundwater dependent ecosystems (GDEs) can be defined as natural ecosystems that require access to groundwater to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services (Clifton et al 2007). GDEs within the tropical rivers region of Australia include the river base flow systems characteristic of the coastal rivers from the north-west to north-east of the region, which are considered to be dependent on base flow during the dry season (Hatton & Evans 1998; Sinclair Knight Merz 2001; Gehrke et al 2004). In addition, riparian vegetation is likely to be largely dependent on groundwater, particularly during the Dry season (O'Grady et al 2006). Consequently, there is substantial overlap between GDEs and other assets described here (eg. waterways, wetlands, riparian zones). Groundwater aquifers, and their associated biophysical attributes (eg. stygofauna communities) are also GDEs in their own right. However, this study was not able to also assess groundwater systems *per se*, other than indirectly, through their linkages with surface water ecosystems.

Biodiversity

The tropical river systems, including their wetlands and estuaries, provide important habitats from a biodiversity perspective, supporting higher levels of species diversity and endemism for many taxonomic groups such as aquatic plants, fishes and aquatic invertebrates than more southerly Australian river systems (Gehrke et al 2004). Information from TRIAP Sub-project 1 (Lukacs & Finlayson 2008) and elsewhere indicates that the region's river systems support at least 170 freshwater fish species, about 150 waterbird species, at least 30 aquatic/semi-aquatic reptile species, around 60 species of amphibians, and over 100 macroinvertebrate Families.

Of the waterbird species, 33 are listed as Migratory Species under the EPBC Act. There are at least 25 identified Important Bird Areas (IBAs) throughout the Northern Tropical Rivers study area, which represent sites of global bird conservation importance (Dutson 2008).

It is clear that there is still a great lack of knowledge and understanding about the biodiversity of the region, in particular the relationships between species and habitats. There is also recognition across the region that some biodiversity attributes have already been damaged by human activities, and that protection and, where necessary restoration, is paramount (Southern Gulf Catchments 2005a).

The northern estuarine ecosystems are important in an international context, as estuaries in Northern Australia contain elements of broader Indo-West Pacific biological groups that have suffered greater disturbances in other locations. Australian estuaries, therefore, constitute biodiversity refuges of international significance (Gehrke et al 2004).

Threatened ecological communities and species

Threatened ecological communities and species reported in this section represent those that are predominantly associated with freshwater and riparian habitats (not including the marine environment).

The only ecological community within the Northern Tropical Rivers study area listed as Threatened under the EPBC Act 1999 is *The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin (GAB)*. Under the EPBC Act this ecological community is listed as 'endangered' and is focused on a interim distribution of springs within the generally accepted boundary of the GAB, as well as others outside the boundary, which are thought to be associated with the GAB (Threatened Species Scientific Committee 2001). The community is comprised of native species that depend on the natural discharge of groundwater from the Great Artesian Basin for their existence (Threatened Species Scientific Committee 2001). Within the Northern Tropical Rivers study area, this community occurs mostly in the southern Gulf region, namely the Leichhardt, Flinders and Norman Rivers, but also with some locations in the northern Gulf and Cape York regions. According to the Threatened Species Scientific Committee (2001), the number of springs has reduced due to the extraction of artesian groundwater from the GAB, and many other springs have shown a reduction in water flow. Some of the major threats to this ecological community include: drawdown of GAB waters; grazing and trampling by livestock and feral animals; landscape-scale modification (eg. dams); and invasion of weeds.

Within the Northern Tropical Rivers study area, there are 14 aquatic/semi-aquatic animal species listed as threatened under the EPBC Act (excluding fully marine species). These include one bird, seven frogs, one reptile, one fish, three sharks and one land-based mammal (Table 2.3).

The region is especially important for waterbirds, with 87 species listed as Migratory under the EPBC Act, 44 species listed under the Japan-Australia Migratory Bird Agreement and 53 species under the China-Australia Migratory Bird Agreement (Franklin 2008). The EPBC Act also lists the estuarine crocodile, *Crocodylus porosus*, as migratory.

Additional aquatic/semi aquatic animal species (or species closely associated with riparian habitats) that have been listed as threatened or protected on international (eg. CITES; IUCN), WA, Qld or NT threatened species lists, include *C. porosus*, freshwater crocodile (*C. johnstoni*), pig-nose turtle (*Carettochelys insculpta*), rusty monitor (*Varanus semiremex*), Merten's water monitor (*Varanus mertensi*), yellow spotted monitor (*Varanus panoptes*), Howard Springs toadlet (*Uperoleia daviesae*), freshwater whipray (*Himantura chaophraya*), dwarf sawfish (*Pristis clavata*), green sawfish (*Pristis zijsron*), Barnett River gudgeon (*Hypseleotris kimberleyensis*), Greenway's grunter (*Hannia greenwayi*), Lorentz's Grunter (*Pingalla lorentzi*), burdekin duck (*Tadorna radjah*), purple-crowned fairy wren (*Malurus coronatus coronatus*), beach stone-curlew (*Esacus neglectus*) and eastern curlew (*Numenius madagascariensis*) (Storey et al 2001; Morgan et al 2005; Queensland Government 2006; Department of Natural Resources, Environment & the Arts 2007; Fox 2007).

2.2.2 Pressures

The pressures and threats to Northern Australia's river and associated wetland systems have been well documented, if not studied, for at least 10 years. In line with the definitions provided in Table 1.1, a **pressure** is defined as:

> *Any human activity or biophysical pattern of change that has the potential to impact the natural environment*;

while a **threat** is defined as

> *Any physical, chemical, or biological agent or process arising from a pressure, which can induce an adverse environmental response*.

The information presented here and in Section 2.2.3 is based on pressures and threats documented in the planning reports of the relevant NRM bodies, as well as jurisdictional SoE reports and other regional reports and publications. There is much commonality among the reported pressures and threats, both spatially and temporally. Moreover, lists compiled by managers and researchers over 10 years ago are still highly relevant (eg. Finlayson 1995; Finlayson et al 1997; Storrs & Finlayson 1997), although several pressures have assumed greater prominence in the past two years (eg. water resource development, climate change).

Table 2.3 Aquatic/semi-aquatic species recorded in the tropical rivers region study area that are Listed as Threatened under the EPBC Act 1999 (excluding fully marine species)

Common Name	Scientific Name	Status	Distribution	Comments
Birds				
Australian Painted Snipe	*Rostratula australis*	Vulnerable	Widespread throughout the region	Threatening processes include loss of habitat due to wetland drainage or water diversion, and habitat degradation due to livestock.
Mammals				
False Water Rat, Water Mouse	*Xeromys myoides*	Vulnerable	Coastal Top End of the NT and eastern Qld, outside of study area	Species habitat is threatened by urban development and mining. Predation by feral cats also poses a threat.
Reptiles				
Gulf Snapping Turtle	*Elseya lavarackorum*	Vulnerable	Only known from the Nicholson River drainage (Gulf of Carpentaria)	Threats are unknown. The species relies on riparian trees for most of its dietary intake.
Amphibians				
Waterfall Frog, Torrent Tree Frog	*Litoria nannotis*	Endangered	Found in the Wet Tropic areas of the region (eg. upper Mitchell River)	Reasons for the decline are unknown. Disease (viral infection or chytrid fungus) may be a factor.
Mountain Mistfrog	*Litoria nyakalensis*	Critically Endangered	Formerly found in the Wet Tropic areas of the region (eg. upper Mitchell River)	Reasons for the decline are unknown. Disease (viral infection or chytrid fungus) may be a factor.
Common Mistfrog	*Litoria rheocola*	Endangered	Found in the Wet Tropic areas of the region (eg. upper Mitchell River)	Reasons for the decline are not well known. Disease (viral infection or chytrid fungus) may be a factor.
Lace-eyed Tree Frog	*Nyctimystes dayi*	Endangered	Found in the Wet Tropic areas of the region (eg. upper Mitchell River)	Reasons for the decline are not well known, although in the past habitat destruction may have been a factor. Disease (viral infection or chytrid fungus) may be a factor.
Magnificent Brood Frog	*Pseudophryne covacevichae*	Vulnerable	Found in the Wet Tropic areas of the region (eg. upper Mitchell River)	Habitat loss and degradation appear to be the greatest threats
Sharp-snouted Day Frog, Sharp-snouted Torrent Frog	*Taudactylus acutirostris*	Extinct	Formerly found in the Wet Tropic areas of the region (eg. upper Mitchell River)	Reasons for the decline are unknown. Disease (viral infection or chytrid fungus) may be a factor.
Tinkling Frog	*Taudactylus rheophilus*	Endangered	Found in the Wet Tropic areas of the region (eg. upper Mitchell River)	Reasons for the decline are unknown. Disease (viral infection or chytrid fungus) may be a factor.

Table 2.3 (continued)

Common Name	Scientific Name	Status	Distribution	Comments
Fishes				
Lake Eacham Rainbowfish	*Melanotaenia eachamensis*	Endangered	Restricted to upper reaches of rivers in Artherton Tablelands; unclear if it is present in TRIAP study area	This species has a very restricted range; although very similar to the eastern rainbow fish (*Melanotaenia splendida splendida*) it is a separate species.
Sharks				
Freshwater Sawfish	*Pristis microdon*	Vulnerable	Widespread across the region	This ray is the largest freshwater fish in Australia, growing to at least 280 cm. Vulnerable to gillnet fishing and harvest for fins.
Speartooth Hark	*Glyphis* sp. A	Critically Endangered	Known only from South Alligator R. in the NT & Bizant River (Qld – out of the study area)	Appears to be restricted to only two or very few localised areas, is very vulnerable to capture, and is likely to still be declining due to pressures such as gillnetting, recreational fishing and habitat degradation.
Northern River Shark	*Glyphis* sp. C	Endangered	Until recently, known only from parts of the Adelaide and Alligator R. systems in the NT; recently recorded in Doctor's Ck, King Sound, WA (A. Storey, UWA, pers comm).	Thought to have very specific habitat preferences and low fecundity, making it extremely vulnerable to any forms of exploitation, such as gillnetting and long lining, and also habitat degradation.
Plants				
Australian Arenga Palm	*Arenga australasica*	Vulnerable	Cape York Peninsula, QLD and Arnhem Land, NT	Threats are habitat degradation and destruction.
	Ectrosia blakei	Vulnerable	Known collections from NW QLD, Cape York and Elcho Island, NT.	No threats reported.
Salt Pipewort, Button Grass	*Eriocaulon carsonii*	Endangered	Occurs on mound springs associated with the margins of the GAB in QLD.	Mound springs are under threat from impoundment and excavation activities, draw down of GAB water and stock grazing and trampling.
	Solanum carduiforme	Vulnerable	Lawn Hill, QLD and isolated pocket in the Gulf of Carpentaria, NT.	Threats are unknown.
Orchid	*Spathoglottis plicata*	Vulnerable	From the Jardine River to the Endeavour River, Cape York Peninsula.	Threats may include plant collection and feral pig foraging.

The major pressures and associated threats to Australia's tropical rivers are summarised in Table 2.4. Collectively, the pressures addressed in this section are often referred to as land use or land management. It is important to emphasise that developments that are planned, operated and managed according to principles of ecologically sustainable development should not threaten natural systems[1]. In this respect, existing reports (eg. NRM planning reports) often refer to the *unsustainable* practice of a particular land use/management activity when discussing its potential impacts to ecosystems (eg. over-grazing, over-extraction of water). This context is implicit in the discussions throughout this report of all the pressures. This section discusses the pressures to the tropical rivers, including brief descriptions of how their associated threats have the potential to cause adverse environmental impacts to tropical river systems. Section 2.2.3 provides more detail on the specific threats.

Table 2.4 Summary of key pressures and their associated threats to Northern Tropical Rivers.[1]

Pressure	Threat							
	G'water extraction	S'water extraction	Water impoundment	Altered fire regime	Land clearance	Invasive flora	Invasive fauna	Contamination
Horticulture	✓	✓	✓	✓	✓	✓		✓
Pastoralism	✓	✓		✓	✓	✓	✓	✓
Crop production	✓	✓	✓	✓	✓	✓	✓	✓
Urban development	✓	✓	✓	✓	✓	✓	✓	✓
Tourism/recreation						✓	✓	✓
Mining	✓	✓	✓	✓	✓	✓		✓
Climate change[2]				✓		✓	✓	

1 The pressures and threats listed in this table are not intended to represent an exhaustive list; rather, they represent the key aspects as guided by relevant existing documents that have articulated stakeholder views.

2 Climate change has additional key threats associated with it that are not listed in this table, but that are discussed in the text (eg. sea level rise, changed rainfall regime).

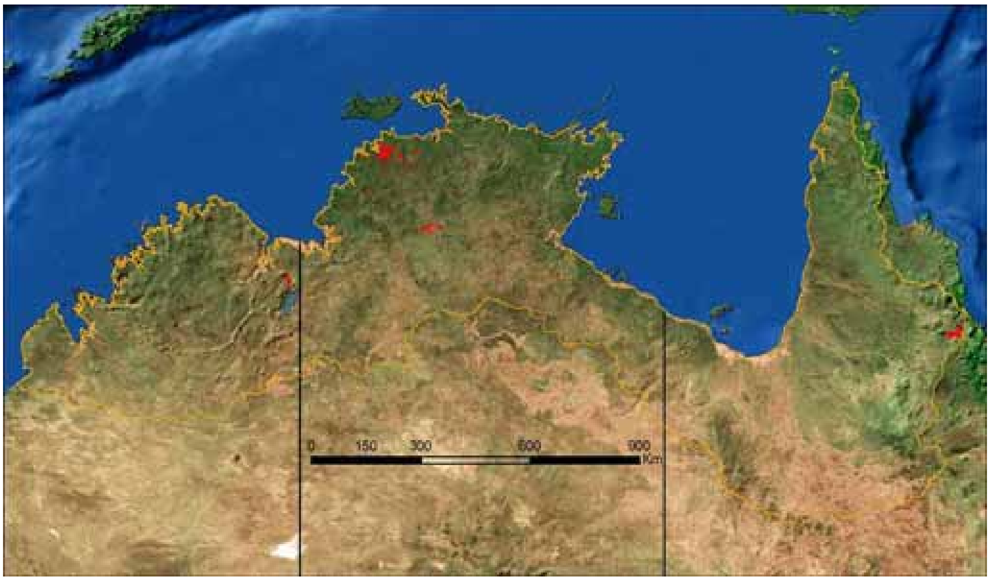
Horticulture

The Australian horticulture industry is heavily reliant on water, accounting for 13% of total water usage (Department of Agriculture, Fisheries and Forestry 2005). Horticulture can impact on the integrity of GDEs, including riverine environments, through the clearing of land and removal of habitat for wildlife and plants, exposing soils to increased surface runoff, wind and water erosion, the use of herbicides and pesticides, and the introduction of exotic species.

Horticultural activities include the large-scale production of fruit, some vegetables, flowers and exotic plants. Currently, activities of these types are not a key pressure across Northern Australia, with the total area under cultivation estimated to be only 267 km^2 (Figure 2.4). This figure has been derived from the Australian Collaborative Land Use Mapping Program (ACLUMP) Catchment Scale Land Use data. However, the specific mapping accuracy of horticulture classes is not reported, and for the NT component at least, is known to be an

1 This may mean that some developments do not proceed because their nature is incompatible with the principles of ecologically sustainable development. For example, an agricultural enterprise that requires the damming of a free-flowing river will be likely to exceed thresholds of ecological impact that cannot be effectively managed.

overestimate (see below). The data were compiled from: visual interpretation of remotely sensed data (satellite imagery and aerial photography); ancillary data containing land use information; and expert knowledge. Horticultural land use in Northern Australia represents approximately 8% of all horticultural activity occurring across Australia, and contributes 5% of the national horticultural yield (Australian Natural Resources Audit 2001). Future development of additional large areas of land for tree crops such as mangoes, cashews and sandalwood may occur (Finlayson et al 1999; A. Storey, UWA, pers comm).



Type of Horticulture	ha
Intensive	284
Irrigated perennial	21 304
Irrigated seasonal	4950
Perennial	36
Seasonal	133
Total	**26 707**

Figure 2.4 Horticultural land use across the Northern Tropical Rivers study area (regions displayed in red). (Data source: Combined *Land Use in Western Australia* (1997), *Land Use Mapping of the Northern Territory* (2002) and *Land Use in Queensland* (1999). Mapping programs conducted under the ACLUMP Catchment Scale Land Use Data). Note that horticulture areas have been cartographically exaggerated for representation in the figure.

In north-west WA a small horticultural industry operates near Broome and Derby (Department of Local Government and Regional Development 2003), but horticulture is predominantly confined to the Ord River Irrigation Area (ORIA), where sugar cane was historically the main crop. However, closure of the region’s sugar mill in late 2007 has led to strong interest in sandalwood (A Storey, UWA, pers comm), which was already experiencing expansion in the region (Kimberley Development Commission 2006). Melons, bananas, mangos and some vegetables are also grown (Kimberley Development Commission 2005). The ORIA includes the largest freshwater storage dam in Australia (Lake Argyle, ~1000 km^2) and an extensive area of agricultural production, with approximately 150 km^2 under cultivation (Ord Irrigation Cooperative 2005; Storey & Trayler 2007). Given the extent of waterway and landscape modification within the Ord River catchment, the resulting changes to the environment (Storey et al 2001), and the plans for expansion of through Ord Stage II and other irrigation schemes (Department of Local Government and Regional Development 2003), the rivers of north-east WA are likely to come under even greater pressure.

Approximately 85 km^2 of land is under horticulture production in the NT (Department of Primary Industry, Fisheries & Mines 2007). Figure 2.5 shows the distribution of horticultural activity in the NT region of the Northern Tropical Rivers study area. However, it represents an approximate two-fold over-estimation of the actual area under horticulture reported by Department of Primary Industry, Fisheries and Mines (2007). This over-estimation may be due to a temporal discrepancy between source data (eg. satellite imagery) and field verification. Land use classes are assigned at the time of data capture (imagery, cadastre and field attribution), and land use may depend on seasonal or annual cycles (Owen & Meakin 2003). However, the distribution of activity between the catchments should be relatively accurate.

The bulk of the horticultural activity occurs in the Finniss River and Adelaide River catchments, with approximately 58 km^2 of land under horticulture (Department of Primary Industry, Fisheries & Mines 2007). The Daly River catchment has approximately 27 km^2 of land under horticulture, focused within the Douglas-Daly and Katherine regions (Department of Primary Industry, Fisheries & Mines 2007).

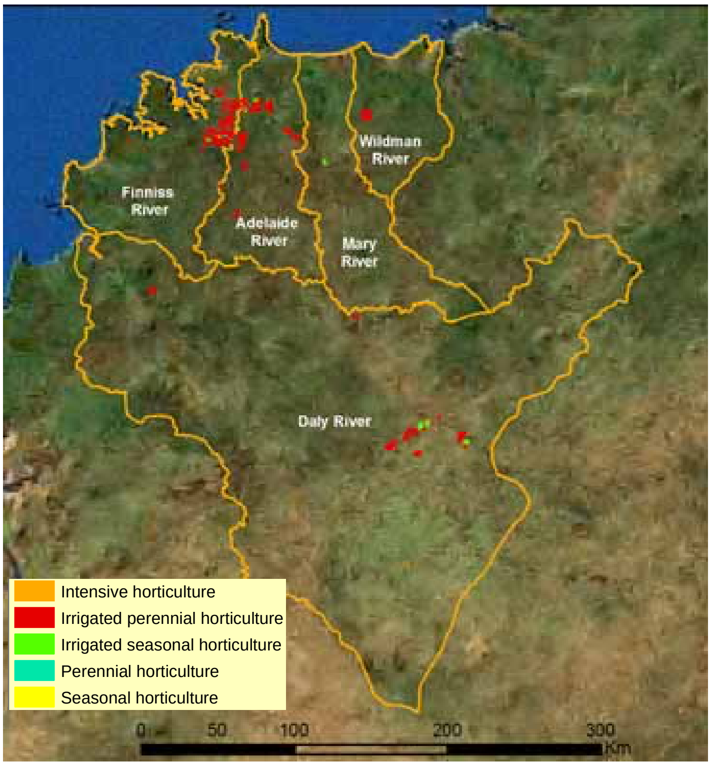


Figure 2.4 Horticultural land use across the Northern Territory component of the Northern Tropical Rivers study area. (Data source: *Land Use Mapping of the Northern Territory* (2002)). Note that horticulture areas have been cartographically exaggerated for representation in the figure. Also, the areal representation is over double the actual figures reported by Department of Primary Industry, Fisheries & Mines (2007). See text for details.

In 2004, the horticultural industry contributed $98.6 million to the NT economy, mostly from fruit and vegetables, of which mango production is the most significant. Sections of the horticultural industry, such as the citrus and ornamental plant markets, have undergone rapid expansion in recent years with growth expected to continue into the future. For example, in the Katherine region, the value of the industry grew from around $9 million in 1997 to around $40 million in 2006 (Department of Primary Industry, Fisheries & Mines 2007).

In Queensland, horticultural activities are concentrated in the northern Gulf region, predominantly in the headwaters of the Mitchell River catchment and to a lesser extent the Gilbert River catchment (McDonald & Dawson 2004). In total, there are over 160 km^2 of irrigated horticulture and cropping in this area (McDonald & Dawson 2004). This concentration in the upper Mitchell River catchment is due largely to the construction of the Tinaroo Dam and associated irrigation channels in the 1950s, which by 2004 was providing about 225 000 ML annually to farms within the irrigation area (McDonald & Dawson 2004). Mangoes are the major fruit crop for the area but avocados, pawpaw, citrus, lychees, longans, passionfruit, coffee, basil, sweet potato and watermelon are also grown (McDonald & Dawson 2004).

Pastoralism

Pastoralism refers to the production of cattle and other grazers on rain-fed native vegetation through to modified irrigated pastures, and is the most common land use across Northern Australia (Whitehead et al 2003), occupying an area of approximately 815 041 km^2 (Figure 2.6). Of this area, approximately 5 573 km^2 is allocated to grazing on modified pastures and the remaining 805 048 km^2 is gazing on natural vegetation. It is important to note that lands designated as pastoral areas will include land used intensively through to land not being grazed at all. The total herd size in Northern Australia is estimated to be from around 5 million (Woinarski et al 2007) to 16 million (Charmley et al 2008). Differences in estimates may be attributable to differences in area of land captured. Regardless of the exact number, pastoralism has had a major effect on the landscape.

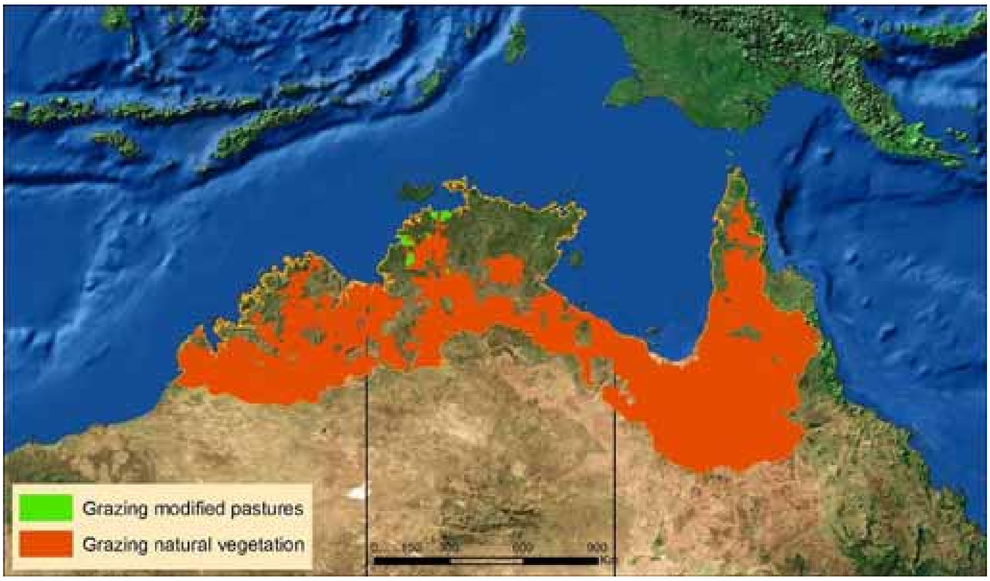


Figure 2.6 Pastoral land use across the Northern Tropical Rivers study area. (Data source: Combined *Land Use in Western Australia* (1997), *Land Use Mapping of the Northern Territory* (2002) and *Land Use in Queensland* (1999). Mapping programs conducted under the ACLUMP Catchment Scale Land Use Data.

Although the Northern Tropical Rivers have experienced less grazing pressure and impact than neighbouring parts of the country (eg. Great Artesian Basin, central-west WA and the Barkley Tableland), an assessment of landscape health by Morgan (2001) clearly showed that catchments in the region that have experienced moderate to heavy grazing pressure exhibited higher landscape stress than catchments with low grazing pressure.

Wetlands, particularly floodplains and riparian environments, represent a nutrient-rich and mesic environment for grazing animals and are often used as alternative stocking sites by pastoralists during the drier months. Widespread modification of wetlands by or for grazing is likely to reduce the range of wetland habitats. Impacts on wetlands from pastoralism can include land clearing/loss of vegetation cover (eg, through grazing and trampling), establishment of monocultures, introduction of weeds, woody thickening, loss of biodiversity and habitat, compaction of soils, soil erosion through overgrazing, the contamination of watering points with nutrients from faecal matter, the exclusion of other animal and the loss of dry season refugia for many species (Storey et al 2001; RNRMCG 2004). Additionally, it is estimated that, between 1947 and 1985, 463 exotic grass and legume species were deliberately introduced into Northern Australia as pasture species. Only 21 of these are now considered useful and 60 (13% of total) are listed as weeds of agricultural or conservation significance (Landcare Council of the Northern Territory 2005). A more recently identified impact of pastoralism, albeit not a direct impact on aquatic ecosystems, is that of methane emissions arising from enteric fermentation in livestock (Charmley et al 2008).

In the Kimberley region, approximately 500 000 beef cattle graze native vegetation over 220 000 km^2 (Kimberley Primary Industry Association 2004). This region is the focus of the pastoral activity in WA, and it supports more cattle than any other region (Kimberley Development Commission 2005). There are 93 pastoral leases, 32 of which are recognised as being under Aboriginal management (RNRMCG 2004). Over-stocking of high capacity lands has, in some areas, resulted in over grazing and associated problems. For example, erosion from poor land management has been observed along both the Victoria and Ord Rivers and resulted in the loss of riparian vegetation and sedimentation of waterways (Finlayson et al 1999).

The cattle industry is the dominant land use throughout the Top End of the NT. The suitability of a monsoonal climate for introduced and irrigated pastures has resulted in an increase of these intensive land use practices (Northern Territory Chamber of Commerce 2005). The major focus of producers in the region is to supply the live export market with approximately 30% of the cattle exported from Australia. The size of the live export market in this region, and its growth following market pressures in the 1990s, has also resulted in the expansion of the hay and feed pellet industries, particularly in the Darwin and Kakadu regions (Hristova & Murti 1998; Northern Territory Chamber of Commerce 2005).

In Queensland, the cattle industry is variably distributed throughout catchments adjoining the Gulf area and the Cape York and central northern regions. This is mainly due to highly variable distribution of suitable soil types. Poor fertility and low carrying capacity result in large properties and very low stocking rates in some parts of the region. In the Cape York region, the pastoral industry occupies approximately 75 000 km^2, but has a production rate less than half of the Kimberley region (Tropical Savannah CRC 1998). However, areas to the south, while also highly variable, have some of the most fertile lands in tropical Australia. This has resulted in a range of grazing practices, from native grassland grazing to improved and irrigated pastures (Tropical Savanna CRC 1998).

Crop production

Crop production, or cropping, includes irrigated or dryland farming of crops such as hay and silage. Cropping is not a major issue within wetlands in Northern Australia. However, the development of land for rice and other crops has been attempted in the past (Chapman et al 1996), and an expansion across the north cannot be ruled out (Finlayson et al 1999). Petheram & Bristow (2008) provide an informative review of the constraints and opportunities for irrigation in Northern Australia. Based on spatial data collected under the ACLUMP, cropping represents approximately only 0.05% of land use across the Northern Tropical Rivers study area, occupying an area of approximately 603 km^2 (Figure 2.7). This is an underestimate as cropping undertaken in the Kimberley was not captured within the dataset.

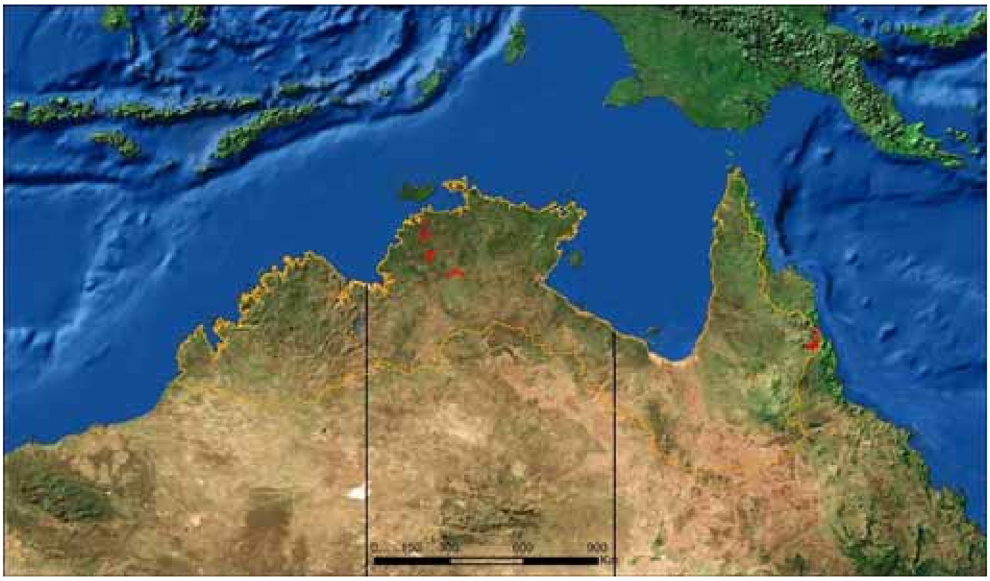


Figure 2.7 Dryland and irrigated cropping land use across the Northern Tropical Rivers study area. (Data source: Combined *Land Use in Western Australia* (1997), *Land Use Mapping of the Northern Territory* (2002) and *Land Use in Queensland* (1999). Mapping programs conducted under the ACLUMP Catchment Scale Land Use Data).

Amongst other things, agriculture can impact the ecological values within catchments through land clearance, the use of chemicals, loss of soils and water extraction (Price et al 2003). Broad-acre cropping and irrigated agriculture can adversely impact floodplains and rivers in a number of ways including salinisation, erosion and sedimentation, changes to rates of sediment delivery, water quality of irrigation return flows and by providing barriers to migration of aquatic species (Storey et al 2001; Price et al 2003). The extraction of excessive amounts of ground and surface water for irrigating field crops can present a clear threat to the aquatic systems, both from where it is sourced and downstream (see Section 2.2.3).

Crop production in the Kimberley region is almost entirely concentrated within the ORIA, and is classified under the ACLUMP as horticulture (see *Horticulture* section and Figure 2.4, above). Until recently, field crops in this area were dominated by sugar cane followed by hybrid seed crops, sorghum, culinary beans and cotton (Kimberley Development Commission 2005). It is anticipated that future expansion of the irrigation area could increase the irrigation zone from 150 km^2 to approximately 300 km^2, with water consumption increasing from 300 to 1000 GL pa (Storey & Trayler 2007). Historically, there were underperforming or failed attempts at growing rive and sorghum (and some other crops) at Camballin on the Fitzroy River floodplain (see Section 2.4.2).

Cropping in the NT is not a major industry, although past and present enterprises include crops like peanuts, sorghum, sesame, cotton, pasture seeds and hay production (Landcare Council of the Northern Territory 2005). The vast majority of current cropping activity occurs in the Daly River catchment. In addition to cropping, agroforestry appears to be a growing industry in the NT, particularly the Daly River catchment, where 1.2 million trees were planted across 12 km^2 during the 2007-08 wet season (Curtain 2008a). Such forestry is expected to have an adverse impact on short-term agricultural development in the region (Curtain 2008b). As in the Kimberley region, there have also been failed attempts at cropping in the NT. Most notably, the Humpty Doo Rice Project, established in the 1950s, proposed to develop 3 000 km^2 of sub-coastal plains for growing rice. However, by the 1960s, commercial rice production had all but ceased, with the project failing for several reasons including the remoteness of the location, inadequate water storage and delivery technology, insufficient funding, poor management structure and animal pests (Fisher et al 1977).

In Queensland, cropping activities are concentrated in the northern Gulf region, predominantly in the headwaters of the Mitchell River catchment (McDonald & Dawson 2004), although some small scale cropping also occurs in the Gregory River and Lawn Hill Creek vicinity, and north of Richmond along the Flinders River (Southern Gulf Catchments 2005a). The potential for agricultural expansion in the southern Gulf was assessed in 2004 (Department of Natural Resources Mines and Energy 2004) and there has been no major further development to date. Sugar cane and tobacco seem to be the major (non-horticultural) crops in the Mitchell River region. McDonald & Dawson (2004) reported that the area under sugar cane had expanded rapidly to occupy about 90 km^2.

Urban development & human settlement

The Northern Tropical Rivers study area is sparsely populated, with a total population of approximately 250 000 at an approximate population density of 0.2 per km^2, more than 10 times lower than the national average of 2.7 per km^2 (ABS 2007). The extent and distribution of urban areas across the study area is shown in Figure 2.8. Approximately two thirds of the region's population is concentrated in the Top End region. According to Gehrke et al (2004), projections for human population growth and expansion of economic activities in the near term are low across most of the region, constrained in part by remoteness, a lack of supporting infrastructure, and the large proportion of land held by Aboriginal Title. However, population growth rate is, and will continue to be, high in some centres, and pressures will be felt in particular regions, particularly in the Kimberley and Top End.

The Kimberley region has an estimated resident population of 36 000 (Kimberley Development Commission 2006), at an approximate population density of 0.1 per km^2. The region's high population growth rate of 2.7% (2000–2005) is more than double the average annual rate for regional WA, and is projected to result in a regional population of over 70,000 by 2031 (Kimberley Development Commission 2006). The development and maintenance of infrastructure is a priority for local governments in the area as the drive for attracting more people to the area continues (Kimberley Development Commission 2006). The main urban/service centres in the Kimberley are Broome (population ~15 000), Kununurra (pop. ~5000), and Derby (pop. ~3600). The proportion of Aboriginal and Torres Strait Islanders in the Kimberley is about 47% (IKNRMG 2004).

The Queensland region has an estimated population of 55 000, with over 50% living in the northern Gulf region. Population density is very low, averaging around 0.1 per km^2. Major centres/regions include Mt Isa (pop. ~21 000), Cloncurry (pop. ~5000), the Mareeba region (pop. ~4500) and Weipa (pop. ~2500) (ABS 2007). The proportion of Aboriginal and Torres

Strait Islanders across the region ranges from approximately 20–25% in the southern and northern Gulf regions to 55% in the Cape York region. Population is decreasing by about 1% pa in the southern Gulf region (Southern Gulf Catchments 2005a) and increasing by about the same amount in the northern Gulf region (McDonald & Dawson 2004).

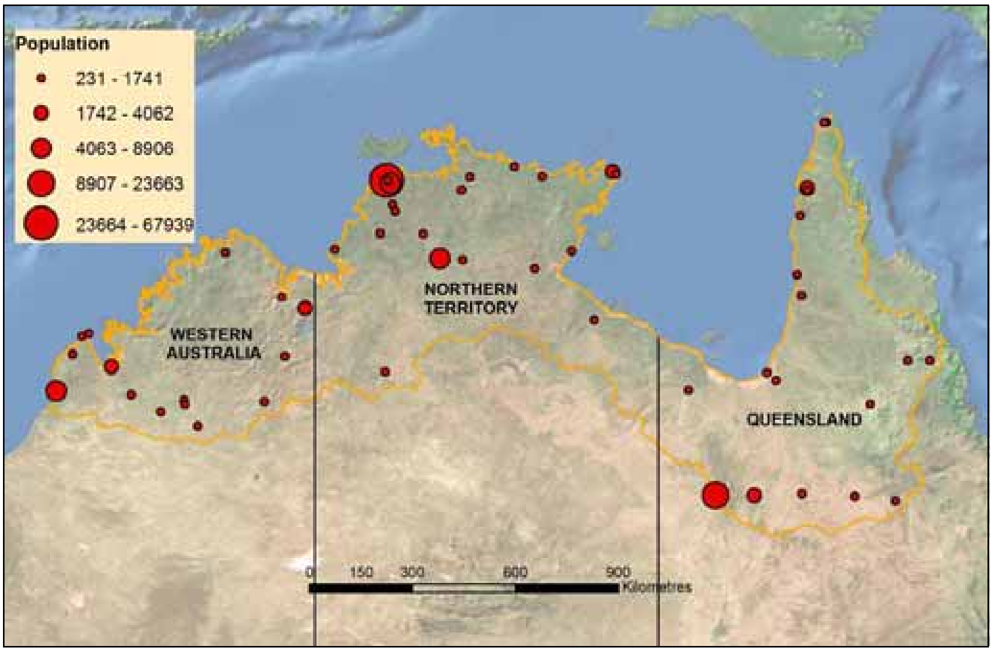


Figure 2.8 Urban areas across the Northern Tropical Rivers study area. (Source: Populated Places (population >200)- Australian Bureau of Statistics as derived from the 1991 Census).

The Top End region has an estimated population of 160 000, with approximately 60% living in the Darwin/Palmerston region (ABS 2007). Population density is low, although somewhat higher than in the WA and Qld regions, averaging around 0.3 per km^2. The Darwin/Palmerston region represents by far the largest population centre in the Northern Tropical Rivers study area (population density – ~400 per km^2; ABS 2007). Other significant population centres (ie. greater than 2000 people) include, Katherine, Nhulunbuy, Galiwin'ku, Maningrida, Nguiu, Tennant Creek and Wadeye (Landcare Council of the Northern Territory 2005). The proportion of Aboriginal and Torres Strait Islanders in the Top End region is about 30% (ABS 2007). Average annual population growth rate in the region from 2000 to 2004 was approximately 1% (ABS 2007).

Increasing urbanisation requires more or increasing amounts water for domestic and industrial purposes, as well as greater clearing of native vegetation for infrastructure (IKNRMG 2004; McDonald & Dawson 2004; Landcare Council of the Northern Territory 2005). Thus, urban development can have major impacts to wetlands and rivers, through the alteration of water regimes (via the utilisation of both surface and groundwater resources; Sinclair Knight Merz 2001), degradation, fragmentation or destruction, contamination, and the introduction and facilitated spread of invasive plants and animals (Bunn et al 1997; Wang et al 2001).

Urban and commercial development can impact surface and groundwater quality particularly through the discharge of sewage effluent (from sewage treatment plants and septic tanks), the use of pesticides and fertilisers in recreational parks and gardens, and industrial chemical spills (Sinclair Knight Merz 2001; Southern Gulf Catchments 2005a). In addition, urban and industrial stormwater runoff can contain elevated levels of contaminants such as suspended sediment, nutrients, heavy metals and hydrocarbons, which can impact on receiving environments such as wetlands, streams and coastal ecosystems (Kumar et al 2002; McDonald & Dawson 2004; Landcare Council of the Northern Territory 2005; Southern Gulf Catchments 2005a).

Tourism and recreational and customary harvest

Waterways and wetlands are important areas for tourism and recreation across Northern Australia. Tourism associated with Australia's tropical rivers includes camping, boating, hunting, angling, bird watching and bushwalking. While populations may be low, visitation through tourism is a major industry for Northern Australia.

In 2003 and 2004, the average annual number of visitors to the Kimberley region was 206 900 (excluding business visitation; Tourism Western Australia 2005). This figure is predicted to grow 5.8% pa for international visitors and 0.9% pa for domestic tourists (Tourism Western Australia 2007). In 2004 to 2005, the average annual numbers of visitors to the Top End and northern Qld were approximately 459 000 and 420 000 people, respectively (Northern Territory Tourism Commission 2005; Tourism Research Australia 2005). For the State of Qld, visitor numbers are predicted to grow 4.1% pa for international visitors and 0.4% pa for interstate visitors (Tourism Queensland 2006). For the NT, visitor numbers are predicted to grow 2.2% pa for international visitors and 1.2% pa for interstate visitors (Tourism NT 2006). A key characteristic of tourism in Northern Australia is that it is highly seasonal, with the vast majority of tourists visiting during the Dry season, with most of the activity focused during only 3-4 months of the year.

At present, the impact of tourism on Northern Australian Rivers and wetlands is most likely low, attributable in large part to the low population pressures and inaccessibility of many areas (Storrs & Finlayson 1997). However, with the projected increased population and tourism growth across parts of the region, it is likely that pressures on the environment from tourism and associated activities will increase (Finlayson et al 1999). Moreover, existing tourist 'hot spots' are already under pressure and are likely to have experienced some impacts (Landcare Council of the Northern Territory 2005). For example, Hill & Mann (2006) noted that tourism in the Kimberley region appears to be poorly planned and controlled in relation to cultural heritage protection, and as a result many tourists are damaging important cultural sites.

Figure 2.9 shows areas of recreation reserves and other places of tourism interest, including the major centres, across the study area. Whilst this is not a quantitative or robust indicator of tourism and recreation pressure (including that from recreational fishing), it does provide a snapshot of tourism and recreation focal points. In general, these places correspond to the major centres and iconic national parks such as Kakadu National Park and Litchfield National Park.

Given the variable nature of the environments across Northern Australia, the extent of the impact of tourism and recreational activities depends on the presence of, and accessibility to, water. For example, access to many waterways and adjoining areas is restricted to specialized vehicles or is inaccessible for much of the Wet season. Tourism and the recreational use of riverine areas can affect the ecological values of these areas in several ways. Impacts to these areas from excessive and unrestricted use include pollution and littering, waterway contamination through the use of fuel, soaps, detergents, sunscreen and insect repellent, vegetation trampling, firewood removal, soil compaction and bank erosion (Finlayson et al 1997; IKNRMG 2004; RNRMCG 2004; Southern Gulf Catchments 2005a).

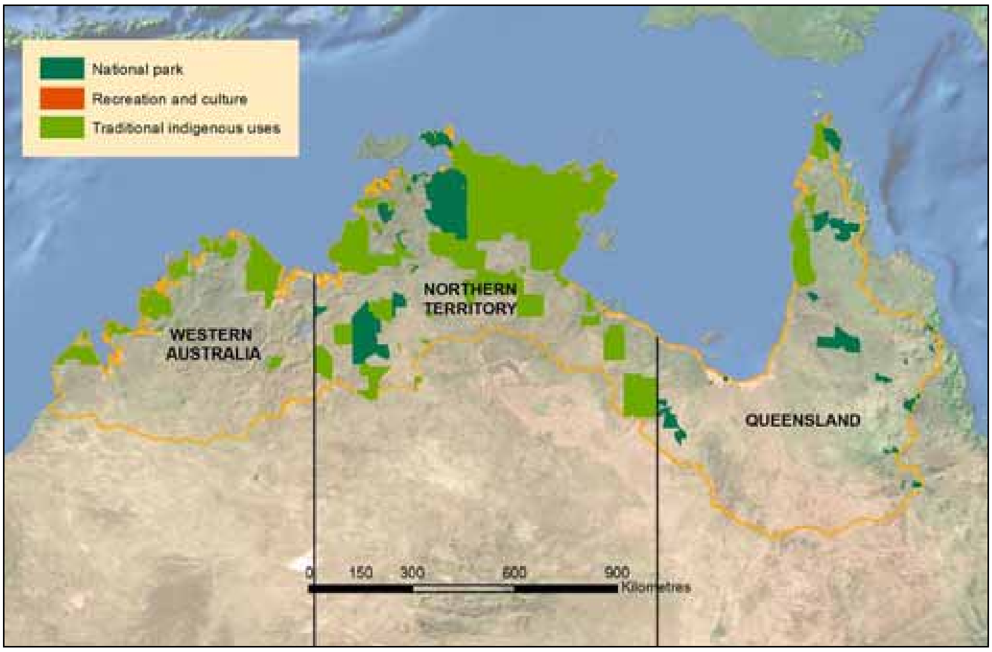


Figure 2.9 Recreation reserves, other places of tourism interest and land utilised for traditional indigenous purposes across the Northern Tropical Rivers study area. (Data source: Combined *Land Use in Western Australia* (1997), *Land Use Mapping of the Northern Territory* (2002) and *Land Use in Queensland* (1999). Mapping programs conducted under the ACLUMP Catchment Scale Land Use Data).

Preliminary studies in Kakadu National Park, NT, looking at the presence of petroleum hydrocarbons from boating and endocrine disrupting compounds (EDCs) from sunscreens at sites of reasonably high boating and swimming usage, respectively, found little to no contamination (van Dam et al 1998; Hogan et al 2004). However, these results do not imply that water contamination is not an issue for particular sites at particular times of the year, particularly because there are many sites across the region that experience much greater tourism and recreation pressure than the sites in Kakadu. The increased use of off-road vehicles and associated trails can potentially expose previously inaccessible areas to disturbance. River reaches at road crossings are particularly susceptible to impacts and pollution from vehicles and campers (RNRMCG 2004). Vehicles, including boats, and people also spread weeds, trample vegetation and/or increase erosion (IKNRMG 2004). There are also concerns among Aboriginal people and natural resource managers that increased boating activity is adversely impacting rivers in localised areas, particularly through bank erosion (Braithwaite et al 1996; De Groot et al 2008; Saynor 2008). Hunting has been a controversial recreational issue across Northern Australia (Finlayson et al 1999) and impacts from these activities are likely to include a reduction in long term persistence of certain species and environmental contamination (eg. accumulation of lead shot in magpie geese; Storrs & Finlayson 1997; Price et al 2003).

Recreational fishing is the biggest tourism-based activity across Northern Australia (McDonald & Dawson 2004; IKNRMG 2004; Landcare Council of the Northern Territory 2005). Across the region, the two key freshwater or estuarine species harvested are barramundi (*Lates calcarifer*) and mud crab (*Scylla serrata*) (Landcare Council of the Northern Territory 2005). From a national survey of recreational fishing for 2000-01, Lyle et al (2003) estimated that 200 000 barramundi and 800 000 mud crabs were harvested by recreational fishers in WA, NT and Qld. Note, however, that this figure includes catch from the eastern coast of Qld. It is difficult to determine the extent of impact recreational fishing has on fish populations, particularly when species are also commercially harvested. Nevertheless, there is some evidence of local declines in fish species.

In areas adjacent to the southern Gulf port of Karumba, Grunter (*Pomadasys kaakan*) are thought to be close to being fully exploited through recreational fishing (McDonald & Dawson 2004). Other reports also document anecdotal reports of negative impacts of recreational fishing on fish stocks in this region (Southern Gulf Catchments 2005a; Greiner 2004, as cited by McDonald & Dawson 2004). According to NT DPIFM (2006), in certain accessible and heavily fished areas, recreational fishing pressure in conjunction with commercial fishing may increase the total harvest in these specific areas to levels approaching full utilisation. Finally, it should be noted that recreational fishers are regulated by the State and Territory Governments, through seasonal closures, size limits and bag limits, and on Aboriginal owned lands.

The Indigenous Fishing Survey of Northern Australia (Coleman et al 2003) examined the fishing activities of many northern indigenous communities from Broome to Cairns. It was found that approximately 900 000 finfish, 1.1 million molluscs, 660 000 prawns and 180 000 crabs and lobsters are harvested each year in Northern Australia. The significance of these figures varies between regions. The total number of finfish harvested by indigenous communities is minor when compared to the 56 million harvested nationally by non-indigenous recreational fishers. However, the total number of finfish caught in the NT by indigenous fishers represents half of the total finfish harvested in the region by both non-indigenous and indigenous fishers (Coleman et al 2003).

Mining

Mining is defined here as the process of removing a targeted resource from the ground (mining) plus the associated minerals processing activities (Lloyd et al 2002). Economically, mining represents one of the largest industries across the Northern Tropical Rivers study area. Whilst figures have not been extracted for the whole study area, the mining and minerals processing industry currently contributes at least $50 billion annually to the Australian economy, and employs over 80,000 people (Price Waterhouse Coopers 2006). As at 2007, there were over 11 000 records of mines of varying status across the region, ranging from undeveloped mineral deposits to shut down and abandoned sites (Figure 2.10a). This provides a broad picture of past, present and future mining activity across the region. About 60% (~7000) of the total number of records represent past operations (ie. shut down and/or abandoned sites; Figure 2.10b), less than 1.5% (~140) represent operating/producing mines (care and maintenance and/or operating sites; Figure 2.10c), and ~30% (~3400) represent potential future operations (ie. undeveloped mineral occurrences; Figure 2.10d). Activity in exploration and mining development is likely to rise over the coming years as the minerals sector in Australia continues to experience strong growth. The region also has its share of abandoned or poorly rehabilitated mines, legacies of past environmental regulations that were insufficient to ensure long-term environmental protection (Ball et al 2001).

