3. Origins of Central Australian Wetlands: Hydrology, Geology, Geomorphology and Past Climates

Scope

The ecological functioning of wetlands is strongly influenced by broader landscape processes. A general understanding of the hydrological systems and geomorphology of the arid NT provides a foundation for understanding the wetlands. Here, a brief overview is given of: the sources of water in those wetlands; the geological origins of the present landscape; knowledge of past climates; and ongoing geomorphic change. The aim is to illustrate the broad processes and time scales involved as a background to understanding the present day distribution and function of arid NT wetlands and their biota. This section also introduces terminology used elsewhere in the report.

3.1 Hydrological Processes in Arid NT Wetlands

Hydrological processes have a fundamental influence on both the existence and ecological function of wetlands. Hydrology is the study of the distribution and movement of water in the natural environment and incorporates the ways in which water reaches a wetland and the frequency, duration and depth of inundation. The movement and retention of water are strongly determined by the shape of the land surface (landform) and by the substrate (soils and rocks). Thus, in the words of Barson and Williams (1991, p.9):

> 'Wetlands are the surface expression of interactions between regional hydrology and geomorphology at a particular position in the landscape'.

The following section provides an introduction to hydrological aspects of arid NT wetlands. Readers seeking a deeper understanding are recommended to commence with the following references. Paijmans *et al.* (1985) provide a general overview of the hydrological cycle as it influences wetlands. Hatton and Evans (1997) summarise aspects of groundwater hydrology and its influence on ecosystems including wetlands. The hydrogeology of the Amadeus Basin is effectively summarised by Jacobson (1996), including the main aquifers, their recharge and the rates at which water moves within them. Various other hydrological sources are cited through the report. The following summary of wetland hydrology was influenced by the sources above but also by information from hydrogeologists based in Alice Springs (Graham Ride, Robert Read and Anthony Knapton pers. comm.).

Sources of Water in Wetlands

Paijmans *et al.* (1985) divide the ways in which precipitation supplies wetlands into four systems, These are described below with some additional interpretation.

> **Regional runoff**: reaches the wetland by in-channel flow from upstream surface runoff. Channel flows may also include some water from groundwater discharge into the channel. Channels may discharge directly into a wetland basin or by side (distributary) channels or by over-bank flow. Under our definition of a wetland, channels themselves and waterholes along them are also wetlands.
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> **Local runoff**: is precipitation in the vicinity of the wetland, including directly over it, delivered by local stream channels and also sheet-flow.
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> **Regional ground water flow**: supplies wetlands in the discharge zones of major groundwater basins such as: the Great Artesian. There are several large hydrological basins in the arid NT, as well as smaller ones, including both confined and unconfined aquifer systems. Boulton and Brock (1999) distinguish 'effluent' streams, those being charged with water entering the channel from ground water, and 'influent' streams, which are those which are losing water into the ground. A single river may cross a series of groundwater discharge and recharge zones, such as the Finke River (G. Ride pers. comm.). Many salt lakes are regional discharge areas (Wischusen 1998) as well as receiving surface water from regional and local runoff.
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> **Local groundwater flow**: describes areas that have 'have recharge and discharge areas on adjacent minor topographic highs and lows, [such as] sand dune ridges and swales'. Groundwater flow paths range from 'a few metres to about a kilometre, with response time no more than a year or two' (Paijmans *et al.* 1985, p.6). In the arid NT it is likely that after major rain events shallow ground water systems also operate between salt lakes and surrounding sandplains and probably over distances greater than 1km. Also, we have documented small-scale wetlands in the arid NT that are dominated by local aquifers in relatively large mountain ranges, not just minor topographic highs.

All four of these supply systems operate in the arid NT, although the distinction between them is not always clear. Their relative importance is discussed for wetland types and for some individual wetlands in the following chapters. Each system can also be a component of water loss from wetlands. However, the main cause of water loss is evaporation (including transpiration by plants). Because annual evaporation is very high across the arid NT, permanent water bodies are rare and nearly all of 'those that do occur depend on groundwater flow' (Paijmans *et al.* 1985, p.4).

