Department of Water
Government of Western Australia

Australian Government

Water notes

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Water notes for river management

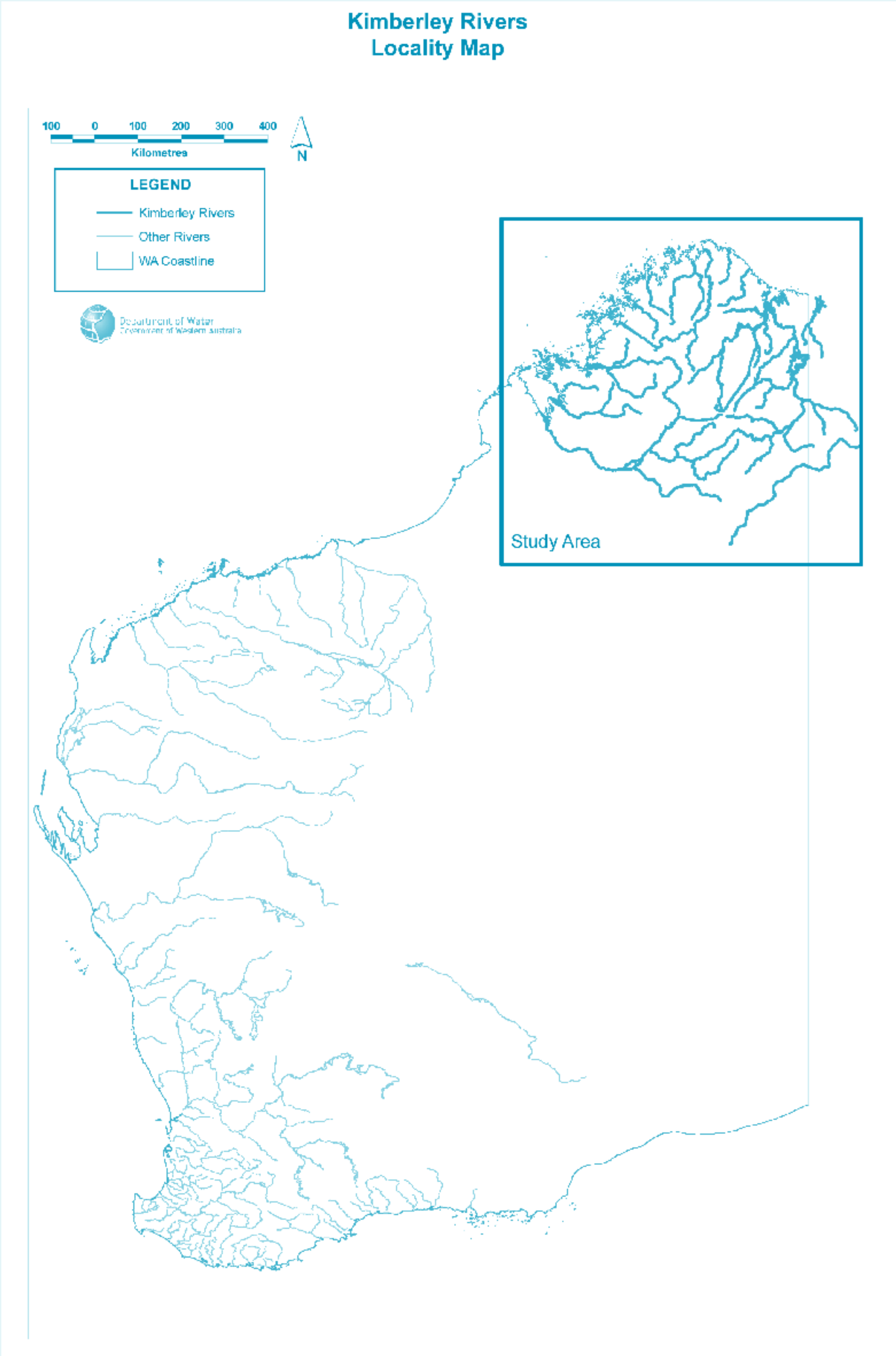
Advisory notes for land managers on river and wetland restoration

The Kimberley river environment

About the Kimberley rivers

King George by Luke Pen

Kimberley rivers come in a variety of shapes and sizes. They include rocky headwater creeks that flow only after heavy rainfall; gorges, where over time water has cut through the rock to form waterfalls and pools; floodplains, where channels can split and rejoin; billabongs that are a refuge for flora and fauna; and tidal reaches where mangrove-lined channels meander over mudflats.



Major waterways of the Kimberley

One feature that all Kimberley rivers have in common is floods. The Kimberley is at the southern edge of the global monsoon system, which exposes its rivers to occasional, intense and widespread rainfall, resulting in floods.

The duration and intensity of a 'wet' season varies enormously from year to year. In addition to floods, smaller, more regular wet-season flows and the long dry season influence the form and function of the Kimberley rivers. The Kimberley rivers and their flora and fauna have adapted to floods and without these floods they would look and function very differently.

Kimberley rivers are valuable wilderness destinations and for fishing, boating, recreation, tourism, stock watering, crop irrigation, power generation, aquaculture and scientific research.

The rivers also have an intrinsic ecological importance. Vegetation in and beside the rivers provides habitat and food for fish, birds and other animals. The fresh water that flows from the rivers into the sea is crucial to the lifecycle of many coastal species and ocean fish.

Kimberley rivers also have cultural and spiritual significance, especially for their traditional owners, as many significant anthropological and archaeological sites are associated with the waterways. New scientific and cultural information about the Kimberley rivers is still being discovered.