In the Top End of the NT, there are currently five major operational mines (Alcan Gove, bauxite mining and alumina refining, Nhulunbuy; GEMCO, manganese, Groote Eylandt; McArthur River Mine, zinc-lead, Borroloola; Ranger Mine, uranium, Jabiru; and Tiwi Islands Minerals Sands Project, heavy mineral sands, Melville Island) (NT DPIFM 2007a). However, future development is expected to be substantial, with at least 14 developments, including new mines and re-opening/working of historic mines, expected between 2006–2010 (NT

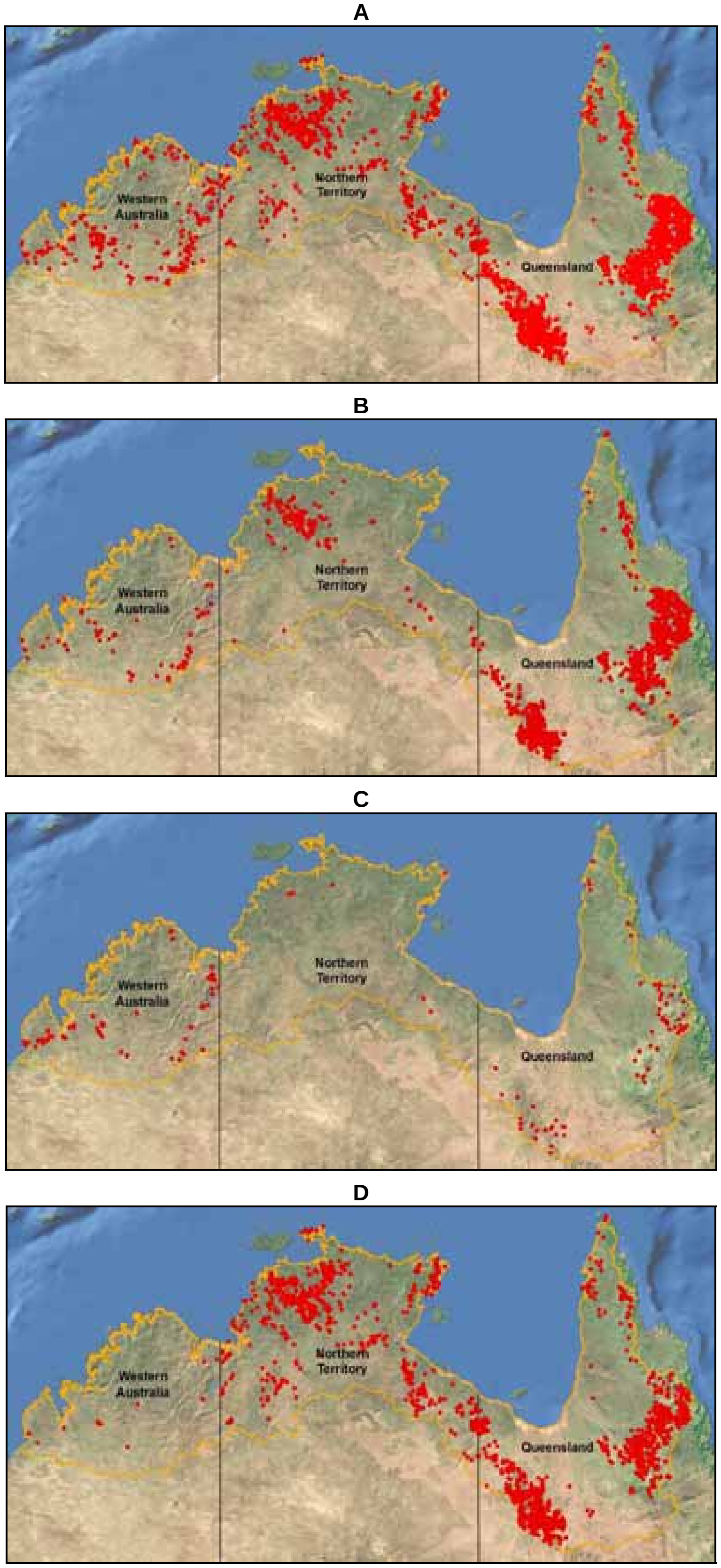


Figure 2.10 Mining activity across the Northern Tropical Rivers study area: A – all records; B - Historical Mines (Shut down & Abandoned); C – Current Mines (Operating & Care & maintenance);and D – Potential Mines (Development, Proposed, Prospect, & Mineral Occurrence). Data derived from MODAT (2005) for NT; MINEDEX (2007) for WA; and IRTM (2006) for Qld.

DPIFM 2007b). The Top End also has a number of legacy/abandoned mines and poorly rehabilitated mines that potentially pose a significant threat to the environment. Examples of these include Mt Todd (gold), Rum Jungle (uranium, copper, nickel, lead) and Nabarlek (uranium). With minerals prices increasing in recent years, a number of other legacy sites, particularly gold mining operations in the Pine Creek region, are in the process of being recommissioned (NT DPIFM 2007b).

In Queensland, mining operations are mostly congregated in three major areas: The upper Gregory, Leichhardt and Flinders River catchments (southern Gulf); the upper Gilbert and Mitchell River catchments (northern Gulf); and the Watson and Embley River catchments (Cape York). Copper, lead, silver and zinc represent the major commodities mined in the upper Gregory, Leichhardt and Flinders Rivers region (Qld NRME 2004). Mining activities in the upper Gilbert and Mitchell Rivers region have occurred since the late 1800s, with gold and tin being the major commodities (MRWMG 2000). In this region there have been substantial impacts on water quality due to unmanaged/uncontrolled seepage or runoff of contaminated waters and sediment (Bartereau et al 1998). Bauxite is mined in the Watson and Embley Rivers region of Cape York Peninsula (Geoscience Australia 2006).

Mining is easily the largest contributor to regional production in the Kimberley. In 2002-03 the mining sector contributed almost 80% of the Gross Regional Product of $1.2 billion (Kimberley Development Commission 2005). The major minerals commodities of the region are diamonds, nickel, iron ore and rock (for construction purposes), with further plans to develop metallic mines in the East Kimberley as well as numerous ventures in the West Kimberley (Kimberley Development Commission 2006). Diamond mining is currently dominated by Argyle Diamond Mine (East Kimberley), with a small contribution from Ellendale Diamond Mine (West Kimberley). Other key operations include Sally Malay (nickel, East Kimberley), Cockatoo Island (iron ore, West Kimberley) and Lennard Shelf (zinc and lead, West Kimberley) (Kimberley Development Commission 2006). According to MINEDEX (2007), the Kimberley does not currently appear to have any abandoned/legacy mines.

Mining operations typically occur at localised spatial scales, and hence, they tend to represent point, rather than diffuse, sources of threats to ecosystems. For threats to surface waters, the potential impacts are typically confined to immediate or near-field downstream features, and can often be controlled to a large degree (Finlayson et al 1999). Such localised practices can affect the ecological values of areas through water contamination, water extraction, and the construction of infrastructure such as roads, bridges, culverts, railways, pipes and power lines.

According to Woodside & O'Neill (1995), impacts of mining-related pollution on biodiversity have been significant in the past. The Rum Jungle copper/uranium mine in the NT (Jeffree & Williams 1975) and the Mount Morgan gold/copper mine in central Qld (Lloyd et al 2002) represent stark examples of the impacts that mining operations have had on Australian tropical/sub-tropical aquatic ecosystems. Typically, mining impacts on aquatic ecosystems result from the entry into natural waters of (often acidic) mine waters containing elevated concentrations of metals and non-metallic inorganics (Lloyd et al 2002; DRCRG 2004). In the case of the above-mentioned operations these included aluminium (Al), copper (Cu), manganese (Mn), uranium (U, Rum Jungle only) and zinc (Zn) (Lloyd et al 2002). Other priority metals or metalloids of potential aquatic ecotoxicological concern for the mining industry in tropical Australia include arsenic (As), cadmium (Cd), cobalt (Co), lead (Pb), nickel (Ni) and vanadium (V) (Markich & Camilleri 1997).

The extraction of groundwater for mining operations, typically for dewatering of mine pits, may threaten water quality and GDEs. Dewatering may have localised impacts on wetlands, terrestrial ecosystems and stygofauna communities that rely on groundwater supply (ie. GDEs). In fact, Sinclair Knight Merz (2001) considered mining, alongside agriculture, to represent the major threatening process to GDEs in Northern Australia, with some of the impacts including:

- Mine dewatering will lower the aquifer pressure or water table. The effect will be greatest for large open cut mines. It also has the potential to reduce discharge flux;
- Water diversion due to mine-related activities can impact on groundwater levels;
- Tailings dams associated with mines may leak or be connected to aquifers such that there is a local elevation in groundwater level; and
- Groundwater quality may be adversely impacted due to solution mining using toxic chemicals. This in turn can have a high impact on GDEs.

In addition, mine pits/voids may change local groundwater flows while they also have the potential to become point sources of hypersaline and heavily contaminated (sometimes acidic) water that can represent a threat to local surface and groundwaters (RNRMCG 2004). Similarly, tailings from the processing of mineral ores, which typically contain high levels of potentially toxic metals, metalloids and non-metallic inorganics, can be improperly stored, with the potential to wash into streams and/or leach into groundwater.

Climate change

Global climate change is now a widely accepted anthropogenic process that will increasingly impact on the environment. The Intergovernmental Panel on Climate Change has concluded that global warming has, and will, continue to occur and that this is very likely a direct result of human activities (IPCC 2007). It is also clear that the inherent vulnerability of many natural systems will result in irreversible impacts to some environments. While the impacts of climate change will vary regionally with natural variation in physical and biological processes, numerous broad effects are projected (IPCC 2007):

- It is likely[2] that the global-average temperature will increase between 1.1 to 6.4°C by the end of the 21st century;
- the global-average sea level is projected to rise between 0.18 to 0.59 m by the end of the 21st century;
- it is likely that the amount of precipitation will decrease in sub-tropical land regions, including northern Australia; and
- it is likely that future tropical cyclones will become more intense with higher wind speeds and more intense precipitation;

CSIRO (2007) considered the likely extent of climate change in Australia, with the following effects projected for the Northern Tropical Rivers study area:

- It is likely that the average temperature will increase between 1 to 4°C by 2070; and

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2 The "likely" estimates provided for temperature and precipitation represent median, or best estimates of changes in these climatic variables. The ranges provided reflect the medians projected for the range of emission scenarios. The ranges are much higher if 10th and 90th percentiles are reported instead of medians. See CSIRO (2007) for more details.

- it is likely that the amount of precipitation will change by -10 to +2%, with the south of the region more likely to experience a reduction in precipitation.

In an Australian context, it is widely acknowledged that climate change will significantly impact upon natural resources, including water and biodiversity, across the country (Hennesey et al 2004; Queensland Government 2005; Allen Consulting Group 2005; Hyder Consulting 2008), although predictions associated with temperature changes are more certain than those associated with precipitation.

The rivers and wetlands of coastal Northern Australia are generally low in elevation and particularly susceptible to climate change through sea level rise and other changes to physical and ecological processes. These ecosystems are considered at great risk and a priority area for climate change research (Allen Consulting Group 2005; Hamilton & Gehrke 2005; Hyder Consulting 2008). The major threat to coastal waterways is through saltwater intrusion whereby highly diverse grass/woodland and freshwater habitats are replaced with salt flats (Woodroffe & Mulrennan 1993; Finlayson et al 1999). This has been observed in the lower Mary River in the NT, where a gradual extension of the tidal influence has adversely affected extensive areas of woodland and freshwater complexes. While the cause of changes to the Mary River is not attributable to climate change (Woodroffe & Mulrennan 1993), in the sense of global warming, it is seen as an analogue of future climate change scenarios (Bayliss et al 1997). The risk of sea level rise to coastal wetlands is addressed in detail in Chapter 3.

Non-coastal wetlands and landscapes of Northern Australia are less likely to be affected by saltwater intrusion. However, they will be affected by other aspects of climate change. Climate change is likely to result in an increase in weather volatility and variability (DRCRG 2004). Extreme variability in weather conditions presents challenges for both agricultural and ecological aspects of the landscape (Finlayson et al 1999). Potential increases in temperature may alter the distribution of riparian, aquatic invertebrate and fish species, with populations contracting or expanding at the edge of their climatic range (IPCC 2007). Species with restricted geographic ranges may be particularly susceptible (Woinarski et al 2007). It is generally accepted that warm-adapted (ie. tropical) species are considered more vulnerable to increased temperatures than cold-adapted species, largely because they live closer to their upper thermal tolerances (Somero 2005). Increasing temperatures may also have significant impacts on aquatic reptiles such as crocodiles and turtles, where sex determination in eggs is linked to a temperature trigger point (see Georges et al 2003 for pig nose turtles in the Daly River).

It is likely that resources and landscapes will change, placing pressure on both economic and ecological values of water dependent systems. Moreover, current environmental threats to aquatic ecosystems (ie. as discussed in this section) will potentially increase the vulnerability of the ecological assets to climate change (National Resource Management Ministerial Council 2004) and vice versa. For example, invasive species, both plant and animal, may be favoured by certain changes to climatic variables and events such as temperature, precipitation, atmospheric CO_2 concentration and extreme events (Dukes & Mooney 1999; CSIRO 2001; Woinarski et al 2007). In addition, Hyder Consulting (2008) warned that pressure to further develop Northern Australia in response to changing climate in southern Australia may be more damaging in the short-term to some ecosystems than climate change.

A study of climate change scenarios and likely impacts on the NT (Hennessy et al 2004) provides the best regional analysis to date for a part of Northern Australia. This report demonstrated that the NT has become warmer and wetter in the last century and predicted that warming will continue, but increases in rainfall will not. The NT is expected to warm, relative to 1990, 0.2 to 2.2°C by 2030 and 0.8 to 7.2°C by 2070. However, warming in the Top End is expected to be towards the lower end of these ranges (Hennesey et al 2004)[3], which is consistent with the latest projections by CSIRO (2007). Rainfall is expected to decrease both in the wet and dry seasons across the NT, but a 400 km-wide zone from Darwin to Camooweal (northwest of Mt Isa, near the Qld border) will experience the least change in rainfall (Hennesey et al 2004). This is also consistent with the recent projections by CSIRO (2007). Climate change, as a result of increased temperatures, is also expected to increase evaporation across the Territory. The effect of higher evaporation will be less severe in the Top End (Hennesey et al 2004); however, the impact of any increase in evaporation on river flows and recharge rates is uncertain.

Increases in cyclone and storm intensity coupled with the above changes are expected to significantly impact the biodiversity of Northern Australia (Allen Consulting Group 2005; Hyder Consulting 2008).

In the Kimberley region it is expected that an increase in monsoonal rainfall will occur as a result of global warming (Allen Consulting Group 2005). This will promote greater vegetative growth in the wetter months and result in increased fuel load in the drier months. It is predicted that fires will become more frequent and of greater intensity in the Kimberley region. This is likely to adversely impact many plant and animal species and riverine systems. Increased monsoonal rainfall and increased frequency and intensity of fires will influence rainfall-runoff relationships, resulting in greater runoff and erosion. This may lead to siltation of river pools and threaten their role as dry season refugia (Storey & Toussaint 2007).

Queensland is likely to experience an overall decrease in mean annual rainfall and this will be coupled with increases in actual evaporation, temperature, soil moisture and runoff (Cai et al 2003). However, it is predicted that there will strong regional differences and that far north Queensland will experience an increase in rainfall intensity and may even become wetter overall (Queensland Government 2005). Higher evaporation rates and temperatures are likely to cause declines in the quality of many waterways and wetlands. Higher intensity rainfall may increase erosion and the sedimentation of rivers and coastal and offshore environments (Queensland Government 2005).

2.2.3 Threats

Groundwater extraction

Groundwater extraction may be used to sustain a number of land uses, including horticulture, pastoralism, cropping, urban (domestic and commercial) and mining, although in western and Northern Australia groundwater is predominantly used for drinking water and industrial uses (Ball et al 2001). Groundwater extraction accounts for only around 20% of all water use, but is becoming increasingly used in many areas (Ball et al 2001). The groundwater resources across the Northern Tropical Rivers study area are generally undeveloped, although areas in the southern and northern Gulf and Cape York regions, which represent part of the GAB, are thought to be over-developed (Figure 2.11). In addition, the Darwin and Katherine regions in the Top End are considered to have a high and increasing level of development.

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[3] It should be noted that the projections of Hennessy et al (2004) were based on outputs arising from the IPCC's Third Assessment Report, which has recently been superseded by the Fourth Assessment Report (ie. IPCC 2007). Comprehensive reviews of regional (ie. sub-national) climate projections and associated impacts are yet to be undertaken based on the current state of knowledge, but are unlikely to be markedly different to existing information.

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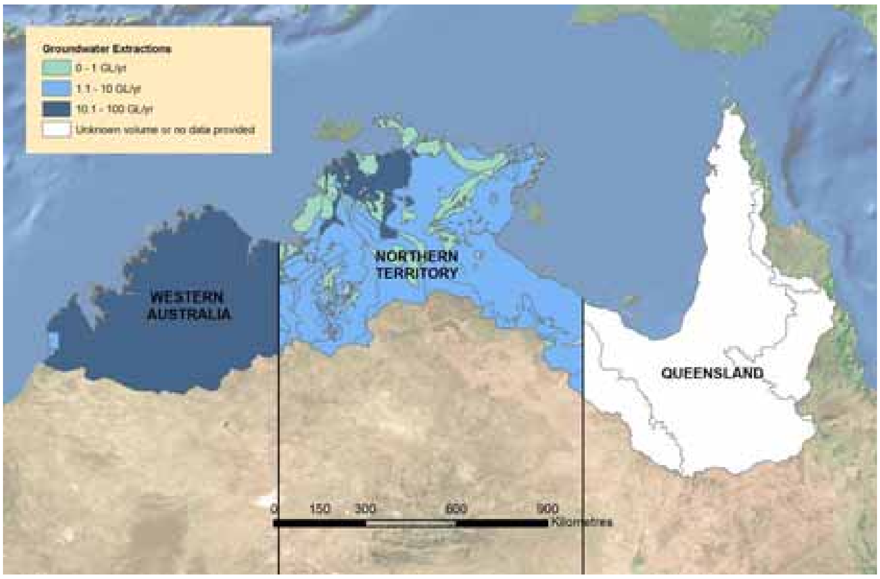

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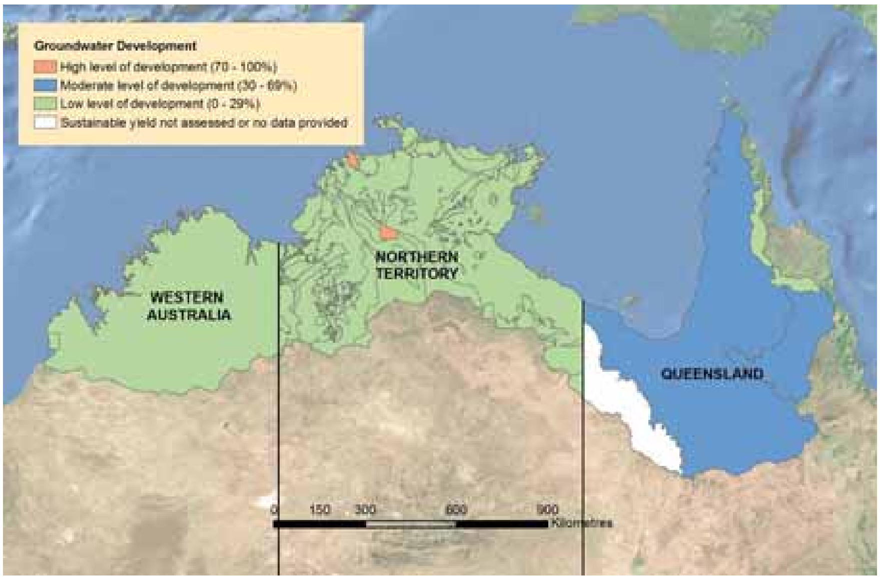

Figure 2.11 Groundwater extractions and resource development across the Northern Tropical Rivers study area displayed by Groundwater Management Unit: A – Groundwater extractions; and B – Groundwater development (Data Source: Australian Water Resources 2005-National Water Commission).

In addition to the potential direct impacts to groundwater ecosystems themselves, probably the key issue regarding groundwater extraction centres around the hydrological link between groundwater aquifers and surface water resources, the nature of which is still relatively poorly understood for most Northern Australian rivers (Hamilton & Gehrke 2005). Over-extraction of groundwater can result in draw-down of the groundwater aquifer and subsequent disconnection with surface GDEs (Bunn et al 1997; Hatton & Evans 1998; Davis et al 2001; Evans 2007). Evans (2007) presented the technical understanding of the effects of groundwater extraction on stream flow in Australia. Notwithstanding a number of complex hydrogeological modifying factors, it can be generalised that groundwater pumping anywhere in a catchment will have a 1:1 impact on reducing stream flow, albeit often with a time lag (Evans 2007). Overall, stream flow will be affected by groundwater extraction in two ways (Evans 2007):

i. decreased recharge or baseflow (ie. interception of groundwater before it can discharge to the stream); and

ii. increased recharge (ie. leakage from the stream to groundwater).

Another issue emphasised by Evans (2007) is that the spatial and temporal characteristics of the hydrological impacts associated with groundwater extraction are highly dependent on the location of the extraction point. GDEs in the immediate vicinity of groundwater bores can be impacted over relatively short timescales. However, the key point is that impacts associated with water extraction can take much longer to manifest themselves, for example, decades or even centuries, with the time lags dependent on numerous factors including distance from the extraction point and the hydrogeological characteristics of the aquifer (Evans 2007).

Bunn & Arthington (2002) defined the following four key principles to highlight the important mechanisms that link hydrology and aquatic biodiversity, and to illustrate the consequent impacts of altered flow regimes:

i. Stream flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic composition;

ii. aquatic species have evolved life history strategies primarily in direct response to the natural flow regimes;

iii. maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species; and

iv. the invasion and success of exotic and introduced species in rivers is facilitated by the alteration of flow regimes.

Apart from in-stream ecosystems, many important aquatic ecosystems are maintained by groundwater (ie. GDEs – eg. wetlands, springs, riparian zones, karst/cave systems). As with streams and their flow, other GDEs will be impacted by groundwater extraction. For example, the temporal and spatial extent of semi-permanent and temporary wetlands, including springs, may be reduced, and wetland vegetation may be dramatically altered (Davis & Froend 1999; Davis et al 2001). In other cases, thresholds may exist where after a certain point the entire wetland ecosystem is destroyed (Hatton & Evans 1998). Alterations to the hydrological regime and, consequently, vegetation structure of wetlands that are normally moist during most or all of the Dry season, may have deleterious consequences to native fauna that have some dependence on such ecosystems (Braithwaite & Werner 1987; Davis & Froend 1999; Landcare Council of the Northern Territory 2005). Wetlands and permanent pools within streams are known to play important roles as wildlife refugia during the Dry season (Storrs & Finlayson 1997; Storey et al 2001; Douglas et al 2005). Consequently, the drying of refugial water bodies has the potential to affect the structure of aquatic communities and reduce the pool of biota potentially available for recolonisation of seasonally inundated wetlands (Humphrey et al 1995, Boulton & Brock 1999, Davis & Froend 1999; Storey et al 2001). Even reductions in river pool size and depth can have marked effects on fish, and to a lesser extent, macroinvertebrate, community assemblages (van Dam et al 2005).

Changes to the natural flow of water or groundwater levels can also impact on aquatic organisms that rely on particular hydrological regimes. In particular, many aquatic organisms are dependent on longitudinal and/or lateral connectivity. The viability of populations of many aquatic species depends on their ability to move freely up and down the stream network, as well as laterally, onto the floodplain habitats during periods of flooding (Bunn & Arthington 2002; Kingsford et al 2005). Reductions in stream flow can reduce stream connectivity, and hence result in major impacts to aquatic populations. Such adverse effects have been well documented for the highly regulated Murray-Darling Basin in southeastern Australia, where dams and weirs have dramatically reduced both longitudinal and lateral connectivity (see Bunn & Arthington 2002 for examples). In addition, numerous estuarine fisheries (eg. barramundi, peneaid prawns) are dependent on, and therefore probably highly susceptible to changes to, the timing, magnitude and duration of freshwater flows into estuaries (Robins et al 2005; also see Chapter 4).

Flow regime is known to play a large role in determining the successional evolution of riparian plant communities and associated ecological processes (Nilsson & Svedmark 2002). Consequently, the structure and dynamics of riparian communities along river and major creek banks could be altered due to lower Dry season base flows and/or overall lower groundwater levels (van der Valk 1991), and groundwater dependent riparian species may die as a result of lowered groundwater levels (Sinclair Knight Merz, 2001; DRCRG 2004). Generally, there is limited understanding of how vegetation adapts to changes in depth, quality and regime of groundwater (Hatton & Evans 1998), although more information is emerging. Sinclair Knight Merz (2001) identified two types of riparian GDEs in Northern Australia as being moderately to highly at risk of impacts due to groundwater extraction, namely, mesophyll palm vine forests and paperbark swamp forests and woodlands.

Reduced base flows could also result in a deterioration of water quality and associated impacts to aquatic life (Sinclair Knight Merz, 2001). According to Evans (2007), water quality implications may, in some cases, be more important than water quantity issues. For example, most river systems in Australia are nitrogen limited (Harris 2001a), and their ecological health is controlled by the availability of nutrients. Surface water is typically nutrient poor while groundwater may often be nutrient rich. Hence, the discharge of groundwater into rivers is often crucial in controlling the health of their ecology (Evans 2007).

Another potential concern is the activation of acid sulfate soils through development or drainage of shallow groundwater resources. Acid sulfate soils are extensive along the coastline of Northern Australia (National Working Party on Acid Sulfate Soils 2000). GDEs that may be affected by acid sulfate soils include groundwater discharge areas of estuarine or coastal systems, aquatic ecosystems occupying estuaries associated with base flow dependent rivers and streams and coastal wetlands dependent on groundwater supply (Sinclair Knight Merz 2001).

Surface water extraction

Surface water extraction may take place to sustain many of the same land uses listed above for groundwater extraction. Across Australia, surface water extraction accounts for approximately 80% of total water use, with groundwater accounting for the remainder (Ball et al 2001). The irrigation sector is the greatest user of surface water, followed by water for domestic and industrial purposes (Beeton et al 2006). Surface water extraction is often tied to the construction of in-stream water impoundments. The issue of in-stream water impoundment is dealt with below, with the discussion here restricted to the extraction of water from natural water bodies. With the exception of a few catchments (eg. Ord River, Darwin River), surface water resources across the Northern Tropical Rivers study area are generally undeveloped and free-flowing (Figure 2.12).

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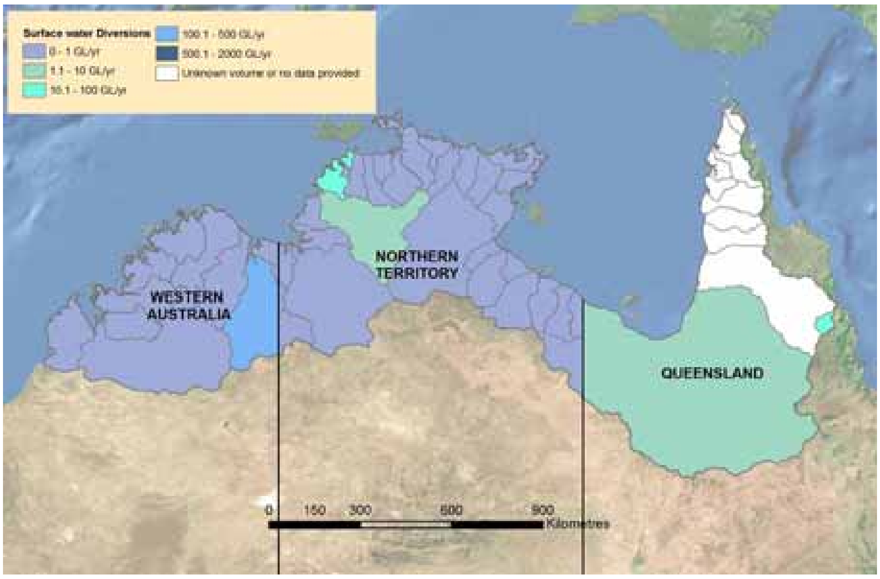

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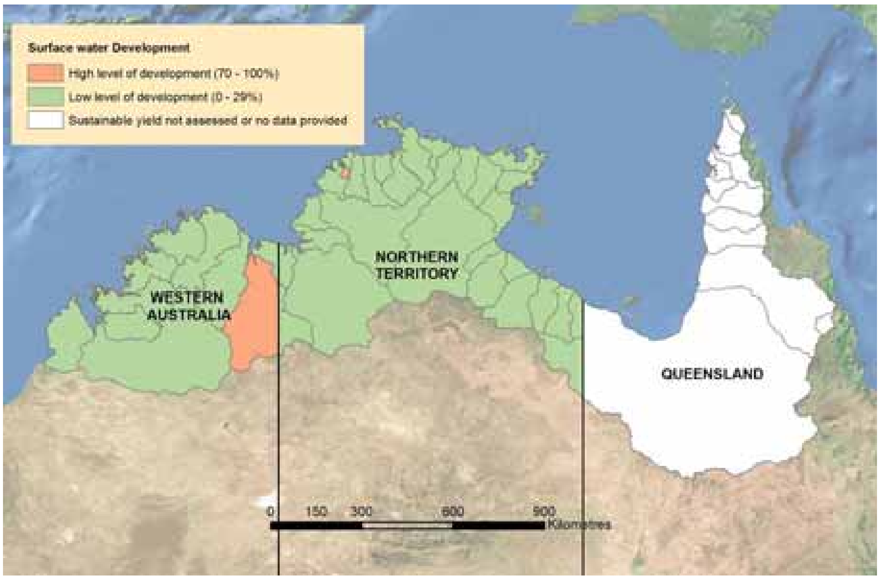


Figure 2.12 Extent of surface water extraction and resource development across the Northern Tropical Rivers study area displayed by Surface water Management Unit: A – Surface water diversions; and B – Surface water development (Data Source: Australian Water Resources 2005-National Water Commission).

The impact of surface water extraction is generally proportional to the volume of water removed from the system. The direct effects of surface water extraction are generally similar to many of those described above for groundwater extraction, although they often can be felt more immediately, and may include (Qld NRW 2007):

- Reduced stream flow
- Altered water temperature
- Altered seasonal flows
- Direct removal of fish from the waterway, particularly larval fish.
- Reduced aquatic habitat

Impacts of these effects will be similar to those described above for groundwater extraction, except that the interaction with GDEs will be different. Typically, GDEs will not be directly affected by surface water extraction. However, given that surface water and groundwater are typically linked, indirect effects may be possible.

Water impoundment

This aspect includes in-stream dams and other barriers such as weirs and barrages. Such structures are typically built in order to provide a consistent water supply for human activities, or to maintain water levels for boating and to prevent saltwater intrusion. The location of major water impoundment structures across the Northern Tropical Rivers study area is shown in Figure 2.13. Unfortunately, these data do not capture the many small structures, such as causeways, barrages and floodplain levees, which whilst probably not acting as complete barriers, may still have some level of ecological impact.

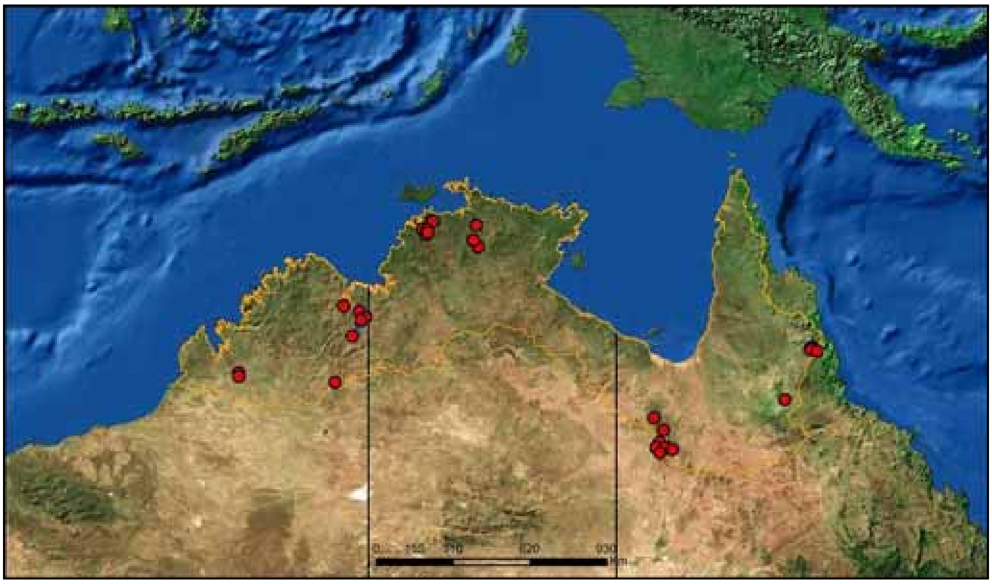


Figure 2.13 Location of major water impoundment structures (dams, weirs) across the Northern Tropical Rivers study area (Source: Dams and Water Storages 1990-Geoscience Australia).

In the Top End there are three major dams located in the Darwin River and Adelaide River catchments. Darwin River Dam (265 000 ML) and Manton Dam (~24 000 ML) provide water supply for domestic and industrial purposes, while Otto Creek Dam is for recreation (Landcare Council of the Northern Territory 2005). In Figure 2.13, the three structures indicated in the central Top End represent town or mining dams/retention ponds, which have no relevance in terms of water resource development. In addition to these structures, in 2005, the Forsyth Creek Dam was constructed on Legune Station, a pastoral property near the NT–WA border. The dam has a 50 000 ML capacity (planned to increase to 150 000 ML) and the water is used to irrigate the downstream floodplain during the dry season. Other waterway barriers in the Top End include a 1.5 metres high weir on the Katherine River, providing storage for Katherine's water supply, and an array of barrages on the Mary River coastal floodplain (Landcare Council of the Northern Territory 2005) designed to control saltwater intrusion.

There are five major dams in the Kimberley: Ord River Dam (Lake Argyle), Kununurra Diversion Dam (Lake Kununurra), Arthur Creek Pilot Dam and Moochoolabra Dam in the Ord catchment; and the Camballin (or Fitzroy) barrage and associated Seventeen Mile Dam on the Fitzroy River (IKNRMG 2004). Lake Kununurra and Lake Argyle supply water for the Ord River Irrigation Area (ORIA), and for generation of hydro-electric power for most of the Kimberley. Arthur Creek Pilot Dam is also a supply source for irrigation and aquaculture, while Moochoolabra Dam provides water supply to the town of Wyndham (IKNRMG 2004). Lake Argyle is the largest man-made water body in Australia, covering an area of 945 km^2, and with a volume when full of approximately 10 700 GL (IKNRMG 2004).

The majority of larger dams in Qld are located in the southern Gulf region. Over 10 significant water storages exist, including Julius Dam, East Leichhardt Dam and Lake Moondarra on the Leichhardt, the Lady Annie Mt Isa Mines storage on the Nicholson River and Corella Dam on the Flinders Rivers (Department of Natural Resources, Mines & Energy 2004; Southern Gulf Catchments 2005a). Lake Moondarra, in the Leichhardt River catchment, is the major source of supply for Mount Isa and the operations of the Mount Isa Mine. Lake Julius, also in the Leichhardt River catchment, is the largest storage in the southern Gulf, and is available as back-up supply for Mount Isa mines and town use, and for use by other mining operations (Southern Gulf Catchments 2005a).

There are few large water storages in the northern Gulf and Cape York regions, with the notable exception of Lake Mitchell, in the upper Mitchell River catchment (McDonald & Dawson 2004). There are several weirs, namely the Glenore Weir (Norman River) and the Walsh River weir network within the Mareeba-Dimbulah Irrigation Area (MDIA), again in the upper Mitchell River catchment. However, the majority of irrigation water is delivered across the Great Dividing Range from Tinaroo Dam in the Barron River catchment (McDonald & Dawson 2004), outside the Northern Tropical Rivers study area. On Cape York Peninsula the Annan River weir, which provides water supply to Cooktown, is the only significant water storage (Cape York Interim Advisory Group 2004). However, this also is outside the study area.

The ecological impacts of river regulation through impounding water have been extensively documented (eg. see Craig & Kemper 1987; Ligon et al 1995; Boulton & Brock 1999; Kingsford 2000). In-stream dams, weirs or other barriers to natural water passage dramatically alter stream flow regime and catchment connectivity, thereby interrupting the natural flows of water, sediments, nutrients, energy and biota, and causing subsequent ecological impacts (Ligon et al 1995; Bunn & Arthington 2002). The effects of changes in flow regime and associated impacts were largely described above, for groundwater and surface water extraction. Some specific and/or additional impacts of impoundments are briefly described below.

Dams, weirs, barrages and causeways can act as barriers to fish, turtles and aquatic invertebrates, with the population viability of many species reliant on their ability to migrate throughout the stream network (Boulton & Brock 1999; Kingsford 2000; Bunn & Arthington 2002; Landcare Council of the Northern Territory 2005). Barriers can also result in increased predation of aquatic species due to localised congregations of species around them (Begg et al 2001; Bunn & Arthington 2002). This effect has been observed at the barrage at Fitzroy Crossing on the Fitzroy River, WA (Morgan et al 2005).

Alteration of flow regime due to damming may include reversal of seasonality, attenuation of minor and moderate floods, reduced flow variability and altered rates of rise and fall of river levels (Kingsford et al 2005). Changes to various components of flow regime (eg. timing, frequency, magnitude, duration, variability) can adversely affect aquatic communities, because most native aquatic species have evolved life history strategies to accommodate the natural flow regime (Bunn & Arthington 2002). This includes dependence on certain cues for critical life events (eg. spawning, migration), and also the ability to access key habitats. For example, by dampening flood peaks, dams typically result in a reduction in the frequency, extent and duration of floodplain inundation (ie. reduced lateral connectivity), and prevent species (eg. fish, birds, reptiles) from gaining access to or utilising important spawning, nursery or foraging habitats (Bunn & Arthington 2002). An additional negative consequence of the altered flow regimes imposed by barriers is that they often favour the invasion and establishment of introduced species, thus, further impacting the aquatic ecosystems (Bunn & Arthington 2002).

Water impoundment may change groundwater level by increasing or lowering surface water levels and altering groundwater recharge and discharge processes (Sinclair Knight Merz 2001). For example, the Ord River Dam and Kununurra Diversion Dam on the Ord River have resulted in rising groundwater levels, with a subsequent effect of increasing salinity in at least one of the region's agricultural zones (ie. the Packsaddle area) and predicted increases in other zones (Salama et al 2002, as cited by IKNRMG 2004).

Other impacts of water impoundment on rivers include the modification of downstream channel and riparian habitat due to altered hydrology, modification and destruction of upstream wetland and riparian habitat due to inundation and impoundment water level fluctuations, and degradation of water quality associated with release of hypolimnetic water from deep, stratified waterbodies, leading to eutrophication, anoxia and changed temperature regimes in downstream receiving waters (Bunn et al 1997; Begg et al 2001; Bunn & Arthington 2002). Impoundments in Northern Australia also unintentionally influence water regimes through often massive evaporation. For example, it is estimated that 25% of the annual inflow into Lake Argyle is lost each year due to evaporation (A Storey, UWA, pers comm).

Altered fire regime

Frequent and widespread fire is a natural process in Northern Australia, with fires burning approximately 250 000 km^2, or approximately 21%, of the region every year. The extent and frequency of fire across the Northern Tropical Rivers study area over the past decade is shown in Figure 2.14. Fires are most frequent in the northern parts of the study area (ie. Cape York Peninsula, northern Top End and north Kimberley), with the north-western Top End being by far the largest area of most frequently burnt land. The southern Gulf catchments are relatively fire free, due mostly to active fire exclusion by pastoralists, as discussed below.

Generally, plant and animal species of Northern Australia are well adapted to, and in many cases, dependent on, fire. In this context, fire can be seen as an asset (Price et al 2003; Bayliss et al 2006; Woinarski et al 2007). However, fire regimes have been significantly altered over the last two centuries, to the point where fire, when managed inappropriately, must be considered a threat. Traditionally, Aboriginal communities lit small fires in the early dry season and, if necessary, re-burnt certain sites later in the dry season resulting in a complex mosaic of burnt landscapes (Price et al 2003). Since European settlement, however, burning practices have changed and modern fire management has proved challenging because of increased dry season fuel loads and landscape flammability often caused by the dominance of grassy weed species (Rossiter et al 2003), the widespread and often uncoordinated burning by humans and the remote nature of much of tropical Australia (Whitehead et al 2003; Woinarski et al 2007).

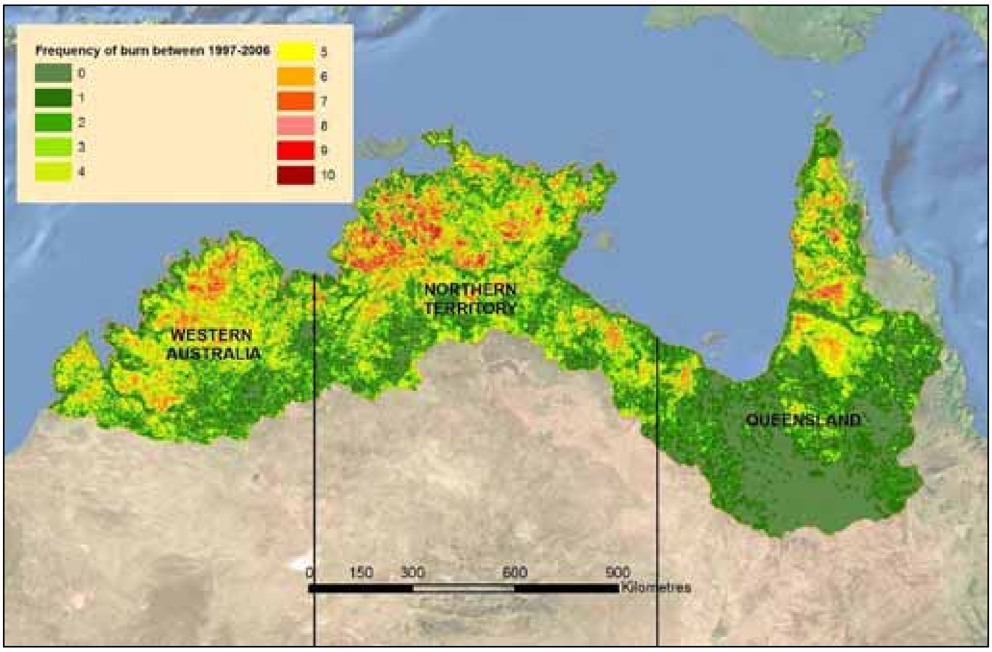


Figure 2.14 Frequency of burning across the Northern Tropical Rivers study area between 1997-2006 (Data source: Derived from NOAA AVHRR satellite imagery (approximately 1.1 km x 1.1 km pixel size) by Remote Sensing Services, Department of Land Information, Western Australia).

This shift in fire regimes combined with difficulties in fire management in remote areas has meant that the fire histories of northern landscapes have become decreasingly patchy. The result is that landscapes are now either characterized by frequent and intense large-scale fires or, in contrast, are infrequently burnt (Russell-Smith 2002). Impacts arising from the former regime include a loss of habitat, resource and structural diversity. Burnt areas are seldom intensively managed for agricultural production, and reduced fire activity generally results in woody thickening, a reduction in granivorous species and, a decline in biodiversity values (Russell-Smith 2002; Sharp & Whittaker 2003).

Under current fire regimes, frequent fires are common across the Top End of the NT where, on average, sites will be burnt once every two years (Landcare Council of the Northern Territory 2005). Changes to other land management practices or landscape features have also affected fire regimes. For example, the coastal floodplains of the NT are subjected to a greater frequency of burning since the removal of buffalo two decades ago (Storrs & Finlayson 1997).

RNRMCG (2004) and Russell-Smith (2005) detailed the key aspects of the current fire regime in the Kimberley. Large parts of the Kimberley experience late burns at the end of the dry season, with the area burnt having increased every year since monitoring began, from 50 000 km^2 in 1994 to 250 000 km^2 in 1998. In the 13 year period from 1993 to 1995, sites were burnt between five and eight times. The ecological effects of frequent late dry season fires on populations of plants and animals are assumed to have a major impact on biodiversity and sustainable land management by all stakeholders. Needless to say, fire management is typically inextricably linked with grazing management.

Fire regime in the southern and northern Gulf regions of Queensland is less well documented. Many pastoralists in the southern Gulf region are reluctant to use fire as a land management tool, and tend to practice a policy of fire exclusion. However, the exclusion of fires, in addition to other land management and environmental factors, may be responsible for the observed increases in woody plant thickening in the region (Savanna Links 2005). Inappropriate fire regimes are partly responsible for some disturbance across the region. However, it is acknowledged that fire is an integral part of the Northern Gulf NRM region (McDonald & Dawson 2004). Extensive fires are a feature of the north-eastern section of the Northern Gulf NRM region. Such fires, often caused by lightning, are rarely started as part of land management activity and typically burn out of control late in the dry season (McDonald & Dawson 2004).

Poorly managed fire can significantly affect the condition of riparian habitats, waterways, wetlands and other water dependent ecosystems. In particular, fire has the potential to affect riparian vegetation communities, as few of these species are fire tolerant (Landcare Council of the Northern Territory 2005). Damage to the riparian fringe can lead to greater in-stream growth of algae and macrophytes and allow greater amounts of soil and nutrients to enter waterways (Finlayson et al 1999; Douglas et al 2003; DRCRG 2004). For example, fire late in the dry season or early wet season can increase erosion and the flow of sediments into aquatic habitats when followed by high intensity wet season rainfall (DRCRG 2004). Townsend & Douglas (2004) found that early dry season fire in Kakadu National Park had a negligible impact on water quality of a seasonally flowing stream. In contrast, Townsend & Douglas (2000) found that a catchment burnt late in the dry season had significantly higher storm runoff concentrations of suspended sediment, iron and manganese. Inappropriate floodplain burning regimes can have significant impacts on floodplain vegetation. Bayliss et al (2006) found that a floodplain burning frequency of at least one in five years was required to maintain high diversity of wetland plant species by preventing the establishment of monocultures of grasses such as native Hymenachne. However, the cumulative effect of changed fire regimes on wetlands (Finlayson et al 1999) and Northern Australian landscapes in general (Whitehead et al 2003), is little understood.

Land clearance/loss of native vegetation cover

In comparison to southern Australia, only minor land clearing has occurred across Northern Australia (Whitehead et al 2003). Land clearance may occur as part of various land uses including horticulture, pastoralism, cropping, urban development and mining. Despite numerous efforts, land clearing spatial data for WA and Qld could not be accessed. Consequently, Figure 2.14 shows the extent of historical land clearance (including major road corridors across the NT section only of the Northern Tropical Rivers study area). Most of this clearing has occurred in the Daly (see Section 2.3 and also Chapters 3 and 4), Darwin/Finniss and Adelaide River catchments, corresponding to the areas of highest urban and agricultural development.

To date, the majority of land clearing in the NT has occurred on freehold tenure (Hosking 2002) and less than 1% of the NT has been cleared for development (NRETA 2006). Brock (2001) identified the following regions as being subject to land clearing pressure: Darwin; Litchfield Shire; the Daly Basin; Tiwi Islands Forestry Project; and Ord River Irrigation Scheme Stage 2. Through the Agricultural Land Cover Change Project 1990-1995 (Barson et al 2000), it was shown that for the selected study site (most likely to be affected by clearing for agriculture) in the NT:

- 59 km^2 were cleared for cropping;
- 11 km^2 were cleared for grazing; and
- 96 km^2 were cleared for infrastructure development and urban expansion.