Groundwater Systems and Terminology

Groundwater includes water in saturated soil and unconsolidated sediments as well as rock aquifers. Rock aquifers store and transmit water in a variety of ways including general porosity, gaps created by fracturing and gaps from chemical reactions such as in calcareous rocks (e.g. limestone caves). The term water-table can apply to various groundwater types.

Aquifer discharge at or near the earth's surface has various expressions; from massive salt lakes to tiny seepages supporting relict fern species. Salt lakes typically have a zone of saturated hypersaline soil (brine pool) below a crust. Places where aquifer discharge creates surface water flows are typically called springs. Where the discharge rate is too low to create running water, terms such as seepage, soak or 'blind spring' may apply. The substrate also influences whether or not there is running water. Even small discharge rates onto rock or clay can produce running water. In sand, coarse gravel and cobbled ground, such as many river beds, a much greater rate of discharge is required to create running water. The flow rate of many springs varies markedly through time, depending on the magnitude of recharge events and the time between them. Some springs dwindle to a seepage or may cease altogether between recharge events. In cases where aquifer discharge rises through a soil layer, transpiration and direct evaporation from the ground will effect the rate of surface water flow. Accordingly, ambient temperatures and the successional state of vegetation can also influence surface flows at such springs.

Some springs are essentially hidden because they discharge into permanent waterholes. Other aquifer discharge may be hidden by the depth of 'soil' above. A fascinating example of this is Palm Valley, where sub-surface aquifer discharge sustains the relict Palm Valley Palm trees in the drainage lines. This is undoubtedly a groundwater dependent ecosystem as defined by Hatton and Evans (1997), yet its status as a wetland is ambiguous. The palm trees gain access to groundwater where the drainage lines are incised into overlying rock strata, but their presence is not obviously dependent on inundation or surface soil saturation.

Some aquifer discharge is directly into river sands. At Running Waters, on the Finke River, the massive rate of discharge produces a large permanent running waterhole, hundreds of metres long. At Ettenia Spring a much smaller discharge produces a short shallow running stream within a sandy creek bed. It is likely that there are various other examples that do not produce any surface flow, being 'hidden' by the depth of sand, gravel or cobbles above.

Although the rivers of the arid NT are dry most of the time, many have water 'flowing' under the sand in the hyporheic zone. Some waterholes are sustained by this hyporheic flow and are 'windows' on the riverine watertable. The water in the hyporheic zone includes a mixture of surface water from runoff that has drained into the sand and water from aquifer discharge. The magnitude of hyporheic flow in arid NT rivers is largely undocumented but it is possible that hyporheic flow may be a significant source of recharge for some aquifers (Graham Ride pers. comm.).

Graham Ride (pers. comm.) reports that the salinity of some long-term/permanent waterholes can vary over time, being generally freshest after river flows, and typically becoming saltier due to a combination of evaporation and saline ground water discharge. He also has evidence that the salinity of discharging ground water can change through time. An example of saline discharge from our work is a change in conductivity in the Finke River from 2700us/cm near Idracowra Homestead to over 4000 us/cm downstream near Horseshoe Bend Homestead. Conductivity was measured in residual (post-flood) flow and the increase in salts corresponds to the confluence of the Finke River and the Karinga Creek Paleodrainage System.