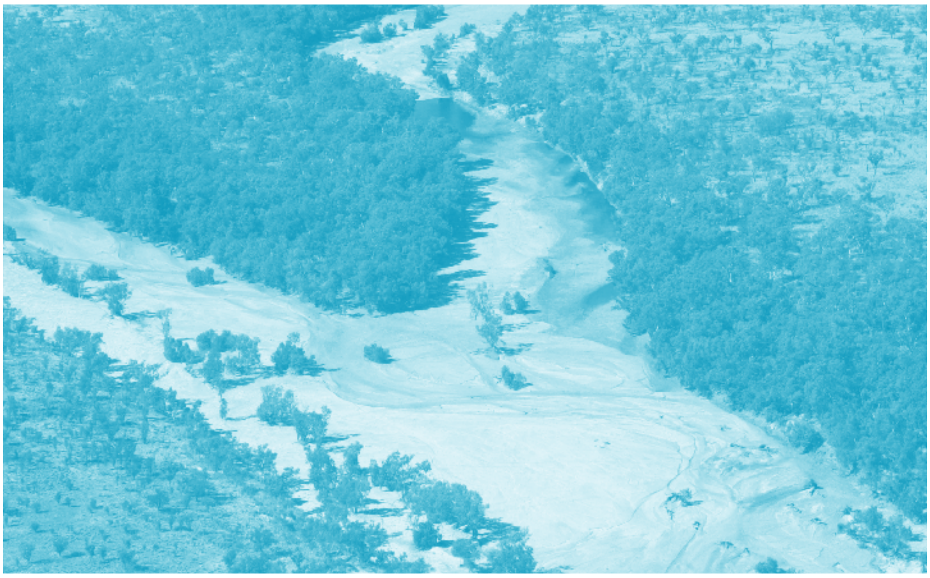
Prince Regent River by Keith Claymore (DEC)

The hydrology of the Kimberley rivers

The shapes and forms of Kimberley rivers

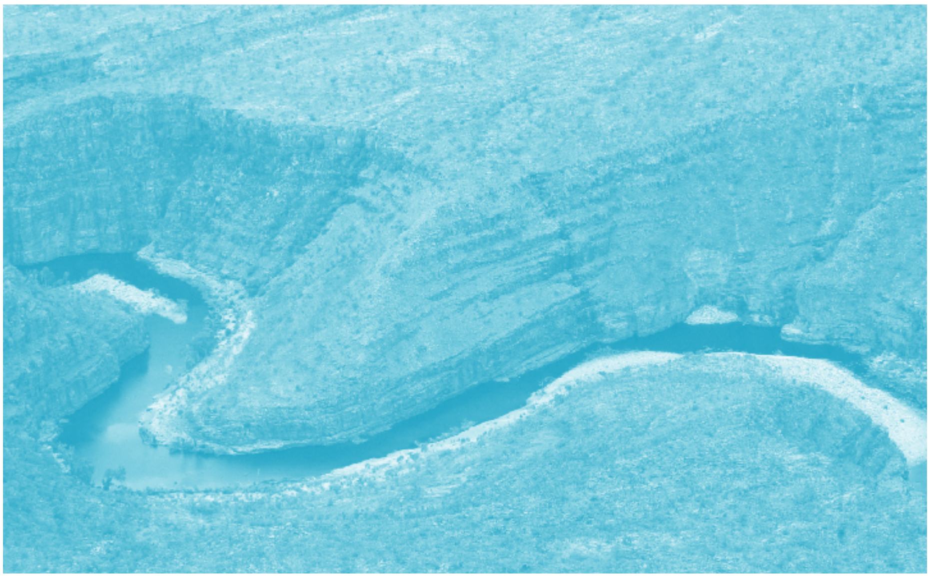
Kimberley rivers are not all the same. Some river channels are sinuous, curving through solid rock or tidal mud; some are full of vegetated islands; others split and rejoin. The river channels can be straight and narrow, or wide and sandy, depending on factors like geological setting (confined or unconfined valley trough), flooding and sediment supply.

Some examples of Kimberley river types are illustrated below.



Lennard River – lower reach

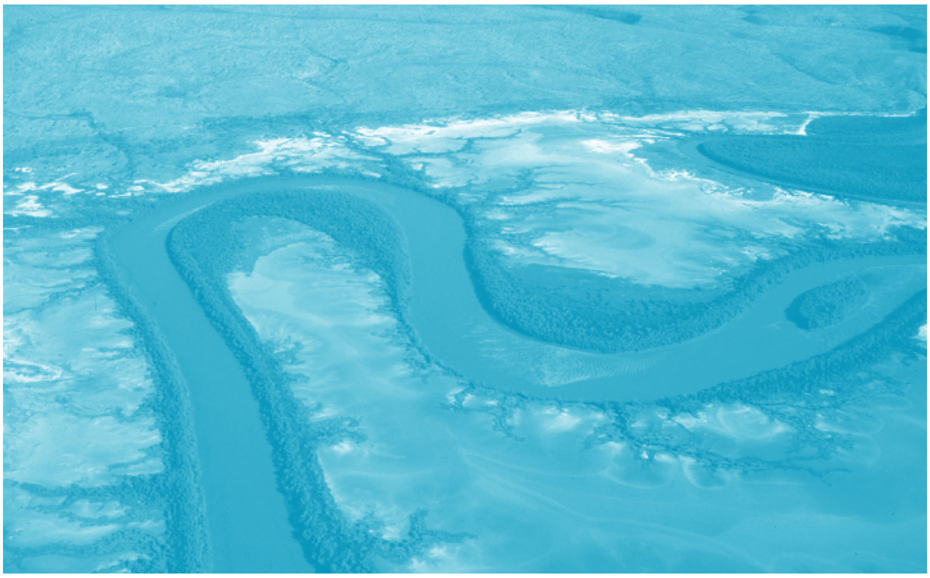
The lower reach of the Lennard River splits and rejoins again and again, creating a lace or fishnet appearance. It is in an unconfined, wide valley and has stable floodplain islands. This form is described as anabranching or braided.



Salmond River – middle reach

The middle reach of the Salmond River meanders majestically through the Pentecost Range. It has cut deeply into the bedrock landscape so that its channel is confined by high rocky walls. Gorges and occasional small pockets of floodplain are present.

On the Fitzroy River, a sandy, moderately sinuous stretch of river meanders through a wide, unconfined alluvial floodplain. It is characterised by point bars, cut banks, levees and backplains. Pools occur at the outer edges of the bends and at shallower sections on the straighter reaches between bends.