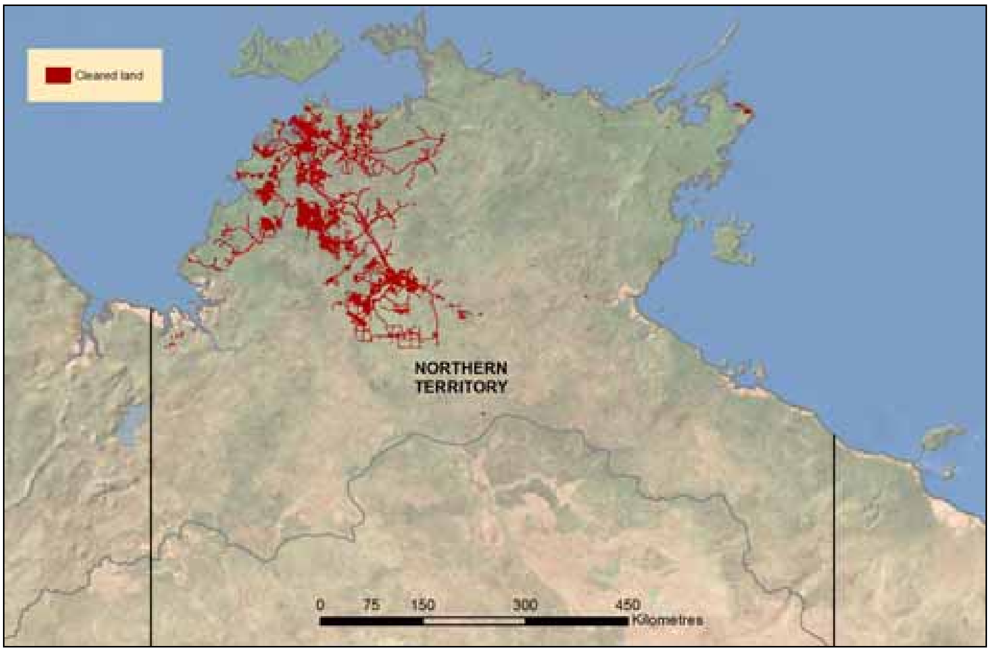


Figure 2.14 Extent of cleared land across the Northern Territory section of the Northern Tropical Rivers study area (Source: NTG- Land Clearing 2005 data). Note that cleared areas have been cartographically exaggerated for representation in the figure.

The NT Planning Scheme Land Clearing Guidelines (NRETA 2006) state that "native vegetation must be retained adjacent to waterways". Drainage lines, watercourses, wetlands or seepage zones are listed as 'do not clear' areas, whilst buffers to watercourses are listed as 'clear with care' areas meaning that advice needs to be obtained on how to minimise impacts prior to clearing. The implementation of a buffer width is dependent on stream order (eg. Intermittent streams [First and second order] – 25-50 m buffer; Creeks [Third and fourth order] – 100 m buffer; River [Fifth and sixth order] – 250 m buffer; and Wetlands – 200 m buffer).

In the southern and northern Gulf regions of Queensland, average annual clearing rate in 2004/05 ranged from 0 to >3% of 2004 wooded areas (Department of Natural Resources and Water 2007a). Only one catchment, the Leichhardt, had a clearing rate >3%, and other catchments with clearing rates of 0.5-1.5% included the Flinders and Upper Norman Rivers (Department of Natural Resources and Water 2007a).

Active land clearance in the Kimberley has been confined mostly to the Ord River catchment, specifically the 150 km^2 of land under cultivation in the ORIA. However, parts of the region, including the Ord and Fitzroy Rivers, are under pressure to be further developed for irrigated agriculture, and additional land clearing, albeit small relative to the size of the region, is likely to occur in the future.

The long history of extensive land clearing in southern Australia has shown that vegetation clearing can directly and indirectly affect aquatic ecosystems in numerous ways (Harris 2001a, 2001b). Land clearing on both small and large scales can change water regimes. River systems are particularly susceptible to native vegetation removal and general land degradation as these processes reduce infiltration and increase runoff (Harris 2001; DRCRG 2004). This may lead to erosion and contribute to flood events and sedimentation (RNRMCG 2004; Landcare Council of the Northern Territory 2005). Clarity of water is important for light penetration into the water column and photosynthesis. Excess sediment in runoff waters can reduce clarity of water and shade aquatic plants reducing growth rates and/or causing dieback. This can lead to de-oxygenation of the water column causing further pressure on aquatic organisms (RNRMCG 2004). Moreover, excess nutrients in runoff waters can lead to eutrophication and algal blooms (Harris 2001a, 2001b).

Changes in rates of run-off and infiltration can alter the hydrology of streams and wetlands also, including the balance between surface and spring flows (DRCRG 2004). Additionally, land clearing can have a significant impact on aquatic ecosystems through the loss of habitat, fragmentation of native vegetation, increased channel instability, changed nutrient availability and, by facilitating the spread of weeds (DRCRG 2004; Landcare Council of the Northern Territory 2005). Chapter 4 describes in further detail the potential impacts of land clearing on aquatic ecosystems, in particular the consequences of increased sediment and nutrient inputs to the surface water quality of streams.

Introduced invasive flora

Over half of the top 20 most destructive invasive plants that occur in Australia (ie. the listed Weeds of National Significance – WONS), are found in the Northern Tropical Rivers study area. Of these, eight can colonise waterways, wetlands or riparian zones, namely pond apple (*Annona glabra*), cabomba (*Cabomba caroliniana*), olive hymenachne (*Hymenachne amplexicaulis*), mimosa (*Mimosa pigra*), rubber vine (*Cryptostegia grandiflora*), parkinsonia (*Parkinsonia aculeata*), mesquite (*Prosopis* spp.) and salvinia (*Salvinia molesta*) (Thorp & Lynch 2000). Other species of significance to the waterways, wetlands or riparian zones of the region, but which are not listed as WONS species, include noogoora burr (*Xanthium occidentale*) and introduced pasture grasses such as para grass *(Urochloa mutica*), gamba grass (*Andropogon gayanus*) and perennial and annual mission grasses (*Pennisetum polystachion & P. pedicellatum*, respectively) (Douglas et al 1998; Thorp & Lynch 2000; Rossiter et al 2003). It should be noted that the northern jurisdictions have adopted, or will soon adopt, revised formal weed risk assessment processes to objectively and rigorously identify high risk weeds (K Ferdinands & S Setterfield, CDU, pers comm).

Weed species can disperse naturally, via wildlife, wind and other natural vectors, but their spread and subsequent establishment in new areas can be facilitated by most land uses as well as climate change (through the development of more favourable changed climatic conditions and increased land disturbance due to extreme events) (Rea & Storrs 1999). Overall, there is limited information on the distribution of weeds across Northern Australia, although Figure 2.15 (A-P) shows the distribution of the WONS wetland weeds and other weed species of significance based on qualitative expert knowledge on condition and trend attributes at the State and subregion levels.

Riparian areas and wetland complexes are extremely vulnerable to infestation by weeds and, are frequently more heavily invaded when compared to surrounding environments (Douglas et al 1998). The presence of invasive flora can result in altered fire regimes, the exclusion of both native flora and fauna species, and increased organic pollution (Rea & Storrs 1999).

Mimosa is a serious invader of floodplains in the NT and now occupies extensive coastal areas (Storrs & Finlayson 1997). It is estimated that mimosa currently infests approximately 800 km^2 of coastal floodplains throughout the NT and that a further 42 000 to 46 000 km^2 of wetlands across Northern Australia could be at risk from mimosa infestation (Walden et al 2004). Of further concern is that the predicted effects of climate change are likely to facilitate the growth and spread of this weed, placing even greater pressure on the wetlands of Northern Australia (Walden et al 2004).

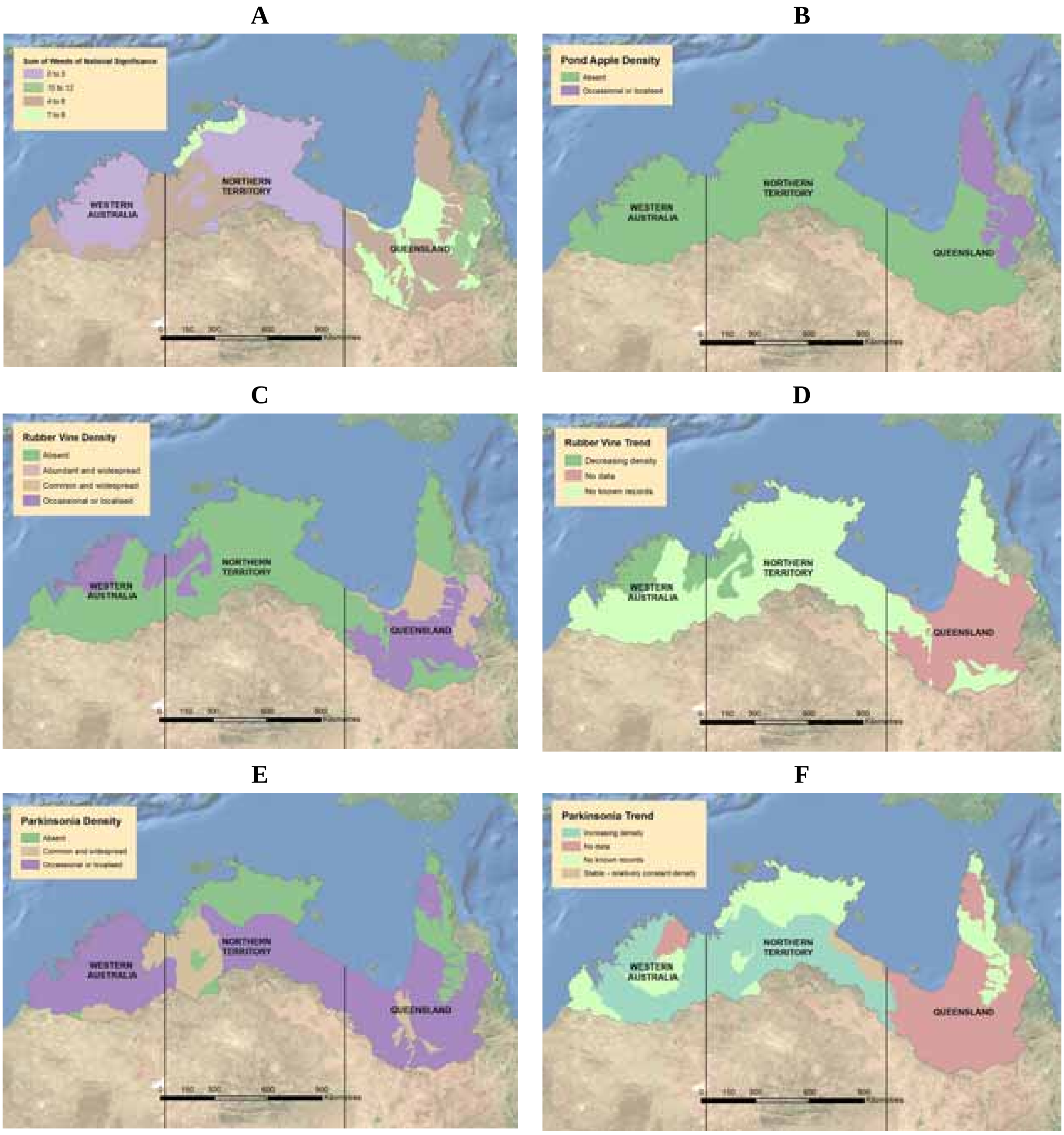


Figure 2.15 Distribution across the Northern Tropical Rivers study area of Weeds of National Significance (WONS) and other significant weed species capable of colonising waterways, wetlands or riparian zones. A – Total sum of weeds; B – Pond Apple (*Annona glabra)* density; C & D- Rubber Vine (*Cryptostegia grandiflora*) density and trend; E & F- Parkinsonia (*Parkinsonia aculeata*) density and trend (Source: Landscape Health in Australia 2000- Department of the Environment, Water, Heritage and the Arts).

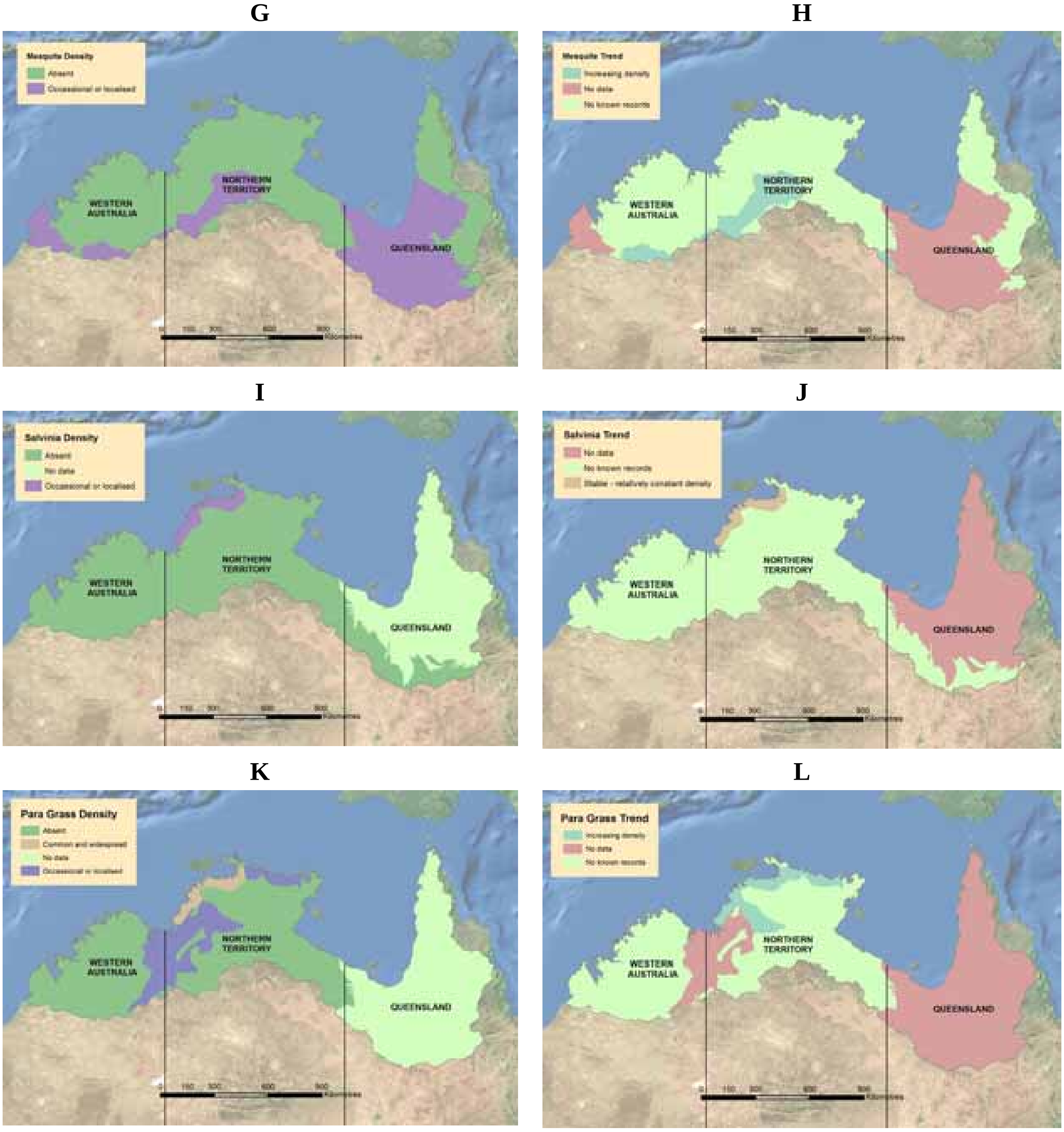


Figure 2.15 (continued) Distribution across the Northern Tropical Rivers study area of Weeds of National Significance (WONS) and other significant weed species capable of colonising waterways, wetlands or riparian zones. G & H- Mesquite (*Prosopis* spp.) density and trend; I & J- Salvinia (*Salvinia molesta*) density and trend; K & L- Para Grass (*Brachiaria mutica*) density and trend (Source: Landscape Health in Australia 2000- Department of the Environment, Water, Heritage and the Arts).

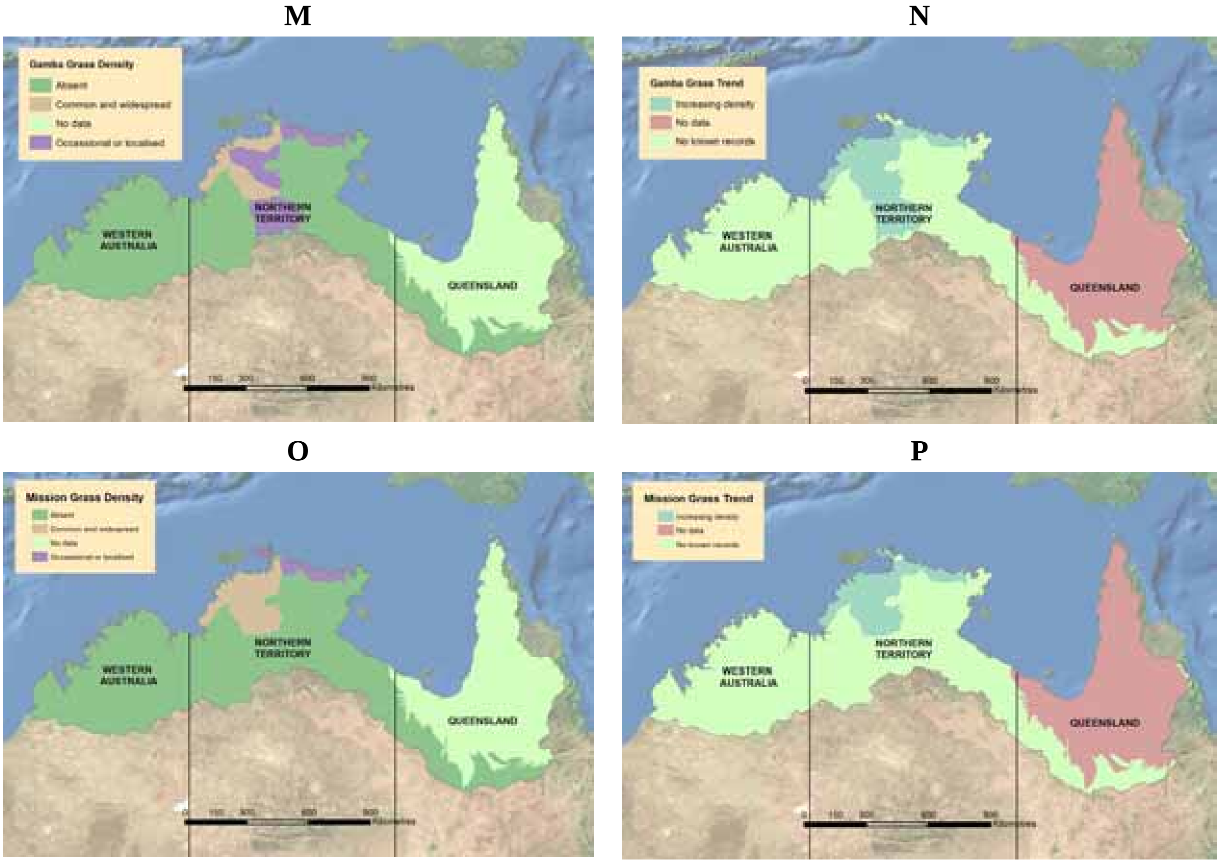


Figure 2.15 (continued) Distribution across the Northern Tropical Rivers study area of Weeds of National Significance (WONS) and other significant weed species capable of colonising waterways, wetlands or riparian zones. M & N- Gamba Grass (*Andropogon gayanus*) density and trend; and O & P- Mission Grass (*Pennisetum polystachion*) density and trend (Source: Landscape Health in Australia 2000- Department of the Environment, Water, Heritage and the Arts).

The potential invasiveness of introduced pasture grasses in Northern Australia has been well documented for many years (eg. Lonsdale 1994; Cook & Dias 2006). Two such species, para grass and olive hymenachne have spread across many wetlands in tropical Australia (Storrs 1999), forming monocultures and impacting on biodiversity (although see Douglas & O'Conner 2003). Olive hymenachne occupies vast areas of coastal northern Queensland and north-western Northern Territory with the potential to form a continuous infestation across the north from Queensland to Western Australia (Australian Weeds Committee 2004). It was introduced as a ponded pasture species and inhabits water up to 2 m deep and prefers areas that receive monsoonal rainfall. It completely replaces native plant species and limits available habitat for fauna species, thereby reducing biodiversity (Weed Management Guide 2003). Olive hymenachne can also adversely impact the water quality in areas it has infested (Weed Management Guide 2003). Other terrestrial pasture grasses, such as gamba grass (*Andropogon gayanus*) are rapidly invading the region's tropical savannas, massively increasing fuel loads and resulting in more high intensity, destructive fires (Rossiter et al 2003). Such fires can in turn impact on wetlands, riparian fringes and waterways, as described above. Additional information on the potential impacts of para grass and mimosa is provided in Chapter 4.

Introduced invasive fauna

Like invasive flora, the presence and spread of invasive fauna, or feral animals, can be facilitated by various land uses as well as climate change and, with respect to the latter, through the development of more favourable climatic conditions and increased land disturbance due to extreme events. Common introduced (non-domestic) vertebrate animals occurring in the Northern Tropical Rivers study area include feral pig (*Sus scrofa*), cane toad (*Bufo marinus*), Asiatic water buffalo (*Bubalis bubalis*), feral cattle (*Bos* spp., including banteng), horse (*Equus caballus*), donkey (*Equus asinus*), camel (*Camelus dromedarius*), goat (*Capra hircus*), wild dog (*Canis familiaris*), cat (*Felis catus*), black rat (*Rattus rattus*), fox (*Vulpes vulpes*) and rabbit (*Oryctolagus cuniculus*) (RNRMCG 2004; Landcare Council of the Northern Territory 2005; Southern Gulf Catchments 2005a). Of these, feral pigs, cane toads, goats, foxes and cats are listed under the EPBC Act 1999 as Key Threatening Processes, with the first two considered to represent significant threats to the values of the rivers and wetlands of Northern Australia. Figure 2.16 shows the distributions of some of the species listed as Key Threatening Processes. Whilst many of the species are widespread across the region, others (fox, camel, rabbit) have a limited distribution, predominantly restricted to the drier southern-most locations, and are not thought to represent major threats to the broader tropical region. Although no exotic fish species have established significant populations in the Northern Tropical Rivers, small incursions of various exotic aquarium fish species have occurred (Storrs & Finlayson 1997; Burrows 2008). Many of the aquatic habitats are thought to be suitable for highly invasive introduced fish species such as mosquito fish (*Gambusia affinis*) and tilapia (Storrs & Finlayson 1997; McDonald & Dawson 2004). In addition, there is a significant threat of invasion from Papua New Guinea of climbing perch (*Anabas testudineus*) (Storey et al 2002), which has already been confirmed on Torres Strait Islands (Hitchcock in press). This highly developed predatory species possesses an accessory respiratory organ, allowing it to survive out of water for several days or weeks in moist conditions, hence giving it the capability to travel and disperse overland into adjacent catchments (Department of Primary Industries and Fisheries 2008).

Across the Top End of the NT, the major introduced species include pig, cane toad, horse, buffalo, cattle, donkey and cat (Landcare Council of the Northern Territory 2005). Asiatic water buffalo once proliferated on the coastal floodplains of the NT, but have largely been eradicated west of Arnhem Land (Storrs & Finlayson 1997) as a result of the national BTEC in the 1980s.

In the Kimberley region, donkeys are the most common feral animal and are considered a major pest by pastoralists (Tropical Savannas CRC 1998). Feral cats are also common across the Kimberley, while feral pig populations are still expanding, and colonisation by cane toads is imminent (IKNRMG 2004, Boulter et al 2006). Other invasive animals in the region include horse, camel and small populations of foxes and rabbits (Tropical Savannas CRC 1998). In terms of aquatic species, redclaw crayfish (*Cherax quadricarinatus*) has been introduced to the Kimberley region from Queensland (as an aquaculture species), and wild populations are now established in the Ord River catchment (Lynas et al 2007).

In Queensland, key introduced species include pig, cat, cane toad, horse, feral cattle, wild dog, rabbit, buffalo, camel, donkey and goat. Of these, cane toad, fox, rabbit, goat, cat, wild dog and pig are declared as pests under the *Land Protection (Pest and Stock Route Management) Act 2002* in Qld (Southern Gulf Catchments 2005a). Foxes and rabbits are limited in extent, restricted to the southern and eastern areas (Cape York Interim Advisory Group 2004; McDonald & Dawson 2004; Southern Gulf Catchments 2005a). The major introduced species directly affecting inland waters in the southern Gulf region are cane toads

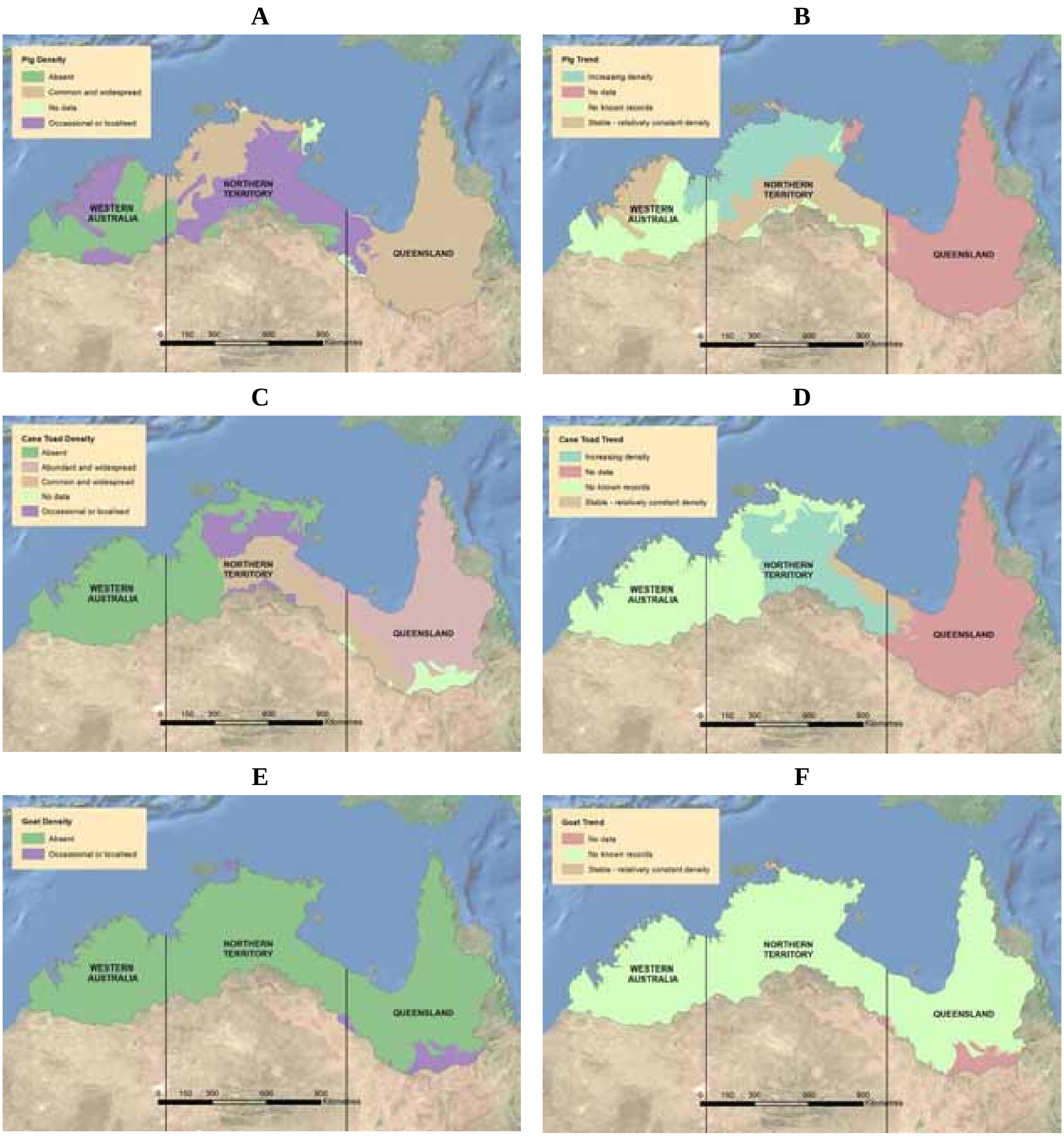


Figure 2.16 Distribution across the Northern Tropical Rivers study area of introduced invasive vertebrate animals listed under the EPBC Act as Key Threatening Processes. A & B- Pig (Sus scrofa) density and trend; C & D- Cane Toad (Bufo marinus) density and trend; E & F- Goat (Capra hircus) density and trend (Source: Landscape Health in Australia 2000- Department of the Environment, Water, Heritage and the Arts).

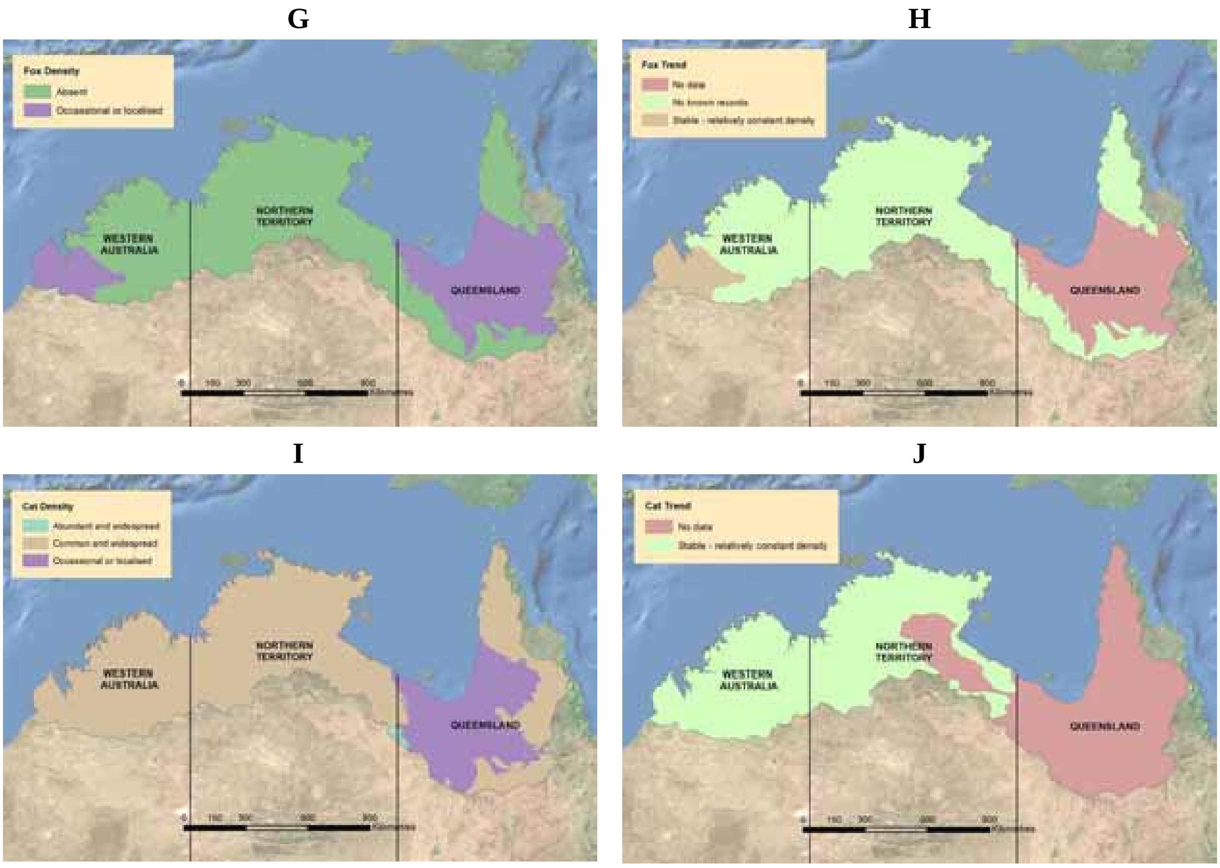


Figure 2.16 (continued) Distribution across the Northern Tropical Rivers study area of introduced invasive vertebrate animals listed under the EPBC Act as Key Threatening Processes. G & H- Fox (*Vulpes vulpes*) density and trend; and I & J- Cat (*Felis catus*) density and trend (Source: Landscape Health in Australia 2000- Department of the Environment, Water, Heritage and the Arts).

and feral pigs with a possible threat of introduction of tilapia (*Oreochromis mossambicus*), which are present in catchments on the Atherton Tablelands in Far North Queensland, adjacent to the Mitchell River catchment of the Gulf region (McDonald & Dawson 2004; Southern Gulf Catchments 2005a). In fact, tilapia has recently been discovered in the Walsh River, in the south-east corner of the Gulf, and a program is underway to attempt to control the incursion (D. Burrows, pers comm., Feb 2008). In the northern Gulf and Cape York region, the introduced species of greatest concern are pig, horse, wild dog, cat (Cape York Interim Advisory Group 2004; McDonald & Dawson 2004) and climbing perch, which are already be present in Torres Strait (Hitchcock in press).

Overall, the impacts of introduced species across the north of Australia remain difficult to quantify (Tropical Savanna CRC 1998), although a substantial amount is known about general impacts. Both aquatic and terrestrial introduced animals can impact on the ecological values of waterways. Early life stages of cane toads (ie. eggs and tadpoles), for example, have been documented as being toxic to, and impacting on, native aquatic species (see van Dam et al 2002 for review of potential cane toad impacts on Kakadu National Park, and Molloy & Hendersen 2006 for the most recent review). Exotic fish species can invade waterways and impact native species primarily through predation, resource competition and disease (Arthington 1991; McDonald & Dawson 2004).

Terrestrial pests can affect aquatic ecosystems and their associated biota by destroying or consuming large areas of vegetation, predation or poisoning of native wildlife, harbouring diseases harmful to native wildlife, competing for resources, increasing erosion and altering water regimes (Storrs & Finlayson 1997; Price et al 2003; McDonald & Dawson 2004; Landcare Council of the Northern Territory 2005; Southern Gulf Catchments 2005a). Feral animals aggregate around water sources and can impact on aquatic biodiversity. Trampling and destruction of wetland and riparian vegetation can be caused by domestic stock, goats, pigs, camels, buffalo and donkeys, and result in additional impacts such as erosion of banks and sedimentation of aquatic ecosystems (Price et al 2003; McDonald & Dawson 2004; IKNRMG 2004; Landcare Council of the Northern Territory 2005; Southern Gulf Catchments 2005a). Other animals such as European rabbits (*Oryctolagus cuniculus*) place heavy grazing pressures on new growth, reducing regeneration and seasonal growth in ephemeral wetlands, although populations in Northern Australia are small (Tropical Savanna CRC 1998; McDonald & Dawson 2004; IKNRMG 2004). Exotic animals can also cause turbidity (when drinking and tramping through wetlands) in the water column leading to reduced light for primary production by aquatic plants and algae, thus reducing the energy capture within aquatic systems (RNRMCG 2004; IKNRMG 2004). Some specific examples of impacts by introduced species are provided below.

Prior to their culling, high densities of water buffalo in the northern floodplains led to damage to water channels and are believed to have caused breaches in coastal chenier ridges, causing or exacerbating subsequent saltwater intrusions into these important freshwater environments (Storrs & Finlayson1997; Landcare Council of the Northern Territory 2005).

Feral pigs are widespread across the region. Selective browsing by feral pigs is a major threat to some rainforest and wetland plants, while pigs may also consume eggs and young of many ground-nesting vertebrates (Landcare Council of the Northern Territory 2005; Woinarski et al 2007). In addition, feral pig damage around waterholes and other wetland areas due to trampling and rooting can be severe, and has been surveyed and documented in various locations (Bayliss et al 2006).

Currently, cane toads occur throughout northern Queensland and the Top End, and have recently spread into the far eastern Kimberley region (Freeland 2005). It remains unclear if cane toads affect the long term viability of populations of species, or the integrity of environments they invade, but their spread warrants rigorous monitoring in new areas of invasion (van Dam et al 2002).

In contrast to their pest status, many introduced animals have significant cultural and economic value. Aboriginal people assign cultural and economic values to various feral animal species (eg. buffalo, pig and camel) and do not assume that all such species cause unacceptable levels of environmental damage (Landcare Council of the Northern Territory 2005). In addition, numerous feral animals are harvested as an economic resource for the meat and live trade market (Landcare Council of the Northern Territory 2005).

Contamination

Contamination of waterways, wetlands and groundwater aquifers can occur through most land use activities. Recognised contaminant threats include herbicides, pesticides and fertilisers used for agriculture and horticulture, metals in mine waste waters, sewage effluent, stormwater runoff from urban areas and sediment and nutrient loads resulting from excessive land clearing, over-grazing or extensive wildfires (Ball et al 2001; Landcare Council of the Northern Territory 2005; Beeton et al 2006).

Unfortunately, the water quality data for the Northern Tropical Rivers area are too scant to make overall conclusions about contamination across the region (Butler 2008). However, the overall lack of development and sparse and low population across the region suggests that contamination of waterways is not likely to be a broad scale problem.

Many land uses and industrial additives can impact on waterways through changes to water quality. Fortunately, the wetlands of Northern Australia are generally not subjected to high levels of pesticides in contrast to those in southern Australia (Finlayson et al 1999). An expansion of agricultural practice throughout tropical Australia could alter this situation. Changed water quality elsewhere has been linked to increased sedimentation and pollutants such as nutrients, pesticides and herbicides (DRCRG 2004). Changes in water quality can greatly affect aquatic biodiversity. These change the chemical environment in which aquatic organisms live, usually to their detriment, but (particularly with regards to nutrients enrichment) can lead to un-natural levels of reproduction in some organisms (eg blue-green algae) and an imbalance in natural ecosystems (RCNRMCG 2004).

Many coastal wetlands of the NT are exposed to herbicides used in weed control despite a lack of environmental testing demonstrating the effects of the chemicals on water quality and ecosystem health (Finlayson et al 1999). An exception to this knowledge gap is the herbicide, tebuthiuron, which was used extensively in the 1990s to control mimosa on Top End floodplains. An ecological risk assessment of tebuthiuron, based on ecotoxicological data for local aquatic species and historical environmental concentrations from two large scale chemical treatment programs on a Top End floodplain, indicated that the herbicide represented a significant and prolonged risk to native freshwater plant species, particularly phytoplankton and floating macrophytes, but a low risk to freshwater invertebrates and vertebrates (van Dam et al 2004). However, it was conceded that the ecological risks of the target weed were likely much greater than those of the herbicide (van Dam et al 2004).

The ORIA, in the east Kimberley, is the most intensively developed area of irrigated agriculture/horticulture in the Northern Tropical Rivers study area and is subject to significant pesticide application. Oliver & Kookana (2005) conducted a high level risk assessment of the herbicides and pesticides used for various crops in the ORIA, concluding that chemicals such as endosulfan, cypermethrin, chlorpyrifos and trifluralin had a high to excessively high risk for transport off-site. Pesticides such as endosulfan have been blamed for fish kills in the Ord River system (Lund 2005). In addition to pesticides, return flows from the irrigation area have resulted in elevated nutrient levels in the lower Ord River, with ANZECC/ARMCANZ (2000) trigger levels regularly being exceeded (Fredericks 2006).

The potential for contamination of riverine aquifers by pesticides and nutrients exists, whereby dependent ecosystems in base flow rivers may be adversely impacted, in particular aquatic communities (Sinclair Knight Merz, 2001). This is of concern in examining the coastal tropical rivers of Australia as many are base flow dependent during the dry season (Hatton and Evans, 1998). Contamination of aquifers with agricultural chemicals can change the chemical composition of the aquifer and thereby alter species composition dependent on the aquifer (Sinclair Knight Merz 2001).

2.2.4 Assets – threats matrix

As discussed throughout the preceding three sections, the ecological assets of the Northern Tropical Rivers, whilst mostly intact and relatively unmodified compared to south-eastern Australia, are nonetheless exposed to various pressures, such as human activities and environmental changes, that have the potential to ultimately diminish or destroy their value.

As noted by Woinarski et al (2007), the extent and relative naturalness of the northern tropical region will not afford it full protection from the various pressures it faces and, therefore, there is a need to heed the early warning signs of decline and degradation. The inter-relationships between the ecological assets of, and threats to, the Northern Tropical Rivers can be simply conceptualised in a matrix. Table 2.5 represents the asset-threat matrix for the Northern Tropical Rivers, showing the situation for (i) the current status of the region (black ticks) and (ii) a potential status of the region based on a significant increase in (a) water resource development centred mainly around irrigated agriculture utilising both ground and surface water, and (b) the number of mining operations (black and red ticks). The future development 'scenario' was chosen given the very strong interest in further developing both industries in the region (see Sections 2.2.2 and 2.2.3). Such matrices can be seen to represent initial conceptual models, albeit not cause–effect models, and their usefulness for tiered risk assessments and subsequent development of cause–effect conceptual models has previously been identified (Hart et al 2005).

Table 2.5 Assets–threats matrix for Australia's Northern Tropical Rivers study area based on (i) the current status in the region (black ticks) and (ii) the potential status given an increase in (a) water resource development centred around irrigated agriculture utilising both ground and surface water and (b) the number of mining operations (black plus red ticks).[1]

Assets	Threats							
	G'water extraction	S'water extraction	Water impoundment	Land clearance/ loss of native vegetation cover	Invasive flora	Invasive fauna	Altered fire regime	Contamination
Waterways	✓ (red)	✓ (red)	✓ (red)	✓	✓	✓	✓	✓ (red)
Wetlands	✓ (red)	✓ (red)	✓ (red)	✓	✓	✓	✓	✓ (red)
Riparian vegetation	✓ (red)		✓ (red)	✓	✓	✓	✓	
Groundwater dependent ecosystems	✓ (red)	✓ (red)	✓ (red)	✓	✓	✓	✓	✓ (red)
Biodiversity	✓ (red)	✓ (red)	✓ (red)	✓	✓	✓	✓	✓ (red)
Threatened communities and species	✓ (red)	✓ (red)	✓ (red)	✓	✓	✓	✓	✓ (red)

[1] NB: an attribution of a threat to an asset/value does not imply that the threat is currently impacting the asset/value, but that, if sufficiently severe or prolonged, it has the potential to do so.

At present, the greatest threats to the aquatic ecosystems of the Northern Tropical Rivers appear to be land clearance/loss of native vegetation cover, primarily due to pastoral activity being the predominant land use, exotic plant and animal species and poorly managed fire. Whilst active land clearance is not a major threat at this scale, native vegetation degradation and loss through grazing pressure is a major issue.

Water extraction and water impoundment do not represent a significant threat to the region's aquatic ecosystems at present. Only in localised areas has surface and/or groundwater extraction (and associated changes to flow regime) had a significant impact on aquatic ecosystems (eg. Ord River, Darwin River, Leichhardt River, GAB springs in the southern and northern Gulf and Cape York regions). However, well documented water resource problems elsewhere in Australia mean that there is a high likelihood in the future of increased pressure on the Northern Tropical Rivers' water resources for agricultural production and other water resource development (Commonwealth Government of Australia 2007). In addition, the current minerals ‘boom’ is likely to result in substantial development of existing mineral prospects over the next decade and perhaps longer. Whilst individual operations are very localised, the potential for mineral development across the majority of the region suggests that it could threaten the aquatic ecological values if not managed properly.

Whilst not incorporated into Table 2.5, climate change, including sea level rise, represents an overarching issue that affects potentially every element and interaction within assets–threats matrix in some way. Thus, in considering future pressures on and threats to the Northern Tropical Rivers’ aquatic ecosystems, the potential impacts of climate change on both the pressures/threats and ecological assets must be considered. Hyder Consulting (2008) provide the most current assessment of this for Northern Australian ecosystems.

The risks of the key pressures and threats to the aquatic ecosystems of the Northern Tropical Rivers are assessed in Chapter 3.

2.3 Daly River (Northern Territory)

The Daly River Catchment is approximately 52 600 km^2 in area and is located approximately 200 km south of Darwin in the NT. Figure 2.17 shows the Daly River catchment and its 16 sub-catchments, and also delineates the area known as the Daly Basin Bioregion. The Daly basin encompasses approximately 19 800 km^2 and occupies 36% of the catchment (Begg et al 2001). The significance of the Daly basin is made clear throughout this section.

Due to the existence of vast underground aquifers, much of the Daly River catchment is a perennially flowing system, which is an atypical water regime for Northern Australia. The abundant water supply and presence of the largest areas of soils suitable for agricultural production in the Top End have made the Daly River catchment a focal point for existing and prospective agricultural development (NT DIPE 2003). Although only small areas of the Daly River catchment have been cleared to date, Hristova & Murti (1998) considered the area has the potential to be one of the last regions in Australia to be cleared and developed for intensive dryland and irrigated agriculture.

Mean annual rainfall for the Daly River catchment varies from around 700 mm in the southern section to over 1300 mm in the north-western section (Erskine et al 2003; Moliere 2008). The mean annual rainfall in the north-eastern section of the catchment (ie. the upper Katherine River) is also high, in excess of 1100 mm, where the catchment extends into the Arnhem Land escarpment and plateau region (Moliere 2008).

The information reported in this section was sourced from the extensive literature on the Daly River. Although numerous meetings were held with, and advice sought from, various stakeholders, predominantly NT Government (NRETA and DPIFM) representatives, no multiple stakeholder workshop was held to discuss the Daly River’s ecological assets and their pressures and associated threats. The decision not to embark on such a process was based on advice sought from NT Government stakeholders at the outset of the project, which indicated that all stakeholders felt that there had been ‘over-consultation’ in the catchment in recent years, and that the information in reports from recent activities/projects in the region (eg. Price et al 2003; DRCRG 2004; Blanch et al 2005) provided an accurate reflection of the issues and views of stakeholders in the catchment.

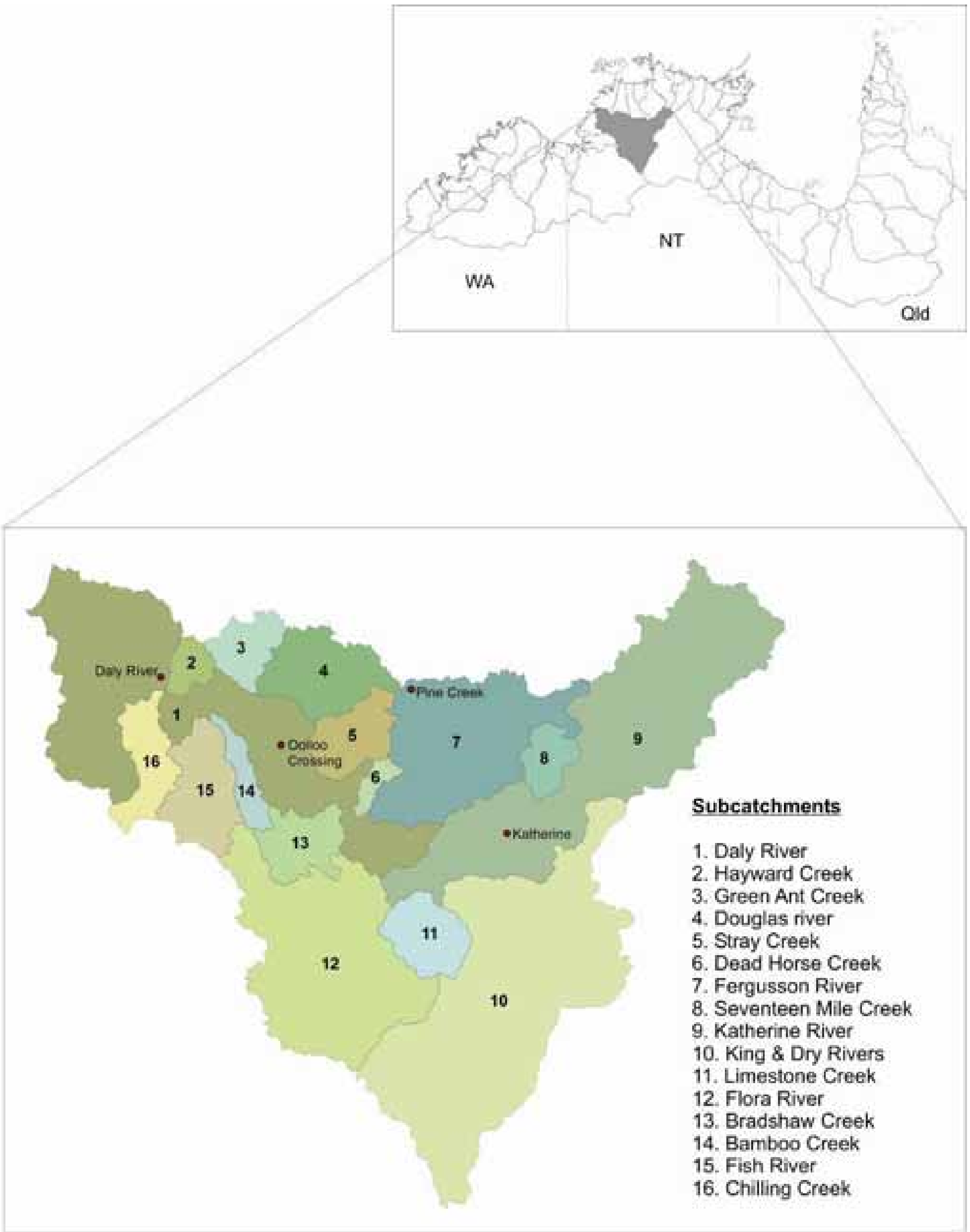


Figure 2.17 The Daly River catchment.