Most of the examples above are from confined aquifers, where a water-bearing rock strata is overlain by relatively impervious strata. The sites of discharge or recharge are where the aquifer rocks are exposed at or near the earth's surface and are typically quite localised. Unconfined aquifers also influence wetlands in the arid NT. Unconfined aquifers include unconfined rock strata, unconsolidated sediments and soil; with the zone of saturation being referred to as the 'watertable'. Watertables can discharge into wetlands at various scales in time and space. For example, some upland creeks can keep running for a few weeks after sustained heavy rains, before drying up. This is assumed to be from short lasting shallow watertables discharging directly along the creek channels. However, this is a minor component of inflow for arid NT rivers compared to those in regions of higher and more regular rainfall. In some cases, soaks may be water-table features rather than the result of confined aquifer discharge. Most of the time and in most places in the arid NT, watertables are very deep, if present at all. Major exceptions to this are some of the main salt lake systems and some saline swamps such as Stirling Swamp in the Ti Tree Groundwater Basin. In these situations the discharge zone is typically spread across a large area and is associated with a topographic low forming a 'window' on the watertable. Groundwater discharge into salt lakes may include more than one distinct aquifer, such as at Lake Amadeus. Jacobson (1996) reports that regional discharge of an unconfined aquifer has created and sustains the salt lake, whilst at some points in the lake, confined aquifer discharge creates relatively fresh springs.

Patterns in Surface Runoff

Although ground water has a profound influence on the permanence and ecology of some wetlands, the majority of the water in arid NT comes from surface runoff. This includes salt lakes and most spring-fed pools. Runoff occurs when surface soil is saturated such that ongoing rainfall cannot soak into the ground and flows over the surface. Depending on the terrain, such runoff may be concentrated into drainage channels or may collect in 'run-on' areas. Water moving over the land in this way is also called sheet flow. Some but not all run-on areas are wetlands. Most of the water in large wetlands comes from runoff that has concentrated in major rivers and creeks. The major rivers are generally dry on the surface, running only when heavy rains fall in the catchments. Sometimes they burst their banks and flood out on the adjacent plains and in some places swamps in the adjacent plains are filled from distributary channels. These are minor channels that flow out from larger channels.

The pattern of rainfall through space and time has an important influence on the inundation frequency and persistence of wetlands. Most of the wetlands in the region are temporary and inundation patterns are as unpredictable as the rainfall. A single intense rainfall event or a series of events from the same cloud system can cause rivers to run or flood; even in relatively dry years. Rivers may run for only part of their lengths or throughout. Some large lakes and swamps may stay dry for several years, yet once full they may be topped up in successive rain events without fully drying out in between.

Various authors have analysed the flow patterns of Australian rivers and noted great variations, especially in the arid-zone (e.g. Puckridge et al. 1998, Boulton & Brock 1999):

> 'flows in Australian streams and rivers are nearly three times more variable than the world average, and those in Australian arid-zone streams are especially variable' (Boulton & Brock 1999, p.18, citing McMahon *et al*. 1992).

The flow regimes of the arid NT are among the most variable in arid Australia, with extreme fluctuations between zero flow (for up to several years), and large intense floods. The duration of channel flows can range from a few hours to many months depending on the intensity, duration, extent and frequency of rainfall. Typically flows are brief, lasting a matter of days or weeks. In rare circumstances flow extends for a period of months. For example, surface water ran in the Todd River at Alice Springs for 67 days in 1974 (Kotwicki 1989 citing Verhoeven) and sections of the Finke River reputedly ran for most of an 18 month period in 2000 and 2001.

Stream flow gauging data exist for various arid NT rivers which would allow their flow regimes to be quantified, but such analysis is beyond the scope of this study. Barlow (1988) analysed steam gauging data for the Todd River, from 1952 to 1988. In that period there were three years of no or minimal stream flow, of which two were consecutive (and 2 years of no data) with the maximum flood height of 3.98m recorded in March 1988.

The rainfall data for the study area indicate that stream flows are more reliable in the north of the study area than in the south.

In recent decades, a conceptual model of water flow and nutrient regimes has been developed for rivers with variable flow, called the 'flood pulse concept'. The following is a summary extracted from Puckridge et al. (1998):

> 'the concept deals only with pulses that overflow the banks ....[and is] based on large tropical rivers' (Puckridge *et al.* 1998, p 55).

They suggest ways of expanding the flood pulse concept to wider applicability:

> 'regular pulses of river discharge are a key factor in the dynamics of river-floodplain systems'.