Durack River – middle reach by Luke Pen

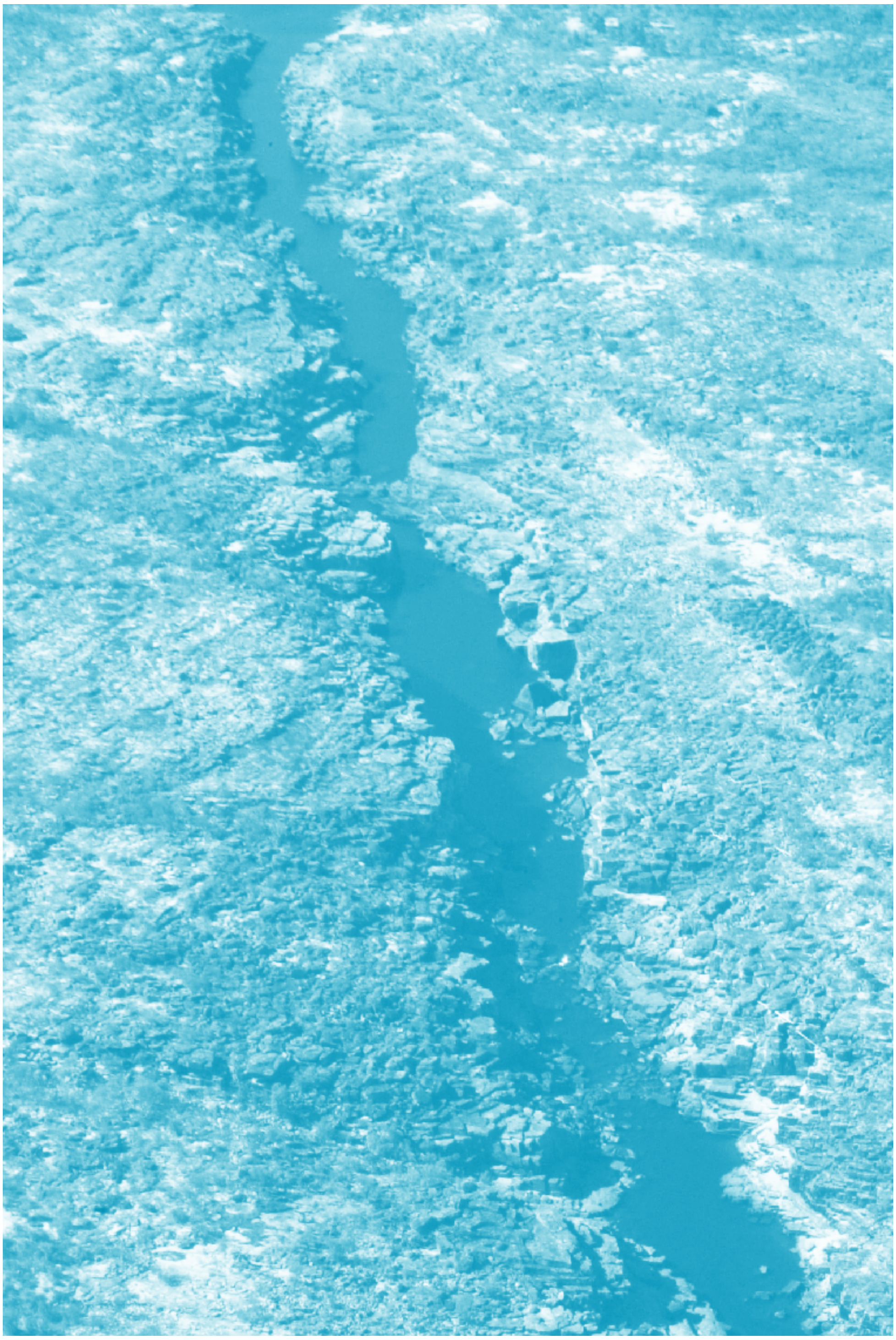
These vegetated islands of the Durack River, up to several kilometres long, do not appear to occur anywhere else. This particular river form has been labelled anabranching because the islands are stable and the active channel splits and rejoins around them. The reach is in an unconfined valley and carries large quantities of sand.

Prince Regent RIver – middle reach

The straight form of this channel on the Prince Regent River is due to a geological fracture line: water follows the weakness in the rocky landscape and erodes it over time. Straight rivers are uncommon in floodplain country, but can occur where the banks are very firm and formed from cohesive soils held together by vegetation.

Fitzroy River – lower reach

Numerous channels divide and rejoin around unstable bars and small islands in this braided river reach of the Fitzroy River. Individual channels vary in width and depth, and banks are irregular and unstable. Vegetation temporarily colonises bars and islands, binding some of the abundant sand until the next flood.



King Edward River – upper reach

In the King Edward River's catchment's headwaters, the rocky landscape, relatively low flow and limited supply of fine sediment create a stable environment that is not prone to change. The headwater creek is confined by bedrock and is characterised by small pools, riffles, runs, step falls and occasional floodplains.

King River – lower reaches

The bends of the river almost double back on themselves in the sinuous channel of the King River, which snakes through a muddy tidal flat. Banks are well defined by the cohesive mud, clay and mangrove roots.

What shapes the Kimberley rivers?

The shape (or form) of a river is the result of many environmental factors acting together. Some of the main factors – geology, climate and vegetation – are discussed briefly below.

Geology, landforms and sediment load

In general

The geology of a catchment directly influences channel form when bedrock or a fault system confines, diverts or cuts across the course of a river and its floodplain. Geology indirectly affects channel form through topography, soil type, vegetation and the amount and type of sediment available for transport by the river.

The geological history of a region might also have influenced the form of a river by changing its slope and sediment supply, either gradually (for example, through a slow uplifting or tilting of the landscape), quickly (for example, through sudden events such as landslides) or both.

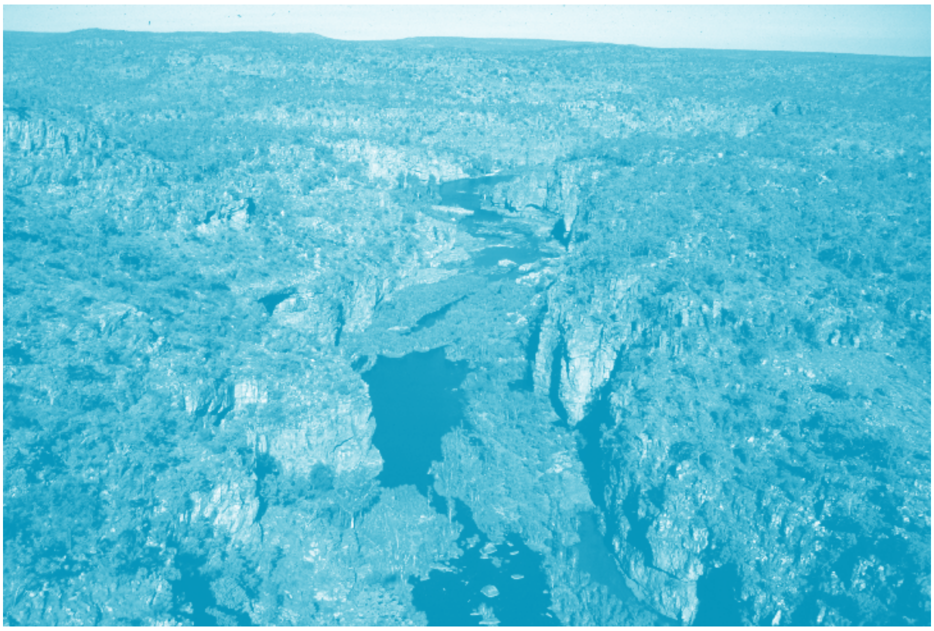
The slope and shape of landforms, such as valleys, affect river forms in several ways; for example, a wide valley floor allows room for curving meanders to develop, whereas very narrow valleys constrain rivers to straighter forms. Steeper slopes can generate faster, more erosive flow than flatter slopes. The amount and type of sediment (the sediment's size and mineral composition) carried by a river and in its bed, banks and floodplain influences channel form as it is eroded and deposited (Water and Rivers Commission, 2002).