2.3.1 Ecological assets

The Daly River catchment is considered a region of very high ecological value and there is broad societal attachment to its pristine beauty and conservation value (Blanch et al 2005; De Groot et al 2008). Consequently, the region's ecological assets and values, which are summarised in Table 2.6, have been extensively described on numerous occasions (eg. Faulks 1998; Begg et al 2001; Price et al 2003; DRCRG 2004; Blanch et al 2005; De Groot et al 2008; and a also see Chapters 3 and 4). This section draws on information from these and other publications. For the most part, details additional to those provided in this section can be obtained from the source references.

Table 2.6 Summary of ecological assets and associated key values for the Daly River, as compiled from key literature sources[1].

Asset	Details
Waterways	4860 km of riverine length, representing 9 geomorphic types, dominated by confined and constrained reaches and anabranching reaches. ***Additional values:*** *Freshwater discharge* – dependence of estuarine/marine fisheries on river discharge *Perennial flow* – discharge from underground aquifers and springs supports strong Dry season base flows in at least seven major rivers/creeks *Habitat for key species* – important species such as pig-nosed turtle, *Vallisneria nana* and various fish (eg. barramundi, freshwater sawfish) are dependent on riverine ecosystems *Water quality* – high, seasonally variable water quality; low ionic strength/alkalinity upstream of Daly basin (granite/sandstone aquifers), high ionic strength/alkalinity within Daly basin (limestone/dolostone aquifers)
Wetlands	Extensive, diverse and largely intact wetland complexes that are important in maintaining biodiversity, and that include 1 wetland complex of national importance ***Additional values:*** *Wildlife nurseries & habitat* – diversity of different wetland types provide a range of habitats and resources for different species under different conditions and at different times. *Erosion control / sediment retention* – floodplains and swamps reduce erosive power of surface runoff and trap sediments before reaching river channels *Water regulation* – the absorbent, dispersive and flow reduction characteristics of wetlands help retain water in the system and attenuate floods
Riparian vegetation	Diverse, largely intact vegetation communities that may comprise nearly 300 000 ha within the catchment; they support very high biodiversity and endemism relative to their extent, and have many important ecological and hydrological functions; vine thickets represent a particularly important riparian community ***Additional values:*** *Erosion control* – riparian vegetation increases bank stability and reduces flow velocity, minimising downstream sedimentation *Habitat for wildlife* – provide shade, nutrients and submerged habitat for aquatic species, and act as corridors and refuges for terrestrial an semi-aquatic species
Biodiversity	Waterbird status of the lower Daly River floodplain satisfies requirements for Ramsar listing; the Daly River supports the largest pig-nosed turtle population in Australia, and contains more species of turtle (8) than any other Australian river; 48 species of estuarine/freshwater fish, including the rare strawman
Threatened species & conservation reserves	Numerous EPBC-listed aquatic/semi-aquatic species, including freshwater sawfish, speartooth shark, northern river shark, freshwater whipray, false water rat; other species of significance include pig-nosed turtle, 'blackmast' strawman, exquisite rainbowfish, and two plant species – *Vallisneria* and *Spirogyra*. At least 10 conservation parks and reserves are located in the catchment.
Limestone and karst habitat	Extensive groundwater aquifers characterised by surface and subterranean karstic features such as vertical shafts, losing streams, springs, dolines, caves and solution sculptured limestone rock; the karst geology is of great importance to the catchment's hydrological regime; stygofauna are present but not well characterised

[1] *Key literature sources:* Faulks (1998); Begg et al (2001); Price et al (2003); DRCRG (2004); Blanch et al (2005).

Waterways

The waterways, or riverine systems, of the Daly River catchment are considered to be in mostly undisturbed condition (Norris et al 2001; Blanch et al 2005). The catchment consists of 16 sub-catchments (see Figure 2.17), with the major rivers (other than the Daly River) including the Katherine, Flora, Fergusson and Douglas Rivers.

Based on the channels classified as '*named or major*' on the GEODATA TOPO 250K Series 2 drainage layer, there is approximately 4860 km of riverine length in the catchment (Figure 2.18; Saynor et al 2008). The geomorphology of the river reaches was classified by Faulks (1998), and more recently using the Northern Tropical Rivers study area classification, by Saynor et al (2008). Based on the classification by Saynor et al (2008), nine geomorphic types are represented in the Daly River catchment, with confined and constrained rivers (49%) and anabranching rivers (17%) dominating. The Katherine, Fergusson, Edith and Daly Rivers are bedrock channels or bedrock confined and constrained channels for much of their length. The low relief southern sub-catchment of the Dry River is characterised by low energy river types with non-channelised valley floors, chain of ponds and anabranching rivers dominating (Saynor et al 2008). The Daly River estuary extends approximately 100 km upstream (DRCRG 2004; Saynor et al 2008).

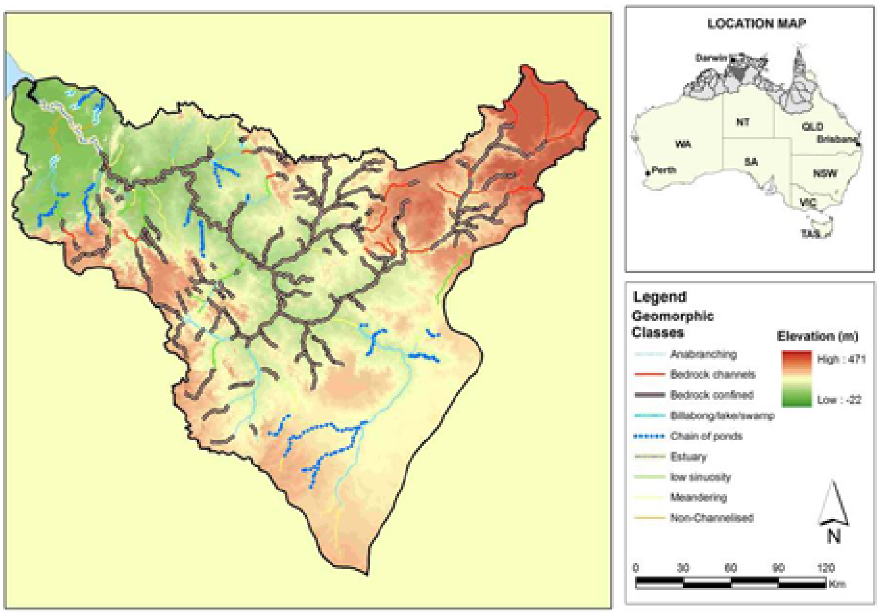


Figure 2.18 The waterways, and their geomorphology, of the Daly River catchment (from Saynor et al 2008).

Additional key values of the waterways of the Daly River catchment are described below.

Freshwater discharge

The Daly River catchment has the largest flow of all NT rivers, with an average annual discharge at Mt Nancar gauging station (just above the tidal reach) of around 7 000 000 ML (Moliere 2008). Due to the large groundwater aquifers supplying the river (see below), dry season flow is far in excess of any other river in the NT (Price et al 2000).

The ecology of estuarine and coastal marine ecosystems is linked to freshwater flows in several ways. Many marine species, including commercially important species such as penaeid prawns and barramundi (*L. calcarifer*), require brackish water at some stage in their life cycle. Sediments and nutrients transported from upstream contribute to downstream and marine primary productivity, including enhancing productivity of commercially important species (Hamilton & Gehrke 2005). Marine–freshwater linkages in most tropical northern rivers tend to be poorly understood. However, analyses reported in Chapter 4 show a strong link between Daly River flow/discharge and the productivity of the commercial and recreational harvest of barramundi fisheries.

Due to its limestone karst geology (see *Limestone and karst habitat*, below) the Daly River may also have subaqueous inputs into the estuarine and/or offshore marine ecosystems with important but unknown roles, as occurs in the Gulf of Carpentaria (Noble et al 1998 as cited by Hamilton & Gehrke 2005).

Perennial flow

The Daly River has a base-flow five times larger than any other river in the NT due to discharge from underground aquifers and springs (Blanch et al 2005). The dry season base flow, which is supported by groundwater discharge to the streams, contributes about 10% (~600 000 ML) of the average annual discharge of the Daly River at Mt Nancar) (Chappell & Bardsley 1985). Three significant aquifers underlie the Daly River system: the Tindal limestone; Oolloo dolostone; and Jinduckin siltstone). These aquifers are recharged via annual wet season rains, and the Tindal limestone and Oolloo dolostone discharge to a number of the catchment's streams through the dry season via springs as well as directly through the riverbed (Tickell et al 2002; Erskine et al 2003; Price et al 2003). Many of the springs are visible in the riverbanks, but the majority of the inflow is via direct seepage into the riverbed (Tickell 2002). The Jinduckin siltstone formation is thought to have little or no discharge to the catchment's surface waters (Erskine et al 2003). Water stored and discharged from the aquifers has a relatively young geological history and highlights the potential sensitivity of the volume of groundwater to water extraction (Blanch et al 2005).

The groundwater discharge supports dry season base flows in a number of the catchment's rivers, including the Daly, Katherine, Flora, Ferguson and Douglas Rivers, and Stray and Green Ant Creeks (DME 1975). The main inflows from the Tindall limestone occur where the Daly, Flora, Katherine and Douglas Rivers cut the aquifer, whilst the Ferguson River, Stray Creek and small tributaries of the Douglas River also receive inflows from this aquifer (Tickell et al 2002; see Figure 2.17 for major sub-catchment locations). The main inflows from the Oolloo dolostone occur in the Daly River, with most of these concentrated within the reach adjacent to the Stray Creek and Douglas River sub-catchments (Tickell 2002; see Figure 2.17 for major sub-catchment locations). An exception to the characteristic of groundwater discharging to surface waters during the dry season is the King River, in the east of the catchment, which is known to discharge a small quantity of water to both the Tindall Limestone and Oolloo dolostone aquifers (Tickell et al 2002).

The perennial nature of the Daly River provides habitat and supports wildlife groupings that do not exist or are poorly represented in other rivers that break up into separate pools during the dry season. The length of the river, variations in its underlying geology and wet season flow regimes result in the seasonal exposure of rock surfaces from overlying sediments. This allows for increased habitat diversity and, when combined with the mix of spring and surface water flows, creates further variety and while providing for these habitats to be used (DRCRG 2004). Hatton & Evans (1998) stated that the base flow communities in Northern Australia are noteworthy from a biodiversity and biological importance perspective. The stretch of the Daly River between Claravale and Beeboom crossing is a groundwater-fed river that is connected to the Daly estuary, and represents a rare river type in the NT (Erskine et al 2003).

Habitat for key riverine species

The waterways of the Daly River catchment provide habitat for numerous important riverine species. These include nationally listed species (see *Threatened species and conservation reserves*, below), as well as regionally listed and iconic species such as the aquatic macrophyte, *Vallisneria nana*, pig-nosed turtle, *Carettochelys insculpta*, freshwater whipray, *H. chaophraya* and barramundi (*L. calcarifer*). *V. nana* is of particular importance because it provides important habitat for a wide variety of turtles, reptiles, macroinvertebrates and fish (Rea et al 2002). Although the types and extent of in-stream habitats is not well known, Faulks (1998) described them to some extent. In-stream habitat diversity was considered high, with long pools dominating all reaches of the Daly River, interspersed by shallower sections and riffles.

Water quality

Seasonal changes in water quality are a feature of rivers and streams in the wet-dry tropics, and the Daly River is no exception. Water quality in the Daly River has been extensively detailed by Rae et al (2002). The dry season water quality in much of the middle reaches of the catchment (ie. the Daly basin region) is influenced by groundwater discharge from largely carbonate aquifers and, hence, is characterised by high electrical conductivity (EC) with high bicarbonate, calcium and magnesium concentrations (Rae et al 2002; DRCRG 2004). During the wet season, surface run-off from rainfall across the catchment enters the river. This water is higher in nutrients and organic matter than the river water and has low conductivity. It is thought that the first flush event of each wet season may be important for delivering dissolved organic carbon and particulate organic matter to the phytoplankton and macroinvertebrates in the river (DRCRG 2004). The depletion of dissolved oxygen as a result of organic matter breakdown is known to cause fish kills, a common phenomenon across Northern Australia.

Another characteristic of the water quality throughout the catchment is that waters upstream of the Daly basin typically have EC values less than 50 µS/cm, while those within and downstream of the basin are typically of the order of 500–600 µS/cm. The former reflect non-carbonate source aquifers such as granite or sandstone while the latter are typical of waters originating from carbonate aquifers such as limestone or dolomite (Tickell et al 2002). Townsend et al (2002) showed a clear differentiation in phytoplankton communities between these two water quality types. Of relevance to aquatic plants, the waters of the Daly River contain very low levels of nitrogen and phosphorus (Ganf & Rae 2007), which make the Daly River potentially susceptible to nutrient inputs from fertilizers and land erosion (Rea et al 2002; Blanch et al 2005).

Wetlands

Extensive wetland complexes occur within the Daly River catchment. These areas are relatively intact and diverse, with large areas supporting flooded savannahs and a variety of fauna (Price et al 2003). Based on the GEODATA TOPO 250K Series 3 waterbodies layer, the area of wetlands in the entire Daly River catchment is approximately 1940 km^2 (Figure 2.19A). However, within the Daly basin alone, Begg et al (2001) calculated there are over 1200 wetlands covering an area of at least 3534 km^2 (Figure 2.19B). The classification by Begg et al (2001), however, included several land types that would not be listed as wetlands in the GEODATA TOPO 250K Series 3 waterbodies layer (eg. damplands, which comprised 152 000 ha).

A

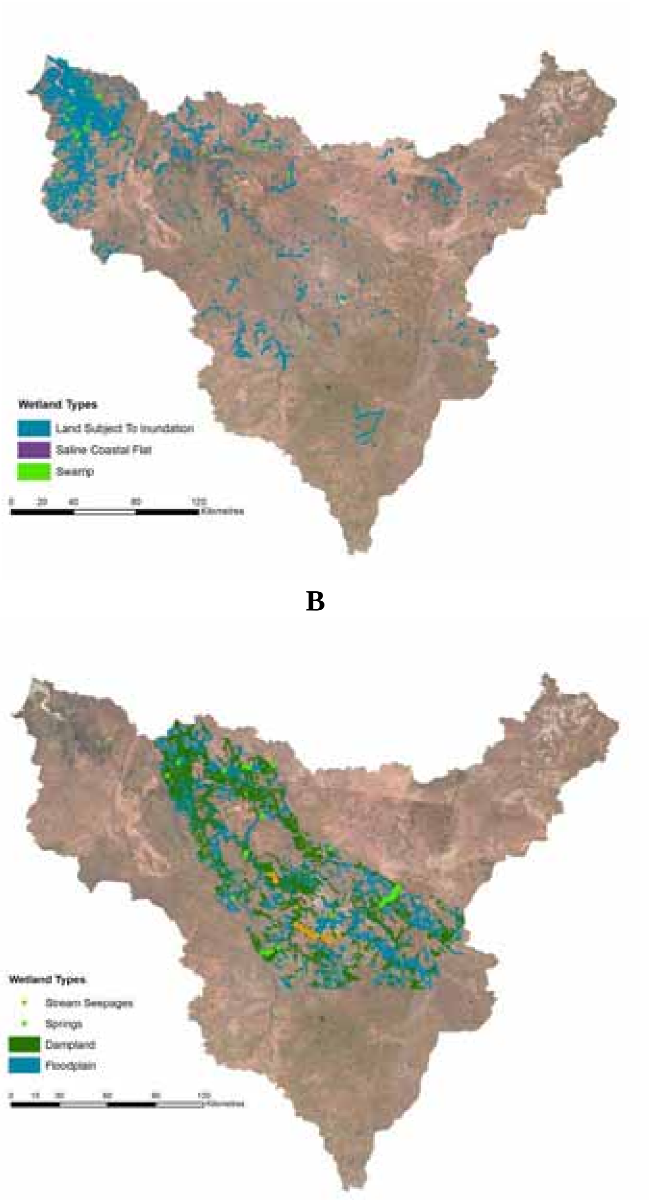


Figure 2.19 The wetlands of the Daly river catchment. – A. All wetlands for the Daly River Basin (based on the GEODATA TOPO 250K Series 3 Geoscience Australia). Features include Land Subject to Inundation, Saline Coastal Flat and Swamp; and B. Wetlands of the Daly Basin Biogeographic Region Boundary (Source: ERISS-Begg et al 2001. Wetland Mapping at 1:50,000).

Although they are small in their extent relative to catchment size, the wetlands play an important role in maintaining biodiversity (Price et al 2003) by providing a succession of resources for fauna (such as magpie geese, *Anseranas semiplamata*) due to the seasonal wetting and drying cycles (Price et al 2003). Notably, the floodplains are ranked in the top three breeding areas for magpie geese (Bayliss & Yeomans 1990). Chapter 4 (Section 4.2) describes in detail the importance of the floodplains as magpie geese nesting habitat in the wet season and dry season refuge habitat in the dry season. Overall, the wetlands are primarily valued for their importance to the recreational fishing industry, tourism, horticulture and the central role they play in sustaining the well-being of Aboriginal communities in the region (De Groot et al 2008).

Two wetland systems within the Daly River catchment are listed in the Directory of Important Wetlands in Australia (Department of the Environment and Water Resources 2007): the 1593 km^2 Daly-Reynolds Floodplain-Estuary System, which includes the entire floodplain and estuary of the Daly River, and the 165 km long Daly River Middle Reaches. Table 2.7 lists the diversity of wetland types found within the Daly-Reynolds Floodplain-Estuary System. The system represents one of the largest floodplains in the NT, and has the largest catchment of the major freshwater floodplains in the Top End (Department of the Environment and Water Resources 2007). The Daly River Middle Reaches includes the main channel and billabongs and swamps within 1 km of the channel. The river reach is considered a major breeding and dry season habitat for freshwater turtles (five species), fishes, and freshwater crocodile (Department of the Environment and Water Resources 2007).

Table 2.7 Wetland types located within the Daly-Reynolds Floodplain-Estuary System (Department of the Environment and Water Resources 2007).

Zone	Wetland types
Marine and coastal	Estuarine waters; permanent waters of estuaries and estuarine systems of deltas
	Intertidal mud, sand or salt flats
	Intertidal marshes; includes salt marshes, slat meadows, saltings, raised salt marshes, tidal brackish and freshwater marshes
	Intertidal forested wetlands; includes mangrove swamps, nypa palm swamps, tidal freshwater swamp forests
Inland waters	Permanent rivers and streams; includes waterfalls
	Seasonal and irregular rivers and streams
	Riverine floodplains; includes river flats, flooded river basins, seasonally flooded grassland, savanna and palm savanna
	Permanent freshwater ponds (<8 ha), marshes and swamps on inorganic soils; with emergent vegetation waterlogged for at least most of the growing season
	Seasonal/intermittent freshwater ponds and marshes on inorganic soils; includes sloughs, potholes; seasonally flooded meadows, sedge marshes
	Freshwater swamp forest; seasonally flooded forest, wooded swamps; on inorganic soils

A comprehensive description of the major wetland types existing in the Daly basin was provided by Begg et al (2001). Ten wetland types were classified and mapped (at 1:50 000 scale): river, creek, channel billabong, backflow billabong, floodplain billabong, floodplain, dampland, sumpland, waterhole and sinkhole or doline. The major wetland types for this part of the Daly River catchment were dampland (1524 km^2; seasonally inundated flat of variable size and shape) and floodplain (2010 km^2) and river/creek channel (25 560 km).

Wildlife nurseries and habitats

Wetlands represent essential habitat for fish, crustaceans, aquatic plants and many frog species. The role of these systems assumes greater importance when considering they occupy a mere 1% of the catchment area (Price et al 2003). Mobile species, such as migratory waterbirds, fish, turtles, reptiles, amphibians and mammals often require a network of wetlands from which they can use the habitats and resources that will meet their needs under different conditions and at different times (DRCRG 2004; Blanch et al 2005). Thus, the value of wetlands is collective rather than individual (DRCRG 2004). Consequently, losses of or damage to elements of the wetland networks/complexes may produce a deficit in resources that some species cannot overcome (Price et al 2003; DRCRG 2004; Blanch et al 2005).

Nursery habitats represent one important habitat type that wetlands provide for numerous species. For example, nursery areas for barramundi are often located in vegetated saline coastal wetlands (Griffin 1995; DRCRG 2004), while, as mentioned above, the floodplain system is one of the most important nesting and nursery grounds in the NT for magpie geese (Bayliss & Yeomans 1990).

Erosion control/sediment retention

Wetlands are widely recognized to function as sediment traps that capture runoff and associated organic material and nutrients (Begg et al 2001). This filtering of particulate matter and slowing of runoff to creeks and rivers is vital to the maintenance of water quality (Blanch et al 2005). The floodplain and swamps systems are likely to play a key role in reducing the erosive power of surface runoff and trapping sediments.

Water regulation

Many wetlands throughout the catchment are sites of recharge and discharge. In general, these systems prolong the time that water is stored in the catchment, by acting as absorbent and dispersive areas, and reducing flow velocity and stabilizing stream flows (Begg et al 2001). They can also act as perched systems that provide water and habitat throughout the Dry season (Begg et al 2001; Blanch et al 2005). The absorbent and dispersive attributes of wetlands gives them an important role in flood attenuation, as does their capacity to desychronise and decelerate flood peaks (Begg et al 2001).

Riparian vegetation

Riparian zones have an ecological significance that far exceeds its small proportion on a catchment scale; they are fundamental to stream and river health (DRCRG 2004). The riparian zones of the Daly River catchment have been recognised as significant habitats for the following reasons (Price et al 2003):

- They provide important ecological services to other systems;
- They are small in extent but provide the core habitat to a large number of species or to a threatened species; and
- They are important linking elements in the landscape (eg. for dispersal or migration).

Based on the Northern Territory National Vegetation Information System (NVIS) 2005 data compiled by the Department of Natural Resources, Environment and the Arts, riparian vegetation in the Daly River catchment covers an area of approximately 289 000 ha (Figure 2.20).

Overall, the riparian habitats are still largely intact (Faulks 1998). The habitats vary from a single line of trees to closed forests characteristic of monsoon-closed forests that occur up to the levee banks, and with distinct zonation controlled by elevation (Lamontagne et al 2005). The zonation is described by O'Grady et al (2002). The riverbanks rise in a series of terraces from the river with *Melaleuca* species occupying the lower terraces behind which are closed monsoon forests. The levee banks are dominated by *Eucalyptus* communities. The riparian vegetation displays complexity in its water use pattern which is evidenced by its structural and floristic complexity (O'Grady et al 2006).

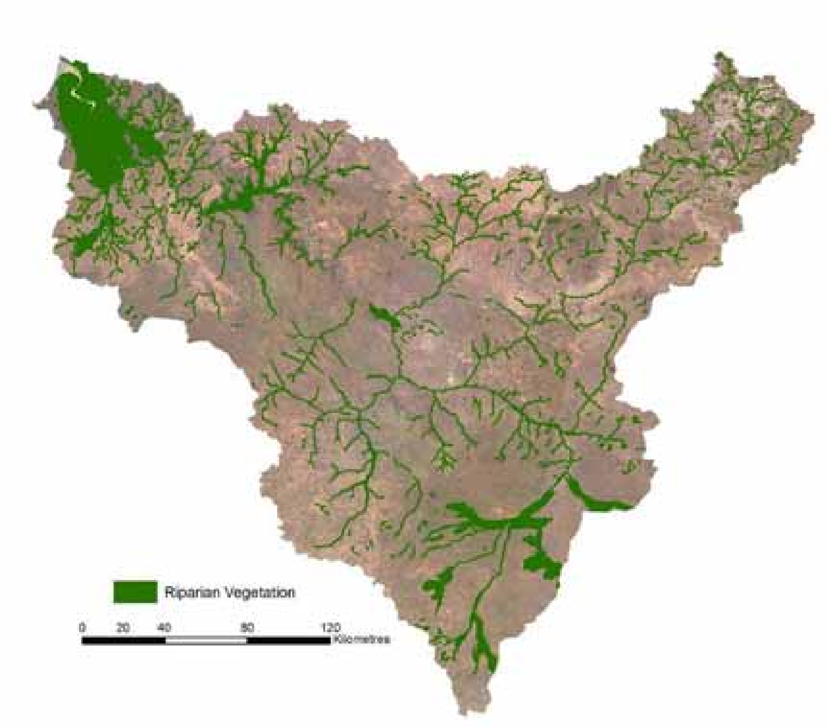


Figure 2.20 The extent of riparian vegetation in the Daly River catchment. (Source: Records deemed to be riparian were extracted from the Northern Territory National Vegetation Information System [NVIS] data produced by the NT Department of Natural Resources, Environment and the Arts).

The riparian vegetation associated with the Daly River is known to be dependent on groundwater to some degree (O'Grady et al 2002). Numerous studies on groundwater use by riparian vegetation in the Daly River have been conducted at Claravale/Dorisvale, downstream of Oolloo Crossing and at the confluence of the Douglas and Daly Rivers (O'Grady et al 2002; O'Grady et al 2006; Lamontagne et al 2005). Within the Daly River riparian zone, *Melaleuca argentea* and *Barringtonia acutangula* have been found to be obligate phreatophytes (meaning they almost rely solely on groundwater in the root zone), whilst a number of species appear to be facultative phreatophytes (meaning they utilise groundwater for a component of their water requirements) (Lamontagne et al 2005). Facultative phreatophytes include *Acacia auriculiformis* and *Casuarina cunninghamiana*, using groundwater at lower elevations but using soil water at higher elevations (O'Grady et al 2006). Generally, trees close to the river or located over shallow water tables use more groundwater than trees located further away from the river where the water table is deeper (O'Grady 2006). Seasonal patterns of groundwater use by riparian vegetation have not been ascertained, as Lamontagne et al (2005) conducted sampling only during the end of the Dry season.

Lamontagne et al (2005) suggested that it is not possible to predict the impacts of different land use scenarios on the Daly River riparian communities because their groundwater dependency has not been fully determined. However, it can be said that extraction of groundwater will affect GDEs. Determining the environmental water requirements of riparian phreatophytes is difficult, but necessary, to develop appropriate management procedures to ensure their survival if future land use impacts on groundwater resources. In establishing environmental water requirements, the relationship between species distribution and depth of water table and the difference between water use in wet and dry years are useful (Lamontagne et al 2005). The Daly River obligate phreatophytes could be adversely impacted if the water table is lowered below 5 m as they will lose their access to groundwater, whilst the facultative phreatophytes would be less impacted as they can use soil water as groundwater becomes unavailable.

A sustained lowering of the water table in the Daly region may result in a decline in biodiversity within the riparian zone, as species less dependent on groundwater become dominant (Lamontagne et al 2005). O'Grady et al (2006) estimated that between 59% and 75% of riparian water use in the dry season is derived from groundwater. Although this estimate was acknowledged as being a crude approximation, it did indicate that the Daly River riparian vegetation is likely to be highly dependent on groundwater, and that this needs to be considered in water allocation planning in the catchment (O'Grady et al 2006).

Monsoon vine thickets are another type of riparian vegetation. This forest type contains a high proportion of endemism; 36 of 585 species (6.2%) that occur in or comprise vine thickets are endemic. Monsoon vine thickets also provide habitat for many animal and bird species including the rainbow pitta (*Pitta iris*), emerald dove (*Calcophaps indica*) and various flying foxes (*Pteropus* spp.) (Blanch et al 2005). Monsoon vine thickets contain 13% of the NT flora in 0.5% of its area (Price et al 2003). In the Daly area, vine thickets are often restricted to areas adjoining rivers and in the north of the basin. However, rainforest patches do occur in the southern part of the basin and growing on limestone outcrops. It is the view of the NT Government that all exiting rainforest patches in the basin be maintained and conserved (Price et al 2003).

Erosion control

Riparian vegetation acts to buffer rivers from erosion, floodwater and soil runoff and pollution (Begg et al 2001; Price et al 2003). The particular structure and persistence of monsoon vine forests, a common riparian community, is important in regulating these functions. For example, their roots bind river and stream banks during floods (Blanch et al 2005).

Habitat for wildlife

Riparian vegetation provides shade and nutrients to river systems while acting as a Dry season refugia for many species (Price et al 2003). It can also act as core habitat and function as corridors for the movement of animals thereby facilitating plant and community connectivity (Price et al 2003; Blanch et al 2005). Fallen riparian vegetation in stream channels provides important shelter habitat for many aquatic species (Blanch et al 2005).

Biodiversity

The high biodiversity of the Daly Basin Bioregion has been detailed by Price et al (2003). The rivers, creeks and wetlands of the region are distinct ecosystems, supporting a wide range of species that do not occur in the wider landscape (Price et al 2003). A total of 421 vertebrate species have been recorded from the Daly Basin (Price et al 2003). There are no species with 50% of their records in the Daly Basin. However, two turtle species have more than 25% of their records in the Daly, suggesting that the river itself is the most significant environment for fauna in the Daly catchment (Price et al 2003). In fact, the Daly River supports eight of the NT's 12 turtle species (DRCRG 2004); this is the greatest number of turtle species for any Australian river (Price et al 2003; Blanch et al 2005). In addition, there are large freshwater and estuarine crocodile populations (Price et al 2003), and Fox (2007) listed nine additional aquatic/semi-aquatic reptile species as being recorded in the Daly River catchment.

Of these species, the most notable is the Pig-Nosed Turtle or Pitted Shell Turtle (*C. insculpta*) (classified as near-threatened in NT), which occurs in Australia and Papua New Guinea and is the remaining species of the family Carettochelyidae. The Daly River supports the largest population of this species in Australia (Georges 2002; Blanch et al 2005). This species is dependent on the highly unusual mosaic of habitat elements provided by the hydrology and geomorphology of the Daly River catchment (DRCRG 2004). They feed predominantly on aquatic macrophytes and invertebrates with their principal food source being *Vallisneria* (*V. nana*; Georges 2002).

The Daly River supports a large diversity of freshwater and estuarine fish. For example, 48 species of fish have been recorded from the river, compared to 33 species in the Murray Darling Basin which occupies an area 19 times larger than the Daly (Blanch et al 2005). Amongst these species are several threatened or rare species such as the freshwater sawfish (*P. microdon*) and freshwater whipray, also known as the giant freshwater stingray (*H. chaophraya*).

The Daly River floodplain is reported to support around 80 species of waterbird and, as mentioned above, is one of the most reliable areas in the NT for breeding by large numbers of magpie goose (Bayliss & Yeomans 1990).

One hundred and ninety-seven species of aquatic macroinvertebrates have been recorded form the Daly system, including a species of Sea Skater (*Halobates acherontis*) only known from one location, 112 km upstream of the mouth of the river (Price et al 2003). The majority of these species are uncommon; the high diversity and low abundance of most taxonomic groups may reflect different in-stream habitats and small scale resource patchiness (Blanch et al 2005). The Daly River also contains corbiculid bivalves, thiarid and viviparid gastropods, three important species of aquatic snails and an uncommon aquatic naucorid (*Aphelocheirus australicus*) known to exist in only high quality waters (Blanch et al 2005). Streams within the Daly River catchment are home to some large and commercially valuable crustaceans such as the giant freshwater prawn (*Macrobrachium rosenbergii*) and the freshwater crayfish (*Cherax quadricarinatus*; redclaw). The role of these large prawns in the food web is not known. However, given their apparent abundance and size, they are likely to be an important food source for large fish, lizards, monitors, turtles and crocodiles (Blanch et al 2005).

Eleven of the 1300 plant species recorded form the Daly Basin are restricted to this region, while a further 26 species have at least half their records from the region (Price et al 2003). Finally, Townsend et al (2002) identified 252 species of diatom and 206 species of phytoplankton in the Daly River Catchment. Of these, 36 had not been reported previously from the NT, and five had not been reported previously from Australia (Townsend et al 2002).

Threatened species and conservation reserves

Thirty threatened species classified under NT and Commonwealth legislation have been recorded from the entire Daly Basin (Price et al 2003). Aquatic ecosystems of the Daly catchment support various aquatic or semi-aquatic threatened species, including the freshwater sawfish (*P. microdon*), false water-rat (*X. myoides*) and possibly the northern river shark (*Glyphis sp. C*) and speartooth shark (*Glyphis sp. A*) (Erskine at al 2003; Price et al 2003; Blanch et al 2005; Table 2.8).

Table 2.8 Aquatic or semi-aquatic species recorded in the Daly River catchment that are Listed under the EPBC Act 1999 or the Northern Territory Parks and Wildlife Conservation Act.

Common Name	Scientific Name	Status	Comments
False Water-rat Water Mouse	*Xeromys myoides*	Listed as Vulnerable under the EPBC Act 1999.	The only known populations in Australia are in coastal areas of the NT and Qld. Loss of trees and coastal development are threatening processes.
Merten's water monitor	*Varanus mertensi*	Listed as Vulnerable under the NT Parks and Wildlife Conservation Act.	Widespread species, but threatened by invasion of cane toads.
Yellow-spotted monitor	*Varanus panoptes*	Listed as Vulnerable under the NT Parks and Wildlife Conservation Act.	Widespread species, but threatened by invasion of cane toads.
Freshwater Sawfish	*Pristis microdon*	Listed as Vulnerable under the EPBC Act 1999.	The largest freshwater fish in Australia, growing to at least 280 cm. Vulnerable to gillnet fishing and harvest for fins.
Speartooth Shark	*Glyphis sp. A*	Listed as Critically Endangered under the EPBC Act 1999.	Known threats include uncontrolled recreation/tourism, gillnetting, recreational line fishing and habitat degradation.
Northern River Shark	*Glyphis sp. C*	Listed as Endangered under the EPBC Act 1999.	Thought to have very specific habitat preferences and low fecundity, making it extremely vulnerable to any forms of exploitation, such as gillnetting and long lining, and also habitat degradation.

The rare strawman (*Quirichthys stramineus* or *Craterocephalus stramineus*), a hardyhead also known as blackmast, is also found in the Daly River system. It is likely that the Daly River represents the largest and most secure population of Strawman in Australia (Price et al 2003; Blanch et al 2005). It is considered that greater importance should be placed on the protection of these species in the Daly than in any other river because of the river's large size and unique hydrology (Price et al 2003).

Aquatic threatened species highlighted by Erskine et al (2003) as suitable target species for setting environmental water allocations were: pig-nosed turtle; freshwater sawfish; freshwater whipray; and strawman. Associated aquatic flora also suggested as target species were *Vallisneria nana* and *Spirogyra*.

The Daly River catchment contains at least 10 conservation reserves or parks, which feature significant ecological, cultural and recreational resources. These include: Tjuwaliyn (Douglas) Hot Springs Nature Park, Flora River Nature Reserve, Butterfly Gorge Nature Park, Umbrawarra Gorge Nature Park, Douglas River/Daly River Esplanade Conservation Area, Daly River (Mt Nancar) Conservation Area, Litchfield National Park, Oolloo Crossing Conservation Area, Cutta Cutta Caves Nature Park, Kintore Caves Nature Park and Nitmiluk National Park (Price et al 2003). According to Price et al (2003), most species are well represented throughout the reserve system.

Limestone and Karst habitat

Karst is a type of limestone rock that has undergone shaping and wear from being dissolved by water. Karst features include surface and subterranean landforms such as vertical shafts, losing streams, springs, dolines, aquifers, caves and solution sculptured limestone rock, and are a key feature of the Daly River catchment (Blanch et al 2005). The karst geology comprises the groundwater aquifers underlying the catchment, and therefore, is of great importance to the catchment's hydrological regime. In addition, karst habitats contain stygofauna communities for which virtually nothing is known (DRCRG 2004). In the Katherine Region alone there are almost 300 sinkholes which allow for significant recharge to the Tindall Aquifer (Karp 2002). According to Blanch et al (2005), the karst features of the Daly Basin are distinctive in that they are constantly being produced and maintained by large amounts of annual rainfall and percolation.

Alterations to the processes that form and sustain karst aquifers affect not only the output of the aquifer but also fauna that inhabit these systems. The movement of water from rainfall to aquifers to rivers is vital for the maintenance of these systems and needs to be protected (Blanch et al 2005).

2.3.2 Pressures

The current pressures on, and threats to, the Daly River catchment have been previously documented by Begg et al (2001), Price et al (2003), DRCRG (2004) and Blanch et al (2005). The summary below draws largely on information from these reports.

Horticulture

Based on the Land Use Mapping of the Northern Territory (2002) data, horticultural activities in the Daly River catchment occupy 52 km^2 and are concentrated in the Katherine region (Figure 2.21). However, this is nearly double the extent reported by Department of Primary Industry, Fisheries & Mines (2007), of just over 26 km^2 of horticulture in the Katherine region and 0.6 km^2 in the Douglas Daly region. Moreover, it has been suggested that the current figure for the Douglas Daly region is 1 km^2 (Greg Owens, pers comm, 2007).

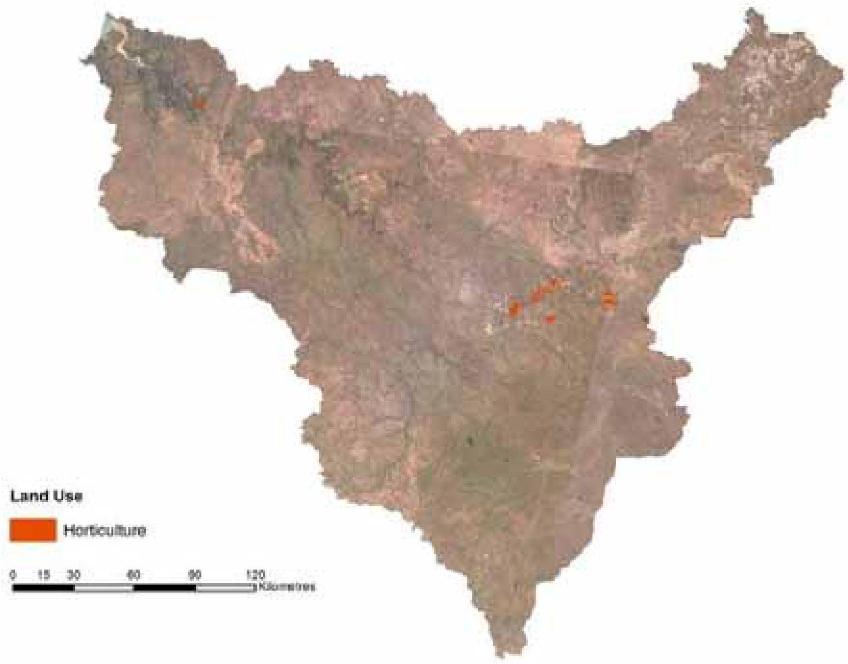


Figure 2.21 Horticultural land use in the Daly River catchment. (Data source: *Land Use Mapping of the Northern Territory* (2002)). Note that horticulture areas have been mapped at the secondary class level and includes intensive horticulture and irrigated perennial and seasonal horticulture. The areal representation is over double the areal figures reported by Department of Primary Industry, Fisheries & Mines (2007).

It is most likely that the 27 km^2 figure is the more accurate estimate of the areal extent of horticulture in the catchment. Supporting this, the estimate corresponds well with the 22 km^2 estimate reported by Petheram et al (2008). The majority of the area under cultivation comprises mangoes in the Katherine region (21 km^2) (Department of Primary Industry, Fisheries & Mines 2007). De Groot et al (2008) reported that there are almost 200 000 mango trees in the Daly River catchment, representing 26% of NT production.

The removal and replacement of natural vegetation for intensive horticulture is particularly apparent in the Katherine municipal area. In this region, irrigation of horticultural crops using groundwater commonly results in falling groundwater levels (Begg et al 2001). In 2001 to 2002, across the Daly Basin sub-region, horticulture production was worth $15 million resulting from 23 km^2 of annual and tree crops (DBIRD 2004). It has been suggested that approximately 1750 km^2 of land in the catchment is suitable for agriculture, including horticulture. Although this area represents only 9% of the Daly Basin sub-region, it is focussed around a few key rivers (ie. Katherine and Douglas-Daly) where the impact is likely to be concentrated and so high (Begg et al 2001). Horticulture around Katherine continues to expand, particularly the mango industry (DBIRD 2004). As mentioned in Section 2.2.2, the value of the horticulture industry around Katherine grew from around $9 million in 1997 to around $40 million in 2006 (Department of Primary Industry, Fisheries & Mines 2007). Development around the Katherine River is relevant to the ecological values of the Daly catchment, as the Katherine River contributes 40% of the total discharge of the Daly River (Begg et al 2001).

Pastoralism

Pastoralism in the Daly River catchment dates back to the 1880s. It is currently the largest land use in the Daly Basin and will continue to dominate the landscape in the future (Price et al 2003; DRCRG 2004). Based on the Land Use Mapping of the Northern Territory (2002) data, grazing activities in the Daly River catchment occupy 23 865 km^2 (Figure 2.22). The majority of this area (21 686 km^2) is classed as grazing natural vegetation, with only approximately 2179 km^2 being classed under grazing modified pastures. The number of animals grazing the pastoral areas of the Daly region is unknown (Begg et al 2001), although it has been estimated that approximately 500 000 cattle inhabit the Katherine region alone (Greening Australia 2003). In a study of the ecological condition of the Daly region, over two thirds of the riparian sites surveyed showed some degree of damage, with access by stock being the most common cause of disturbance (Faulks 1998). About 75% of the Daly Basin has been identified as able to support some type of pastoral activity (Begg et al 2001). In the instance where stocking rates are low and native vegetation is intact, pastoralism has less of an impact on the environment compared with intensive agriculture (Price et al 2003).

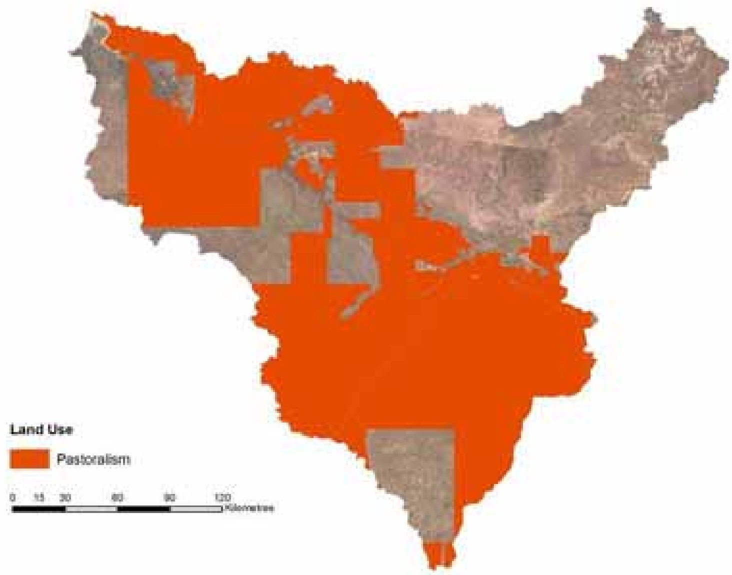


Figure 2.22 Pastoral land use in the Daly River catchment. (Data source: *Land Use Mapping of the Northern Territory* (2002)). Note that pastoral areas have been mapped at the secondary class level and includes grazing modified pastures and grazing natural vegetation.

The use of improved pastures is likely to increase in the Daly region. The NT Government is currently promoting improved pastures and predicts that most of the expansion will occur in the Tipperary Downs property group, an area that constitutes 50% of the DRCRG focus area (DBIRD 2004). Improved pastures can achieve 20 to 30 times the production levels of native pastures (DRCRG 2004). However, improved pastures can have a major impact on biodiversity, particularly for arboreal species (because of tree removal) and plants and ground-dwelling fauna (due to resulting monoculture habitat) (Price et al 2003).

Vegetation loss may also result from high stocking densities, and vegetation density and species composition changes can be the product of cattle grazing (Price et al 2003). Grazing (and up to 6 years of cropping) in the Ruby Downs area resulted in soil erosion rates up to 13 times the rate of soil formation (Elliott et al 2002 as cited by Erskine et al 2003). Other impacts of cattle grazing are centred on water holes, and can adversely affect native species (Price et al 2003).

Crop production

The history of cropping ventures in the Daly Basin was detailed by Price et al (2003). Numerous crops such as sugar cane, cotton, peanuts and sorghum have been planted with varied success (Yeates 2001; Price et al 2003; Department of Primary Industry, Fisheries and Mines 2007). At present, the cropping sector is restricted to mostly production of hay and silage for cattle feed and field crops such as peanuts (DRCRG 2004; Department of Primary Industry, Fisheries & Mines 2007). Based on the Land Use Mapping of the Northern Territory (2002) data, cropping activities in the Daly River catchment occupy approximately 352 km^2 (Figure 2.23).

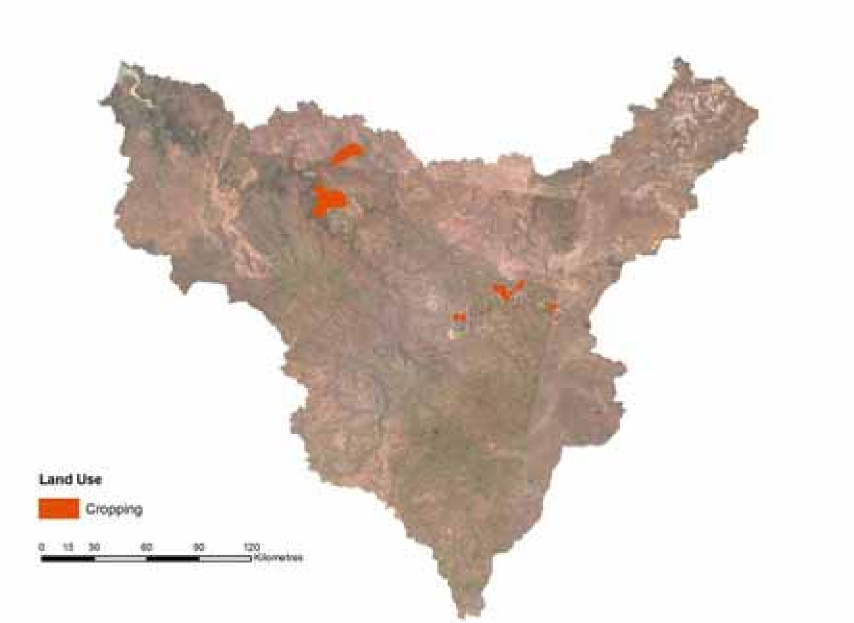


Figure 2.23 Cropping land use in the Daly River catchment. (Data source: *Land Use Mapping of the Northern Territory* (2002)). Note that cropping areas have been mapped at the secondary class level and includes cropping and irrigated cropping.

Given the water and other specific requirements for an area to be agriculturally viable (eg. soil, slope, access, etc.), the land within the Daly basin identified as having high potential is quite limited, representing less than 10% of the total area. However, this area is concentrated in one region, comprising the majority of the Douglas River, Stray Creek and Fergusson River catchments. As such, the likely pressure on local water resources and native vegetation in this area will probably be high. The water demands of irrigated cropping are evident by examining the estimated potential irrigable area utilising dry season run of river flows. Even with approximately 50% of the Daly River base flow being allocated for irrigation, the total irrigable area would amount to <1% of the Daly basin (Begg et al 2001). Thus, care needs to be taken that irrigated cropping activities do not develop beyond the extent that can be supported whilst maintaining adequate environmental flows. Petheram et al (2008) outline the relevant features of the Daly River catchment and their implications on tropical irrigation.

Without water allocated for irrigation and relying on wet season rainfall, crops such as sorghum, maize, sesame, peanuts, mung beans, soy beans, hay and grass seed may be grown (Price et al 2003). Due to the high intensity of rainfall in the Top End, cropping results in soil loss. Without conservation practices the rate of soil loss in the Daly Basin is estimated at 1 cm in soil depth annually (Price et al 2003). The impacts of soil loss on waterways can include increases in turbidity due to suspended soil, changes in physico-chemical composition of the waterway, and sedimentation of the river bed, which may affect aquatic plants (Price et al 2003; DRCRG 2004). Fish kills may become more frequent and severe if the water quality of the first flush is not managed for pollution impacts as a result of agricultural development (Erskine et al 2003).

Urban development

Currently, urban development is concentrated in the Katherine region, and occupies an area of only 2% of the Daly Basin (Figure 2.24). The region's population in 2001 was approximately 14 000, of which 10 000 (71%) lived in Katherine (DRCRG 2004). Other significant centres in the region are Pine Creek (600 people), Daly River (Nauiyu) Community (450 people). Land for the proposed Town of Fleming (NT Portion 2535) has been set aside within the Daly basin, at the junctions of the Oolloo and Jungawa Roads, in the Daly River sub-catchment. Population growth in the region is projected to be slow. For example, the population of Katherine is projected to increase 15-30% between 1999 and 2021, an annual average increase of only around 1% (ABS 2001). However, townships near new mining operations, such as Pine Creek, have recently experienced large increases in population.