Ongoing study of the Coongie Lakes area of the Cooper Creek system have provided insights into the floodplain ecosystems of arid Australian systems with episodic floods.

A model called DRY/WET was formulated to describe the ecological dynamics associated with episodic floods in rivers in the Australian arid zone and was based on studies of the Coongie Lakes area of the Cooper Creek system (Puckridge *et al.* 1999). This model may have limited applicability in the NT because of important differences in rainfall patterns and the landform of the floodplains. A subsequent study of selected Lake Eyre Basin rivers is currently underway, called ARIDFLO (Puckridge *et al.* 2001).

In the arid NT, intense episodic rainfall events have an important influence on patterns of wetland inundation as well as mitigating the prevailing aridity of the general landscape. Additional information on describing the frequency and duration of inundation events is presented in chapter 5 in the discussion of attributes for classifying wetland types.

3.2 Geology and Paleoclimate

Past climates are part of the key to understanding the contemporary distributions of wetland plants and animals, particularly those with poor dispersal mechanisms. Wetland environments are assumed to have been more widespread and less temporary during various past periods of moister climate. Similarly, at times, drainage systems have been more active than at present and at times are presumed to have sustained year round flow. Such times are referred to as 'pluvial' periods, although evidence is still inconclusive as to their timing. It is also believed that past drainage networks and many of the present day rivers had more connectedness with each other.

The Origins of the Biota

One of the defining characteristics of arid NT wetlands is the occurrence of fish, aquatic invertebrates and aquatic and semi-aquatic plants that are separated by great distances from other populations of the same or related species. These disjunct populations result from some combination of contemporary dispersion and relictualism. Relictual species are those with highly restricted populations believed to be relicts of previous more widespread distributions; often associated with a wetter climate. Accordingly, some contemporary wetlands or their biota may be relicts of previously more widespread wetlands (Williams 1998c; Davis & Froend 1998; Morton *et al.* 1995; Latz 1996, Williams & Allen 1987; Keast 1959). Isolation also occurs through landscape formation processes at various scales in time and space. Changing climates have interacted with geological processes of landscape uplift to drive the erosion and deposition to create the contemporary landscape, drainage networks and wetlands. Periods of aridity are associated with wind driven erosion and the creation of sand dunes. Wetter periods are associated with the action of rivers in transporting sediments and with larger and more interconnected wetland systems.

Williams and Allen (1987) summarise knowledge of the origins of the fauna of Australian inland waters and Allen *et al.* (2002) discuss the evolutionary origins of the fishes.

Geological History

The information presented below commences with a brief account of the geological development of the landscape of central Australia and the relationship between the formation of the Australian continent and past climate. This sets the time scales for subsequent discussion of more recent prehistoric climates of the past tens of thousands of years.

Popular science education has created a general awareness that large parts of central Australia were once occupied by a vast inland sea or seas. It is important to note that the vast sea or seas were far back in geological time, before the Australian continent existed as we now know it. The rocks of the Amadeus Basin extend roughly from Alice Springs to Uluru (Ayers Rock) and are formed from sediments deposited in marine waters at various times between about 850 and 400 million years ago (Ma) and at its largest the Amadeus Sea (850-750 Ma) extended several hundred kilometres in all directions from the location where Alice Springs is now (Thompson 1991). The most recent major uplift occurred around 340 to 310 Ma on the northern edge of the Amadeus Basin, called the Alice Springs orogeny (Thompson 1991), creating the precursors to the present day MacDonnell Ranges. The once vast mountains are now mostly eroded away, with the resulting sediments over 3km deep (Thompson 1991). However, the remaining mountains still create some active drainage including towards the present day Lake Amadeus. Various other marine basins resulted in sedimentary deposition to form the Georgina, Wiso and Ngalia sedimentary basins (Thompson 1991). Many of the rocks that form the hills and ranges of the present day are of even older origin than the sediments of the Amadeus Basin, including the Musgrave and Mann Ranges in the south and the Arunta Block to the north.