In the Kimberley

The northern half of the Kimberley is an ancient sandstone plateau with scattered volcanic outpourings. Over time the plateau has eroded to form a relatively flat but rugged terrain with shallow, sandy soils. Wrapping around the southern margins of the plateau is a band of mixed rock types with many faults and folds. The soils here are shallow sands and loams with pockets of red duplex soils. Because most of the north Kimberley is rocky and soils are thin, heavy rain runs quickly over the land surface, almost immediately producing high flow levels in creeks and rivers.

The southern part of the Kimberley is a younger sedimentary basin and so is less rocky and rugged than the north. Its plains and hills typically have more soil (massive earths, cracking clays and yellow duplex soils), so runoff from rainfall is often less and slower. Also, slopes are generally less steep and valleys broader so that high flows are more spread out and their energy is dissipated.

The Kimberley's age, which has seen long periods of rock weathering and erosion, has resulted in its rivers typically having low–moderate slopes and large sediment loads. Some Kimberley rivers follow geological faults and fractures. Since these weaknesses erode faster than the surrounding land, they often form unusually straight channels. The Prince Regent River is the clearest example of a river directed by a fault system.



Prince Regent River by Luke Pen

Tectonic uplifting of the Kimberley about 20 million years ago provided the steeper slopes and faster flowing water required for many rivers to cut deep gorges. The result is especially visible in northern coastal areas such as the lower reaches of the Berkeley, King George and King Edward rivers, which have spectacular cliff walls and waterfalls.

Climate, river flow and floods

In general

A region's current climate influences the form of a river through rainfall, evaporation and temperature. These affect river flow, sediment transport and bank cohesiveness, as well as vegetation type, density and distribution. A region's climate history has a continuing influence on its rivers through soil properties, weathering rates, sediment supply, bank/bed cohesiveness and vegetation. For example, in some locations earlier aridity and water-table fluctuations cemented the soils so that they now resist erosion and restrict channels from changing form.

River flow and floods – the volume and speed of water moving along a river and the way it is distributed – strongly affect channel form. The average and extremes of flow volume and velocity help determine erosion rates and the amount and type of sediment that can be moved down a river. These factors influence the shape, width and depth of a river. The effects of past flow patterns may still be seen in rivers today. For example, present channels sometimes lie within still-discernible wider and deeper channels that were scoured by higher flows in the past. Earlier flows and floods might have influenced the sediment deposits that present channels flow through, over or around. River flow and floods also affect the type, structure and density of aquatic, riverside and floodplain vegetation, which in turn influences channel form.

In the Kimberley

The Kimberley has two dominant seasons: a hot, wet season from November until April and a warm, dry season from May until October. The average annual rainfall in the north-west Kimberley, 1400 millimetres, is similar to that of the extreme south-west of Western Australia; however, almost 90% of this rain falls during the wet season, while falls for the remainder of the year are light and sporadic. Annual rainfall decreases inland, and in the southern Kimberley averages around 350 millimetres.

Like rainfall, river flow in the Kimberley is extremely seasonal, with approximately 80% occurring in the five months between December and April. During this period, Kimberley rivers discharge, on average, about 32 000 gigalitres of water into the Timor Sea; this is approximately three-quarters of the state's total discharge to the ocean. Annual flow in the Kimberley varies considerably, especially in the drier southern Kimberley, and is much less consistent than in Australia's south-west or along the east coast.

The duration and maximum flow of Kimberley rivers depend on the type of rain and landscape characteristics such as geology, vegetation and soil moisture. For example, a thunderstorm typically results in rapid runoff and small surges in ocean discharge, whereas light monsoonal rain falling over several days produces a moderate but sustained flow. Dissipating tropical cyclones generate widespread heavy rain and floods. Flood flows in the major Kimberley rivers are among the largest in the world for similar-sized catchments (see figure 1).

Flood flows, combined with regular wet-season flows, are very important in shaping the form of Kimberley rivers. Flooding flushes pools and billabongs and deposits sediment on floodplains. Other wet-season flows transport and deposit sediment within channels and provide water for vegetation.

The recent climatic history of the Kimberley is unclear. Research suggests that monsoon rainfall has been similar to today's for at least 3000 years. Cemented soil, formed during a more arid period more than 6000 years ago (perhaps during the last glacial maximum, approximately 18 000 years ago) still influences channel form in some areas of the Kimberley.

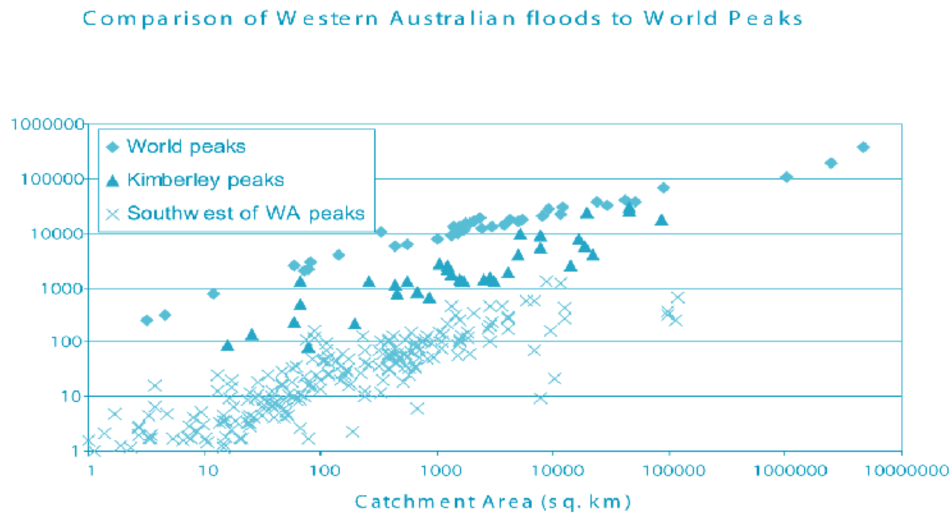


Figure 1: Comparing Western Australian floods with world flood peaks.