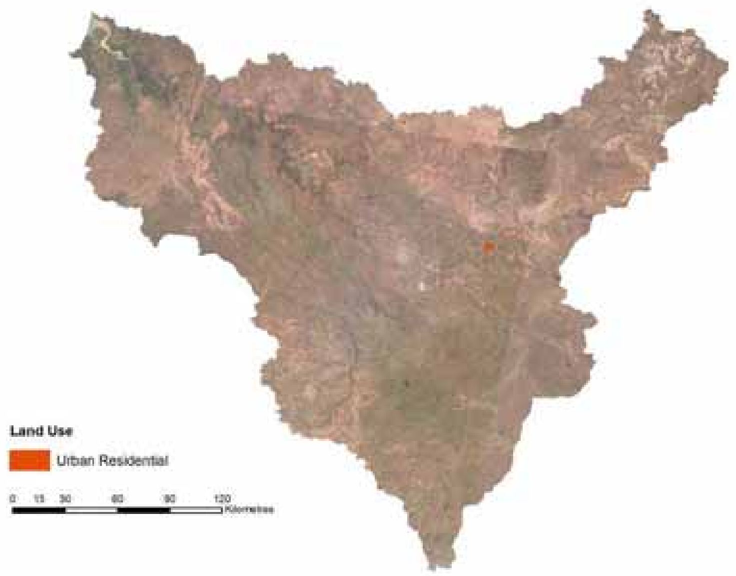


Figure 2.24 Urban residential land use in the Daly River catchment. (Data source: *Land Use Mapping of the Northern Territory* (2002)).

Katherine's public water supply is drawn from Donkey Camp Pool (above Donkey Camp Weir) on the Katherine River (Landcare Council of the Northern Territory 2005). The currently licences extraction limits for this storage is approximately 4500 ML pa (Jolly 2001; DRCRG2004). The towns of Katherine and Pine Creek and the communities of Nauiyu Nambiyu, Kybrook Farm, Binjari, Eva Valley and Barunga have their own sewerage systems, with the treated effluent from the Katherine sewerage treatment plant discharged into the Katherine River (DRCRG 2004).

The Katherine River contributes approximately 40% of the total discharge of the Daly River (Faulks 1998); with the Daly River catchment's urban development and horticultural activities both concentrated in the Katherine region and largely dependent on water from the Katherine River, any further development activity in the catchment may the potential to impact negatively on the water regime of the Daly basin (Begg et al 2001).

Tourism and recreational and customary harvest

While the numbers of visitors or tourists to the Daly region is unknown, reliable data are available for Katherine. In 2004 to 2005, 250 000 people visited the Katherine region (Northern Territory Tourism Commission 2005). The current level of hunting and harvesting that occurs in the Daly region is not considered an immediate threat, as management protocols are in place (Landcare Council of the Northern Territory 2005). However, it is acknowledged by the NT Government that limited information exists on the impacts of harvest levels on the long-term persistence of some species such as mullet, catfish, and freshwater crayfish, which are taken by recreational fishers or as part of Indigenous customary harvest (DIPE 2005).

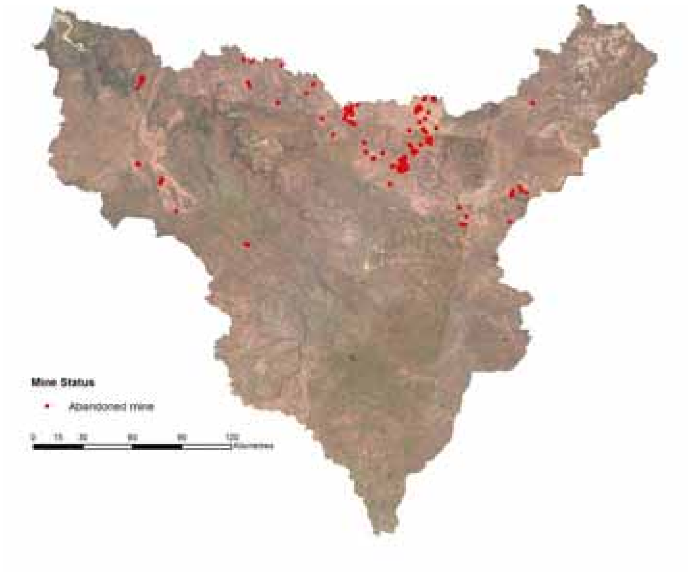
The Daly River is important for recreational fishing, accounting for 5% of the recreational fishing effort in the NT (DRCRG 2004). Associated with this, tourism in the catchment is highly dependent on recreational fishing. The closure of the Daly River to commercial barramundi fishing in 1989 due to concerns of overfishing, has ensured that the quality of fishing in the river has steadily improved. The tidal freshwater reaches between the Daly River Crossing and Moon Billabong are the most intensively fished areas by recreational fishers (DRCRG 2004). Every year the Daly River hosts two major barramundi tournaments – the *Barra Classic* and the *Barra Nationals*. Catch data from these tournaments are used by fisheries managers, and have also been utilised in Chapter 4 (Section 4.3). According to DRCRG (2004), there is insufficient knowledge to determine the sustainable yield levels for recreational fishing in the Daly River, although current offtake is estimated to only be about 15% of the biomass of unfished stock levels (see Chapter 4). De Groot et al (2008) noted concerns amongst local Aboriginal people about impacts of fishing boats on the Daly River, particularly in terms of bank erosion.

The Aboriginal people of the Daly River catchment also have a traditional association with the aquatic resources, and collect and use them in both traditional and modern ways (DRCRG 2004; Jackson 2004). Jackson (2004) provides a detailed account of the use of land and water resources by Aboriginal people in the Daly River catchment. Various aquatic species in the NT are known to be important for Aboriginal peoples, including mullet, barramundi, stingray, cherabin (freshwater crayfish) and turtle (Coleman et al 2003). In the Daly River catchment, birds, insects, reptiles, fish and water lilies are all utilised in traditional ways, mostly as a food resource (Jackson 2004). In addition, there are various initiatives to assess the viability of customary harvesting of traditional resources as economic opportunities.

Mining

Mining activities in the Daly Basin began in 1872 and have continued sporadically (Price et al 2003). Mining occupies a relatively small proportion of the land use within the Daly region. At present, there are no active mining operations in the Daly River catchment, although there are numerous historical mines (Figure 2.25A) and potential mines that includes mineral occurrences and prospects (Figure 2.25B). In 2003, 118 mining titles were granted in the Daly Basin totalling 53 km^2 and exploration licenses were applied for or granted over an area of 1600 km^2 (Price et al 2003). The largest mine sites within the Daly catchment are Mt Todd in the Yinberrie Hills, Maude Creek, Dorisvale and some operations within the Pine Creek Goldfields. The effects of mining tend to be localized, although downstream impacts cannot be discounted. Discharges of acidic mine waters during the Wet season are known to occur from mines within the catchment (DRCRG 2004), including the abandoned Mt Todd mine on the Edith River, in the Ferguson River sub-catchment. Fish kills in the Daly River catchment have been observed and attributed to mine water discharges (Begg at al 2001). Mines are also difficult to rehabilitate to their original state and associated tailings dams have been known to cause mortality in birds as a result of toxic chemicals (Price et al 2003). According to DRCRG (2004), the Daly basin region is considered to be highly prospective for diamonds, gold, zinc, barite, tin and nickel, and, due to the presence of substantial ore deposits, it is expected that mining will expand in the future.

A



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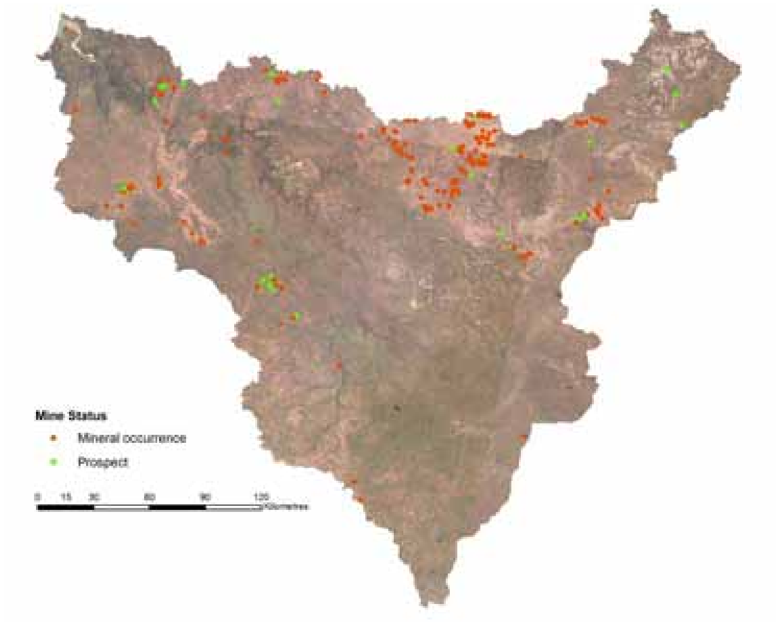


Figure 2.25 Mining status in the Daly river catchment (Source: NTGS MODAT, 2005). – A. Historical mines (listed as abandoned in MODAT); and B. Potential mines (mineral occurrence and prospect in MODAT).

Climate change

A study on the effect of climate change on the NT (Hennessy et al 2004; see details in Section 2.2.2) suggested that rainfall will decrease and evaporation will increase, while more recently, CSIRO (2007) has indicated little change in rainfall for the far north. A decrease in rainfall may affect the perennial stream flow regime of the Daly River. Consequently, DRCRG (2004) recommended that climate change be considered directly in risk assessment processes and water allocation systems within the area. In addition, saltwater intrusion due to sea level rise and storm surge associated with more intense storm events may penetrate the freshwater wetlands on the floodplain of the lower Daly River (see Chapter 3). Changes in climate, most notably temperature and atmospheric CO_2 concentrations, may alter the structure of riparian vegetation communities. Bowman & Dingle (2006) measured a 21% expansion of the endemic monsoon forest species, *Allosyncarpia ternata*, in Kakadu National Park, over the past 50 years, a period when fire regimes have been generally unfavourable for such expansion. They suggested the forest expansion might be due to a regionally wetter climate since the mid 20^{th} century. It is also clear that vegetation across Northern Australia is becoming more woody at the expenses of grasses (Bowman et al 2001; Woinarski et al 2007). Whilst this effect might be due to recent land management practices, climatic changes have also been implicated. This is contrary to popular belief which suggests that increased late hot fires resulting from, amongst other factors, increased fuel loads following the removal of feral buffalo, are driving these systems to the more fire tolerant grasslands.

2.3.3 Threats

Groundwater extraction

Groundwater is the only water supply currently proposed for irrigated crops in the Daly Basin. The groundwater supply within the region is restricted by limited flow and cannot support large scale irrigation (Price et al 2003). In 2004, there were 1970 bores registered in the Daly River Surface Water Catchment (DRCRG 2004). Under existing licences, the current maximum permissible extraction limits average approximately 29 000 ML pa (2004–2010), although it is unlikely all of this is extracted (DRCRG 2004). According to Commonwealth of Australia (2007a) groundwater use across the catchment totals approximately 16 500 ML/year or 2.5% of the sustainable yield of almost 650 000 ML/year across the four Groundwater Management Units (ie. Tindall-Katherine Water Control District and the Unincorporated Areas of the Jinduckin Formation, Oolloo Limestone and Tindall Limestone). Approximately 65-70% of the groundwater use derives from the Tindall Limestone aquifer in the Katherine region (DRCRG 2004; Commonwealth of Australia 2007a).

Groundwater extraction will impact the flow of perennial springs which may cease to flow in the Dry season (Price et al 2003). Additionally, lowering the water table through groundwater extraction may cause drought in groundwater dependent habitats in the Dry season and result in a reduction of dry season flow in the Daly, Katherine and Flora Rivers (Price et al 2003).

It is suggested that groundwater extraction may be a larger threat to wetland hydrology in the Daly basin compared with surface water extraction (Begg et al 2001). Furthermore, many of the region's wetlands are dependent on groundwater particularly in the Dry season. Some of the effects of over-extraction of groundwater identified by Begg et al (2001) were:

- Reduced Dry season base flows in waterways dependent on groundwater input during the Dry season;
- Cessation of flows therefore impacting on organisms dependent on particular flow regimes; and

- Reduction in the spatio-temporal extent of semi-permanent and temporary wetlands that are related to groundwater aquifers.

The risk of soil salinisation due to irrigation is low because the high rainfall during the wet season flushes salts deep underground and the groundwater has a low mineral content (Price et al 2003). Reduction in dry season base flows due to groundwater extraction may increase the likelihood of thermal and/or oxygen stratification resulting in a fish kill event (Erskine et al 2003).

It is unknown to what extent groundwater extraction will result in ecological impacts because the ecosystems in the Daly River catchment are adapted to high variability in the water regime. Moreover, it is still unclear as to the extent that the groundwater resource in the catchment will be utilised for further development (this is addressed to some extent in the following section on surface water extraction). However there are predicted ecological implications of further groundwater extraction for riparian vegetation communities, water quality, aquatic habitat and aquatic biota (Begg et al 2001).

Surface water extraction

Water is extracted from the waterways within the Daly basin for irrigation/horticulture, stock and domestic purposes (Begg et al 2001). According to DRCRG (2004), there were 26 surface water extraction licences and 10 licence applications within the Focus Area (broadly, the Daly basin). The current maximum permissible extraction limits total approximately 10 000 ML/year (DRCRG 2004). This represents around 0.1% of the average annual discharge of the Daly River (see Chapter 4, Section 4.2.1 for details). Jolly (2001) estimated that unlicensed water extraction (surface and groundwater) to be around 1000 ML. O'Grady et al (2002a) estimated surface water extraction to be approximately 16 000 ML/year or around 0.2% of average annual discharge. However, this catchment-wide analysis can be somewhat misleading, as the majority (~85%) of surface water extraction occurs in the Katherine River, which represents about only 30% of the mean annual discharge of the Daly River catchment. Hence, the Katherine River catchment is under greater pressure from surface water extraction than the rest of the Daly River catchment. This is even more so when one also considers that surface water is typically extracted during the dry season, when groundwater-derived base flows in the Katherine River are much lower (eg. ~90 ML/day) (Begg et al 2001).

Despite the low current water usage rates cited above for groundwater and surface water (on a whole of catchment basis), future water allocation in the Daly Region has received considerable government and community attention over the last several years. Through stakeholder consultations, DRCRG (2004), identified water extraction as a potential key threat to in-stream and floodplain environmental flows and, hence, the "condition" of Daly River aquatic ecosystems. Water allocation plans for the region were not yet finalised at the time of publication of this report, but it is clear that the use of ground and/or surface water in the Daly River catchment for agricultural purposes is a key future issue. Indeed, the Daly River is one of numerous rivers across the Northern Tropical Rivers study area that has been identified as having potential for further agricultural development. Erskine et al (2004) proposed a series of guidelines for environmental water allocation in the Daly River catchment, focusing on the maintenance of: flood peaks during the wet season; minimum streamflows during the dry season; dry season groundwater levels and inflows from springs to the Daly River; groundwater and surface water quality. Further details on, and assessment of the potential ecological impacts of, reduced flows due future water extraction from the Daly River are provided in Chapter 4.2.

Price et al (2003) summarised the potential effects of a reduction in flow of the Daly River itself:

- *There will be less total aquatic habitat.*
- *Some habitats such as riffles (shallow fast running rocky areas) may become drastically reduced in size.*
- *The temperature of the water may increase, because there is less water for the sun to heat.*
- *Oxygen levels may fall.*
- *Important cues for breeding may be interrupted, although it is thought that most NT fish species breed and migrate in the wet season, when the impacts of irrigation on flows will be negligible.*
- *Riparian vegetation will be further from the water (both laterally and vertically), and may suffer from reduced water availability.*

It has also been suggested that the extraction of large volumes of water combined with a series of low rainfall years may result in the Daly River ceasing to flow (Price et al 2003). Appropriate water allocation planning needs to be in place prevent such a situation from occurring.

Water impoundment

There are two weirs used for water supply purposes in the Daly River catchment. The Donkey Camp Weir (~1500 ML) on the Katherine River, which provides Katherine's water supply (Norris et al 2001; Jolly 2002); and a small weir (~100 ML) on a tributary of Copperfield Creek in the Fergusson River catchment, which provides Pine Creek's water supply (Jolly 2002). Over the past 25 years there have been a number of potential dam sites identified within the Daly basin. Begg et al (2001) listed the following sites as having potential for construction of large dams:

- Douglas Dam located on the Douglas River above Butterfly Gorge (inundate 5,400 ha of land);
- Edna Creek Dam in the Stray Creek catchment (inundate 3,800 ha of land);
- Keckwick Dam on the Katherine River;
- Nancar Dam on the lower reaches of the Daly River;
- Umbrawarra Gorge on Stray Creek; and
- McAdams Creek.

However, due to its underlying limestone (karst) geology, the basin is not the ideal location for dams (Begg et al 2001). Moreover, one of the core principles in the Daly River Community Reference Group's Terms of Reference for advising the NT Government on long-term ecologically sustainable development in the Daly basin region, was that there should be no dams on the Daly River (DRCRG 2004). Nevertheless, the potential impacts of damming on aquatic habitats of the Daly River catchment were summarised by Price et al (2003) as follows:

- Most NT fish species are migratory and will be unable to negotiate such barriers;
- Dams may prevent the first floods of the wet season, which play a very important rejuvenating role because they flush aquatic habitats, and enable aquatic species to re-colonise estuarine floodplains;

- River water temperature may become colder because water released from dams is often from great depth, and much colder than surface water. This can have severe impacts on species populations, communities and ecosystems;
- Patterns of erosion and deposition will be altered because dams have a large effect on both high and low flow regimes; and
- Dams will affect the normal transfer of materials (eg. nutrients, sediment, woody debris, detritus) through the system.

Altered fire regime

Fewer fires are lit across the NT now than compared to pre-European settlement. One result of this shift in fire management is that most fires occur towards the end of the dry season and are large (Price et al 2003). In the Daly Basin, the pattern of burning closely follows the focus of land management with areas intensively managed for open grazing and cropping less frequently burnt. Price et al (2003) suggest that approximately 50% of the Daly Basin is burnt more than once every two years, and that in some regions fire is far more frequent than in the past. The above two statements are supported by Figure 2.26, which shows fire frequency for the Daly River catchment during the period 2003-2006. The regions of highest agricultural activity, around Katherine and in the Green Ant Creek, Douglas River and Stray Creek catchments experiencing relatively low fire frequency, with other areas across the northern half of the catchment experiencing much high fire frequencies. According to DRCRG (2004), the prevailing fire regimes in the Daly Region have not been described in detail, so it is difficult to specify the regimes that will maintain the present situation.

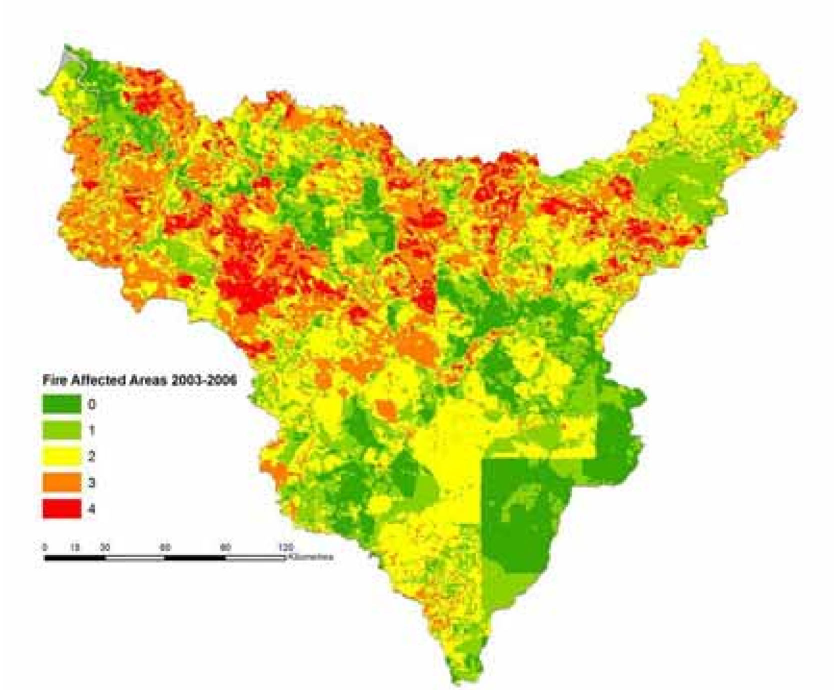


Figure 2.26 Fire Affected Areas (FFAs) composite for 2003-2006 in the Daly River catchment. FAAs for each calendar year are attributed with a value of 1 and all layers summed, creating a layer with values from 0 to 4. (Source: Derived from day-time passes of Terra & Aqua MODIS satellite imagery using the 250 m channels (red and NIR) and a time difference of usually 3 to 7 days, local knowledge and feedback from stake holders- Tropical Savannas CRC in conjunction with Bushfires NT).

Land clearance/loss of native vegetation cover

At a catchment level, 4.1% or 2160 km^2 (216 000 ha) of 52 580 km^2 (5 258 000 ha) has been cleared of native vegetation (DRCRG 2004; Blanch et al 2005). Clearing rate and extent is examined in detail in Chapter 4 (Section 4.4). The NT Government has identified another 1100 km^2 (110 000 ha) as suitable for clearing (DBIRD 2004), although there is currently a moratorium on land clearing in the lower half of the catchment until March 2010. The most current estimate of area of native vegetation cleared in the Daly Basin is 2320 km^2 (232 000 ha; Figure 2.27) representing 11% of the basin (NT NRETA 2006). This compares with 1940 km^2 (194 000 ha; 9.3%) of native vegetation cleared up until 2002 (Hosking 2002), which is a further 380 km^2 (38 000 ha) or 2% increase in land clearing over a 4 year period. Riparian zones generally are not included within subdivisions and are required to be fenced off (Begg et al 2001) and, therefore, should not be subject to land clearing. According to WWF & ECNT (2007), despite the clearing moratorium, nearly 175 km^2 of land in the catchment was approved for clearing between 2003 and 2007, with most of this (~87%) designated for improved pastures. It should be noted, however, that moratorium does not cover the area around Katherine, which supports substantial horticultural activity.

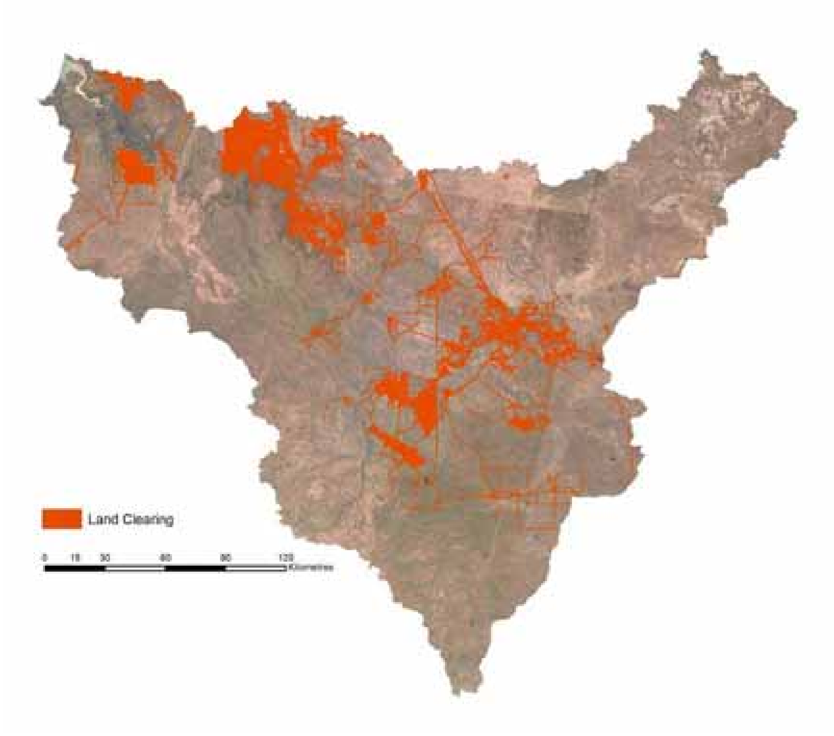


Figure 2.27 Land clearing in the Daly river catchment (Source: NTG- Land Clearing 2005 data). Note that cleared areas have been cartographically exaggerated for representation in the figure.

Riparian and other vegetation, however, can be lost due to other activities. Faulks (1998) attributed damage to riparian and stream areas in the Daly River catchment to access by stock. Loss of vegetation cover due to stock grazing is not captured by land clearance data and, unfortunately, there are few quantitative data for the catchment to indicate the extent and magnitude of this activity. Mott et al (1979) and Bridge et al (1983) described the formation of patches of bare, degraded land in the Katherine region associated with grazing or simulated over-grazing activities. Given that about three quarters of the catchment has been identified as being able to support some type of pastoral activity (Begg et al 2001), the potential for loss of vegetation cover due to this land use could be considered significant. On the other hand, grazing activities have also resulted in increases in the density of woody vegetation in savanna grassland landscapes, possibly as a result of a shift in vegetation structure to less flammable species coupled with reduced fire frequency (Sharp & Whittaker 2003).

The majority of clearing has occurred in the Green Ant Creek subcatchment (DRCRG 2004) for agricultural purposes and, approximately 60% of this sub-catchment has been cleared (see Chapter 4, Section 4.4 for details). Table 2.9 summarises the magnitude of clearing in each sub-catchment. Other sub-catchments where there has been substantial clearing for agricultural activities are the Douglas River, Limestone Creek and Stray Creek catchments. Some clearing for urban development has occurred around Katherine in the Katherine River sub-catchment. Tipperary Station is the largest single area of extensive clearing in the NT with much of the clearing activity taking place in the late1960s and late 1980s (Hosking 2002; Brock 2000). There has been no clearing recorded in Seventeen Mile Creek, Fish River and Bamboo Creek sub-catchments (DRCRG 2004).

Table 2.10 summarises the land clearing statistics by land tenure based on 2005 land clearing data supplied by the NT Government. The results are comparable to those of Hosking (2002) for the Daly Basin to 2001, in that the majority of clearing has taken place on Perpetual Pastoral Lease (PPL) followed by Freehold (F). Current clearing is focused on land with moderate to high agricultural capability for improved pastures (Begg et al 2001), and is facilitated by the NT Government promoting these farming systems to the community (DBIRD 2004). The majority of clearing on pastoral lease tenure has occurred on Tipperary Station prior to 1990 (Hosking 2002). It should be noted that less than 50% of the Daly Basin has conditions suitable for agricultural practices that would require clearing (Price et al 2003).

Table 2.9 Magnitude of land clearing in the Daly River summarised by sub-catchment (Source: DRCRG 2004).

Daly River subcatchment	Area of subcatchment (ha)	Area cleared (Historical) (ha)	Area cleared (% subcatchment)
Daly River	888 400	10 888	1
Chilling Creek	124 100	136	<1
Hayward Creek	47 200	1890	4
Fish River	174 800	0	0
Bamboo Creek	60 200	0	0
Green Ant Creek	91 400	53 869	59
Douglas River	196 400	30 354	16
Stray Creek	121 600	12 099	10
Bradshaw Creek	118 100	131	<1
Dead Horse Creek	27 800	892	3
Fergusson/Edith River	478 800	7098	2
Flora River	673 600	24 375	4
Katherine River	956 900	43 557	5
Limestone Creek	127 500	21 011	16
King & Dry Rivers	1 101 200	9509	<1
17 Mile Creek	69 600	0	0
Total (Catchment)	***5 257 600***	***215 810***	***4.1***

Table 2.10 Clearing within the Daly River catchment based on Northern Territory Government land clearing GIS data current to 2005 and Northern Territory cadastral data containing tenure type.

Tenure	Area of Daly Catchment (ha)	Area of Daly Catchment (%)	Clearing (ha)	Clearing (%)	Total Area Cleared (%)
Building Lease (BL)	2.93066	0.00	2.93068	0.00	0.00
Crown Lease Perpetual (CLP)	692174.87	13.01	5549.64	2.11	0.10
Crown Lease Term (CLT)	29931.04	0.56	2948.92	1.12	0.06
Freehold (F)	1953167.84	36.70	70929.69	27.01	1.33
Govt. Set Aside (G)	90.724	0.00	75.5437	0.03	0.00
Occupational Licence (OL)	49.2352	0.00	23.4463	0.01	0.00
Pastoral Lease (PL)	1055586.46	19.83	36701.89	13.98	0.69
Perpetual Pastoral Lease (PPL)	1378586.87	25.90	144840.74	55.16	2.72
Reserve (RES)	1385.02	0.03	9.10177	0.00	0.00
Special Purpose Lease (SPL)	1631.66	0.03	76.3968	0.03	0.00
Vacant Crown Land (V)	209341.61	3.93	1444.34	0.55	0.03
Total	***5321948.26***		***262602.6393***		***4.93***

There are numerous biophysical and ecological effects that can occur as a result of land clearance or loss of vegetation cover. Firstly, loss of native vegetation through clearing equates to a loss or fragmentation of wildlife habitat. A wildlife survey in the Daly Basin showed that species richness for plants, mammals, birds, frogs and reptiles was lower in cleared quadrats compared to uncleared quadrats (Price et al 2003). However, it is noted that some grassland species are not adversely impacted by clearing (Brock 2000). Secondly, runoff from rainfall increases substantially when ground cover is reduced to below 50% in the region (Price et al 2003), and this in turn can result in increased soil erosion and sedimentation of waterways (Boulton & Brock 1999), and increased surface water flow volume. Elliott et al (2002, as cited by DRCRG 2004) found that net soil losses from grazed and/or cropped hillslopes at sites in the Daly Basin and around Pine Creek over the last 40 years were up to 13 times the rate of soil formation, even when treated with contour banks. Increased runoff associated with cleared land can also increase the intensity of extreme flood events (Brock 2000; Price et al 2003). However, DRCRG (2004) noted that research on agricultural practices and soil erosion in the Daly River catchment has led to the development and implementation of conservation farming practices, in particular the use of a ground surface cover (mulch) to conserve soil and water and minimise run-off and soil erosion.

Land clearance can also have impacts on groundwater interactions and functions. For example, clearing of native vegetation for improved pasture and irrigated agriculture is likely to have significant impacts on recharge to groundwater aquifers (O'Grady et al 2002). However, unlike catchments in southern Australia, the risk of dryland salinisation resulting from removing vegetation in the Daly Basin is low as removal is not expected to sufficiently alter the water table for this to occur (Price et al 2003).

Introduced invasive flora

The perennial flow of the Daly River is likely to inhibit the establishment of significant aquatic weeds; however, associated waterways and water-dependent ecosystems will be vulnerable (DRCRG 2004). The spread of invasive flora can be facilitated by vehicles and boats. Two weeds of particular concern in the Daly region are Olive Hymenachne and salvinia, both of which are listed as Weeds of National Significance and a known threat to wetlands (DRCRG 2004; DIPE 2005). Twenty seven weed species have been found in the Daly Basin (Price et al 2003). The results of a wildlife survey (Price et al 2003) showed that Hyptis (*Hyptis suaveolens*) and Wild Passion Fruit (*Passiflora foetida*) were the most common weeds occurring in quadrats. A study of the Daly region in 1998 found that riparian weeds were widespread throughout the waterways of the Daly catchment (Faulks 1998). This appears to remain the case from more recent studies (Price et al 2003). The DRCRG (2004) identified that mimosa and noogoora burr (*Xanthium occidental*) were of most concern to the wider community, and that weeds in general are viewed as threats to biodiversity, economic gain and recreational activities. Another serious wetland weed that occurs on the Daly River floodplain is para grass, and although it is not currently present at a high density. Nevertheless, it has the potential to suddenly increase in extent (a "sleeper weed") and form large stands of dense monocultures. The ecological risks of para grass and mimosa on the Daly River floodplain are assessed in detail in Chapter 4 (Section 4.2).

A range of drier habitat-preferring weeds have also colonized the Daly catchment including grasses and pasture species; however, drainage lines and areas of high cattle disturbance are more heavily infected across the region (Whitehead et al 2003).

Introduced invasive fauna

Feral animals do not occur in unusually high densities within the Daly region (DRCRG 2004). Invasive vertebrate species in the area include the cane toad (*Bufo marinus*), donkey (*Equus asinus*), horse (*Equus caballus*), pig (*Sus scrofa*), feral cats (*Felis catus*) black rat (*Rattus rattus)*, house gecko (*Hemidactylus frenatus*) and water buffalo (*Bubalus bubalis*) (Price et al 2003).

Impacts from hoofed ungulates such as water buffalo, pigs, horses and donkeys are not widespread, as while these animals are common in the Daly region, they are limited to a small proportion of the area (Price et al 2003). The impacts of horses and donkeys are unknown in the Daly region. The effects of buffalo on river and wetland environments are well documented. Trampling of riparian areas, waterway banks and associated systems can lead to erosion and sedimentation and indeed has been observed in some areas of Kakadu as a result of buffalo damage (DRCRG 2004). It is believed they are fairly common in the northern parts of the Daly region, but damage associated with their presence is unclear. Pigs are also quite common in the Daly River basin and, along with other ungulates are considered to be key vectors of weed spread (Price et al 2003). Both the black rat and house gecko, while abundant in some areas are restricted to urban areas and do not present a broad conservation threat (Price et al 2003).

The arrival of the cane toad will affect some features of the aquatic environment. In 2004 the cane toad was sighted at Woolianna on the lower Daly River, and cane toads have been present in Katherine Gorge since 2001. Pigs are fairly common throughout the Daly region (Price et al 2003) and carry diseases like *Leptospirosis* that infect other wildlife and can be transmitted to humans. Additionally, pigs can potentially host many livestock diseases such as bovine brucellosis and tuberculosis, and foot-and-mouth disease. Small populations of exotic fish are known to inhabit some NT waterways and the risk of further introductions will increase with greater human access to waterways (DRCRG 2004).

Contamination

Pesticides and fertilisers are used extensively in agricultural projects with in the Douglas Daly River catchment, as they are elsewhere in the NT. No information is available on the impact of these chemicals on wetlands or associated areas (Storrs and Finlayson 1997). Of concern to the Daly River and associated tributaries are insecticides recommended for use in the region. One such insecticide, endosulfan, has been shown to kill fish in low concentrations. The surfactants in certain herbicides have also been known to affect frogs (Price et al 2003). Runoff due to high rainfall can result in fertiliser and pesticide pollution of aquatic habitats (Price et al 2003). These chemicals can also filter into the groundwater in low concentrations (Price et al 2003). Pesticide drift from aerial spraying needs to be managed to reduce its potential impact on the environment (Price et al 2003).

Elevated nitrate concentrations have been reported in the lower reaches of the Douglas River during the dry season (Townsend et al 2002; Erskine et al 2003). Despite the circumstantial association with high land clearing in the catchment, the source of the elevated nitrate concentrations has not been confirmed. Some possible causes include pollution from septic tank leakage from a caravan park; nutrients originating from animal faeces such as bat droppings; seepage of nitrogen into the groundwater from current or past application of fertilisers; and growing of nitrogen-fixing legumes in agriculture (Schult & Metcalfe 2006). The issue of nutrient inputs to the Daly River catchment’s waterways, particularly the elevated nitrate concentrations, is described and assessed in detail in Chapter 4 (Section 4.4).

2.3.4 Assets – threats matrix

Table 2.11 represents the asset-threat matrix for the Daly River catchment, showing the situation for (i) the current status of the catchment (black ticks) and (ii) a potential status of the catchment based on a significant increase in (a) water resource development centred mainly around irrigated agriculture utilising ground and/or surface water (black plus red ticks). The future development 'scenario' was chosen given the strong interest in further developing both industries in the region (see Sections 2.3.2 and 2.3.3).

Table 2.11 Assets–threats matrix for the Daly River catchment based on (i) the current status in the catchment (black ticks) and (ii) the potential status given an increase in water resource development centred around irrigated agriculture utilising ground and/or surface water extraction (black plus red ticks).[1]

Assets (& key values)	**Threats**							
	G'water extraction	S'water extraction	Water impoundment	Land clearance/ loss of native vegetation cover	Invasive flora	Invasive fauna	Altered fire regime	Contamination
Waterways	✓	✓		✓	✓	✓	✓	✓
Freshwater discharge	✓	✓		✓			✓	
Perennial flow	✓	✓						
Habitat for riverine species	✓	✓		✓	✓		✓	✓
Water quality	✓	✓		✓	✓	✓	✓	✓
Wetlands	✓	✓		✓	✓	✓	✓	✓
Wildlife nurseries & habitat	✓	✓		✓	✓	✓	✓	✓
Erosion control/sediment retention	✓			✓	✓	✓	✓	
Water regulation				✓	✓	✓	✓	
Riparian vegetation	✓	✓		✓	✓	✓	✓	
Erosion control	✓	✓		✓	✓	✓	✓	
Habitat for wildlife	✓	✓		✓	✓	✓	✓	
Biodiversity	✓	✓		✓	✓	✓	✓	✓
Threatened species &conservation reserves	✓	✓		✓	✓	✓	✓	✓
Limestone & karst habitat	✓			✓				

[1] NB: an attribution of a threat to an asset/value does not imply that the threat is currently impacting the asset/value, but that, if sufficiently severe or prolonged, it has the potential to do so.

Based on the existing information on the Daly River, the greatest threats to the aquatic ecosystems at present appear to be land degradation/loss of native vegetation cover, exotic plant and animal species and poorly managed fire. Loss of native vegetation is largely due to grazing activities, and is considered a threat largely because grazing is by far the predominant land use in the catchment. Wetland, riparian and aquatic weeds and exotic animal species exist in the catchment and are already having, or have the potential to have, an impact on wetlands and waterways and associated species. Fire regimes are clearly influenced by human activities and the extent of exotic grasses within the catchment, and this may be resulting in impacts on aquatic ecosystems.

Agricultural development, and its associated clearance of land and extraction and potential contamination of surface and/or groundwater, does not yet pose a significant threat at the catchment scale (but does at the sub-catchment scale – see Chapter 4). However, this situation may change over the next 10-20 years, as pressure to develop agricultural enterprises in the region increases. At this stage, it appears unlikely that water resource development will be accompanied by the construction of dams, so water impoundments are unlikely to become a threat. Similarly, mining, whilst potentially expanding in the catchment does not appear as if it will result in catchment-scale threats.

The risks of the key pressures and threats to the aquatic ecosystems of the Daly River catchment are assessed in Chapter 3 and, for some, in further detail in Chapter 4.

2.4 Fitzroy River (Western Australia)

The Fitzroy River catchment covers an area of approximately 94 000 km^2 in the far west of the Northern Tropical Rivers study area (Figure 2.28), and is Western Australia's largest river in terms of average annual discharge. The long-term average discharge is approximately 6,150 GL, although the average since the 1960s is approximately 7000 GL (Ruprecht & Rogers 1998; Moliere 2008). The Fitzroy River is one of the largest unregulated rivers in Australia, but given its occasional high discharge, has long been identified as having the potential to supply quality water to not only the Kimberley, but also other parts of Australia (WA Department of the Premier and Cabinet 2006). In addition, the catchment has long been of interest for agricultural development (Storey et al 2001). However, more recently, there have been national and local calls to ensure the appropriate protection of the ecological and cultural values of the Fitzroy River (Cullen 2003; Hill et al 2006; WWF 2007).

There is considerable spatial variation in mean annual rainfall in the Fitzroy River catchment, with less than 400 mm pa in the catchment's south-east (Christmas Creek catchment) to about 900 mm pa in the north (Hann River catchment) (Storey et al 2001). Approximately 90% of the rainfall occurs between November and March, associated with monsoonal activity and occasional tropical cyclones.

Upstream of Fitzroy Crossing, which is located about halfway, or 300 km upstream on the Fitzroy River, the catchment consists predominantly of seasonally flowing streams. Downstream of Fitzroy Crossing, the river takes the form of a wide floodplain (Goh 1998), and the main channel has a more permanent flow, with only occasional zero flow periods. Flow in the river channel is maintained through the Dry season by drainage from the sandy floodplain alluvium (Environs Kimberley 2007; Moliere 2008). In dry years, the surface flow in the downstream reaches may cease, with the river developing into a series of disconnected pools and billabongs (Morgan et al 2002; A Storey, UWA, pers comm).

The information reported in this section was sourced from key literature on the Fitzroy River or Kimberley region, and complemented by a stakeholder consultation workshop held in Derby in February 2006 to reassess the existing information. The details of the workshop are reported in Bartolo (2006a).

2.4.1 Ecological assets

Considerable research on some of the key ecological assets and their associated values/functions has been undertaken (eg. fish, waterbirds), but information on others (eg. aquatic invertebrates, energy flows) is generally lacking. In the most comprehensive study,

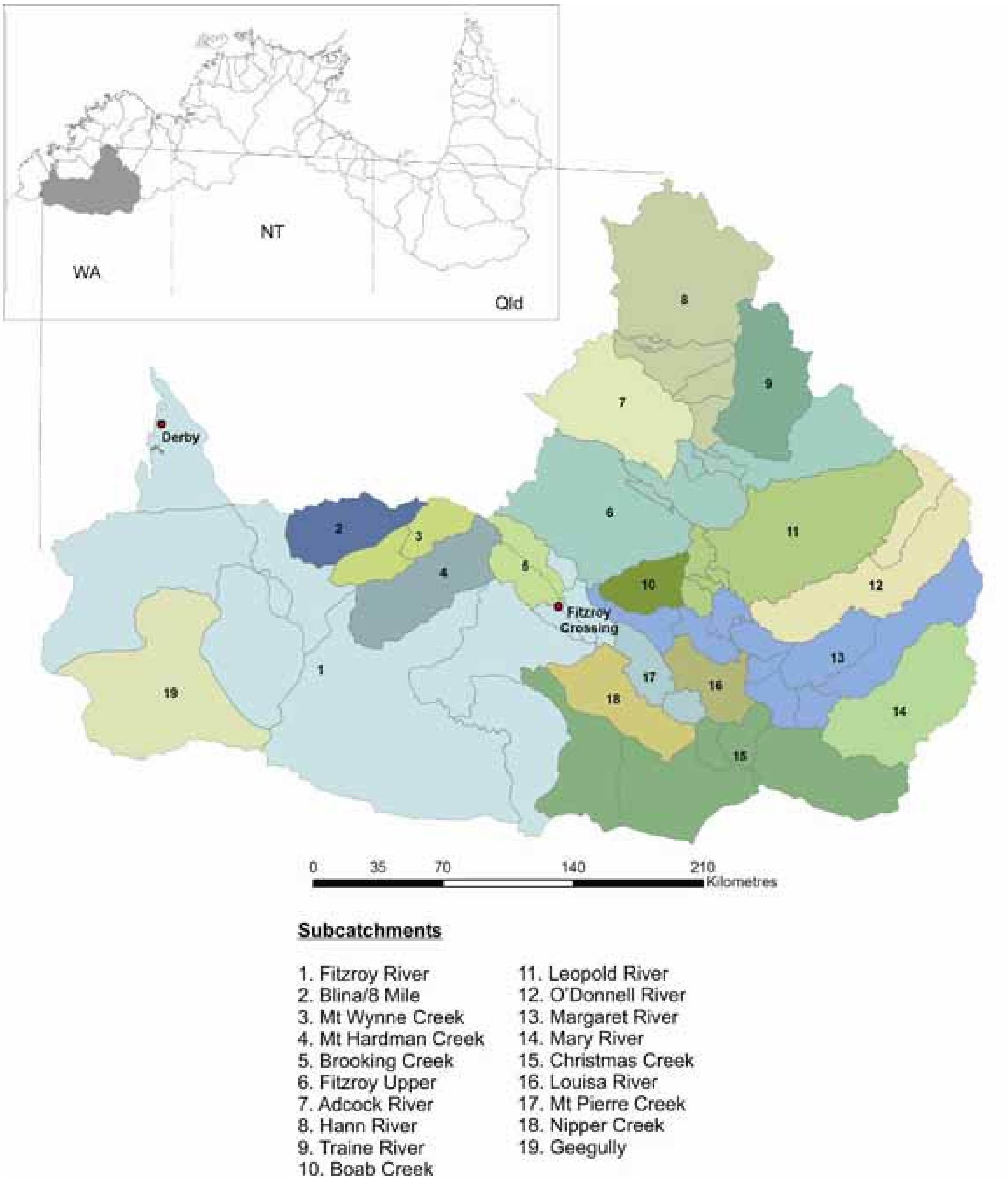


Figure 2.28 The Fitzroy River catchment.

Storey et al (2001) identified the ecological values of the Fitzroy River and its floodplain, concluding that they are of significant ecological value. It has also been emphasised that there is an inextricable relationship between the ecological and cultural values of the Fitzroy River (Storey et al 2001; Storey 2006). Additionally, Sutton (1998) described the natural environmental values of the Fitzroy River region, encompassing both terrestrial and aquatic ecosystems. Additional efforts have been undertaken in the Fitzroy River and broader Kimberley region to identify river values and ecosystem goods and services (Stoeckl et al 2006; Straton 2006). Although the emphasis was on socio-cultural values and economic valuation, much of the information documented by this work is highly related to this section. A summary of the ecological assets of the Fitzroy River is provided in Table 2.12.

Table 2.12 Summary of ecological assets and associated key values for the Fitzroy River.

Asset	Details
Waterways	8145 km of riverine length, representing 11 geomorphic types, dominated by anabranching (45%) and bedrock confined and constrained rivers (39%). ***Additional values:*** *Habitat for fish* – deep, permanent river pools act as dry season refugia for a high diversity of fishes, while gorge and tributary sites provide habitat for small and some rare species. *Freshwater discharge* – WA's highest discharge river, at ~7000 GL yr^{-1}; dependence of estuarine/ marine fisheries on river discharge. *Water quality* – high, seasonally variable water quality, although there are little data to enable a proper assessment; streams in the catchment's northern headwaters seem to be of lower ionic strength/alkalinity than those in the south of the catchment.
Wetlands	Extensive, generally intact wetlands, dominated by the Fitzroy River floodplain in the lower-mid reaches, with other wetland types including ephemeral swamps, lakes and lagoons, and permanent springs; three wetlands of national importance are listed in the catchment. ***Additional values:*** *Wildlife nurseries & habitat* – all wetlands provide critical dry season refugial habitat for waterbirds and aquatic species; during the wet season, the floodplain represents breeding and nursery habitat for waterbirds and aquatic species. *Erosion control/sediment retention* – despite previous degradation, the size and low gradient of the floodplain enables it to store and disperse flood flows, thereby minimising excessive/accelerated erosion and facilitating sediment/nutrient deposition. *Water regulation* – the floodplain has a large storage capacity, enabling it to regulate wet season flood flows and contribute to/prolong dry season base flow and groundwater recharge.
Riparian vegetation	Generally intact fringing riparian vegetation, with *Eucalyptus camaldulensis* and *Melaleuca* spp. predominant among at least five vegetation associations. Other riparian habitats, mainly associated with the floodplain, have been degraded due to historical over-grazing. ***Additional values:*** *Erosion control* – intact fringing riparian vegetation minimises excessive/ accelerated bank erosion, and captures erosion from terrestrial habitats. *Habitat for wildlife* – thought to be valuable as wildlife corridors and supporting a high diversity of native animals, but overall, little is known.
Biodiversity	Aquatic biodiversity appears to be high, although only a few taxa groups have been well studied; approximately 40 species of freshwater and estuarine/marine fish, with freshwater fish diversity very high by WA standards; at least 68 species of waterbird, with numbers at key sites sometimes >20 000, fulfilling Ramsar criteria. Also supports JAMBA/CAMBA species and Freckled Ducks (WA Priority species). *Endemism* – high endemism amongst the fish, similar to the rest of the Kimberley; at least 2 fish species endemic to the Fitzroy River, while another 16 endemic to the Kimberley.
Threatened species	Numerous EPBC and/or IUCN-listed aquatic/semi-aquatic species, including freshwater sawfish, dwarf sawfish, northern river shark, freshwater whipray, Barnett River gudgeon and purple-crowned fairy wren.

Waterways

The waterways, or riverine systems, of the Fitzroy River catchment are mostly unregulated and undamaged (Storey et al 2001). The catchment consists of 19 sub-catchments (see Figure 2.28). The upper catchment is divided into the two main sub-catchments of the Fitzroy and Margaret Rivers. The main tributaries of the upper Fitzroy River include the Hann, Adcock, Louisa and Little Fitzroy Rivers, while those of the Margaret River include the Mary, Leopold, O'Donnell, Gidden, Little Gold and Laura Rivers (Ruprecht & Rogers 1998). The upper tributaries drain mainly rocky country in the north and east of the upper catchment and contain numerous gorges (Environs Kimberley 2007). The main tributaries of the river below Fitzroy Crossing are Christmas, Mt Hardman, Mt Wynne and Geegully Creeks (Ruprecht & Rogers 1998). The lower catchment is not confined by bedrock, and is dominated by the expansive Fitzroy floodplain (Environs Kimberley 2007).