Even when the Australian continent developed to approximately its current size and shape, it did not occupy the same place relative to the poles, the equator and other landmasses. Australia is believed to have separated from the Gondwana super continent about 53 million years ago (Beckman 1996). There is fossil and pollen evidence that Australia had a generally cool wet climate at that time (Truswell & Harris 1982). When Australia separated from Antarctica, global oceanic and atmospheric circulation systems would not have resembled their current patterns until continental drift moved the various continents to approximately their current positions. One major ongoing influence on the climate of central Australia would have been the distance from the coast and a correspondingly low rainfall relative to the whole continent (Williams 1984).

For a more detailed introduction to the geology of the area and mountain building and sedimentary deposition, readers are referred to Thompson (1991) and to Jacobson (1996).

Paleoclimate and Vegetation

Information on past climates comes mainly from studies of sediments and organic matter trapped within them, including pollen, but also from geological features created by relatively recent glaciation around the world and chemical analysis of polar ice deposits and organic matter trapped in ice. Wetlands are particularly important areas for the storage of pollen that can be used to study past climates and vegetation.

Studies of vegetation change in response to climatic change and evolution draw largely on pollen in the sediments of ancient swamps and lakes (the study of palynology). Examples for central Australia include Bowler (1982) and Truswell and Harris (1982) in the *Evolution of the Flora and Flora of Arid Australia* (Barker and Greenslade 1982). Bowler provides an account of patterns of aridity across the continent going back to 20 million years in time when the spatial arrangement of the continents was significantly different from today and global atmospheric patterns were correspondingly different. Trusswell and Harris discuss the evolution of Australian flora and the past vegetation of today's arid zone from even earlier in geological and evolutionary time. In the distant past, today's arid zone was covered in rainforest (Trusswell & Harris 1982), however that was prior to the existence of most of today's species and barely relevant to understanding present day relictualism.

Williams (1984) indicates that the major drainage systems of central and western Australia became 'defunct' during the Miocene (about 10 million years ago). At that time they ceased to form coordinated or integrated networks.

In more recent times (past 2.5 million years) climate fluctuations have possibly resulted in the present lakes being larger and more permanently inundated at various times.

Dodson (1994) reviews Australian vegetation history and response to climate changes in the Quaternary (back to about 1.8 million years ago) including a paragraph on the arid zone in the past 10,000 years. However, there is scant evidence for the arid zone. A map of vegetation history sites in Dodson (1994) shows a major site at Lake Frome in South Australia and a minor site closer to the NT, in the Dalhousie area, and Barlow (1994) refers to pollen analysis of Eocene Hale River deposits in central Australia.

In relatively recent geological times (last few million years), when the landscape has been broadly the same as now, the world has experienced alternating glacial and interglacial phases, as described by Beckman (1996) and summarised below. The glacial periods (ice-ages) have been relatively dry and cool, with the interglacials at the opposite extreme of warmer and moister weather. Incidences of each of these extremes have lasted a few thousand years, separated by much longer periods of less dramatic fluctuations. The last ice age peaked about 18,000 years ago and we are now experiencing an interglacial climate. Barlow (1994) observes that in the Australian arid zone the driest periods are associated with lower temperatures rather than higher ones.