Vegetation

In general

Vegetation influences channel form by slowing the water running off a catchment after rain. Vegetation also increases the strength of riverbanks and floodplains.

A well-vegetated catchment reduces runoff by reducing the amount of rain that hits the ground, slowing the flow of water across the landscape and allowing it to filter into the ground via pores and root spaces. This decreases erosion and the amount of new sediment entering a channel, both of which affect channel form.

The type, structure and density of plants growing alongside a river influence bank and floodplain strength and slow the water's speed. Each tier of vegetation – understorey, mid-storey and upper storey – is important. For example, dense, deep-rooted vegetation helps hold channel banks together. Bushy vegetation with a dense understorey of grasses creates more friction to slow flow than bare ground does. Changes in vegetation – from grazing by stock or feral animals, fire or changing rainfall – can have a serious effect on river forms.

In the Kimberley

Catchment vegetation is dominated by tall-grass savanna woodland, curly spinifex savanna woodland, tree savanna, pindan (acacia thickets with scattered trees), tall and short bunch-grass savanna or spinifex steppe. This cover of vegetation, although seemingly thin, plays a role in slowing the flow of rainfall over the landscape, and its effectiveness depends on factors such as the rainfall's intensity and duration.

Common riverside plants include pandanus, paperbarks, acacias, ghost gums and snappy gums. Rushes and sedges can be scarce along grazed waterways.

Plants that colonise channel floors and bars during low-flow periods stabilise sediment deposits and encourage further deposits by reducing flow speeds. Very dense vegetation can also cause channel erosion if it severely restricts the channel's dimensions or diverts flow. Large floods occasionally rip up riverside vegetation and wash away the underlying sediment.

How much water is there?

Just how much water is in the Kimberley? Consider the following:

- In 1993, the peak flow on the Fitzroy River was 23 000 cubic metres per second. In less than three hours this could have supplied Perth with enough water for a year. In six hours the same amount of water would have filled Sydney Harbour.
- In 2000–2001, the Ord River discharged 1500 million cubic metres per second, which is an amount equal to all the divertible water resources in Western Australia in an average year. This sustains one of the state's largest horticultural precincts, generates power for 2 towns and Argyle diamond mine, and provides a controlled reservoir upon which a booming tourism industry and recreational activity is supported.
- The peak flow of the 1956 Ord River flood, 38 000 cubic metres per second, would have filled Sydney Harbour in less than three hours. Flood pulses and flow regimes maintain the internationally recognised ecological values of the lower and upper Ord.

Although these figures show that the Kimberley can have a lot of water, these events are sporadic and unpredictable. The Kimberley also has many poor wet seasons.

The long-held perception that floods and wet-season runoff are a source of abundant 'spare' water may be an exaggeration produced by overly simplistic analysis. Estimates of the sustainable flow yield of Kimberley rivers have been based on records from less than 30 years and the Kimberley's annual rainfall varies considerably, with the last 15 years records having been well above the historic average rainfall. This, uncertainty concerning climate change and growing awareness of the importance of flooding for healthy landscapes are causing scientists and resource managers to re-evaluate resource estimates.

Regulating Kimberley rivers

The most ambitious project to regulate river flow in the Kimberley is on the Ord River. During the early 1960s the Kununurra Diversion Dam was built as the first stage in the development of broad irrigated agriculture in the Ord River valley. The dam formed Lake Kununurra, and the town of Kununurra and the farms of the Ord River irrigation area grew up around it.

In the early 1970s the Ord River was dammed to provide a more reliable supply of water for the irrigation areas. Lake Argyle, formed by the dam, is the largest man-made body of water in Australia. Its volume when full (when the dam starts to spill water) is approximately 10 700 GL, or roughly 15 times the combined volume of all of Perth's water-supply dams. When the dam is full Lake Argyle covers 945 square kilometres. Since 1996, a hydroelectricity plant has operated at the dam, supplying power to Kununurra, Wyndham and Argyle Diamonds' mine. The volume of water available for consumptive use has been determined based on the ecological water requirements of the lower ord, the existing needs for hydro power, agriculture and riverside usage along with projected future demands (*Ord River Water Management Plan*, 2007).

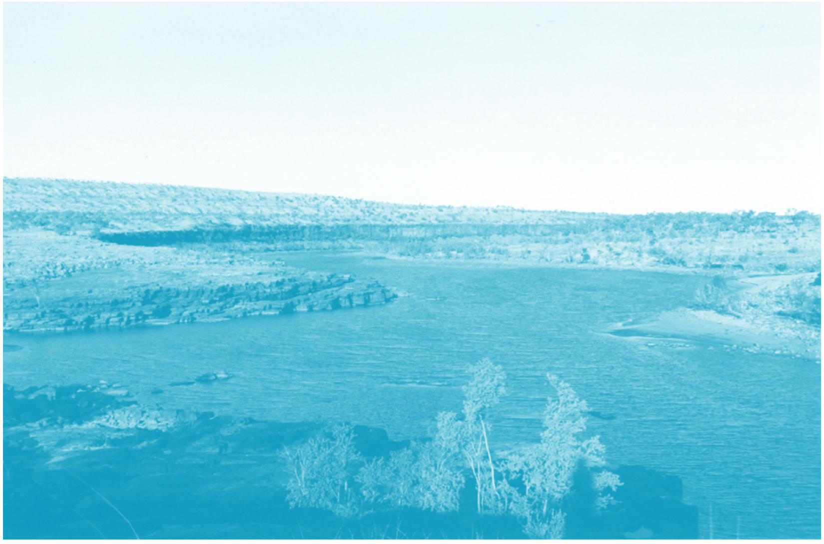
The regulation of flow on the Ord River has had a major impact on the hydrology, ecology and socio-cultural values of the river. The land behind the dam walls has been permanently flooded and the variability of river flow downstream has been altered, with fewer high flows and more low flows. High evaporation rates and losses from irrigation and seepage result in a significant reduction in the river's total annual flow. The stable water body has resulted in riparian vegetation flourishing along its edges and being subsequently recognised as an internationally significant wetland, affording it Ramsar listing. However some ecological values such as fish passage and many indigenous socio-cultural values have been lost such as significant ceremonial sites, dry season pools, hunting grounds and ready access to the river.