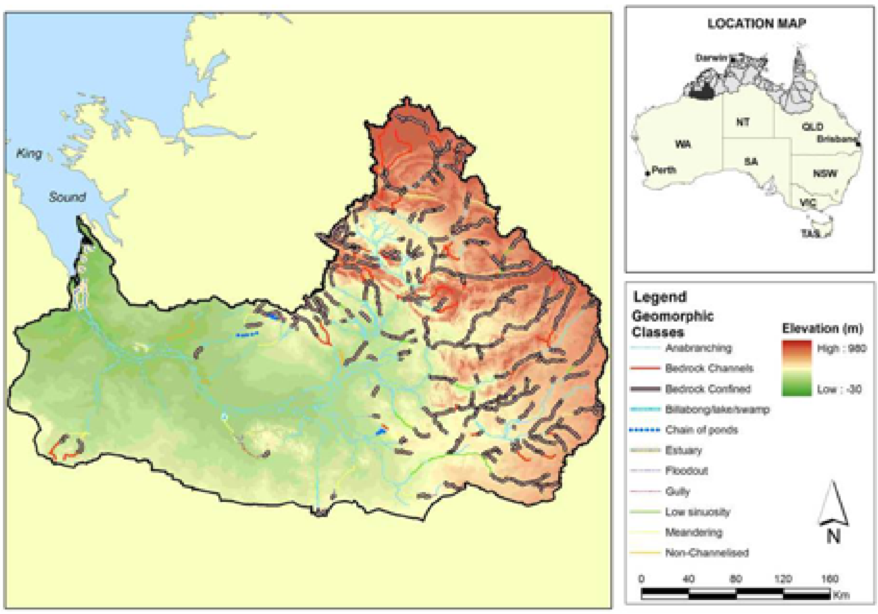


Figure 2.29 The waterways, and their geomorphology, of the Fitzroy River catchment (from Saynor et al 2008).

Based on the channels classified as '*named or major*' on the 1:250 000 drainage dataset produced by Geoscience Australia, there is approximately 8145 km of riverine length in the catchment (Figure 2.29; Saynor et al 2008). The geomorphology of the river reaches was classified and described in detail by Taylor (2000) and more recently, using the Northern Tropical Rivers study area classification, by Saynor et al (2008). Based on the classification by Saynor et al (2008), 11 geomorphic types are represented in the Fitzroy River catchment, with anabranching rivers (45%) and bedrock confined and constrained rivers (39%) dominating. Five of the geomorphic types (chain of ponds; gully; floodout; lakes, swamps and billabongs; and non-channelised valley floors) represent less than 3% of the river length (Saynor et al 2008). As indicated above, anabranching rivers, splitting and rejoining around large alluvial islands, dominate in the floodplain of the lower catchment and are also common in the southern part of the upper catchment, while bedrock and bedrock confined and constrained rivers dominate in the northern part of the upper catchment (Sutton 1998; Saynor et al 2008). Deep permanent pools occur along the whole length of the main lower Fitzroy

River channel, separated by shallower reaches that display braided planforms with large sand bars and midchannel islands (Taylor 1998). The main channel varies in width from ~70 m in pool sections to >500 m in braided sections (Storey et al 2001).

The Fitzroy River estuary extends approximately only 40 km upstream from the river's mouth at King Sound. A detailed summary of the geomorphology and ecology of the Fitzroy River estuary was provided by Storey et al (2001), and is not addressed here. Additional key values of the waterways of the Fitzroy River catchment are described below.

Habitat for fish

The river itself represents an extremely important habitat for fish species, with the large deep pools in particular acting as dry season refugia and containing a high diversity of fishes, including some rare or threatened species (also see below; Storey et al 2001; Morgan et al 2002). Key species include the freshwater sawfish (*P. microdon*), dwarf sawfish (*P. clavata*) and freshwater whipray (*H. chaophraya*) (Morgan et al 2002; Thorburn et al 2004a, b). The river pools are of high cultural importance, with traditional owners referring to them as 'living water' (Storey et al 2001; Storey 2006). Gorge and tributary sites typically provide habitat for smaller freshwater species (eg. western rainbowfish, spangled perch, glassfish, barred grunter, bony bream), including the rarer species such as the Barnett River (*H. kimberleyensis*) and false-spotted (*Mogurnda oligolepis*) gudgeons (Sutton 1998; Morgan et al 2002).

Freshwater discharge

As reported above, the Fitzroy River has the highest discharge of any river in WA. According to Ruprecht & Rogers (1998), the long-term average discharge is approximately 6150 GL, with the average since 1968 being closer to 7000 GL. Based on a long-term gauging station dataset containing 24 years of complete data between 1957 and 2003, Moliere (2008) calculated the mean annual discharge at Fitzroy Crossing (GS802055) as being almost 7700 GL. Unfortunately, due to the brevity of the record period (~8 years), they did not calculate a mean annual discharge for the downstream-most gauging station at Willare (GS802008). Approximately 90% of the annual streamflow occurs between January and March (Ruprecht & Rogers 1998; Moliere 2008). Peak flood flows of approximately 30 000 cubic metres per second have been recorded, and the river has flooded in 20 of the last 30 years. The largest recorded flood (in 1983) is estimated as having a 25 year recurrence interval (A Storey, UWA, pers comm).

Although there is little information on it, the freshwater discharge of the Fitzroy River is likely to play an important role in productivity in King Sound, as has been documented for other large river systems elsewhere in Northern Australia (eg. Flinders River, Qld; Staples & Vance 1987; Department of Natural Resources Mines and Energy 2004).

Water quality

There is little published literature on the water quality of the Fitzroy River. Moreover, Butler (2008) concluded that existing WA Government water quality monitoring data for the Fitzroy River, whilst available for 17 sites, were insufficient to properly analyse spatial and temporal (seasonal) water quality characteristics.

Ruprecht & Rogers (1998) provided a very broad overview of salinity and turbidity. The salinity of the Fitzroy River is very low, although may be elevated in pools which persist late into the dry season. The salinity ranges from ~0.07–0.7 ppt in the lower rainfall (<600 mm/year) catchments and ~0.03–0.5 ppt in the higher rainfall catchments (>600 mm/year) (Ruprecht & Rogers 1998). During the dry season, large tides connect the upper estuary with freshwater pools in the lower Fitzroy River (Thorburn et al 2004), increasing their salinity.

Turbidity in the Fitzroy River and its tributaries is seasonally affected, being high during peak flows in the wet season and low during the dry season. The turbidity of the streams in the southern portion of the Fitzroy catchment appears to be higher than that in the north, with turbidities in excess of 1000 NTU recorded (Ruprecht & Rogers 1998). This may be due, in part, to (i) greater grazing pressures in the southern catchments (see Sections 2.4.2 and 2.4.3), and (ii) the northern catchments being predominantly ‘hard rock’ and less erodable.

Water physico-chemical data collected as part of the AusRivAS program in the Fitzroy River provides some indication of water quality. River/creek electrical conductivity (EC) and alkalinity range from ~30–800 µS/cm and ~10–250 mg/L $CaCO_3$, respectively. Waters arising from springs can have high ECs (600–800 µS/cm) and alkalinity (~400 mg/L $CaCO_3$). Although data are limited, streams in the headwaters of the Fitzroy River, such as the Hann River, appear to have the lowest EC (~40 µS/cm) and alkalinity (~10 mg/L $CaCO_3$), which corresponds to the sandstone geology of the northern-most part of the Fitzroy catchment.

Wetlands

Recently, Vernes (2007) compiled existing information on wetlands in the Kimberley, including the Fitzroy River, to highlight the knowledge base and the information gaps. The floodplains of the lower Fitzroy River are probably the most dominant wetland type, with other types including swamps, lakes and lagoons, most of which are ephemeral. Permanent freshwater springs are also known to occur. Based on the GEODATA TOPO 250K Series 3 waterbodies layer, the area of wetlands in the entire Fitzroy River catchment is approximately 655 900 ha (Figure 2.30). However, according to Vernes (2007), apart from the well known and extensive Camballin black soil floodplain wetlands (ie. Le Lievre and Moulamen swamps), few other individual or aggregate swamps are noted in the literature. Although not specific to the Fitzroy River catchment, there is a very strong connection between the ecological and cultural values of the wetlands, and Storey et al (2001) and Storey (2006) noted that pressures on wetlands would threaten both sets of values.

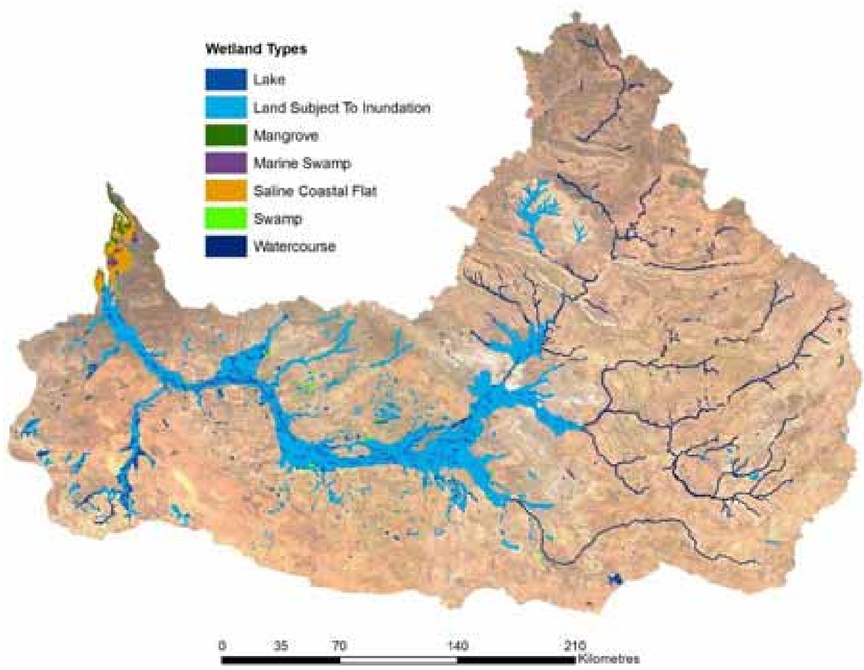


Figure 2.30 The wetlands of the Fitzroy River catchment. (Source: GEODATA TOPO 250K Series 3-Waterbodies layer, Geoscience Australia). Features include Lake, Land Subject to Inundation, Mangrove, Marine Swamp, Saline Coastal Flat , Swamp and Watercourse.

The Fitzroy River floodplain lies downstream of Fitzroy Crossing, and extends some 300 km to the coast (Sutton 1998; Morgan et al 2002). Apart from the Camballin wetlands, the floodplain is most extensive north of Noonkanbah, approximately 100 km upstream and downstream of Camballin and Fitzroy Crossing, respectively (Sutton 1998). Also between Camballin and Fitzroy Crossing, there exist a large number of small wetlands on the floodplain, which hold water for short periods after flooding and provide important habitat for waterbirds and other species during these periods (Sutton 1998). Wet season runoff produces a high frequency of floodplain inundation, with substantial parts of the floodplain being inundated on average every second year, and some degree of river flooding every year (Storey et al 2001).

Mound springs are known to occur in the south-west of the catchment, around the headwaters of Geegully Creek (Storey et al 2001; Vernes 2007). The springs are most likely important for remnant flora and aquatic fauna, but have been little studied. The wetlands upstream of Fitzroy Crossing are generally ephemeral, however, permanent pools exist in the various gorges within the Kimberley plateau.

The Fitzroy River has three wetlands listed as nationally important (Lane et al 2001). These are the Camballin floodplain (or Le Lievre Swamp System), Geikie Gorge and Gladstone Lake. The Camballin floodplain comprises Le Lievre Swamp, 17 Mile Dam, Moulamen Swamp, Snake Creek (billabong) and numerous unnamed seasonal wetlands (Department of the Environment and Water Resources 2007), and constitutes significant waterbird habitat, with at least 67 species recorded and bird numbers often in excess of 20 000 (Halse & Jaensch 1998). The Camballin floodplain system of wetlands is described in more detail by Sutton (1998). Both Geikie Gorge and Gladstone Lake lie in the upper Fitzroy catchment. Geikie Gorge constitutes a 13 km long, 100 m wide permanent gorge pool on the Fitzroy River, approximately 30 km upstream of Fitzroy Crossing, and represents a major drought refuge area for freshwater fishes and marine fishes that occur well inland in the Fitzroy River system (Department of the Environment and Water Resources 2007). Gladstone Lake, located in the Hann River catchment, constitutes the largest permanent freshwater wetland in the Central Kimberley and is an important refuge area for waterbirds and other fauna (Department of the Environment and Water Resources 2007; Vernes 2007). There are no Ramsar listed wetlands in the Fitzroy River catchment, although the Camballin floodplain has been assessed as meeting the Ramsar criteria (Halse & Jaensch 1998).

Wildlife nurseries and habitats

The wetlands of the Fitzroy River are known to provide critical habitat, particularly refugial habitat for wildlife, although less is known about the extent and importance of nursery habitat. Moreover, Sutton (1998) highlighted that much ecological information relating to the requirements for, and use of, the floodplain for feeding, breeding and nursery habitat by aquatic biota (eg. frequency, extent, duration of floodplain inundation, nutrient dispersal, habitat maintenance) is unknown.

The Camballin floodplain is known to be an area that provides important breeding and general habitat for magpie geese and other waterbird species (Halse & Jaensch 1998; Storey et al 2001; Department of the Environment and Water Resources 2007). Halse & Jaensch (1998) identified a range of wetland habitats in the Fitzroy catchment as being important for waterbirds and other vertebrate species, including: vine thickets and mudflats near the river mouth; small seasonal floodplain wetlands/aggregations, particularly between Camballin and Fitzroy Crossing; large floodplain wetlands at Camballin and Noonkanbah; and permanent billabongs and pools along the river channel. The importance of the permanent billabongs and pools as fish habitat has been detailed above for the riverine habitat. Additionally, the many permanent pools/springs in the catchment also act as refugia for remnant populations of plants and animals from earlier, wetter, geological times. The key ecological reason for the listing of the aforementioned three wetlands of national importance is their significance in terms of providing habitat for wildlife, particularly for birds and fish during the dry season (Department of the Environment and Water Resources 2007). During the wet season, the floodplain environment of the lower Fitzroy is important not only as spawning grounds for many of the river's fish species, but also acts as a nursery ground for many of the freshwater species (Morgan et al 2002).

Erosion control/sediment retention

Water dependent ecosystems such as springs, marshes and floodplains support a diversity of sedges and herbs that function to stabilize the sediment and provide habitat for fauna (IKNRMG 2004). According to Taylor (1998; 2000), despite previous degradation of the Fitzroy River floodplain due to pastoral activities, evidence suggests that the floodplain is aggrading, probably due to a combination of a recent increase in flood frequency and improved rangeland management techniques. The length (~300 km), width (5–25 km) and extremely low gradient (0.0003 m) of the floodplain (Taylor 1998) facilitate its capacity to store and disperse flood flows and reduce flood flow velocity, thereby minimizing excessive erosion and facilitating sediment and nutrient deposition and soil and groundwater recharge.

Water regulation

Little has been recorded regarding the role of the Fitzroy River's wetlands in regulating river water regimes and flow throughout the year. As briefly described above, the floodplain provides the river with significant storage capacity below Fitzroy Crossing (Storey et al 2001). This acts to regulate flood flows during the wet season, but is also likely to contribute to base flow in the lower Fitzroy River during the dry season. Freshwater springs are known to occur throughout the Fitzroy catchment (Storey et al 2001; Vernes 2007), however, their role in contributing to base flow or the presence of water is unclear.

Riparian vegetation

As primary producers, riparian plants represent the foundation of in-stream food webs based on riparian inputs (ie. nutrients – N, P, C), and also provide shade, habitat and control erosion (Froend et al 1998). Riparian vegetation in the Fitzroy River catchment covers an area of approximately 8410 km^2 (Figure 2.31) based on the records deemed to be riparian extracted from the Western Australia National Vegetation Information System 2007 [NVIS] data produced by the WA Department of Agriculture and Food. This areal extent (and associated Figure 2.31) are based on the best available data at this time. It should be noted that the data are not purpose built to extract the information required to assess riparian extent.

The riparian vegetation of the Fitzroy River has been characterised to some extent, although there are still major gaps in knowledge, particularly the number and types of priority riparian taxa (Froend et al 1998; Sutton 1998; Storey et al 2001). In an attempt to partially address this problem, Storey et al (2001) described in some detail the riparian vegetation communities at 20 sites throughout the Fitzroy catchment. Fringing riparian vegetation in the upper Fitzroy River is dominated by *Eucalyptus camaldulensis*, with *Terminalia platyphylla* along the main channels. Other species associated with this riparian zone include *Melaleuca argentea*, *Melaleuca leucadendra*, *Ficus coronulata*, *Ficus racemosa*, *Lomphostemon grandiflorus* (formerly *L. suaveolens*), *Nauclea adunatus*, *Andersonia gregorii* and *Eucalyptus polycarpus*. The levee crests, which are often 1 km wide, are dominated by *Eucalyptus papuana*, while the levee back slope areas are dominated by *Eucalyptus microtheca* (Froend et al 1998). Grasses and sedges are dominant in the understorey and in some swamps form the principal cover when trees and shrubs are absent (Storey et al 2001). The floodplain supports an array of vegetation associations. The levee back slopes are populated by scattered *Lysiphyllum cunninghamii* and *Eucalyptus microtheca* (Froend et al 1998; Storey et al 2001). *E. camaldulensis* and *T. platyphylla* occur along the main channels, while many smaller tree species such as *Melaleuca* spp., *L. cunninghamii, Acacia* spp, *Brachychiton* spp, *Planchonia careya* and *Pandanus* spp. exist to form a dense fringe to the channel (Storey et al 2001). Several riparian or aquatic plant species are listed as Priority Species on the CALM Declared Rare and Priority List, including *Acacia gloeotricha*, *Nymphoides beaglesnsis* and *Fimbristylis sieberiana* (Sutton 1998; Storey et al 2001).

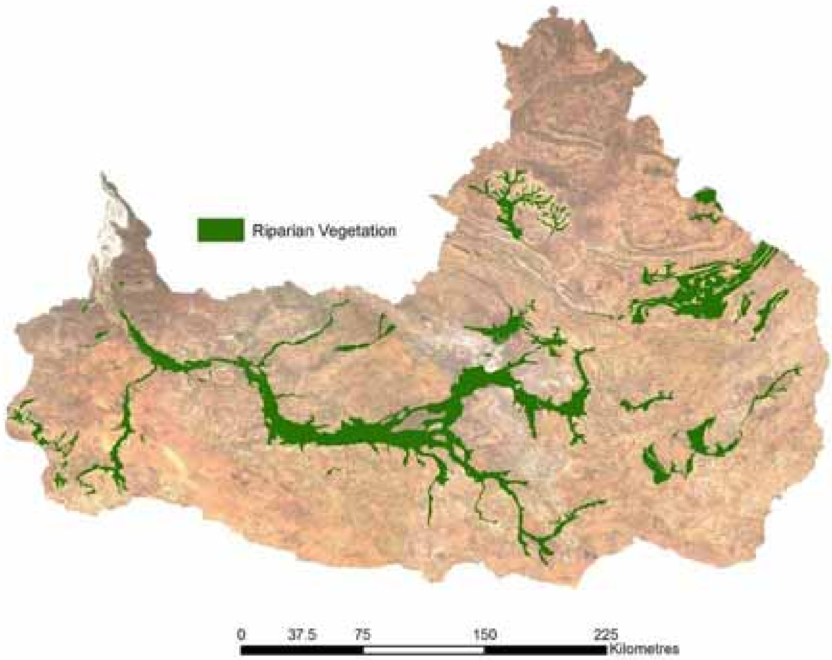


Figure 2.31 The extent of riparian vegetation in the Fitzroy River catchment. (Source: Records deemed to be riparian were extracted from the Western Australia National Vegetation Information System 2007 [NVIS] data produced by the WA Department of Agriculture and Food)

Dowe (2008) attempted to classify and describe the riparian zones of the Northern Tropical Rivers study area. Five Riparian Vegetation Associations based on elevation were recognised for the Fitzroy River. *E. camaldulensis* and *Melaleuca* spp. were predominant throughout the five associations with *Corymbia bella* and *L. grandiflorus* each present in two of the associations. However, when ground-truthed in the Flinders River (Qld – see Section 2.5), the classification scheme was shown to have a prediction accuracy of less than 60%.

Following a field survey in 2000, Storey et al (2001) noted the following about the riparian vegetation of the Fitzroy River:

- The riparian vegetation is in good health, as determined by vigour, disturbance, weediness, diversity and population structure;
- Weediness on the river banks and through most of the riparian zone is low, although there were exceptions to this where livestock have access (high stocking rates only) or where the flow regime had been altered (eg. Camballin); and

- Livestock disturbance is less than expected. Although stock have access to most of the river, severe physical disturbance of the river banks and trampling of the riparian vegetation was the exception.

This assessment of the status of the fringing riparian vegetation is in contrast to previous reports of rangeland, levee and floodplain condition. Froend et al (1998) summarised the findings of WA Department of Agriculture surveys in 1981. Over 50% of the area of levee crests and backslopes were classed as moderately or severely degraded, while 59% of the area was classed as bad range condition. Whilst the riparian zone appears generally in good condition relative to the adjacent terrestrial habitats, Storey et al (2001) did note numerous sites where riparian vegetation was damaged and erosion and/or weed invasion were occurring, due mostly to livestock (and possibly feral animal) access to the stream channel.

Unlike the research on the Daly River riparian vegetation water requirements (see Section 2.3.1), there appears to be little if any information available on the water requirements of the riparian vegetation of the Fitzroy River. Froend et al (1998) recognised that any assessment of the impact of altered flow regimes should include the identification of the water requirements of the riparian vegetation, and listed numerous characteristics that should be considered. Storey et al (2001) identified many attributes of riparian vegetation that will be affected by altered flow regimes/river regulation, and discussed in some detail how riparian communities of the Fitzroy River might be impacted. This is further discussed in Sections 2.4.2 and 2.4.3.

Erosion control

As described above, studies suggest that the riparian vegetation of the Fitzroy is relatively intact and healthy when assessed using criteria such as vigour, disturbance, weediness, diversity and population structure (Storey et al 2001). This will minimise the extent of bank degradation but, as Storey et al (2001) noted, the natural hydrological regime of the Fitzroy River is one that results in naturally high levels of riparian disturbance that results in a continuous process of erosion and deposition. Nevertheless, the relatively healthy state of the Fitzroy River riparian vegetation is likely to protect against excessive/accelerated bank erosion.

Interestingly, the bank stabilisation properties of riparian vegetation have been identified as a potential problem if the Fitzroy River hydrological regime was regulated through impoundment. In addition to continuing channel encroachment through sedimentation processes, bank/sediment stabilisation by riparian vegetation would have a long term impact on the area of available in-stream habitat due to the reduction or loss of deeper pools, bank undercuts, backwaters and available snags (Storey et al 2001).

Habitat for wildlife

For the Kimberley region, riparian zones are reported to be valuable as wildlife corridors and habitats, and are known to support an outstanding diversity of native animals (IKNRMG 2004; RNRMCG 2005). Little is documented, however, on the role of riparian zones in the Fitzroy River catchment in providing habitat for wildlife. According to Halse & Jaensch (1998), the permanent pools and billabongs of the Fitzroy River support rich terrestrial animal communities because of the availability of water and the associated dense riparian vegetation. In addition, some predominantly riparian-dwelling species have been documented as occurring in the Fitzroy catchment, including the yellow-spotted monitor (*Varanus panoptes*; Fox 2008) and the purple-crowned fairy-wren (*M. coronatus coronatus*; Storey et al 2001), the latter species being listed as “Threatened” under the Western Australian Wildlife Conservation Act (Storey et al 2001).

Biodiversity

The wetlands within the Kimberley region are important ecosystems that provide many values, such as wildlife corridors, rare habitats, breeding areas, drought refuge, threatened species and high diversity (RNRMCG 2005). Given the monsoonal nature of rainfall in this area, waterholes, river pools, marshes and cave systems support, and are in fact crucial to, the survival of many mammals, birds, fish, reptiles, amphibians and invertebrates (IKNRMG 2004; RNRMCG 2005). Whilst these values and functions are relevant to the broader Kimberley region, they are all applicable to the Fitzroy River. However, unlike the Daly River (ie. Price et al 2003; Blanch et al 2005), to date, there has been no full synthesis of the known biodiversity of the Fitzroy River.

The fish communities are probably the most comprehensively studied fauna group of the Fitzroy River, both in terms of their biodiversity and threatened or important species. Storey et al (2001) reported that 35 fish species from 21 families were recorded from the Fitzroy River alone. Subsequent surveys have identified additional species, such that the known species found in the non-tidal freshwaters of the Fitzroy River can be put at 40 species (24 freshwater and 16 marine/estuarine; Morgan et al 2002). According to Morgan et al (2002), the freshwater fish diversity (24 species) is very high by WA standards, being around 3–4 times higher than recorded for all rivers of the Pilbara region (10 species) and south-west regions (12 species) combined. The high diversity may be both a factor of the large catchment size and the high degree of variable habitats, particularly when comparing the main channel, billabongs and creek systems of the floodplain to the high relief gorge and waterfall country in the headwaters (Morgan et al 2002).

As reported above, the Fitzroy River catchment, or at least numerous specific areas within it, harbours relatively high waterbird diversity and numbers. According to survey data from 1986 to 1983 summarised by Storey et al (2001), 68 waterbird species have been recorded in the Fitzroy River catchment. The Camballin floodplain represents the most important waterbird habitat by far, with 67 species recorded from this location, and total waterbird numbers often in excess of 20 000 (Halse & Jaensch 1998; Storey et al 2001). In terms of abundance, key species included magpie goose, plumed whistling duck, wandering whistling duck, grey teal and glossy ibis.

Based on very limited datasets, Fox (2008) reported 10 species of aquatic/semi-aquatic reptiles as being recorded from the Fitzroy River. These included freshwater crocodile (*C. johnstoni*), three species of turtle (*Chelodina rugosa*, *Emydura australis*, *Emydura victoriae*), three species of monitor (*V. mertensi*, *Varanus mitchelli*, *V. panoptes*), and three species of colubrid snake (*Fordonia leucobalia*, *Myron richardsonii*, *Stegonotus cucullatus*). Estuarine crocodiles (*C. porosus*) may also enter the lower Fitzroy River, although according to Thorburn et al (2004), this species rarely penetrates upstream beyond the estuary. Based on a nationally collated fauna database (OZCAM; accessed in 2006), there are 25 native frog species recorded for the Fitzroy River. Given that there are 31 native frog species recorded for the Daly River, where there has been more intense survey effort, it is quite likely that the figure for the Fitzroy River is an underestimate.

Stygofauna are also considered an important aquatic community. Although few surveys have been conducted, Sutton (1998) considered the occurrence of a diverse and unique stygofauna in karst, sediments, groundwater and wetlands of the Fitzroy River as highly likely. Studies have revealed pockets of endemism amongst the stygofauna in karst of the Devonian Reef system, between Geikie Gorge and Fitzroy Crossing (Sutton 1998).

Endemism

The fish communities of the Fitzroy River support a high degree of endemism. At least two species are thought to be endemic to the Fitzroy River (ie. Greenway's grunter, *H. greenwayi*; Barnett River gudgeon, *H. kimberleyensis*), while an additional 16 are endemic to the Kimberley. Storey et al (2001) listed the hardyhead, *C. lentiginosus*, as being thought to be endemic to the Fitzroy River, however, this species was subsequently recorded elsewhere in the Kimberley (Allen et al 2002). Sutton (1998) suggested that the largely unknown stygofauna and aquatic macroinvertebrate communities of the region are also thought to support many endemic species. Whilst this may be true for stygofauna, it is unlikely to be the case for macroinvertebrates, which tend to be reasonably cosmopolitan across the Northern Tropical Rivers (Humphrey 2008; A Storey, UWA, pers comm). However, endemism among aquatic crustaceans, such as shrimps and isopods, is known to occur in rocky escarpment habitats elsewhere in the Northern Tropical Rivers study area (eg. north-western Arnhem Land; Finlayson et al 2006). Similarly, according to IKNRMG (2004), some groups of species of isopods, ostracods, snails and other aquatic invertebrates can be endemic to one group of springs. However, there appears little specific data and knowledge on endemic aquatic invertebrates in the Kimberley, including the Fitzroy River. Unfortunately, the majority of aquatic invertebrate data for the region are at the Family, not species, level, greatly limiting assessments of conservation status in terms of endemicity and species rarity (Storey et al 2001).

The high endemicity of the Kimberley is thought to be a consequence of the rugged topography, diverse habitats and high rainfall that have acted as isolating mechanisms and have thus enhanced speciation (Allen and Leggett 1990 as cited by Morgan et al 2002). According to Storey et al (2001), despite the high levels of endemism, the fish fauna of the Fitzroy River and many other Kimberley rivers, remains the most poorly documented and least understood of Australia's freshwater fishes. This has been addressed to some extent since, however, the statement almost certainly holds true for many other fauna groups also.

Threatened species

Aquatic and semi-aquatic species known for the Fitzroy River that are listed as Threatened or Endangered (or equivalent) under Commonwealth legislation are listed in Table 2.13. It is noteworthy that no aquatic or semi-aquatic species recorded for the Fitzroy River catchment have been identified as "rare or likely to become extinct" under the Western Australian Wildlife Conservation Act 1950 (WA Government 2006). This Act does, however, list the burdekin duck (*Tadorna radjah*) and freshwater (*C. johnstoni*) and saltwater (*C. porosus*) crocodiles as "Other specially protected fauna". RNRMCG (2005) noted that particular water dependent ecosystems are valuable as habitat for threatened species. For example, riparian vegetation along the Fitzroy River is recognised as a stronghold for the purple-crowned fairy-wren (*M. coronatus coronatus*), a threatened species under WA legislation (Storey et al 2001). In addition, the Fitzroy River channel and its associated permanent pools are considered important habitat for immature freshwater sawfish (*P. microdon*; Thorburn et al 2004a). The northern river shark (*Glyphis* sp. C), which is known from the Fitzroy River estuary (ie. King Sound), has not as yet been encountered in the freshwater reaches of the Fitzroy River (Thorburn et al 2004b).

According to Morgan et al 2005, the Fitzroy River houses a number of fishes that are also listed as threatened by the IUCN, including the Freshwater whipray (*H. chaophraya*; Vulnerable), Dwarf Sawfish (*Pristis clavata*; Endangered), *Glyphis* sp. C (Critically Endangered), *P. microdon* (Endangered), *H. greenwayi* (Data Deficient) and *H. kimberleyensis* (Near Threatened/Lower Risk) (Morgan et al 2005).

Table 2.13 Aquatic or semi-aquatic species recorded in the Fitzroy River catchment that are Listed as Vulnerable or Endangered under the EPBC Act 1999.

Common Name	Scientific Name	Status	Comments
Freshwater Sawfish	*Pristis microdon*	Listed as Vulnerable under the EPBC Act 1999.	The largest freshwater fish in Australia growing to at least 280 cm. Vulnerable to gillnet fishing and harvest for fins.
Northern River Shark	*Glyphis sp. C*	Listed as Endangered under the EPBC Act 1999.	Thought to have very specific habitat preferences and low fecundity, making it extremely vulnerable to exploitation (eg. gillnetting and long lining, and also habitat degradation).
Purple-crowned Fairy-wren (western)[1]	*Malurus coronatus coronatus*	Listed as Vulnerable under the EPBC Act 1999.	Major threats are habitat loss due to livestock grazing and frequent burning.
Australian Painted Snipe	*Rostratula australis*	Listed as Vulnerable under the EPBC Act 1999.	Major threat to the species in the Kimberley region is from overgrazing.

1 Whilst not an aquatic or semi-aquatic species, the purple-crowned fairy-wren is very closely associated with dense riparian vegetation of permanent rivers and springs.

2.4.2 Pressures

Horticulture

At present, horticulture is not a major industry in the Fitzroy River catchment. According to the Kimberley Development Commission (2006), a small horticulture industry operates near Broome and Derby, and produces mangoes, melons, bananas and sweet potatoes. Plans to expand the current industry in the west Kimberley are being considered. Expansion of horticulture in the region has been proposed, however, water availability may limit the extent to which this can occur (Broome Planning Steering Committee 2005). If horticulture was to develop, groundwater resources in the Fitzroy Basin may well be seen as a potential, reliable source of water.

Pastoralism

In terms of area, pastoralism is by far the major land use in the Fitzroy River catchment, and along with the Ord catchment, the Fitzroy River forms a key centre of pastoral activity within the Kimberley region. Based on the *Land Use in Western Australia* data (1997), grazing activities in the Fitzroy River catchment occupy approximately 89 403 km^2, or 95% of the catchment (Figure 2.32).

The Rangeland Management Branch of the Division of Resource Management (1981) detailed the state of land degradation in the Fitzroy River Valley as a result of pastoral activities. Pastoral activities commenced in the Fitzroy River catchment in the 1880s. According to KWRDO (1993, as cited by Lindsay & Commander 2006), sheep numbers peaked in the West Kimberley at 307 000 head in 1941, and cattle at 812 000 in 1970. Up to the 1950s, the lack of available water away from the river meant that stock was concentrated along the river frontages, which included the riparian fringe and levee back slopes and backplains of the floodplains. This resulted in excessive grazing and trampling of the river frontage vegetation, particularly the levee crests and levee back slopes, to the point that, by 1980, these areas had still not recovered. However, other land/vegetation types within the frontages, including the riparian fringe, apparently did not show any significant deterioration. The general intactness of the riparian fringe was further verified by Storey et al (2001), who found this community to be in comparatively good condition. The degraded conditions elsewhere in the river frontages are further reflected by the fact that the *Australia-Wide Assessment of River Health* classified the Fitzroy River catchment as 'significantly impaired', due mostly to the impacts of grazing (Halse et al 2002). Nevertheless, according to the Australian Natural Heritage Database (2007) the condition of the river frontage and the wetlands has improved greatly in the last 20 years due to reduced cattle numbers and improved regional pastoral management.

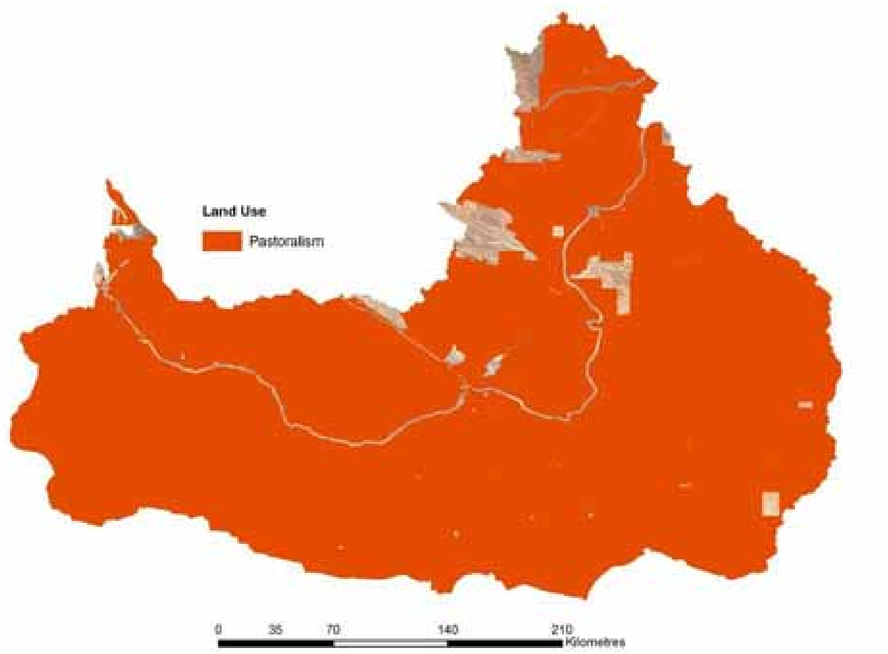


Figure 2.32 Pastoral land use in the Fitzroy River catchment. (Data source: *Land Use in Western Australia* (1997)). Note that pastoral areas have been mapped at the secondary class level and includes grazing natural vegetation.

Bartolo (2006a) noted some concerns amongst pastoral stakeholders in the Fitzroy River catchment that not all pastoral properties use fencing to prevent stock from accessing the river and its riparian fringes, although it was acknowledged that the current management is far better than in the 1960s when stock numbers were far higher and were less controlled. The erosion caused by excessive grazing and trampling has exacerbated weed infestation, particularly noogoora burr (*X. occidentale*) and rubber vine (*C. grandiflora*) (Bartolo 2006a). Unrestricted stock access to pools within waterways and wetlands causes environmental disturbance through the loss of natural fringing vegetation, weed invasion, compacted soils, erosion and poor water quality (WA Department of Water 2006). Additionally, faecal material builds up in natural waters causing nutrient enrichment, potentially leading to algal blooms that may be toxic to stock and aquatic biota (WA Department of Water 2006).

Crop production

Irrigated cropping has occurred historically in the Fitzroy River catchment, albeit mostly unsuccessfully, near Derby in the early 1920s (Yeates 2001), and on a relatively large scale at Camballin from the 1950s to 1980s. At the time of development, the Camballin Irrigation Project was the first large scale rice growing area in WA and second only in size to the Murrumbidgee Irrigation Area in New South Wales (Yuhun 1989). To provide water supply for irrigation, the Camballin weir (also known as the Fitzroy barrage) and the Seventeen Mile Dam were constructed in the late 1950s, while various additional water control infrastructure (eg. canals, levees) were constructed up until 1980 (Yuhun 1989). The two major crops were rice and sorghum, with a maximum area under cultivation of 20-30 km^2, while others such as legumes, oats and cotton were trialled but never commercially cropped (Yuhun 1989: Storey et al 2001). During the period of operation, crops and infrastructure, including water control structures, were regularly damaged or destroyed by flooding. The project ceased in 1983 after a major flood breached levees and destroyed the largest, intensive grain sorghum operation ever undertaken in the West Kimberley. Ultimately, the project's long-term failure was due to numerous problems including regular flooding, poor pest control/management (of birds and insect pests), unreliable water supply during the dry season, remoteness of the area, poor planning and lack of experience (Yuhun 1989).

At present, there is only very limited commercial crop production occurring in the Fitzroy River catchment, namely for pasture seed production. This cropping is associated with the areas of horticultural activity near Broome and Derby (see *Horticulture*, above) (Kimberley Development Commission 2006). Nevertheless, the failure of the Camballin project has not deterred interest in an irrigated agriculture industry in the Fitzroy River catchment. Cotton research trials were undertaken in areas near Broome through the 1990s (although this is outside the Fitzroy River catchment) and also, again, at Camballin in 1994 (Yeates 2001). In 1998, the WA Government and Western Agricultural Industries (WAI) signed a Memorandum of Understanding (MoU) for the commencement of cotton trials and associated feasibility studies relating to a proposal to develop a large-scale genetically modified cotton industry using water extracted from the Canning Basin and from three dams proposed to be built on the Fitzroy River (Hill & Mann 2006). However, since then, the WA Government has ruled out the construction of dams on the Fitzroy River, and in 2004, did not extend its MoU with WAI (Hill & Mann 2006).

Urban development

While the population of the Kimberley region is small, the high growth rate and development focus of the regional authorities (see Section 2.2.2) indicates that urban development may arise as a key environmental pressure in the near future. Urban areas occupy a minimal area of the Fitzroy River catchment, and are represented by the townships of Derby and Fitzroy Crossing, which have estimated populations of 5000 and 1500, respectively (Kimberley Development Commission 2007). These centres service pastoral, tourism and mining activities in the region. In 2005, the combined population for the Derby-West Kimberley and Halls Creek Shires (excluding the township of Halls Creek), within which much of the Fitzroy Catchment falls, was approximately 12 000, with the Indigenous population comprising more than 50% of this figure (Kimberley Development Commission 2006). The average annual population growth rates for the two Shires from 2004 to 2005 were 2.4% and 3.3% respectively, at least double the rate for regional WA (Kimberley Development Commission 2006). At least 130 aboriginal communities occur throughout the area (Toussaint et al 2001); the largest community is at Noonkanbah (population 250), which is located on the edge of the Fitzroy River, about 100 km downstream of Fitzroy Crossing.

Water supplies for Derby, Fitzroy Crossing and Camballin are sourced from production bores located near the townships (Kimberley Development Commission 2006; WA Department of Water 2006b). The public water supply for Derby is sourced solely from the confined Erskine Formation aquifer, which is protected against contamination from human land uses by an overlying (confining) shale formation (Water and Rivers Commission 2001). In 2005-06, 920 ML of water was sourced from this supply, about 800 ML of which was for urban water use

(Economic Regulation Authority 2006). According to Australian Water Resources (2005a), the sustainable yield of the Derby Groundwater Management Area, which occupies an area of 34 km^2, is approximately 6170 ML, and in 2004-05, the total groundwater extraction was approximately 2540 ML, or 41% of the sustainable yield. There is a marked difference between the 2004-05 and 2005-06 extraction estimates, however, it is unclear whether the Erskine Formation aquifer and the Derby Groundwater Management Area correspond to the same water source. At Fitzroy Crossing, the Water Corporation is licensed to draw 250 ML annually for public water supply purposes. Between 1996-97 and 2001-02, annual production increased from 150 ML to 213 ML, and is predicted to increase by about 5% per year (WA Department of Environment 2004). Consequently, annual abstraction is expected to exceed the current licensed allocation by 2006-07, reaching approximately 271 ML by this time (WA Department of Environment 2004). Additional to the public bores, some town-based communities, the school and the hospital are serviced by private bores located outside the water reserve. At Camballin, the Water Corporation is licensed to draw 50 ML annually for public water supply purposes, with annual abstraction over the past 10 years ranging from around 20 to 40 ML (WA Department of Water 2006b).

Both Derby and Fitzroy Crossing have deep sewerage systems. The wastewater treatment plant for Fitzroy Crossing is licensed for a maximum inflow of 700 kL per day, being equivalent to approximately 3000 people (Shire of Derby/West Kimberley, WA Planning Commission & Banuba Inc 2005). After being treated to a tertiary level, the waste water is discharged into the Fitzroy River (Shire of Derby/West Kimberley, WA Planning Commission & Banuba Inc 2005). All treated wastewater from the Derby Wastewater Treatment Plant is used to reticulate the Derby golf course and also maintain a constructed wetland that provides habitat for birds (Water Corporation 2006).

Tourism and recreational and customary harvest

In the Kimberley region, recreation and tourism often focus intensive activity on specific locations, particularly along rivers and river crossings and permanent pools and waterholes (RNRMCG 2004). In the Fitzroy River catchment, the major centres supporting tourism-based activities are Derby and Fitzroy Crossing, but no doubt other areas along the river frontage also are utilised, including notable area such as Geikie Gorge National Park. Between 2002 and 2006, the annual average number of visitors to the Derby-West Kimberley Shire was approximately 74 700 (Tourism Western Australia 2007). Although the Shire does not include all of the Fitzroy River catchment and does include areas outside the Fitzroy River catchment (eg. Lennard River catchment), the visitor numbers are still a useful guide. According to Storey et al (2001), the high eco-cultural values of the Fitzroy River provide it with significant tourism potential. However, Bartolo (2006a) and Straton (2006) both noted concerns from stakeholders in the Fitzroy River region about unplanned and unmanaged tourism, including: rubbish generation; potential pollution of the river through leakage of septic tanks; unmanaged fires; and impacts on important aquatic species such as sawfish (also see below).

As stated in Section 2.2.2, recreational fishing is the biggest tourism-based activity across Northern Australia. The Fitzroy River is promoted for its recreational fishing, although few data are available on the status of the main recreational fish species of the river. According to Newman et al (2006), barramundi stocks in the King Sound management area, which includes the Fitzroy River, are being harvested at sustainable levels. Straton (2006) noted some stakeholder concerns about the potential negative impacts of increased recreational fishing in the Fitzroy River between Yeeda Station and Camballin. At places like the Camballin barrage and Telegraph Pool, sawfish are often the targeted species (Morgan et al 2005; Bartolo 2006a) or are inadvertently caught and left on the shore to die by people fishing for bait to catch barramundi (A Storey, UWA, pers comm). According to Morgan et al (2005), the majority of sawfish encountered at the Camballin barrage have fishing line tangled around their rostrum.

It is well known that Aboriginal groups harvest aquatic fauna from the Fitzroy River either to eat or use as bait to catch larger animals (Storey et al 2001). There appear to be no suggestions in the literature that such customary harvest poses any threat to the biota of the river.

Mining

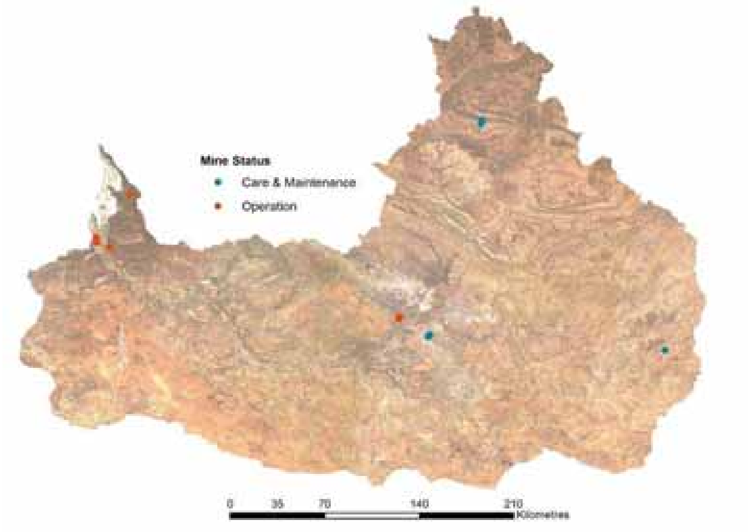
Mining activities in the Fitzroy River region began in 1872 and have continued sporadically (Price et al 2003). Mining occupies a relatively small proportion of the land use within the Fitzroy River catchment. At present (based on MINEDEX (2007) for WA), there are 17 active mining operations (Figure 2.33a) in the Fitzroy River catchment (see below), as well as numerous historical mines (Figure 2.33b) and exploration leases and known mineral deposits (Figure 2.33c). Mineralogically, the Fitzroy catchment is characterised by the Devonian reef system, which is a 350 million year old marine reef system that contains lead and zinc deposits and petroleum accumulations (ACIL Tasman & WorleyParsons 2005). Other minerals found in the region include diamonds and gold. Diamonds are the only mineral currently being mined in the Fitzroy River catchment. Lead and zinc were mined at Pillara, about 30 km south-east of Fitzroy Crossing, as recently as 2003 (Kimberley Development Commission 2006), with this operation expected to recommence in 2007 (Xstrata 2007).

At present, two large mining operations occur within the Fitzroy catchment, namely the Ellendale diamond mine and Blina petroleum extraction facility. The Ellendale Lamproite field is located 130 km east-south-east of Derby. Mining commenced in mid-2002 and production is expected to increase following further expansion (Kimberley Development Commission 2006). In addition, a number of companies hold promising tenements within the region, which they plan to investigate further for their potential to host economic diamond deposits (ACIL Tasman & WorleyParsons 2005). Commercial oil production currently occurs at the West Kora, Blina/Boundary and Sundown/West Terrace/Lloyd well sites, approximately 80 km east of Derby. In 2005, production volumes were relatively small, at approximately 30 000 barrels a year (ACIL Tasman & WorleyParsons 2005; Kimberley Development Commission 2006). In addition to these operations, various quarry industries (ie. sand, gravel, rock, aggregate) operate near Derby (ACIL Tasman & WorleyParsons 2005).

According to ACIL Tasman & WorleyParsons (2005), there is good potential for the discovery of additional base metal deposits in the Lennard Shelf and Fitzroy Trough areas, which are located in the middle and lower Fitzroy River catchment, downstream of Fitzroy Crossing. Additionally, numerous unmined deposits are known to exist in the Fitzroy catchment, including iron ore at Grant Range, Shore Range and Jimberlura, and gold at Richenda River, Turtle Creek, Mount Bell, Mount Behn and Mount Broome deposits (ACIL Tasman & WorleyParsons 2005).