Various authors have suggested the timing and nature of climate changes in arid Australia during the past tens of thousands of years; the period of most relevance to interpreting both the present day distributions of wetland biota and the phenomenon of relictualism. A recent synthesis of information for past climates in Australia is found in Allan and Lindesay (1998). An earlier, more detailed synthesis of information and evidence on past climate variations for the Australian arid zone can be found in Williams (1984), who indicates that during the glacial-interglacial cycles of the past 2.5 million years, 'the climate of Australia has probably oscillated from relatively warm and wet through cool and moist to cold and dry on at least twenty occasions' (Williams 1984, p.72). Around 30,000 years ago, central Australia experienced a significantly wetter and cooler climate than at present, becoming dry and cool towards the glacial peak (20-18,000 years)(Williams 1984). Kotwicki (1989) cites Bowler (1978) to the effect that the ancestral Lake Eyre, called Lake Dieri, was constantly filled for a long period from about 45,000 to 25,000 years ago. It should be noted that most of this filling could have been predominantly from distant catchments in the north east, which now reach the lake though the Georgina and Diamantina Rivers and Cooper Creek. Central Australia would probably have been relatively dry due to its distance from coasts, but quite possibly wetter than at present. Lampert (1989) states that for the south-eastern section of the arid zone, between 10,000 and 5,000 years ago conditions were the moistest and warmest of the past 30,000 years. It is possible that the arid NT was correspondingly moist and warm and many of the rivers may have flowed much more frequently than at present, if not continuously. In contrast, about 18,000 to 15,000 years ago the centre of the continent was possibly so arid as to preclude human occupation (Lampert 1989).

English (1998a & 1998b) discusses the paleoclimate and geomorpoholgy of the present day Lake Amadeus and cites evidence from Chen and Barton (1991) that a 'fluvial lacustrine phase persisted in the present day Lake Amadeus for at least 5 m.y. [million years] before the onset of hyper-arid Quaternary conditions' with aridity generally intensifying from 2 Ma (million years ago) to 10,000 y BP (English 1998a, p.60) (note: BP = before present). Thus, around one million years ago, Lake Amadeus may have been a freshwater lake, but then became saline before becoming generally dry, as summarised by English (1998a):

> 'Aridity intensified during the Pleistocene (2 Ma-10 000 y BP) although the whole Quaternary is characterised by oscillating climatic regimes. By 750 000 y BP, saline conditions prevailed at Lake Amadeus (Chen & Barton 1991), which contracted, dried up and evolved into a groundwater discharge zone and salt lake. According to work elsewhere in central Australia, the last major channel-sand loads accumulated during two interglacial periods around 250 000 and 110 000 y ago (Nanson *et al*. 1992).' (English 1998a, p.60)

3.3 Geomorphology

Wetland Landforms and Development

A detailed examination of wetland geomorphology in the arid NT is outside the scope of this study but it is important to understand its dynamic nature. Paijmans *et al*. (1985, p15) describe wetlands as ephemeral features of the landscape, because many wetland types are created and destroyed relatively quickly compared to other elements in the landscape.

Arid NT wetlands are predominantly formed by processes of wind and water movement; both in the erosion of surfaces and the deposition of barriers to water movement (e.g. river levee banks, sand dunes). Also, various human earthworks modify existing wetlands and create new ones but they are not considered here. Glaciation, volcanism and earthquakes have not had an obvious role in forming present day landforms in this region, unlike some other parts of Australia. Large meteoritic impacts have been involved in the formation of some landforms, but not to the extent that they are an important part of wetland geomorphology.

Most wetlands occur in closed depressions (basins) which over time are infilled with water born sediments or are breached when a retaining barrier is dissected by water flow. Many channel based wetlands are also ephemeral in that channels on lowlands change their exact course and even waterholes in rocky gorges may be scoured out or infilled with sediments in particular flow events. Pickup (1991) discusses geomorphological process in floodplains (in the broad sense) and Patton *et al.* (1993) present a detailed analysis of the lower Ross River area where massive movement and deposition of sediments has occurred during extreme flood events in the past thousands of years. Typically, only extreme flood events influence erosion and deposition in the broader landscape outside of established channels and Pickup (1991) emphasises the overriding importance of sporadic mega-floods in central Australian landscapes, which far outweigh the effects of more frequent river flows such as those recorded in the past 100 years.

Rainfall runoff and erosion are influenced by factors such as drought and contemporary grazing as well as rainfall intensity (Pickup 1991). Changing fire regimes may also be important (P.Latz pers. comm.). Indeed large and intense fires can have a more pronounced effect on vegetation cover than drought.