Other dams in the east Kimberley are the Moochalabra Dam, which is the main source of water for the town of Wyndham, and the smaller Arthur Creek dam, built on a small tributary of the Dunham River to supply water to a small irrigation area.

On the Fitzroy River, attempts were made to use water for irrigated agriculture at Camballin in the 1950s and 60s. A barrage was built across the main stream of the Fitzroy River, canals and levees were constructed and Uralla Creek, a tributary of the river, was dammed to form the 17 Mile Dam. Attempts to grow cotton were unsuccessful because the extreme flood regimes damaged the irrigation infrastructure, and during the long dry season the water supply proved unreliable. The landowners are constructing water infrastructure to grow fodder crops, but much of the equipment remains in a poor state of repair and the issues of protecting infrastructure from flooding, while provision of a secure water supply year round will continue to be a significant management issue for irrigation development on the Fitzroy. The barrage remains as a barrier to the migration of aquatic fauna and there are ongoing discussions about how to restore fish passage.

The Barrage at Camballin

Floods



The Gascoyne River in flood

Is water going to waste?

When rivers flood, we often hear people talk about 'all that water going to waste'. How much water is wasted? Is it really wasted? What role do floods play in the Kimberley environment? What are the ecological costs and benefits of flooding? Floods are a natural and critical part of tropical river ecology and are essential for maintaining healthy river systems and cycles. Several characteristics of a flood result in landscape change including: its maximum and average flow speed, its duration, the area it covers and when it occurs in relation to other floods and climatic conditions. Floods and peak flow volumes result in highly dynamic river landscapes through processes such as erosion, floodplain - river channel interaction, altering channels, and changing vegetation. These processes affect sediment erosion and deposition, water quality, flora and fauna.

Floods are an integral feature of a river system's function. Floods flush out sediment, organic debris and other material from pools and channels, maintaining their depth and water quality. Floods also deposit sediment on channel banks and floodplains, renewing topsoil and dispersing seeds. These processes can be quite destructive and contribute to spreading weeds and erosion, particularly in areas where the bed and banks of watercourses have been disturbed for roads, dams or infrastructure. These very high volume flows can be very destructive to man made structures such as impoundments.

Floodwaters join channels to floodplains, giving wildlife access to new food sources and the temporary habitats that are necessary for the lifecycles of certain species. Harnessing floodwater – for example, for irrigation or domestic supply –

reduces the power of a flood to flush pools and diminishes the extent to which water spreads over the floodplain. The effect of harnessing floodwater depends on factors such as the characteristics of the channel and surrounding landscape, the size of the flood and the volume of water harnessed.

So, is water being wasted? The Kimberley rivers were formed by flooding and continue to be renewed and reshaped by flooding. The region's plants and animals have adapted to flooding and floodplain environments as integral parts of their life cycles. People who rely on the rivers and riverine resources have also developed management regimes and customary practices that respond to the flood cycles. **Water, and its highly variable flow regime, is thus not being wasted in the Kimberley.**

Using nature to investigate floods

How can you tell if a river in the Kimberley has experienced a flood? With some detective work in the field, combined with modern technology to determine geological age, scientists can sometimes reconstruct flood histories, including magnitude and frequency.

Flood reconstructions are important for development planning – such as the placement and design of bridges or houses – for water management and for climate modelling. Reconstructions are needed because many Kimberley rivers have no flow-gauging stations due to the vast extent of the region and high level of inaccessibility. Even where there are gauging stations, flow records usually go back only several decades – a dilemma in a region where large floods occur on time scales of hundreds of years.

Nature leaves many clues that record the passage of a flood. Clues to recent floods include:

- logs, branches and/or twigs caught high on the upstream side of trees
- tree trunks stained with mud
- trees that have been bowled over in a downstream direction – some may have new shoots growing upwards at right angles to the original trunk
- a 'bath-tub rim' of twigs, leaves and grasses at the high watermark
- ripple marks in silt or sand high on banks or on the floodplain
- a layer of pebbles and/or cobbles carried up over finer soils by stronger than normal flows.

Pentecost River March 2002 from Gibb River Rd US by Michael Harris

The clues used to identify earlier floods are more subtle. An important clue is a 'slack water' deposit: the sediment left when a flood recedes. Such deposits are sometimes found in places such as caves high up in gorge walls. Scientists can calculate a flood's magnitude from the height of the deposit above the channel floor, the width of the gorge and other factors that affect flow, such as the slope of the land. Techniques such as radiocarbon and thermo-luminescent dating are then used to determine the age of each sediment layer. In some cases sediment deposits surrounding waterfall pools and floodplain deposits are included in the calculations. 'Slack water' investigations have been carried out at sites in the Kimberley, including Windjana Gorge, Geikie Gorge and the Fitzroy River floodplain.