ACIL Tasman & WorleyParsons (2005) considered a range of potential environmental impacts associated with additional mining development in the West Kimberley, including factors such as greenhouse gas emissions, fauna and flora, wetlands, marine protection, soils and landform and conservation lands and other environmentally sensitive areas. Environmental effects within the Kimberley region are closely managed, and the Department of Environment is responsible for approving all groundwater extraction and surface water diversion proposals (IKNRMG 2004). As the Fitzroy catchment is one of interest in the

A



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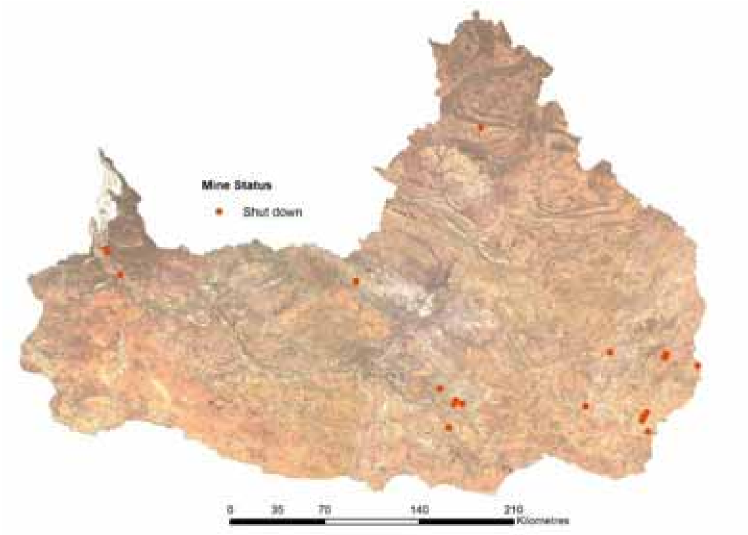

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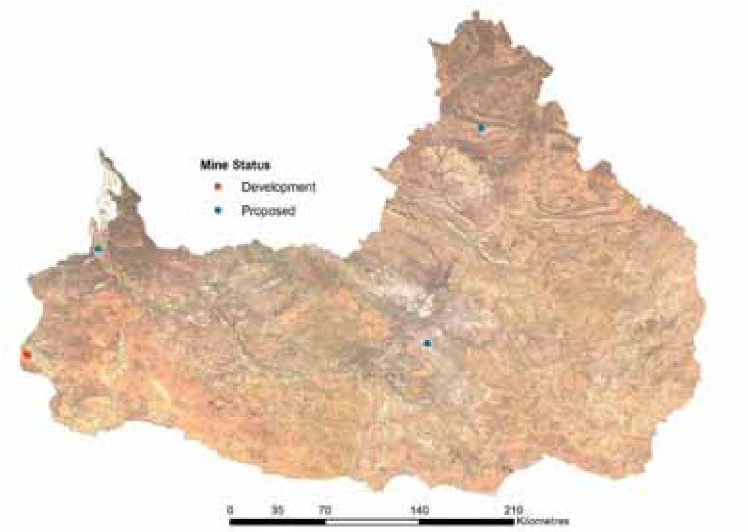


Figure 2.33 Mining status in the Fitzroy River catchment (Source: Western Australia MINEDEX, 2007). – A. Active mining operations (listed as 'care and maintenance' and 'operation' in MINEDEX); B. Historical mines (listed as 'shut down' in MINEDEX); and C. Potential mines (listed as 'development' and 'proposed' in MINEDEX).

Kimberley and a potential site for future exploration activities (ACIL Tasman & WorleyParsons 2005; Kimberley Development Commission 2005), mining operations will continue to be monitored by the WA Government.

Climate change

There have been no studies to assess the implications of climate change specifically for the Fitzroy River or Kimberley region. According to CSIRO (2007), climate change in the west Kimberley region by 2070 could result in the following (best estimate) changes:

- Annual average temperature: +1.5 to +4°C;
- Annual average rainfall: -10 to +2%;
- Average number of days per year >35ºC (projected for Broome): from 54 (at present) to 86–220.
- Average annual extreme precipitation intensity (by 2050): +1 to +4%

The uncertainty surrounding these projections is described in detail by CSIRO (2007). Little is documented about the potential effects of climate change to the ecological values of the Fitzroy River, although the issue has been identified in various fora and reports (IKNRMG 2004; Bartolo 2006a; Hill et al 2006). IKNRMG (2004) noted that there is general agreement that climate change will impact on the biodiversity of the Kimberley region, but to what extent it is unknown.

2.4.3 Threats

Groundwater extraction

At present, groundwater demand in the Fitzroy River catchment appears relatively low. Groundwater is extracted in townships and communities for urban, industrial and/or small scale irrigated horticulture activities, and also for stock drinking water. Groundwater demand is most likely greatest in the Derby region, with water from the Erskine Formation aquifer supplying the largest township in the catchment as well as small scale horticultural activities (Water and Rivers Commission 2001). Although there appears to be no estimate of the annual average groundwater extraction from the Fitzroy River catchment, the size of the groundwater resource (ie. the Fitzroy Alluvium alone has an estimated storage capacity of 13 000 GL; Lindsay & Commander 2006) and the estimated sustainable yield for the catchment (ie. 188 GL; BRS 2007a) suggest that the groundwater resource is presently not under threat.

Notwithstanding the low current extraction rates, the groundwater supply of the Fitzroy River catchment is considered a valuable resource for irrigated agricultural activities. Although no large developments are currently in operation, the potential for development of this resource, and the threats this would pose, is likely to remain, particularly while the WA Government retains a policy of no dams on the Fitzroy River. For example, industry stakeholders have recently noted that there is 250 000 ha of land in the Fitzroy river catchment that could be developed for irrigated agriculture (Straton 2006).

Storey et al (2001) noted the lack of knowledge about the relationships between surface water and groundwater in the Fitzroy River, including how they relate to the presence/persistence of waterholes on the floodplain. In characterising the hydrology of the Fitzroy Alluvium, Lindsay & Commander (2006) concluded the key environmental implications of large scale groundwater extraction would be the disruption of the ecological balance in and around permanent pools, both in, and away from, the main river channel. During the dry season, the alluvial aquifer supports these pools, as well as springs, which act as refugia, representing the only permanent water source for terrestrial, aquatic and avian wildlife (Storey & Beesley 1998; Lindsay & Commander 2006). Based on an assumed extraction rate of 200 GL/year (drawn from the proposal to source and transport water from the Fitzroy River to Perth; see *Surface water extraction*, below), Lindsay & Commander (2006) estimated there would be a corresponding drawdown of about 0.5 m at the river bed. The specific ecological consequences of this are difficult to predict. However, van Dam et al (2005) described a clear positive relationship between macroinvertebrate and fish community assemblages (and hence ecological values) and maximum depth of river pools in the De Grey River, in the Pilbara, suggesting that reduced pool depth due to groundwater extraction could adversely affect the ecological values of the pools. Groundwater drawdown will also likely affect groundwater dependent vegetation, although there appears no information on this for the Fitzroy River. Additionally, Sutton (1998) noted that any activity affecting groundwater distribution, flow or quality could have significant impacts on the unique karst habitats and their associated fauna, including stygofauna.

Surface water extraction

According to Australian Water Resources (2005b), water consumption within the Cape Leveque Coast, Fitzroy River, and Lennard River Surface Water Management Areas was estimated at 8685 ML. Within the above region, agriculture comprises approximately 30% of total water consumption, urban/domestic use approximately 28%, and mining, manufacturing and other minor activities the remainder (Australian Water Resources 2005b). Even if the above consumption estimate comprised the total surface water consumption within the Fitzroy River catchment alone, it would still represent around only 0.1% of the total annual discharge of the Fitzroy River. Hence, based on current consumption, the surface waters of the Fitzroy River are not currently under threat from over-extraction.

Regardless of the current low levels of surface water extraction, the Fitzroy River, with its high annual discharge, has always been clearly identified as a key catchment for potential water resource development, particularly irrigated agriculture. This was illustrated by the failed Camballin Irrigation Project, and more recently by the WA Government and WAI's interests through the 1990s in developing a cotton industry supported by groundwater (see *Groundwater extraction*, above) and surface water from proposed dams for irrigation (see *Crop production*, above). With the latter venture having been shelved in the early 2000s, it is unclear when, or if, the Fitzroy River's surface waters will be harvested for large-scale intensive irrigated agriculture. However, as the west Kimberley region has already been identified as suitable for cotton growing (Yeates 2001), and the Australian Government has established a group to identify Northern Australian catchments that can support increased consumptive water use (www.environment.gov.au/water/action/development/index.html), it is highly likely that there will be further pressure on the catchment for irrigated agricultural development.

In addition to being used for agricultural purposes, the surface waters of the Fitzroy River have also been identified as potentially supplying the future urban water needs of Perth, some 1900 km to the south. An initial proposal to canal water from the Fitzroy River to Perth was first developed in 1993 (Lindsay & Commander 2006), and the concept was resurrected by the WA Government in 2005. An Expert Panel was appointed to independently review options of transporting water by canal, pipeline or ocean transport, from the Fitzroy River to Perth (WA Department of the Premier and Cabinet 2006). Water quantity scenarios assessed ranged from 50 GL to 200 GL per year. The final report of the Panel (WA Department of the Premier and Cabinet 2006) concluded that the water supplied by the options would cost at least five times more than if supplied by other available options, and would offer no other significant advantages to the State's development.

The interest in regulating the surface waters of Fitzroy River catchment so they can be utilised for either irrigated agriculture or drinking water supply for Perth has prompted substantial consideration of the potential environmental impacts. Much of this has focused on the impacts of regulating the river through dam construction, which is discussed in more detail in the following section.

Water impoundment

At present, the Fitzroy River has two major storages (Figure 2.34): 17 Mile Dam, with a capacity of almost 5500 ML (BRS 2007a); and Fitzroy Dam with a capacity of 4650 ML (as extracted from Geosciences Australia's GEODATA TOPO 250K Series 3-Dam walls layer). 17 Mile Dam was constructed to service the Camballin Irrigation Project, from the late 1950s to early 1980s. Although the associated impoundment on the main channel of the Fitzroy River is a barrage (Plate 2.1), and therefore does not impede high flows, it still represents a barrier that can affect the ecology and hydrology of the river.

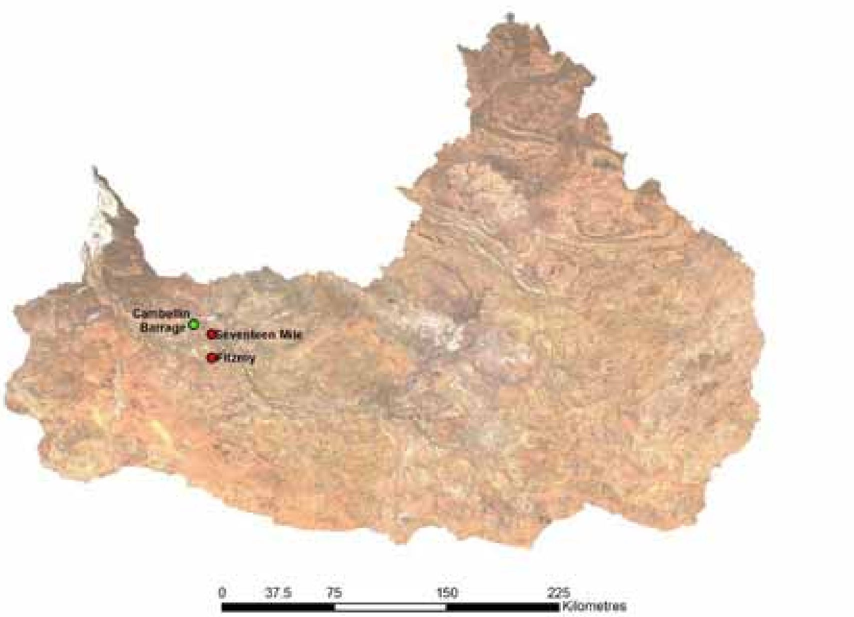


Figure 2.34 Dams (displayed in red) for the Fitzroy River (Source: GEODATA TOPO 250K Series 3-Dam walls layer, Geoscience Australia) and Camballin Barrage (displayed in green) (Source: GEODATA TOPO 2.5 M -Localities layer, Geoscience Australia).

Numerous studies have described or assessed the impacts of the Camballin barrage on the Fitzroy River. The barrage's biggest impacts occur as a result of its function as a barrier to the movement of aquatic species. Morgan et al (2005) calculated that in most years the barrage stops fish movements for up to nine months of the year, while in eight of the last 17 years it was negotiable for only up to two months per year. However, these periods also include the dry season low flow periods, when fish migration would be unlikely to occur even in the absence of a barrier. Also of importance is the timing of fish migrations; most fish migrate during the late wet season to early dry season, and this period is truncated by the effects of the barrage (A Storey, UWA, pers comm). In addition to preventing aquatic species migrations,

Plate 2.1 The Camballin barrage on the Fitzroy River (after Storey et al 2001).

which typically are critical for species' life cycles, the barrage leads to congregations of predatory species (including bull shark, *Carcharhinus leucas*) that in turn affects prey species and disrupts important ecological aspects of the system (Morgan et al 2005).

It is also known that recreational fishers congregate at the barrage, potentially placing further pressure on trapped species (Storey et al 2001; Morgan et al 2005). Morgan et al (2005) also noted the high incidence of individuals of the threatened freshwater sawfish (*P. microdon*) entangled in fishing line. Species other than fish are also affected, with the barrage also impeding the upstream movement of the prawn, *M. rosenbergii* (also known as Cherabin), which is an important food species and whose annual migrations are apparently a precursor to the general movement of fishes in the river (Storey et al 2001). In addition to the impediment of upstream migration, the barrage has the potential to impede downstream migration, which is extremely important for maturing barramundi, freshwater sawfish and other species that require the estuarine or marine environment for breeding (Morgan et al 2005).

Although the Camballin barrage does not impede high flows, it can still affect river hydrology. For example, lesser floods and "freshers" may not be transmitted downstream beyond the barrage (Storey et al 2001). High flows are also diverted down Snake Creek (the tributary used to divert water to 17 Mile Dam), creating permanent water and relatively stable water levels that have resulted in the establishment of a riparian zone of even-aged mature *M. leucadendra* representative of a modified, stable hydrology rather than that of a natural seasonal floodplain (Storey et al 2001). Unnaturally protracted periods of inundation of areas of the floodplain associated with impoundment of water upstream of the barrage have also been noted to result in some riparian vegetation die-off as well as erosion (Storey et al 2001).

In addition to the existing barrier in the Fitzroy River, the potential effects of more extreme river regulation, in the form of the construction of dams, as has been previously proposed (see Hill & Mann 2006), have also been assessed. The major proposal, by WAI in the mid-1990s, proposed three dam sites, on the Dimond, Margaret and Leopold gorges. If all three dams were constructed, they would regulate 76% of the catchment area above Fitzroy Crossing, reducing flood intensities by up to 70% (Storey & Beesley 1998; Storey et al 2001). Sutton (1998) and Storey et al (2001) described the potential impacts of river regulation on the ecological values of the Fitzroy River, where necessary, using the impacts of the Ord River Dam on the Ord River (ie. an example of large-scale regulation by total impoundment) as evidence. The major potential impacts of damming include: simplification and narrowing of downstream riparian zones; loss of important extensive river-floodplain connectivity; reduced variability in river-flows; an associated increase in the abundance of species (including some endemics), including weeds, better adapted to more stable wetter or drier hydrological conditions; and the isolation (physical and genetic) of many fully aquatic species (eg. fish, crustaceans). Geomorphically, a dam would modify sediment delivery to the lower reaches and the deposition of material in the estuary, with subsequent potential effects of the distribution of mangroves. Reservoirs produced by dams are an ideal habitat for mosquitoes, which include the vectors for several human viruses (Storey & Beesley 1998). Overall, Storey et al (2001) saw the major consequence of river regulation as the loss of connectivity in three dimensions: upstream-downstream, river-floodplain, and surface to groundwater, and that the loss of these connections would have major ecological consequences.

Altered fire regime

Unmanaged or uncontrolled fire in the Fitzroy River catchment has been documented as contributing to land degradation and direct impacts on native fauna (Lawford 2006 ; Tredwell 2006). Between 1993 and 2005, the Kimberley was the most extensively and frequently burnt region in WA. During this period, much of the land in the lower to mid reaches of the Fitzroy River catchment (ie. below Fitzroy Crossing) was burnt between five and eight times, with the great majority of fires occurring in the mid to late dry season, until the rains of the new wet season start (Russell-Smith 2005). Late dry season fires usually burn over very extensive areas (ie. tens of thousands of square kilometres), are more likely to be of high intensity, are less patchy (ie. leaving few unburnt areas), and affect all the major land uses across the region (Russell-Smith 2005). In considering the impacts of late dry season fires on water quality, Russell-Smith (2005) relied on studies undertaken in the NT (eg. Townsend & Douglas 2000 – see discussion of *Altered fire regime* for the Daly River, in Section 2.3.3), and noted that more knowledge of the implications of fire on soil structure and water quality in the Kimberley is needed. WA Environment Protection Authority (2006) noted that almost all riparian vegetation across the region was at risk because of changed fire regimes compounded by grazing pressure, as well other factors such as feral herbivores, and changed hydrology. The finding of Storey et al (2001), however, that the riparian vegetation on the Fitzroy River was generally in good condition (see Section 2.4.1), suggests that fire in the catchment may not be having a serious impact on this habitat type.

Soil erosion is exacerbated on bare, burnt land and leads to river silting, reduced water quality and the formation of extensive mudflats in the river mouths and estuaries (WA Environment Protection Authority 2006). Such effects have been reported by Aboriginal people elsewhere in the Kimberley (WA Environment Protection Authority 2006), and could conceivably also occur on the Fitzroy River. Additionally, wetlands such as mound springs are also at risk because of fire (WA Environment Protection Authority 2006).

Land clearance/loss of native vegetation cover

According to Commonwealth of Australia (2007b), only 370 km^2 of the total Fitzroy River catchment area of ~94 000 km^2 (or <0.004%) represents cleared/modified native vegetation. Much of the area of cleared/modified native vegetation may relate to the maximum area of land used for crop cultivation during the Camballin Irrigation Project. However, if one considers the likely extent of native vegetation removal or modification due to overgrazing, the true value of cleared and/or modified native vegetation must be significantly higher. For example, the Rangeland Management Branch of the Division of Resource Management (1981) reported that at least 1300 km^2 of the river frontages (primarily the floodplain regions), which occupy an area of around 5800 km^2 or 6% of the catchment, was in bad range condition with moderate or severe erosion, although some recovery has been observed in the past 20 years (Australian Natural Heritage Database 2007). RNRMCC (2004) suggested that overgrazing by domestic and non-domestic herbivores several decades ago has caused complete vegetation removal or at least reduced density in some areas, resulting in erosion and sedimentation of waterways, and represents one of the most serious causes of waterway degradation in the Kimberley (see *Contamination*, below).

Active land clearance in the Fitzroy River may become a bigger issue in the future if parts of the catchment are developed for irrigated agriculture. If the perceived 2500 km^2 of suitable agricultural land was developed and cleared, this would represent about 2.2% of the Fitzroy River catchment. For comparison, the area of land currently cleared for irrigated agriculture on the Ord River is approximately 150 km^2 or only 0.2% of the catchment area (64 000 km^2). However, it is unlikely that a large scale intensive irrigated agricultural industry will be developed on the Fitzroy River for many years, particularly considering that the Ord Stage 2 development, which will comprise an additional 300 km^2 of land under cultivation, will most likely proceed first (Storey & Trayler 2007).

Introduced invasive flora

Weeds are considered a substantial problem in the Fitzroy River catchment, although there are little quantitative data on their distribution and extent. Some weeds, including rubber vine (*C. grandiflora* – a WONS species) and noogoora burr (*X. occidentale*), are thought to threaten economic, social and environmental values in the region, including access to the river, pastures, native vegetation, and riverbank stability (Bartolo 2006a; Straton 2006).

Noogoora burr and parkinsonia (*P. aculeate* – a WONS species) are widely distributed along the Fitzroy River, and other riparian weeds including passion fruit/vine (*P. foetida*) and coffee bush (*Leucaena leucocephala*) are becoming more widespread (RNRMCG 2004). Noogoora burr is a woody herb that grows up to two metres and replaces native vegetation while being a poor inhibitor of erosion (Tropical Savanna CRC 1998). Over 360 km of the Fitzroy is infested with thick stands of noogoora burr with large sections of the river closed to any access for fear of further transmission (Tropical Savanna CRC 1998). The establishment of noogoora burr in the 1950s was one of the reasons for pastoralists changing from sheep to cattle grazing (A Storey, UWA pers comm). Parksinonia has also heavily invaded the banks of the Fitzroy River and has the further potential to colonise vast areas of the region (Tropical Savanna CRC 1998). The extent of parkinsonia in the Fitzroy River catchment appears unknown. However, across north-western WA it is known to be distributed across more than 500 000 hectares, including large infestations along the Fitzroy, Ord and De Grey Rivers (Agriculture & Resource Management Council of Australia & New Zealand, Australian & New Zealand Environment & Conservation Council and Forestry Ministers 2000a). Three infestations of rubber vine have been found in WA: Koolan Island in 1992, south of Kununurra in 1997 (Agriculture and Resource Management Council of Australia and New Zealand, Australian & New Zealand Environment & Conservation Council and Forestry Ministers 2000b), and at Willare Bridge on the Fitzroy River in 2005 (Western Australian Herbarium 2007). The infestation at Willare Bridge was an estimated 270 ha, and a program for eradication was funded in 2005-06, the outcomes of which appear not to have been reported.

The introduced pasture grass, buffel grass (*Cenchrus ciliaris*), occurs in the Fitzroy River catchment and is viewed as a serious weed in Kimberley conservation parks and reserves (Tropical Savanna CRC 1998). As far as can be ascertained, other invasive introduced pasture greases, such as para grass, gamba grass and mission grass are not yet present in the Fitzroy River catchment.

Although the riparian vegetation along the Fitzroy River was considered to be in good condition despite some areas demonstrating high levels of invasion by various weed species (Storey et al 2001), the broad occurrence of exotic weeds in river and wetland areas throughout the region is not well known or documented as there is no major program dealing with environmental weeds in the area (Graham 2001; RNRMCG 2004).

Introduced invasive fauna

Woolnough et al (2005) surveyed the extent of knowledge within the WA Government on the distribution and abundance of selected vertebrate pest species. Feral species considered to be present in the Fitzroy River catchment included (accompanied by general abundance estimates) camel (low; only in the south of the catchment), donkey (*E. asinus*; low to medium), horse (*E. caballus*; low), cattle (low), pig (*S. scrofa*; low to high), wild dog (low to medium), fox (isolated pockets; Saunders et al 1995) and rabbit (isolated pockets; Tropical Savannas CRC 1998).

The Fitzroy River catchment probably has the highest feral pig abundance in WA (Woolnough et al 2005). Twigg et al (2005) observed pigs within a 150 km^2 study site in the Fitzroy River catchment to be present in densities of 3–8 km^{-2}, and to typically be concentrated around waterholes, billabongs and the river itself. Pig impacts in the Fitzroy River include the fouling of waterways, erosion of riverbanks, the spread of noxious weeds and associated degradation of riparian zones (Storey et al 2001; Twigg et al 2005). Donkeys also are prevalent in the catchment, although control programs that have been undertaken since the late 1970s have had considerable success, leading to a decline of donkey numbers in the Kimberley from densities of about 2 donkeys km^{-2} in some areas to local eradication (Woolnough et al 2005). Donkey impacts include soil erosion and damage to native vegetation and watercourses, including riparian zones (Storey et al 2001; Woolnough et al 2005). Horses and feral cattle are less prevalent than pigs and donkeys, but nonetheless can causes impacts to riparian zones through over-grazing, trampling and the spread of weeds (Storey et al 2001; Woolnough et al 2005). Foxes, wild dogs and feral cats are also present in the Fitzroy River catchment and, through predation, can impact on birds, insects, reptiles and fish (Saunders et al 1995; Woolnough et al 2005; Bartolo 2006a).

The cane toad (*B. marinus*), although yet to reach the Fitzroy River, will almost certainly do so within the next 5 to 10 years. Quantitative data on cane toad impacts emerging from the NT suggests that populations of some aquatic and terrestrial species are impacted, in some cases, resulting in localised extinctions (Oakwood 2004; Doody et al 2006). While the long-term consequences of cane toad impacts are still unclear, there are also emerging data to suggest that many species are unaffected, or that following initial declines populations recover (Shine et al 2006). Once cane toads cross the NT-WA border and become established in the Ord River catchment, their transfer to the rest of the Kimberley, as well as the rest of WA, will be relatively rapid as there will be no quarantine control on their accidental movement in vehicles and freight. In addition, the headwaters of the Ord and Fitzroy River abut, providing a direct means of invasion.

Contamination

As mentioned earlier, the AusRivAS-based assessment of river condition classified the Fitzroy River catchment as 'significantly impaired', due mostly to the impacts of grazing (Halse et al 2002). Poor grazing management is most likely to affect the river through (i) physical disturbance to the riparian and associated littoral habitats (ie. habitat modification), and also (ii) contamination of the water with sediment eroded from the degraded landscape and nutrients from animal faeces and urine (WA Department of Water 2006a). It should also be noted that other introduced (feral) animals can also cause such water quality impacts. Although there are few data available to properly assess the effects of sediment and chemical contamination on the Fitzroy River, Ruprecht & Rodgers (1998) noted that the generally higher turbidities in the south of the catchment may be due, in part, to greater grazing pressures in this area. It is possible that water quality has improved since grazing practices were improved, although increased sediment delivery to the river would, presumably, continue to occur until substantial vegetation recovery has occurred.

Contamination of the Fitzroy River catchment's aquatic ecosystems can potentially arise through numerous other land uses/activities, including irrigated agriculture, mining and urban development/human settlements. According to IKNRMG (2004), small irrigation ventures in the Fitzroy River catchment may cause pollutants to enter the Fitzroy River, although there appear to be no data to support this. With regards to agricultural development in the catchment, reduced water quality through contamination by pesticide usage, siltation and mobilisation of soil nutrients have been identified as important issues (Storey & Beesley 1998; Storey et al 2001). Interestingly, Storey et al (2001) recounted observations by local Aboriginal people of "skinny" or unhealthy aquatic fauna and waterbird deaths during the period of the Camballin Irrigation Project, with the apparent effects being attributed by Aboriginal groups to widespread use of pesticides. However, the lack of systematic data for the effects of the Camballin project on the aquatic fauna of the Fitzroy River limits the ability to assess this possible impact (Storey et al 2001).

Mining has the potential to affect the water quality of the Fitzroy River through the discharge of mine waters containing salts and metals, although at present there are few active mines in the catchment. At Ellendale, possible impacts on surface water, which have to be managed and monitored, include run-off from waste dumps that may contain sediment and low levels of metals and water discharged from the tailings storage facility that may contain low levels of metals, processing chemicals and flocculants (WA Environment Protection Authority 2005). With the current interest in further developing the mineral reserves in the West Kimberley (ACIL Tasman & WorleyParsons 2005), regulators will need to ensure that water management on mine sites is undertaken such that the risk of contamination of ground and surface waters is minimised, and that appropriate water quality monitoring and assessment programs are in place.

Sewage effluent is discharged from the Fitzroy Crossing wastewater treatment plant into the Fitzroy River (Shire of Derby/West Kimberley, WA Planning Commission & Banuba Inc 2005). However, the effluent here is treated to a tertiary level, and is unlikely to represent an unacceptable risk to the water quality and ecology of the river. Less is known about the extent to which sewage from septic tank systems throughout the catchment leaks into groundwater and subsequently into surface water ecosystems. However, Birdwood Downs Station, near Derby, recently has been constructing sub-surface flow sewage treatment wetlands or 'gardens' in aboriginal communities to prevent sewage leaking from septic tank systems from further contaminating spring waters and groundwater, thereby improving overall hygiene and health (Tredwell 2006).

Future offshore or coastal developments in the region have the potential to substantially alter the estuarine environment of the Fitzroy River catchment. According to ACIL Tasman & WorleyParsons (2005), there is the potential for marine degradation and pollution to occur during the construction and operation of shipping, offshore or port developments as a result of associated activities such as dredging, ballast water discharge, oil spills and runoff from ship loading wharves. Up until 2003, the Port of Derby operated as an export facility for lead/zinc concentrate (Kimberley Development Commission 2006), and may again do so in the future, as prices for both lead and zinc increase (ACIL Tasman & WorleyParsons 2005).

An additional potential source of contamination is through uncontrolled tourism, with waterholes being contaminated by cleaning products (eg. soaps, detergents), sunscreen and insect repellents from tourists washing and swimming (IKNRMG 2004; RNRMCG 2004). These activities tend to occur in the dry season, when the pools and waterholes are not being flushed. However, the significance of this issue in the Fitzroy River catchment is unquantified.

Overall, and apart from the poor grazing practices of the past, the lack of development in the Fitzroy River catchment means that contamination of the waters is likely to be very low compared to more developed catchments elsewhere. The existing rich aquatic community of the Fitzroy River (see Section 2.4.1) suggests that water quality impacts have not been severe.

2.4.4 Assets – threats matrix

Table 2.14 represents the asset-threat matrix for the Fitzroy River catchment, showing the situation for (i) the current status of the catchment (black ticks) and (ii) a potential status of the catchment based on a significant increase in (a) water resource development centred mainly around irrigated agriculture utilising both ground and surface water and (b) the number of mining operations (black plus red ticks). The future development 'scenario' was chosen given the very strong interest in further developing both industries in the region (see Sections 2.4.2 and 2.4.3).

Based on the existing information on the Fitzroy River, the greatest threats to the aquatic ecosystems at present appear to be land degradation/loss of vegetation cover (due to pastoral activities; although the current problems are largely a consequence of historical poor grazing practices), exotic plant and animal species and poorly managed fire. Water impoundment, in the form of the Camballin barrage, does not have a major impact on the catchment's aquatic habitats and biota, apart from localised impacts at the barrage and associated with the historical Camballin irrigation infrastructure. However, the barrage is considered to have an impact on the ability of aquatic species to access appropriate habitat, and on populations of some threatened species due to increased predation pressure.

At present, water extraction does not appear to be a major threat to the catchment. However, it is undoubtedly an emerging issue, and future large scale regulation and utilisation of the Fitzroy River's water resources could well have a major impact of the aquatic ecological assets. Additionally, significant mining expansion in the catchment is a distinct possibility and would have the potential to impact aquatic ecosystems through contamination, water extraction and other associated threats (eg. weeds).

Table 2.14 Assets–threats matrix for the Fitzroy River catchment based on (i) the current status in the catchment (black ticks) and (ii) the potential status given an increase in (a) water resource development centred around irrigated agriculture utilising both ground and surface water and (b) the number of mining operations (black plus red ticks).[1]

Assets (& key values)	Threats							
	G'water extraction	S'water extraction	Water impoundment	Land clearance/ loss of native vegetation cover	Invasive flora	Invasive fauna	Altered fire regime	Contamination
Waterways	✓ (red)	✓ (red)	✓ (red)	✓	✓	✓	✓	✓ (red)
Habitat for fish	✓ (red)	✓ (red)	✓	✓	✓			✓ (red)
Freshwater discharge	✓ (red)	✓ (red)	✓ (red)	✓			✓	
Water quality	✓ (red)	✓ (red)	✓ (red)	✓	✓	✓	✓	✓ (red)
Wetlands	✓ (red)	✓ (red)	✓ (red)	✓	✓	✓	✓	✓ (red)
Wildlife nurseries & habitat	✓ (red)	✓ (red)	✓ (red)	✓	✓	✓	✓	✓ (red)
Erosion control/sediment retention	✓ (red)	✓ (red)	✓ (red)	✓	✓	✓	✓	
Water regulation	✓ (red)	✓ (red)	✓ (red)	✓	✓	✓	✓	
Riparian vegetation	✓ (red)	✓ (red)	✓ (red)	✓	✓	✓	✓	
Erosion control	✓ (red)	✓ (red)	✓ (red)	✓	✓	✓	✓	
Habitat for wildlife	✓ (red)	✓ (red)	✓ (red)	✓	✓	✓	✓	
Biodiversity	✓ (red)	✓ (red)	✓ (red)	✓	✓	✓	✓	✓ (red)
Endemism	✓ (red)	✓ (red)	✓ (red)	✓				
Threatened species	✓ (red)	✓ (red)	✓	✓	✓	✓	✓	✓ (red)

[1] NB: an attribution of a threat to an asset/value does not imply that the threat is currently impacting the asset/value, but that, if sufficiently severe or prolonged, it has the potential to do so.

2.5 Flinders River (Queensland)

The Flinders River catchment is located in Queensland's southern Gulf region and covers an area of approximately 109 000 km^2 (Saynor et al 2008). The catchment falls largely within the Gulf Plains and Mitchell Grass Downs bioregions, with minor extensions within the Northwest Highlands, Einasleigh Uplands and Desert Uplands bioregions (Sattler & Williams 1999). At a length of 840 km, the Flinders River is the longest river in Queensland, arising on the slopes of the Great Dividing Range (Gregory Range), flowing in a westerly direction for approximately 250 km before heading northwest and north to the Gulf of Carpentaria (Figure 2.35).

Rainfall in the catchment is significantly influenced by seasonal monsoons, with the majority (~80%) falling between December and March (Department of Natural Resources, Mines and Energy 2004). Across the catchment, mean annual rainfall ranges from approximately 450 mm in the south/south-east (upper Flinders, Cloncurry and McInlay Rivers) to approximately 900 mm in the north (lower Flinders River floodplain) (BOM 2007). Like rainfall, streamflows are highly seasonal and variable. Flooding during summer and cessation of flows

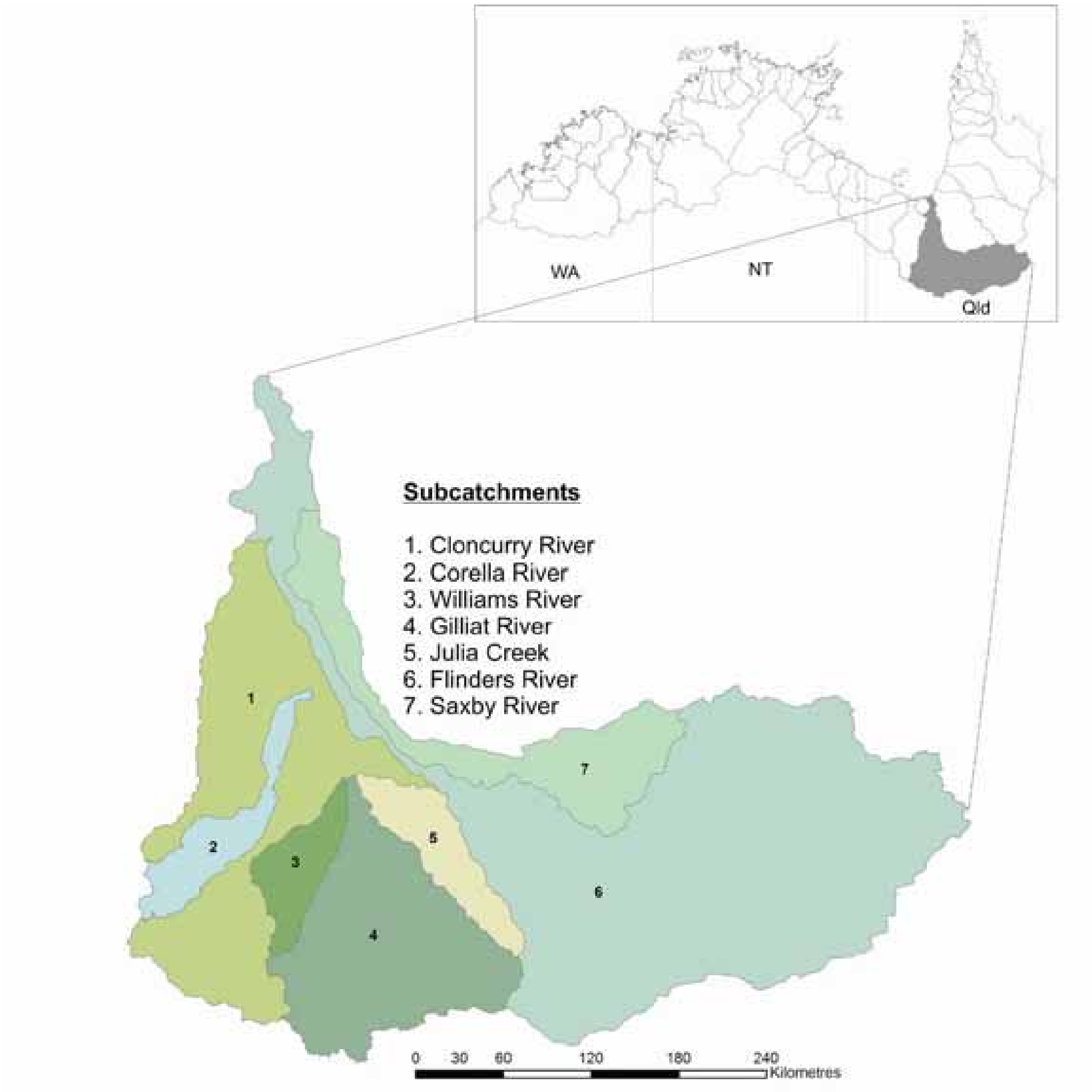


Figure 2.35 The Flinders River catchment .

during the dry season are common characteristics of the Flinders River and most of its tributaries. Frequent widespread flooding occurs in the Flinders River catchment, which is comparatively flat and subject to intense monsoonal rains (Department of Natural Resources Mines and Energy 2004). Mean annual discharge for the Flinders River catchment is reported to be in the order of 3000–4000 GL, (Department of Natural Resources, Mines and Energy 2004; Commonwealth of Australia 2007c; Moliere 2008), although BRS (2007b) reported that annual runoff is in the order of 5200 GL.

The information reported in this section was sourced from key literature on the Flinders River or Southern Gulf region in general, as well as a stakeholder consultation workshop held in Richmond in June 2006 to reassess the existing information,. The details of the workshop are reported in Bartolo (2006b).

2.5.1 Ecological assets

Compared to the Daly and even Fitzroy River catchments, there have been few efforts to describe the ecological assets and values of the Flinders River catchment. The hydrology of the catchment is reasonably well documented and understood (Department of Natural Resources, Mines and Energy 2004; Moliere 2008; Queensland Government 2007), while the geomorphology also has been described to some extent (Brennan & Gardiner 2004; Saynor et al 2008). In terms of the biology, the fish fauna were only properly surveyed recently (Hogan & Vallance 2005), while there does not appear to be a great deal of information on other components of the aquatic ecosystems. A summary of the ecological assets of the Flinders River is provided in Table 2.15.

Table 2.15 Summary of assets and associated key values for the Flinders River, as compiled from key literature sources.

Asset	Details
Waterways	Almost 30000 km of riverine length, representing 9 geomorphic types, dominated by anabranching (78%) and bedrock confined and constrained rivers (13%).
	Additional values:
	Freshwater discharge – seasonally flowing, but represents a significant input to the Gulf of Carpentaria for maintenance of fish and prawn productivity and associated fisheries.
	Water quality – very little data; generally high, seasonally variable water quality
Wetlands	Not extensively studied; springs of the Great Artesian Basin (GAB) are well represented, with over 100 known in the catchment. The springs are culturally and biologically important, but have been substantially impacted by human activities.
	Additional values:
	Wildlife nurseries & refugia – little information; The Morning Inlet/Bynoe River area represents important coastal/estuarine habitats for fish. Some swamps and the springs are known to represent important refugia for waterbirds and other fauna.
Riparian vegetation	Generally intact riparian vegetation, with *Melaleuca bracteata, M. leucadendra* and *Eucalyptus camaldulensis* predominant. Fringing riparian vegetation sparse in the Mitchell Grass plains of the southern catchment. Some riparian areas are degraded due to weed infestation.
	Additional values:
	Erosion control/sediment retention – Little information available due to lack of studies.
	Habitat for wildlife – Little information available due to lack of studies.
Biodiversity	Not extensively studied, but considered to be representative of the broader southern Gulf region; 41 species of fish recorded in the freshwater reaches, but actual figure could be closer to 60; Little information for other taxa.
	Additional values:
	Endemism – few known species endemic to the Flinders River, but regionally endemic species occur in the catchment, including some associated with the GAB springs (eg. snails, shrimp, isopod); suspected to be additional unidentified endemic species associated with GAB springs.
Rare and threatened species	Not extensively studied; EPBC-listed species are freshwater sawfish and Australian painted snipe only; some riparian plant species listed as rare.
	Overall, the catchment is very poorly represented in terms of conservation reserves.

Waterways

The Flinders River catchment consists of seven sub-catchments (Figure 2.35), with the associated river systems all free-flowing and largely unregulated (Queensland Environment Groups 2006). The major tributaries of the catchment include the Flinders, Cloncurry, Dugald, Corella, Williams and Stawell Rivers (Brennan & Gardiner 2004). In the south-east, the Flinders and Stawell Rivers drain the elevated plains of the Einasleigh Uplands, while in the south-west, the Cloncurry, Williams, Dugald and Corella Rivers arise on the dissected plateaus of the Mt Isa Inlier (Brennan & Gardiner 2004). In their mid to lower reaches, all the rivers traverse the relatively low elevation lands of the Gulf Plains.

Based on the channels classified as '*named or major*' on the 1:250 000 drainage dataset produced by Geoscience Australia, there is approximately 29 927 km of riverine length in the catchment (Figure 2.36; Saynor et al 2008). According to Saynor et al (2008), nine geomorphic types are represented in the Flinders River catchment. Of these, however, anabranching rivers are by far the predominant geomorphic type, representing 78% of the river length, and dominating throughout the catchment, except for the uplands in the southwest and the eastern part of the catchment (see Figure 2.36; Saynor et al 2008). The next most represented river type is bedrock confined and constrained rivers (13%), with the remaining seven geomorphic types (meandering; bedrock; low sinuosity; chain of ponds; wandering; non-channelised valley floors, estuarine) representing a total of less than 10% of the river length. The Flinders River estuary, which includes much of the Bynoe River, extends approximately 100 km inland, and is classified as a tide-dominated delta (Brennan & Gardiner 2004). Commonwealth of Australia (2002) reported the estuary to be in *Near Pristine* condition. Brennan & Gardiner (2004) classified the geomorphic types of the major tributaries of the Flinders River catchment in more detail than can be provided here. Additional key values of the waterways of the Fitzroy River catchment are described below.

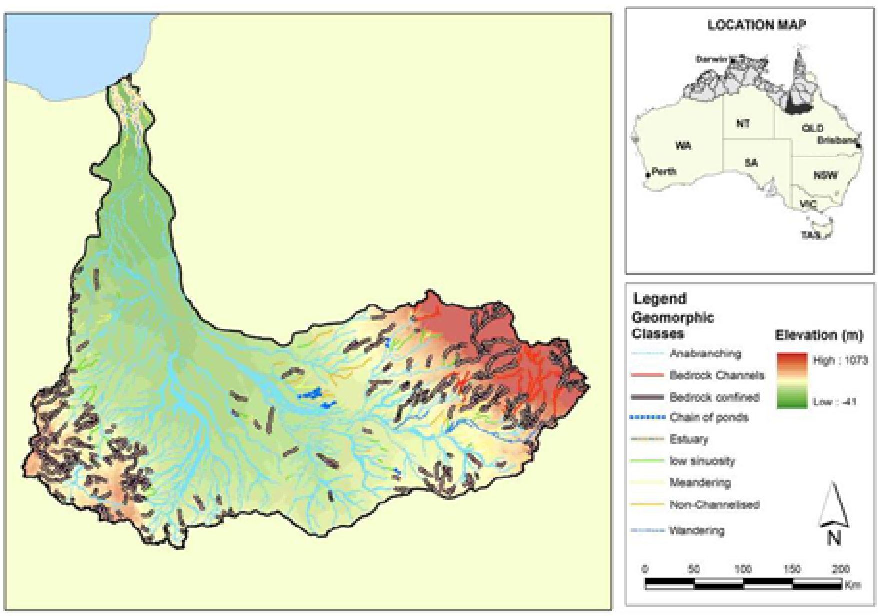


Figure 2.36 The waterways, and their geomorphology, of the Flinders River catchment (from Saynor et al 2008).

Freshwater discharge

As reported above, the mean annual discharge of the Flinders River catchment has been variously reported as being between approximately 3000–5200 GL (Department of Natural Resources, Mines and Energy 2004; BRS 2007b; Moliere 2008). Based on a long-term gauging station dataset containing 24 years of complete data between 1957 and 2003, Moliere (2008) calculated the mean annual discharge at Walkers Bend (915003A) between 1969 and 2004 as being approximately 3100 GL. Annual discharge is, however, variable, generally ranging between approximately 0.3 and 6000 GL over this period (10^{th} and 90^{th} percentile annual discharges, respectively). Discharge from the Flinders River to the Gulf of Carpentaria is known to be important for fish (eg. barramundi) and prawn productivity and fisheries in the Gulf (Staples & Vance 1987; Department of Natural Resources Mines and Energy 2004; Hogan & Vallance 2005).

Most of the Flinders River catchment has only seasonal flow, although some perennial flow and waterbodies occurs in some headwater streams (eg. Reedy Creek) that arise in the basaltic areas in the east of the catchment. There is no flow within the majority of the catchment for more than half of the year and this is attributed to the fact that rainfall is relatively low in this catchment compared to the rest of the tropical rivers region (Moliere 2008). Flood peaks in the hydrographic records for Hughenden and Richmond indicate that major floods occur every 4-20 years, with heights ranging from 2-4.5 m at Hughenden and 5-12 m at Richmond (BOM 2006). Butler (2008) analysed the relationship between rainfall and flow for the Flinders River. The river experiences numerous small spates of flow, indicating that at least some runoff is delivered to the river during most significant rainfall events. The pulses generated by these inflows subside rapidly, and flow rates often fall back to very low levels between events. In fact strong baseflows are maintained for no more than 4 to 5 weeks at a time during most wet seasons, and for less than 3 months even in the wettest years (Butler 2008).

Little has been recorded regarding the role of the Flinders River in regulating water regimes and flow throughout the year. There are no major dams within the Flinders River catchment, and only 0.52% of flow has been reported as ‘diverted’ (Queensland Government 1999). The largest water storage area in the Flinders River catchment is Corella Dam, at 15 800 ML capacity, which makes it relatively small compared to dams in other catchments (NR&M 2006).

Water quality

There is an extreme paucity of water quality data for the Flinders River (Southern Gulf Catchments 2005b; Butler 2008). Southern Gulf Catchments (2005b) noted that the National Land & Water Resources Audit recommended the further development of water quality monitoring programs in the Gulf of Carpentaria catchments in order to be able to properly gauge status and issues. Whilst the Department of Natural Resources & Water has water quality records for 47 monitoring stations within the Flinders River catchment (nrw.qld.gov.au/watershed/precomp/nf_wqi/915_flin.htm), only 10 of these have datasets with >20 records for key water quality variables (Figure 2.37). These data, whilst insufficient to fully analyse and characterise spatial and temporal water quality characteristics and trends for the Flinders River (as discussed by Butler 2008), nevertheless provide an indication of general water quality in the catchment. In the upper south-west of the catchment (5 sites), pH, EC and water hardness are typically in the range 7–8, 100–800 µS/cm and 30–200 mg/L (as $CaCO_3$), respectively; in the upper east of the catchment (4 sites), 7–8, 200–1100 µS/cm and 60–250 mg/L (as $CaCO_3$), respectively; and in the lower catchment (1 site) 7–8, 80–300 µS/cm and 10–100 mg/L (as $CaCO_3$), respectively.

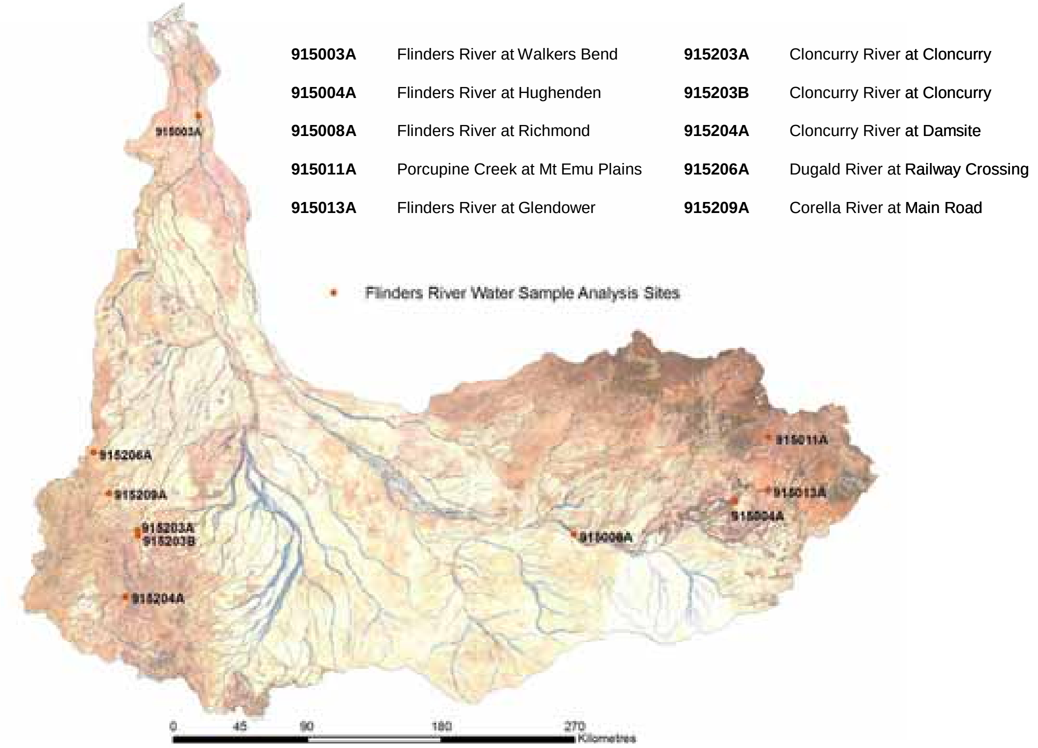


Figure 2.37 Flinders River catchment water quality sampling sites with greater than 20 records for key water quality variables (pH, EC, hardness) (Source: Water Sample Analysis Index 2007, Queensland Government Department of Natural Resources and Water- http://www.nrw.qld.gov.au/watershed/precomp/nf_wqi/index.htm).