During major river flows, large amounts of sediment in the channel are mobilised by mixing with water. Therefore, river channel depths can markedly increase during flows. Barlow (1988) estimated that stream sediments in the Todd River were disturbed to a maximum depth of 3m below the pre-flood river bed during the 1988 flood. However, cross-sections of the river bed prior to and following that flood showed little change. The rates at which river levels rise and fall through a flow event probably influence the manner in which sediments are scoured from the river and redeposited. Thus some waterbodies may be deepened in one flow event and filled in with sediment in another. The amount of vegetation cover and the intensity of rainfall events also influence runoff and flow patterns (Pickup 1991; G. Ride pers. comm.).

Past climate changes have had an important influence on the geomorphology of depositional features in the landscape; particularly sand dunes but also sand plains and alluvial plains and fans. Periods of higher rainfall are presumed to have resulted in increased fluvial erosion in upland areas and sediment transport to lowland areas. In drier times, winds move and structure sediments, such as in the formation of sand dunes. Various authors present evidence that the Simpson Desert dunefields were actively formed during a much drier and windier climate associated with the last ice age; between 25,000 and 13,000 years ago (Wasson 1984). Jacobson (1996) dates the stabilisation of dunes in the Lake Amadeus area as occurring in the period of 14,000 to 34,000 years BP, based on thermoluminescence dates of dunes at Yulara and Curtin Springs.

Salt lakes and claypans are predominantly flat due to the erosive action of wind across their unvegetated surfaces. Salt lakes are formed by the concentration of saline ground water which discharges into them and many have permanently saturated brines in the soils, even though the surface may be a dry saline crust (Jacobson 1996).

Where saline playas have become isolated from the ground water discharge system, they may become vegetated, and consequently aeolian (wind borne) sediments may be trapped: a process described as 'playa capture' (Jacobson and Jankowski 1989). Claypans east of the Stuart Highway, in the Karinga Creek paleodrainage area may also be 'abandoned playas' being 'well above the regional water table' (Jacobson 1996, p. 261).

Various authors give accounts of the geomorphology of present day landscapes, including wetlands. A valuable general summary of the processes of erosion and deposition that form and modify wetlands is given by Paijmans *et al*. (1985) in *Aspects of Australian Wetlands*. More detailed accounts of the geomorphology of the arid NT can be found in texts such as Mabutt's *Geomorphology of the Alice Springs area* (1962) and *Desert Landforms* (1977) and a useful summary is given for the Simpson Desert region by Purdie (1984).

Large Prehistoric River Floods

Large flood events have a particularly important geomorphic influence, through the erosion and deposition of sediments. New swamps, claypans and watercourses may be created by large floods whilst others may cease to function as wetlands for many years because water has been diverted along new or different paths. Studies of the Todd and Hale rivers have indicated that those watercourses have significantly changed their paths in recent thousands of years with floodout areas moving over 100 km (M. Burke seminar).

Studies of river geomorpohology indicate that there have been various extremely large floods in the past few thousand years that exceed those experienced in the past 100 years of written records (Pickup *et al.* 1988; Pickup 1991; Paton *et al.* 1993; Bourke 1994, 1998 & 1999). These are sometimes referred to as mega-floods or paleo-floods and are very important in landscape formation and modification. Whether such floods correspond to climatic fluctuations or are extreme events within the current climatic regime is perhaps just a matter of definition. Sediment dates indicate that a mega flood occurred on the Hale River in the order of 1000 years ago, with slack water deposits in Ruby Gap National Park measuring 12.5m high (Burke 1999).

English (1998a) reports a 1km wide swathe cut through the sand dunes, that extends north from the termination of the channel of Britten-Jones Creek and towards Lake Amadeus. It is not known when the large flood event occurred which cut through the dunes, but in 1974 water flowed along the swathe (G. Griffin, pers. comm., cited in English 1998a).

Knighton and Nanson (2000) note the most recent major pluvial period for the Cooper Creek as having been about 100 ka BP (i.e. 100,000 years ago).