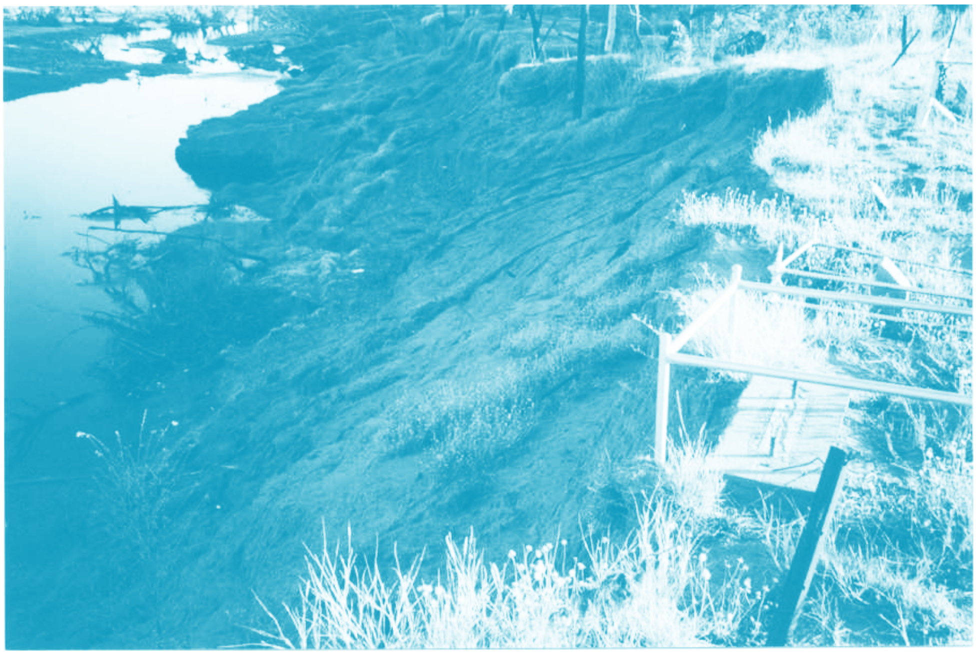
Big floods in the Kimberley

Case study 1: Fitroy River

The Fitzroy River has seen several significant floods during the past 100 years. One of the largest occurred in 1993 when the peak flow at Fitzroy Crossing was estimated to have been greater than 25 000 cubic meters per second. This is equivalent to the volume of water of 15 Olympic swimming pools passing every second. The flooded area extended from the junction of the Margaret and Fitzroy rivers to the coast – about 350 kilometres – and its width ranged from 5 kilometres to about 25 kilometres. It took more than a week for the flood peak to move from Fitzroy Crossing to Willare Bridge, near the river's outlet at King Sound. Observers commented that the area looked like an inland sea.

Road access was cut to Fitzroy Crossing and several other low-lying communities and pastoral stations on the Fitzroy and Margaret rivers and Christmas Creek, limiting the delivery of food and other supplies. Livestock were drowned and infrastructure, such as roads, fences, windmills and machinery, was damaged.

A flood warning service is now in place on the Fitzroy River to enable people to prepare for large floods. Changes in river levels, detected by DoW gauging equipment, are automatically communicated by satellite to flood forecasters who then predict the level and timing of potential river peaks and issue appropriate warnings.



Fitzroy Pioneer cemetry by Jacinta Christie 2002

Gogo old hstd flood levels by Ewen Bell 2001

Case study 2: Pentecost River

A fishing trip to the lower Pentecost River now would not be the same as before the 2001–2002 wet season.

Before February 2002, the riverbank downstream of the Pentecost River crossing on the Gibb River Road was shady, with paperbarks and gum trees lining the riverbanks and floodway, and the track was bumpy but in good shape. You could set up on the grass and fish all day.

In February 2002, the Pentecost River experienced a major flood that was caused by a deep monsoonal low-pressure system moving slowly across the Kimberley. Widespread heavy rainfall resulted in extensive flooding across the Kimberley. Daily falls exceeded 100 millimetres – on 20 February 111 millimetres fell in Kununurra, on 21 February 153 millimetres fell at El Questro and on 22 February 150 millimetres fell at Mount Hart.

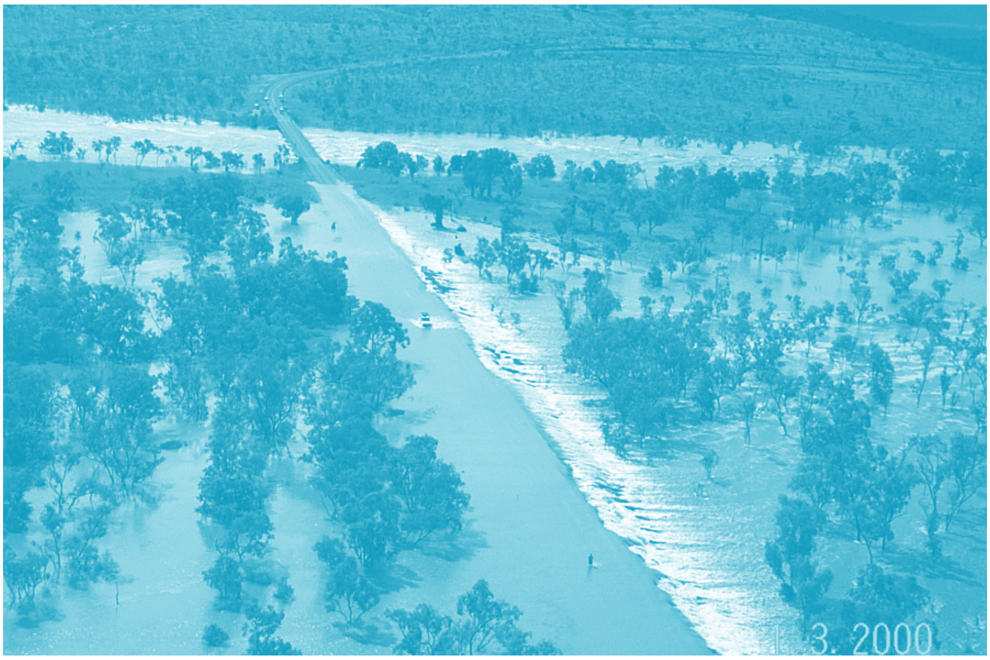
Floodwaters poured down the Pentecost River and relandscaped the old fishing spots. Many trees were washed away or bowled flat by floodwaters, and leaves were stripped from those left standing. Soil was eroded from the banks and floodways – in some cases leaving holes metres across. Some tracks became funnels for floodwaters and were eroded into huge washouts and gullies. These flood events also provide much needed flushing of the system and plays an important part of the nutrient cycles and sediments budgets.
The flood changed the nature of nearby rivers too. On the Durack River, Jack's Waterhole, a popular camping place off the Gibb River Road, was washed away. At El Questro Wilderness Park, near the junction of the Chamberlain and Pentecost rivers, park managers had to replant lawns, clean up mud-stained cabins and regrade tracks.

The Pentecost River after the 2002 flood by Luke Pen

Case study 3: Ord River

The largest recorded flow on the Ord River, approximately 30 800 cubic metres per second, was observed in February 1956 near the site of the present-day dam wall at Lake Argyle. The Ord River also experienced major floods in 1959, 1960, 1966, 1971, 1980 1993, 2001 and 2006.

The two dams on the Ord River have greatly reduced the flood flows in the lower Ord River, and floodwaters are now discharged over several months. The combined outward flow through Lake Argyle's dam valves and spillway has not exceeded 1000 cubic metres per second since the dam's construction in the early 1970s, despite flows into the dam estimated at more than 10 000 cubic metres per second. Lake Argyle acts as a buffer between the upper and lower catchments. Because of this buffer, the town of Kununurra has a low risk of being directly affected by flooding, even though the road connecting Kununurra and Wyndham with Halls Creek has been known to be cut by local floodwaters for days at a time. Flood flows downstream of the Kununurra Diversion Dam are now dominated by the flows from the Dunham River, despite its catchment area being less than 10% of the size of the Ord River's catchment.