In general, water quality in the Flinders River catchment is thought to be relatively unimpacted by urbanisation and industry. However, many waterholes experience high exposure to, and are affected by, livestock and/or feral pigs (D Burrows, JCU, pers comm). Areas near mining operations in the western part of the catchment may also have water quality issues, but little data are available. Input from grazing activities may influence water quality, as would some forms of agriculture. Hogan & Vallance (2005) reported the Flinders River to have generally high turbidity and an associated lack of submerged aquatic vegetation.

Wetlands

The wetlands of the Flinders River have not been extensively characterised. However, the springs associated with the GAB have been reasonably well studied (Fensham & Fairfax 2003; 2005). About 100 springs have been located within the Flinders River 'supergroup' (Fensham & Fairfax 2005), consisting of both recharge (0.23 km^2) and discharge (0.14 km^2) springs (Fensham & Fairfax 2003). The springs represent environments of permanent moisture within a semi-arid environment and, hence, are very important both culturally and biologically. However, exploitation of the groundwater resource of the GAB to support pastoral and, to a lesser extent urban and mining activities, has placed great pressure on the groundwater supply and its associated spring wetlands (Fensham & Fairfax 2003; see Sections 2.5.2 and 2.5.3). Based on the GEODATA TOPO 250K Series 3 waterbodies layer, the area of wetlands in the entire Flinders River catchment is approximately 834 km^2 (Figure 2.38).

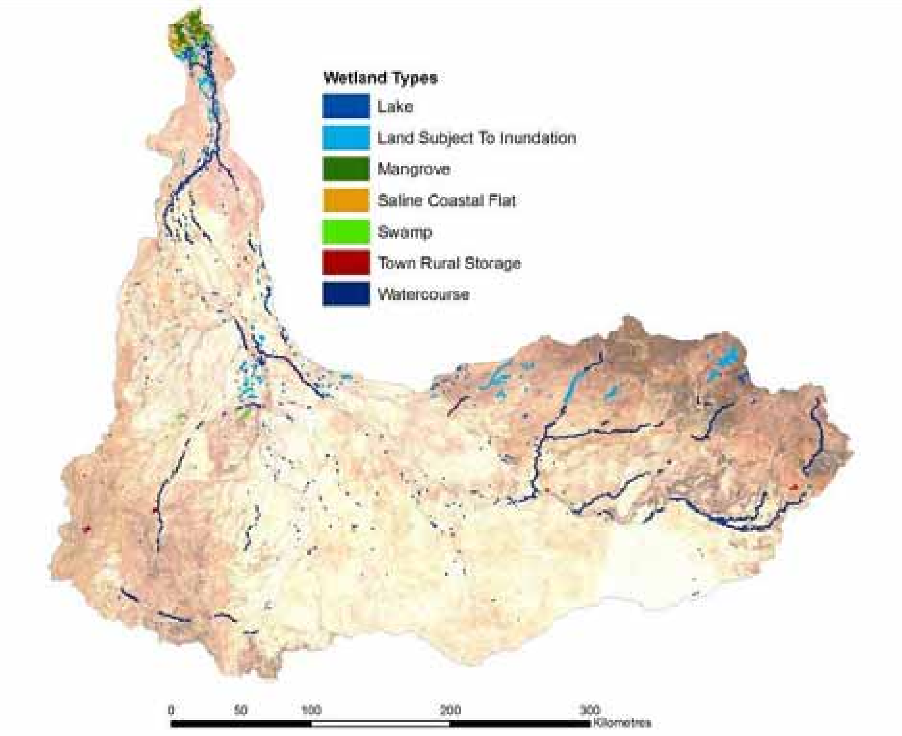


Figure 2.38 The wetlands of the Flinders River catchment. (Source: GEODATA TOPO 250K Series 3-Waterbodies layer, Geoscience Australia). Features include Lake, Land Subject to Inundation, Mangrove, Saline Coastal Flat, Swamp, Town Rural Storage and Watercourse.

There are three wetlands of National Importance in the Flinders River catchment, Lignum Swamp, the Southern Gulf Aggregation and Stranded Fish Lake (Department of the Environment and Water Resources 2007).

Lignum Swamp (90 km NE of Cloncurry) is an impeded drainage depression covering around 2.4 km^2 is semi-permanent with variable depth, and represents an important refuge for waterbirds and other fauna. The vegetation comprises extensive areas of *Muehlenbeckia florulenta* and *Marsilea drummondii* in the wettest areas, and *Polygonum* sp., *Chenopodium auricomum* and *Melochia multiflora* on the margins. The site experiences disturbance due to cattle grazing (Department of the Environment and Water Resources 2007).

The Southern Gulf Aggregation spans the coastal zone of several catchments in the southern Gulf, including the Flinders River, and represents the largest continuous estuarine wetland aggregation in Northern Australia. It comprises many wetland types, including drainage depressions, swamps and salt flats, and is one of the three most important areas for shorebirds in Australia. The area has experienced only a relatively low level of grazing disturbance, although feral pigs and horses are common (Department of the Environment and Water Resources 2007).

Within the Southern Gulf Aggregation is Stranded Fish Lake (40 km WSW of Karumba), which consists of a deflation hollow between eroded beach remnants and has both marine and freshwater inundation. The marine inundation occurs during the highest astronomical tides whilst freshwater inundation is locally derived. The site is a refuge for both fish and bird species, and apart from the salt tolerant *Halosarcia pergranulata* is devoid of vegetation (Department of the Environment and Water Resources 2007).

Wildlife nurseries and refugia

As noted above, the three nationally important wetlands all provide important refuge habitat for fauna. An additional protected area, which lies within the Southern Gulf Aggregation, is the Morning Inlet/Bynoe River Fish Habitat Area, comprising coastal and estuarine habitat adjacent to and including the mouth of the Flinders River. This does not include any freshwater habitats, but does include the Flinders River Reserve which extends upstream from the mouth for approximately 20 km into areas with seasonal freshwater inundation. The Fish Habitat Area is protected under the Fisheries Act (1994) and seeks to prevent habitat damage, but allows most types of fishing and water activities.

Springs also are known to act as refugia, for both full and semi-aquatic species. Palmer (1884) reported that an open spring in the area had 'numerous small fish'. This spring, and all others in the same spring group, is now dry (Fensham & Fairfax 2002). Moreover, it is possible that the fish previously reported were a highly restricted, even endemic, species (D Burrows, JCU, pers comm). Fensham & Fairfax (2003) listed several fish species associated with the GAB springs in Queensland, and also noted the existence of endemic snails (terrestrial and aquatic), an endemic shrimp and two new species of isopods. There appears to be little information, however, on the fauna reliant on the springs in the Flinders River catchment. As only a sub-set of the Qld GAB springs has been surveyed, there is little doubt that additional aquatic species (many endemic) reliant on the springs as refugia, will exist (Fensham & Fairfax 2003).

In the upper (eastern) reaches of the catchment, some perennial waterholes and river pools provide habitats and breeding areas for many fish and other animals (Hogan & Vallance 2005). In fact, the many waterholes elsewhere in the catchment, including the extensive lowland reaches, are also likely to provide important aquatic habitat (D Burrows, JCU, pers comm).

Riparian vegetation

Based on the Queensland National Vegetation Information System (NVIS) Version 4 data compiled by the Qld Government, riparian vegetation in the Flinders River catchment covers an area of approximately 19 150 km^2 (Figure 2.39). Data were derived from the Queensland Herbarium Regional Ecosystems (2003 and 2005) and Remnant Vegetation Cover (2003 and 2005).

Studies suggest that the riparian vegetation of the Flinders River catchment is relatively intact and healthy when assessed using criteria such as disturbance and diversity (Department of Primary Industries 1993). However, some areas have significant infestations of woody weeds such as prickly acacia, mesquite, parkinsonia and rubber-vine. Dowe (2008) provided a preliminary description of the riparian vegetation of the Flinders River catchment based on both existing data and a field survey. The dominant riparian structural species include *Melaleuca bracteata, M. leucadendra* and *Eucalyptus camaldulensis*. Some different associations occur in areas where there is relatively higher rainfall (*L. grandiflorus*), the lower elevated (*C. bella*) and higher elevated areas (*Casuarina cunninghamiana*, *Melaleuca trichostachya*), or where the geology is different to that which occurs over most of the catchment. In the far southern parts of the catchment, riparian vegetation may be sparse where watercourses pass through Mitchell grass plains.

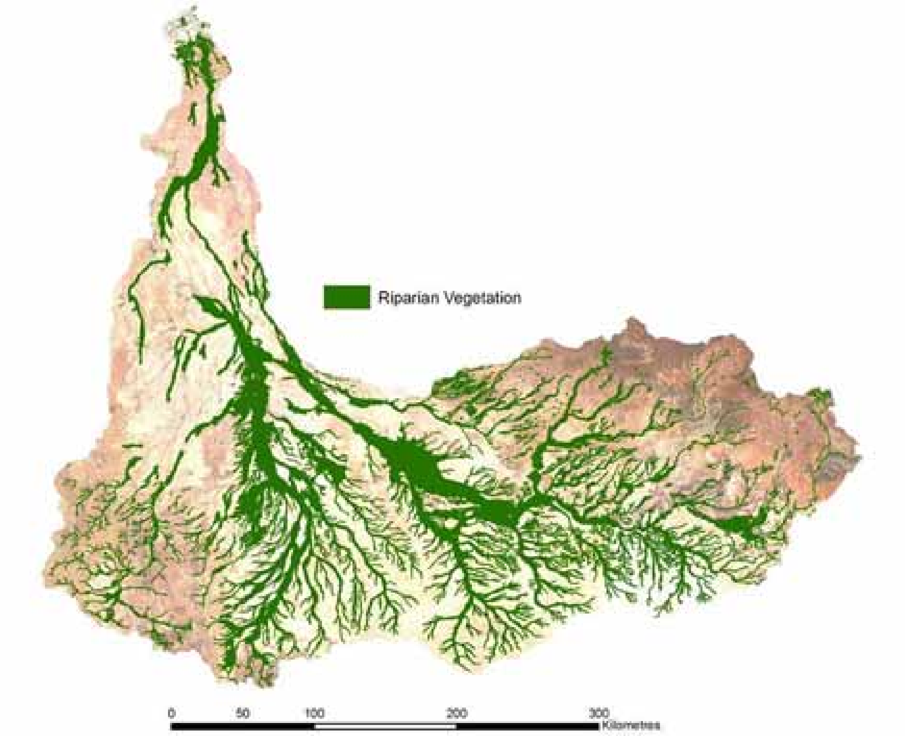


Figure 2.39 The extent of riparian vegetation in the Flinders River catchment. (Source: Records deemed to be riparian were extracted from the Queensland National Vegetation Information System [NVIS] Version 4 data produced by the Queensland Government)

Erosion control/sediment retention

Water dependent ecosystems such as springs and floodplains support a diversity of riparian vegetation that function to stabilize the sediment and provide habitat for fauna. Little specific research on this has been conducted in the Flinders River catchment. It would be suspected that riparian vegetation would impose a significant influence on erosion control and sediment retention, as with riparian vegetation in climatically and geologically similar catchments.

Habitat for wildlife

Particular waterway systems are valuable as wildlife corridors and provide rare habitats and support important ecological values such as breeding areas. However, there is little published information on the significance of riparian vegetation in the Flinders River catchment as habitat for wildlife.

Biodiversity

Biodiversity across much of the catchment is homogeneous, although in areas of the catchment to the east and west, diversity increases because of geological formations, edaphic conditions, either increased or reduced rainfall and increasing elevation. Areas of higher diversity include the significant wetlands, Lignum Swamp and Stranded Fish Lake (Blackman et al 1996). Both of these formations are exceptional in that they represent hydrologically and ecologically unique phenomena. In addition perennial springs, waterholes and river pools provide for habitats and breeding areas for many species.

Hogan & Vallance (2005) reported 41 fish species from the freshwater reaches of the Flinders River. This included freshwater fish and estuarine vagrants that also live in freshwaters, and several new records for the catchment. Potentially new species recorded for the Flinders River included the Papuan River Sprat (*Clupeoides* cf. *papuensis*), Tadpole Goby (*Chlamydogobius ranunculus*) and freshwater whipray (*H. chaophraya*). With further survey effort there will almost certainly be more species found, including possibly even some as yet undescribed species. The actual figure could lie closer to 55-60 (D. Burrows, JCU, pers comm). Fox (2008) reported only seven aquatic/semi-aquatic reptiles (crocodile – *C. johnstoni*, *C. porosus*; turtle – *C. rugosa*, *Elseya latisternum*, *Emydura subglobosa*; monitor – *V. mertensi*; and colubrid snake – *Tropidonophis mairii*) as being recorded in the Flinders River catchment, however, this figure is considered unreliable due to the paucity of reliable reptile data for Queensland.

Endemism

There appear to be few known endemic aquatic species in the Flinders River catchment, and no known endemic fish in existence (D Burrows, JCU, pers comm). There appear to be no endemic species of plants, although some species with restricted distributions may have a significant part of their distribution within the catchment. Endemism associated with the springs of the GAB is known to occur, however, there is little known about this for the GAB springs within the Flinders River catchment (see *Wetlands – Wildlife nurseries and refugia*, above). Moreover, the springs, and associated endemic species have long been under threat from the extraction of artesian groundwater and, more recently, invasive species (Fensham & Fairfax 2003).

Threatened species and conservation reserves

The Flinders River catchment has not been studied in detail with regards to rare and threatened species. Table 2.16 list the aquatic/semi-aquatic species known to occur in the catchment, which are listed as rare or threatened. In addition to the vulnerable-listed freshwater sawfish (*P. microdon*) and Australian painted snipe (*R. australis*), there are a number of riparian plant species listed as rare, including *Callistemon chisholmii*, *Fimbristylis micans*, *Labichea brassii*, *Rhamphicarpa australiensis* and *Trachymene glandulosa*. In addition, both crocodile species are protected in Queensland (Fox 2008).

Table 2.16 Threatened aquatic or semi-aquatic species in the Flinders River catchment (adapted from EPA 2006).

Fauna type	Vulnerable	Rare
Fish	Freshwater sawfish (*Pristis microdon*)	
Birds	Australian painted snipe (*Rostratula australis*)	
Plants		*Callistemon chisholmii* (Myrt.)
		Fimbristylis micans (Cyper.)
		Labichea brassii (Caesalpini.)
		Rhamphicarpa australiensis (Scrophular.)
		Trachymene glandulosa (Apiac.)

The Flinders River catchment is very poorly provided with protected areas with only three National Parks present, and a single declared marine/estuarine Fish Habitat Area. Of the three national parks, Porcupine Gorge National Park is completely within the catchment, whilst White Mountains and Blackbraes National Parks have minor extensions into the Flinders River catchment from adjoining areas. Porcupine Gorge National Park is situated in the eastern section, and includes a unique gorge topography, occupying about 54 km^2 (<0.05% of catchment area) and is among the most biologically diverse areas within the catchment. Of the three national parks, Porcupine Gorge (an upper section of Porcupine Creek, which is a tributary of Flinders River) is the only national park that includes riparian areas of significance, with seasonal water-flow and some perennial waterholes.

2.5.2 Pressures

According to Commonwealth of Australia (2007c), the current development pressure in the Flinders River catchment is low. The pressures on the catchment are described below.

Horticulture

There are no commercial horticulture industries in the Flinders River catchment. However, according to the Department of Natural Resources and Water (2006), the Cloncurry Shire Council was considering funding studies to develop an irrigable area for short-term horticulture crops to the north of Cloncurry, based on flood harvesting. The interest in developing a horticulture industry in this region is based primarily on the need to develop a local economy that is less dependent on mining, in particular, the Ernest Henry mine, which is scheduled for closure around 2010-2012 (Department of Natural Resources and Water 2006). Elsewhere in the catchment, horticultural development is seen as a means to diversify income for graziers.

Pastoralism

Pastoralism has been the major rural industry in the Gulf of Carpentaria since the mid 1800s. It remains the predominant land use activity in the Flinders River catchment covering approximately 109 000 km^2 and accounting for approximately 98% of land-use (Figure 2.40). Annual production for the catchment in 2001/02 exceeded $55 million and was increasing at an average annual rate of 10% (Department of Natural Resources and Water 2006). The primary cattle breeds are Brahman and Brahman Cross. Transport of cattle is primarily by road train and to a lesser extent by rail, and saleyards are situated in the major towns on the Flinders Highway. As riparian lands are mainly unfenced in the Flinders River catchment, the impact of cattle is significant (Department of Primary Industries 1993). Mitchell grasses, *Astrebla* spp., still dominate in the Mitchell Grass Downs, but introduced pasture grasses are now predominant in other areas. Vegetation thickening has been related to grazing activities, as well as some forms of riparian erosion (Bastin et al 2003).

Crop production

Apart from hay production, which occurs around Hughenden and Richmond to a limited extent, there is no significant cropping within the Flinders River catchment (Southern Gulf Catchments 2005a). The existing operations exist essentially to value add cattle production, through direct feeding of irrigated pasture, fodder and grain crops (Department of Natural Resources and Water 2006).

Cotton was trialled at sites near Richmond, but the main restrictions on cotton production include a lack of permanent water supply and uncontrollable insect problems (Yeates 2001). Other cropping has been attempted in the catchment, mostly focused around Richmond. Dryland cropping of sorghum for silage was undertaken in the 1950s, with a switch to shallow storage irrigation in the 1960s and 1970s. Cotton and other irrigated crops (eg. lucerne) were tried during the 1960s, 1970s and 1990s. These ventures all failed due to the aforementioned problems (Yeates 2001).

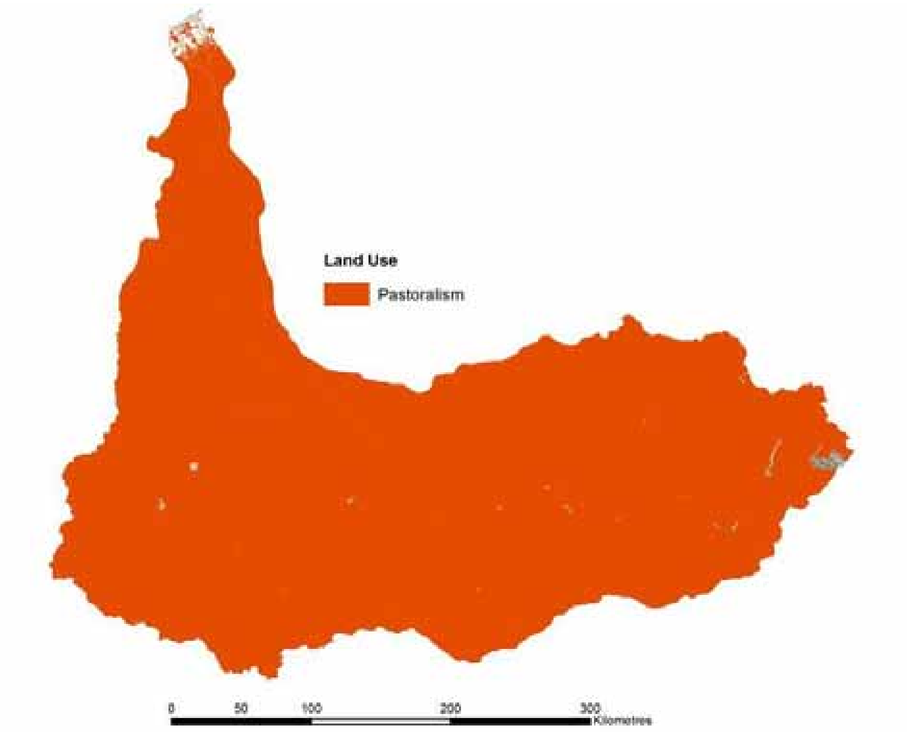


Figure 2.40 Pastoral land use in the Fitzroy River catchment. (Data source: *Land Use in Queensland* (1999)). Note that pastoral areas have been mapped at the secondary class level and includes grazing natural vegetation.

Cotton production has been proposed and promoted again more recently. In 1999, a pre-feasibility study for an in-stream irrigation dam on the Flinders River near Richmond was conducted for the Queensland Government (Yeates 2001), with trials undertaken during 2000-2002. While successful agronomically, the trials were discontinued due to distance from processing facilities and greater returns being available through the production of silage crops as part of a beef feedlot operation (Department of Natural Resources Mines and Energy 2004). Constraints associated with cotton production in the region included risks of salinity and limited soil suitability. The area of potentially irrigable land has been estimated at approximately 120 km^2. The Qld Department of Natural Resources developed a scenario that involved 80 km^2 of this land used for cotton production, however, such plans are yet to eventuate. Bartolo (2006b) noted concerns amongst local land owners that agricultural development opportunities were not being actively pursued by government.

Yeates (2001) briefly considered the major environmental concerns associated with cotton farming in the Flinders River catchment, which included salinisation, chemical contamination of the freshwater, and potentially, also the estuarine and highly productive marine ecosystems of the Gulf of Carpentaria.

More recently, the Flinders Shire Council commissioned a study on behalf of the Flinders Shire Council assessing the development of a water supply scheme based on a dam at Mt Beckford, upstream of Hughenden. It was estimated there was potential to irrigate 4600–9100 ha of land. However, this proposal has not progressed as yet due it failing specific exclusionary criteria applied by the Gulf Region Water Planning Advisory Committee to potential development options (Department of Natural Resources and Water 2006).

Queensland Government soil investigations in the Flinders River catchment, particularly around Richmond, have shown that large areas, which potentially could be supplied with water, have significant development limitations associated with unsuitable levels of salinity or sodicity (Department of Natural Resources Mines and Energy 2004). Whilst some areas of soils near Richmond have been identified as suitable for irrigation (Shields, 2003, as cited by Department of Natural Resources Mines and Energy 2004), by and large the adverse soil characteristics of the majority of the area are likely to constrain the scope and scale of any future irrigation developments.

The Department of Natural Resources Mines and Energy (2004) stated that additional work would be required to identify potential long-term impacts of irrigation on the landscape, streams or groundwater systems, and whether innovative irrigation practices could be utilised to minimise impacts and ensure sustainable development. Regardless of the possible constraints to expand the irrigated agriculture industry, there is continued strong local interest within the catchment to do so.

Urban development

The potential for urban development in the Flinders River catchment is presently very limited. There have been significant recent declines in population numbers in most urban centres, and this trend is predicted to continue or possibly increase (see Section 2.2.2). The current population is just under 7000, and current and projected population growth rate is <0.5% (Department of Local Government and Planning 2003). The major townships (and their populations) in the catchment are Hughdenden (~1500), Richmond (~1200), Cloncurry (~3800) and Julia Creek (~600) (Department of Natural Resources Mines and Energy 2004).

Apart from Cloncurry, which draws its town water from Chinaman Creek Dam, the major townships source their town water supplies from sub-artesian aquifers (Department of Natural Resources Mines and Energy 2004; Southern Gulf Catchments 2005b). Richmond uses approximately 780 ML/year, while the Richmond Shire is also authorised to take 200 ML annually from the Flinders River for recreational purposes (Southern Gulf Catchments 2005b). Hughenden and Cloncurry have entitlements for 1150 ML/year and 900 ML/year (surface water), respectively (Southern Gulf Catchments 2005b).

There appears to be little available information on sewage/wastewater treatment for the townships in the Flinders River catchment.

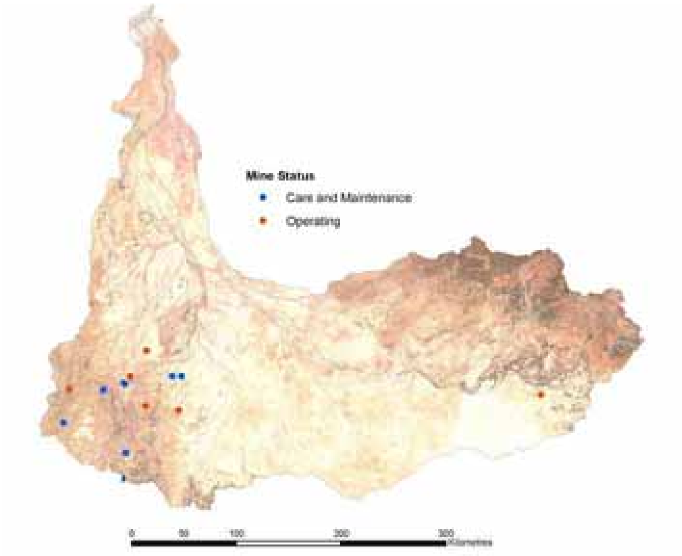
Tourism and recreational and customary harvest

The primary tourist attractions within the Flinders River catchment centre on the gorge and associated river systems of Porcupine Creek (partly within Porcupine Gorge National Park), sites associated with fossil observation and fossicking around Richmond, and activities related to the pastoral industry. Many of the towns on the Flinders Highway offer simple recreational pursuits, and various types of accommodation. Tourism is mostly associated with pass-through traffic using the Flinders Highway. As the Flinders River has very limited permanent water (apart from the tidal lower reaches), recreational fishing and associated activities such as camping do not threaten the riparian areas.

Mining

Mining has been confined predominantly to the south-western section of the Flinders River catchment (Figure 2.41), with silver, lead, gold and copper being mined by both open cut and underground methods. The major operational mine in the catchment is the Xstrata Ernest Henry mine, 40 km north of Cloncurry. The mine produces about 115 000 tonnes of copper and 147 000 ounces of gold in concentrate, most of which is trucked to Mount Isa. Mining is

A



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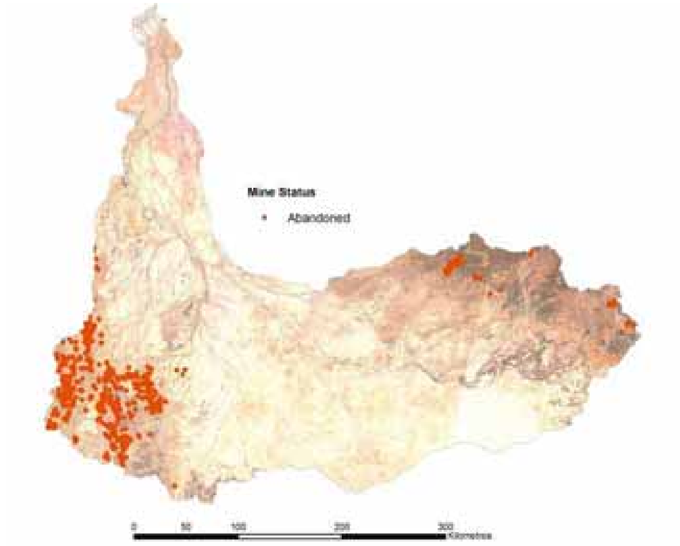

Figure 2.41 Mining status in the Flinders River catchment (Source: Queensland IRTM, 2006). – A. Active mining operations (listed as 'care and maintenance' and 'operating'); and B- Historical mines (listed as 'abandoned' in MINEDEX).

likely to cease in 2010–12 (Queensland Department of Mines and Energy 2006). There are also numerous smaller operations and prospects in the southeast of the catchment, including Cudeco Ltd's discovery of the high grade Rocklands copper deposit, 17 km west-north-west of Cloncurry, and other deposits at Dugald River, Cloncurry project – Ivanhoe, Cloncurry project – Exco, White Range, Roseby and Eloise (Queensland Department of Mines and Energy 2006). From 1997–2003, total production from mining in the Flinders River catchment averaged around $325 million, at an average annual growth rate of 21.3% (Department of Natural Resources and Water 2006).

As can be seen in Figure 2.41, there are many abandoned mines in the south-west of the catchment, with some also in the east of the catchment. Abandoned mines represent a potential threat to water quality through the unmanaged/uncontrolled seepage or runoff of contaminated waters and sediment. Such issues have been well documented for the Mitchell River (eg. Bartereau et al 1998; MRWMG 2000), but far less so for the Flinders River.

Climate change

There has been no research specifically undertaken in the Flinders River catchment to address climate change. According to CSIRO (2007), climate change in the Flinders River catchment region by 2070 could result in the following (best estimate) changes:

- Annual average temperature: +1.5 to +4°C;
- Annual average rainfall: -10 to +2%;
- Average annual extreme (99th percentile) precipitation intensity (by 2050): -1 to +2%.

The highest reductions in rainfall (ie. up to -10%) are projected to occur in the south and south-east of the catchment, while the highest increases in extreme precipitation intensity are projected to occur in the north of the catchment. The uncertainty surrounding these projections is described in detail by CSIRO (2007). Little is documented about the potential effects of climate change on the ecological values of the Flinders River, although the issue has been identified in various fora and reports. For example, Southern Gulf Catchments (2005b), identified the loss of low-lying land in coastal areas due to sea level rise (and associated riverine erosion and sediment loss), alterations in weed and feral animal distribution and shifts by individuals and populations towards higher latitudes as being significant potential effects of climate change in the region.

2.5.3 Threats

Groundwater extraction

According to BRS (2007b), there are almost 2000 production bores present in the Flinders River catchment. However, at present there is no estimate of extraction from these bores. Groundwater is extracted from the bed of the Flinders River for some minor cropping activities near Hughenden, and bores for pastoral needs are widespread throughout the catchment. Pastoralists, and to a lesser extent mining operations and townships, have utilised groundwater from the GAB since the 1870s, although it is unclear when the first bores were sunk in the Flinders River catchment. The impacts of long-term artesian groundwater extraction on the GAB springs within the Flinders River catchment (and the GAB region overall) have been severe, particularly for discharge springs. According to the Queensland Environment Protection Agency (2005) only 36% of the GAB pre-1900 discharge spring-groups are still functioning today. Of the 100 or so springs within the Flinders River catchment, approximately 75 are now inactive due mostly to draw down from water extraction, with discharge flow rate since 1900 estimated to have reduced from 5.41 ML/day to 0.27 ML/day (Fensham & Fairfax 2003). Moreover, the high rate of spring loss has almost certainly resulted in the loss of some endemic species (Fensham & Fairfax 2003). Capping of bores and installation of piping has resulted in the return of flow to at least one spring, however, the Flinders River spring ‘supergroup’ is still heavily impacted (Fensham & Fairfax 2003; Queensland Environment Protection Agency 2005).

A licence is required to take subartesian water not connected to artesian water in the Mount Isa Subartesian Area and Great Artesian Basin Subartesian Area unless the water is to be taken for stock and domestic purposes only (Department of Natural Resources and Water 2006). In the Flinders Rivers River catchment, licensed entitlements for subartesian water total approximately 3500 ML pa (Department of Natural Resources and Water 2006). Where such subartesian water is extracted within 1 km of a watercourse, it is considered to be surface water (Queensland Government 2007).

Surface water extraction

Since 2003, a moratorium has been in place on water entitlements, while the Gulf Water Resource Plan was developed. At present, surface water entitlements for the Flinders River catchment total approximately 20 500 ML pa, with 91% allocated for irrigation and the remainder for urban/industrial (Department of Natural Resources Mines and Energy 2004; Department of Natural Resources and Water 2006). This figure represents about 0.5% of the mean annual discharge (depending on the discharge figure used). However, according to the Department of Natural Resources and Water (2006), only about 9600 ML pa, or 40%, of the total allocated entitlement of surface water and subartesian water (see above), is actually used, indicating that there are significant constraints to development. Factors influencing this could include: distance to markets; soil suitability and availability of good quality agricultural land; availability of water; and infrastructure.

In considering potential for future development over the next 10 years, the *Gulf draft water resource plan social and economic assessment report* proposed a probable additional (future) water demand of approximately 5000–28 500 ML pa, while the Gulf Community Reference Panel nominated an additional demand of 75 000 ML pa (Department of Natural Resources and Water 2006). Outstanding applications for water entitlements in the Flinders River that were lodged but not processed prior to the commencement of the moratorium being declared totalled 54 000 ML (although it is unclear how many of these will be approved once the moratorium is lifted). The stalled proposal to irrigate between 4600 ha to 9100 ha of land near Mt Beckford, also upstream of Hughenden, was estimated to require 33 000 ML pa to 66 000 ML pa (Department of Natural Resources and Water 2006). The above figures, although ranging somewhat, provide some insight into the extent of shorter-term demands for additional water in the Flinders River catchment.

The *Water Resource (Gulf) Plan 2007* (Queensland Government 2007) was released in 2007. In addition to recognising all existing entitlements, the Plan specifies additional strategic and general unallocated water reserves of 20 250 ML and 80 000 ML, respectively, for the Flinders River. Strategic reserves are to be allocated only for State Purposes (ie. a project of State or regional significance, town water supply or ecotourism in a Wild river area), while general reserves can be allocated for future consumptive use by urban, rural or industrial sectors without compromising the environment or the security of supply to existing water users (Department of Natural Resources and Water 2006). At present it is unclear what effect the *Water Resource (Gulf) Plan 2007* will have on water extraction in the Flinders River catchment, as it is yet to be implemented.

In recent years, direct pumping from the river into off-stream impoundments (ie. water harvesting) has been considered a more cost-effective option over the development of in-stream impoundments (Department of Natural Resources Mines and Energy 2004; Department of Natural Resources and Water 2006). This is largely because:

- there is limited potential for constructing large in-stream infrastructure works;
- there is a lack of large contiguous areas that could be developed for large-scale irrigation schemes, and water harvesting offers more scope for irrigation at dispersed sites in the basins; and
- crop planting can be geared to a known water supply at the end of each wet season, whereas a water supply scheme requires considerable excess capacity in order to supply water at specified reliabilities over the long term.

However, a limitation of water harvesting is that it tends to favour the production of short-term crops; perennial crops and year-round rotations need to be supported by permanent water supplies during the dry season.

There have been no published studies into the effects of surface water extraction on the Flinders River. According to Queensland Environment Groups (2006), the Queensland Department of Natural Resources and Water published a modelling study on the impacts of surface water extraction for irrigation on flows of the upper Flinders River. However, the Department of Natural Resources and Water stated that no such report was produced (P. Huber, pers comm., February 2008). Regardless, Queensland Environment Groups (2006) suggested that reduction in flows in the Flinders River could impact on a number of endemic and rare fish species, including the tentatively described Papuan River Sprat (*C.* cf. *papuensis*) and Tadpole Goby (*C. ranunculus*). Hogan & Vallance (2005) highlighted the importance of the Flinders River for the productivity of recreational and commercial fisheries in the region, suggesting that development of natural resources in this catchment is more likely to adversely affect the fisheries than development in the neighbouring catchments.

Water impoundments

Existing and proposed water impoundments in the Flinders River catchment are shown in Figure 2.42. There are no dams on the Flinders River, but there are small dams on the Corella and Cloncurry Rivers. The Corella Dam was constructed in 1959 for the Mary Kathleen mine and township (which have since been abandoned), and has a capacity of 15 800 ML. The small Chinaman Creek Dam, on the Cloncurry River, which has a capacity of only 2750 ML, and provides the water supply for the township of Cloncurry (Department of Natural Resources Mines and Energy 2004). This impoundment is too minor to be included in the dataset used for Figure 2.42. According to Hogan & Vallance (2005), there do not appear to be any physical barriers to fish movement in the Flinders catchment, at least not while there are sufficient flows. Marsden & Stewart (2005) identified two barriers in the Flinders River catchment as requiring remedial works to enable fish passage. These were the Normanton Road Causeway and the Old Normanton – Cloncurry Road Causeway (two similar barriers were also identified in the Bynoe River catchment, which forms a large part of the Flinders River estuary). While fish passage would be provided at these sites during high flows, which is usually for periods of up to two weeks during the wet season, it ceases once flows drop and create a hydraulic jump across the causeways (Marsden & Stewart 2005). As noted by Marsden & Stewart (2005), fish migrations occur throughout the year on a variety of low and moderate flows, and these barriers have the potential to deny hundreds of thousands of fish access to habitat essential for survival.

There have been several studies to assess the feasibility of dams on the Flinders River to support irrigated crops, including cotton. These have included proposed dams ~40 km upstream from Hughenden (mid 1980s) and near Richmond (late 1990s) (Yeates 2001). More recently, the Queensland Government short-listed a proposed off-stream storage in the Flinders River catchment for more in-depth analysis (Department of Natural Resources Mines and Energy 2004). The proposed Flinders River-O'Connell Creek off-stream storage requires water to be diverted from the Flinders River via a weir, and is estimated to cost from $57 million to $80 million (excluding the costs of distribution and reticulation to farms). However, based on initial investigations, there did not appear to be sufficiently large contiguous areas with acceptable levels of salinity and sodicity that could be supported by the scheme (Department of Natural Resources Mines and Energy 2004). In addition, the highly variable streamflow in the Flinders River would undermine the potential to supply water to farms at specified reliabilities (Department of Natural Resources and Water 2006).

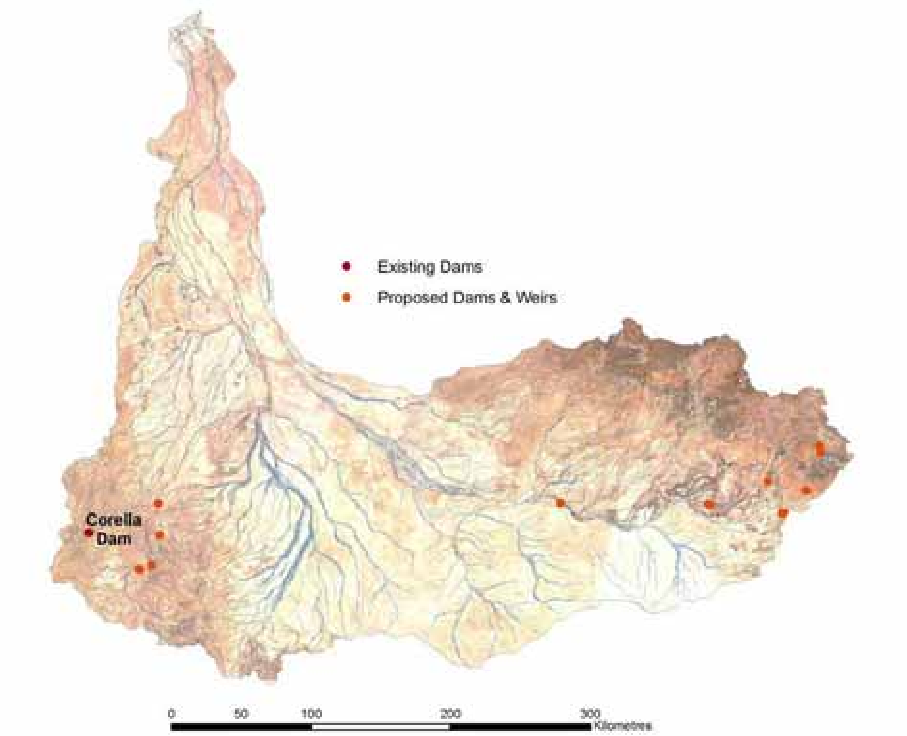

Figure 2.42 Distribution of existing dams and proposed dams and weirs in the Flinders River catchment (Source: Queensland existing dams and Queensland proposed dams and weirs, Queensland Government, 1993-current).

The potential ecological impacts of dams, weirs or other diversion structures on the Flinders River (eg. barriers to fish migration, loss of riparian habitat, altered sediment/nutrient delivery) have previously been identified (eg. Southern Gulf Catchments 2005b; Queensland Environment Groups 2006), but not fully investigated.

Altered fire regime

There is not much information specific to the fire regime and burning practices within the Flinders River catchment. Overall, it is thought that the fire regime in the catchment is generally uncoordinated with annual and/or otherwise regular burning occurring in the middle and lower catchment areas, with no controlled burning in the headwaters. Best practice for fire management is not fully understood, partially because it varies considerably across the region and seasonally (Southern Gulf Catchments 2005a). What is clear is that there is little traditional burning occurring in the Flinders River catchment. Fire frequencies have been increased where rubber vine (*C. grandiflora*) occurs, but have otherwise decreased on the Mitchell Grass Downs, thus encouraging the spread of prickly acacia (*Acacia nilotica*). Active fire exclusion is common and employed so that pasture can be used as livestock forage rather than as fuel for fire. However, the reduction in the frequency of fires is thought to have facilitated the woody vegetation thickening that has been observed across the region's rangelands (Woinarski et al 2007).

Land clearance/loss of native vegetation cover

Only relatively small areas of land have been cleared in the Flinders River catchment, and land clearance is not considered a major threat in the region (Southern Gulf Catchments 2005a). According to the Department of Natural Resources and Water (2007b), woody vegetation clearing rate in the Flinders River catchment (combined data for Flinders and Cloncurry Rivers; representing 91% of the entire catchment) during 2004/05 was around 56 km^2, with an annual average since 1988 of around 34 km^2. Since 1988, the average rate equates to approximately 610 km^2 of woody vegetation cleared, which represents 0.6% of the catchment area or 1.8% of the remaining 32 830 km^2 of woody vegetation. According to Commonwealth of Australia (2007c), clearing of vegetation (mainly gidgee, *Acacia cambagei*) on the slopes of north-east corner of the Mitchell Grass Downs bioregion, which is located around Hughenden in the Flinders River catchment, occurred in the 1980s and 1990s.

Native vegetation can also be destroyed by continuous uncontrolled grazing, however, in contrast to the Fitzroy River catchment in WA (see Section 2.4.3), there is little documented evidence of overgrazing and associated land degradation in the Flinders River catchment. Nevertheless, Southern Gulf Catchments (2005b) reported that the region's extensive grasslands have been reduced in foliage cover due to grazing pressure, although the Mitchell grass communities have proved to be highly resilient pasture grasses. Commonwealth of Australia (2007d) noted that in some areas of the Gulf Plains bioregion, which includes a substantial portion of the Flinders River catchment, there has been extensive degradation of riverine environments because cattle concentrate in these areas towards the end of the dry season when feed is scarce. However, it was not specified whether this is occurring in the Flinders River catchment. Bartolo (2006b) and Southern Gulf Catchments (2005b) both reported stakeholder observations of erosion in the catchment due to livestock, which would suggest some vegetation damage/destruction, although the extent of this is unclear.

Introduced invasive flora

Overall, there is little specific information regarding weed issues in the Flinders River catchment, although they are considered a major threat to biodiversity and other ecological values (Fensham & Fairfax 2003; Southern Gulf Catchments 2005a, 2005b; Bartolo 2006b). Rubber vine (*C. grandiflora*) and prickly acacia (*A. nilotica*) are the two most prevalent weeds throughout the Flinders River catchment, and have been ranked by stakeholders as the most serious in terms of impact (Bartolo 2006). Prickly acacia, although typically not considered a wetland or waterway weed, is reported as growing along watercourses and drainage lines (Mackey 1996). Other established wetland weeds include parkinsonia (*P. aculeata*), mesquite (*P. pallida*) and castor oil bush (*Ricinus communis*). Less frequent but potentially of concern include bellyache bush (*Jatropha gossypiifolia*) and parthenium (*Parthenium hysterophorus*) (Southern Gulf Catchments 2005b).

Other wetland weeds of concern that are suited to, but not yet established in the region include cabomba (*C. caroliniana*), mimosa (*M. pigra*) and salvinia (*S. molesta*). Fensham & Fairfax (2003) suggested that the establishment and growth of exotic perennial pastures, including para grass (*B. mutica*) and hymenachne (*Hymenachne acutiglumis*), may well represent the next major threatening process that could further degrade the GAB springs.

Local authorities are responsible for weed control across the catchment. However, Southern Gulf Catchments (2005a) noted that weed management across the region has been poorly resourced and difficult to undertake.

Introduced invasive fauna

Overall, there is little specific information regarding feral animal issues in the Flinders River catchment, although numerous exotic species are known to occur in the region (e.g. pigs, cats, horses, cattle, rabbits, cane toads) and to have substantial ecological impacts (Southern Gulf Catchments 2005b). Densities of feral pigs in the region are thought to be higher than in most other parts of Australia (Southern Gulf Catchments 2005b). Hogan & Vallance (2005) reported pig damage along the margins of waterholes in the Flinders River catchment.

Rabbits, which are restricted to the south of the catchment, also occupy the riparian zone, with burrowing causing bank erosion. Cats impact upon birds, reptiles and small mammals, whilst wild dogs both kill and harm livestock and to a lesser extent wildlife (Southern Gulf Catchments 2005b). Cane toads occur where there is permanent water, primarily associated with urban areas and off-stream water impoundments. Introduced fish species have not been detected in the Flinders River catchment (Hogan & Vallance 2005), although the Queensland Department of Primary Industries and Fisheries monitors the Flinders and other Gulf rivers due to their proximity to the Burdekin River catchment and catchments around Townsville, which harbour populations of tilapia and other exotic fish species.

Contamination

Although recognised as a potential threat to the surface and groundwaters of the region (Southern Gulf Catchments 2005b), there is little information on the extent of contamination of waterways within the Flinders River catchment. Activities/pressures in the region identified as potentially contributing to contamination of waterways include mining, irrigated agriculture, grazing, urban development and tourism (Department of Natural Resources Mines and Energy 2004; Southern Gulf Catchments 2005b).

2.5.4 Assets–threats matrix

Table 2.17 represents the asset-threat matrix for the Flinders River catchment, showing the situation for (i) the current status of the catchment (black ticks) and (ii) the potential status of the catchment based on a significant increase in water resource development centred mainly around irrigated agriculture utilising surface and groundwater (black plus red ticks). The future development 'scenario' was chosen given the strong interest in further developing irrigated agriculture in the region (see Sections 2.5.2 and 2.5.3).

Based on the existing information on the Flinders River, the greatest threats to the surface water ecosystems at present appear to be land degradation (due to pastoral activities), exotic plant species, poorly managed fire and extraction of groundwater from the GAB. The extent of the threat of exotic animal species is unclear due to a lack of information. However, numerous feral species are known to exist in the catchment and are thought to cause substantial impacts.

Whilst surface water extraction and water impoundment do not represent a major threat to the catchment at present, the use of river water for irrigated agriculture is undoubtedly an emerging issue, and probably the most likely development scenario for the catchment. Future large scale regulation and utilisation of the Flinders River's surface water resources could well have a major impact of the aquatic ecological assets. Mining in the catchment may expand significantly. However, at present it is not considered as significant a threat as surface water extraction and water impoundment for irrigated agriculture.

Table 2.17 Assets–threats matrix for the Flinders River catchment based on (i) the current status in the catchment (black ticks) and (ii) the potential status given an increase in water resource development centred around irrigated agriculture utilising surface water (black plus red ticks).[1]

Assets (& key values)	Threats							
	G'water extraction	S'water extraction	Water impoundment	Land clearance/ loss of native vegetation cover	Invasive flora	Invasive fauna	Altered fire regime	Contamination
Waterways	✓	✓ (red)	✓ (red)	✓	✓	✓	✓	✓ (red)
Freshwater discharge	✓	✓ (red)	✓ (red)	✓		✓	✓	
Water quality	✓	✓ (red)	✓ (red)	✓	✓	✓	✓	✓ (red)
Wetlands	✓	✓ (red)	✓ (red)	✓	✓	✓	✓	✓ (red)
Wildlife nurseries & refugia	✓	✓ (red)	✓ (red)	✓	✓		✓	✓ (red)
Riparian vegetation	✓	✓ (red)	✓ (red)	✓	✓	✓	✓	
Erosion control/sediment retention	✓	✓ (red)	✓ (red)	✓	✓	✓	✓	
Habitat for wildlife	✓	✓ (red)	✓ (red)	✓	✓	✓	✓	
Biodiversity	✓	✓ (red)	✓ (red)	✓	✓	✓	✓	✓ (red)
Endemism	✓	✓ (red)	✓ (red)	✓	✓	✓		
Threatened species & conservation reserves	✓	✓ (red)	✓	✓	✓	✓	✓	✓ (red)

[1] NB: an attribution of a threat to an asset/value does not imply that the threat is currently impacting the asset/value, but that, if sufficiently severe or prolonged, it has the potential to do so.

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