The Dunham River in flood

Computer modelling of two flood scenarios illustrates how the two dams have reduced the extent of flooding in the lower Ord River.

Before damming, a flood with a 10% probability of occurring would have broken out from the main Ord River channel to inundate the large meander loops between Carlton Crossing and The Rocks. Such a flood would also have covered a large portion of Mantinea Flat and Parry Lagoons and a major part of Carlton Plain. A larger flood (one with a 1% probability) would have inundated much of the current irrigation area on Ivanhoe Plain and flowed around House Roof Hill to the north, flooding Carlton Plain.

In contrast, after dam construction a 10% probability flood is likely to inundate only a relatively small area of the meander loops, the Mantinea Flat, Parry Lagoons and Carlton Plain. A 1% probability flood would not flow around House Roof Hill and the average depth of floodwaters would be significantly reduced.

The dams and the subsequent changes to the flooding on the lower Ord River have changed the flora and fauna of the river and floodplain. Nevertheless, modified rivers such as the Ord River are often still ecologically and socially valuable. For example, Lake Kununurra and Lake Argyle are listed under the Ramsar Convention for their diverse bird life.

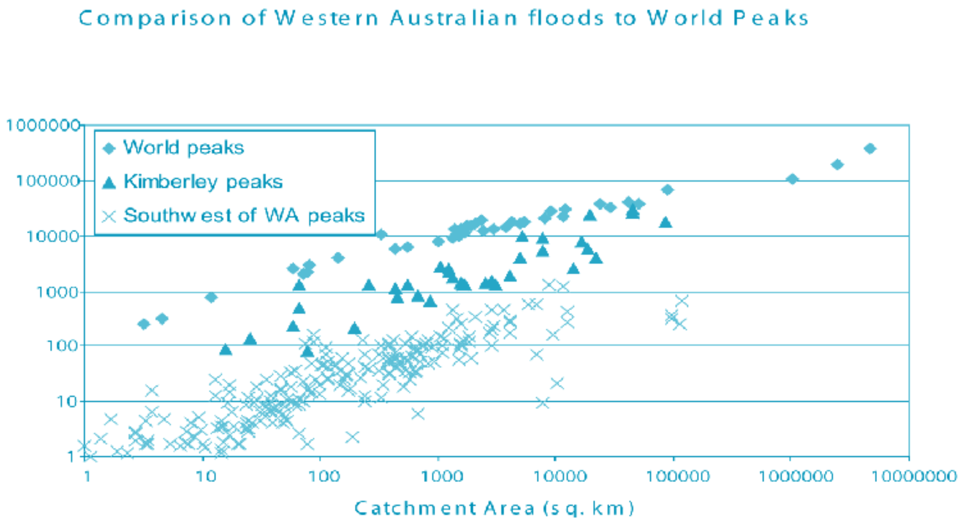


Figure 2: The effects of dams on streamflow in the lower Ord River (Rodgers 1996)

Figure 2 shows that the maximum extent of flooding is significantly lower after dam construction than it was before the dams were built.

Biodiversity of Kimberley rivers

Watery habitats

Every river hosts a variety of habitats where animals and plants live. Typical watery habitats associated with the Kimberley rivers include the following.

Pools, backwaters and edgewaters

Slowly flowing or still areas within rivers and creeks, such as pools, backwaters and edgewaters, are the preferred habitat of species that are unable to cope with fast-moving water and they also serve an important function as fish nurseries. Many of the Kimberley's native fish species are found in such places. Macroinvertebrates found in slower flowing areas are adapted to tolerate the lower oxygen levels. Tiny plankton-like plants and animals are also found in these habitats.

River pools are an especially important habitat for aquatic fauna during the dry season, when long sections of rivers and creeks dry out. Permanent, deep river pools provide a dry-season refuge for aquatic fauna that have not adapted to tolerate drought.

Flooded areas

Flooded areas are crucial to the lifecycles of the Kimberley rivers' flora and fauna. Areas next to rivers and creeks that are seasonally inundated provide habitat and food for small crustaceans, wading birds, frogs and fish. Many species migrate from rivers into annual creeks or onto the floodplain to spawn in flooded vegetation. Juveniles then develop in these 'nurseries' before moving downstream to more permanent waters. Many species are dependent on these floodplain habitats for parts of their lifecycle.

Sand

Invertebrates that live in sand are often burrowers with long, thin bodies and thick body walls that enable them to withstand the abrasive sand. Because of its unstable and mobile nature, sand is not a common habitat for many macroinvertebrates.

Vegetation

Vegetation, whether in-channel, on the riverbank, submerged, floating or on the floodplain, provides shelter for native birds, invertebrates, frogs and fish, enabling them to escape predators and the harsh sun.

Where vegetation is plentiful, food is also abundant. Many macroinvertebrates are found among vegetation: either feeding directly on the vegetation or on the attached algae. Other macroinvertebrates, including some molluscs, attach themselves or cling to the vegetation. From here they are able to obtain food by filtering small particles from the water.

Rapids

Swiftly flowing stretches of water where the flow is rippled or broken and cascades over rocks or logs are known as rapids or riffles. Turbulent and well-aerated water is favoured by filter-feeding macroinvertebrates such as blackfly larvae, which exploit the current to gather food.

Woody debris

Large pieces of woody debris, such as tree branches or trunks, provide secure roosting, preening and feeding sites for cormorants, darters, egrets, herons and other birds. Native fish are more abundant and diverse in rivers where woody debris is present. The fish take advantage of the shelter the debris provides from fast flowing water, predators and the sun.

Food, in the form of invertebrates and aquatic vegetation, is also often more plentiful around woody debris. In sandy rivers, woody debris that is submerged or semi-submerged in pools along the watercourse provides a stable environment for macroinvertebrates. These animals are often more abundant, diverse and productive on wood than elsewhere in sandy rivers. Some macroinvertebrates are specifically adapted to woody debris habitats and have specialised mouthparts with which to gouge and tunnel into the submerged wood.

Damp

An often overlooked habitat in rivers is the hyporheic zone (from the Greek: *hypo* meaning under and *rhoia* meaning flow). The hyporheic zone occurs under the sediment of the stream bed and beyond the banks. Depending on the size of the pore spaces between sediment grains, this damp habitat can provide ample oxygen and food to support an array of invertebrate life, often to depths of 60 centimetres below the riverbed. Some invertebrates are highly specialised and only found in this habitat, while others may use it as a short-term refuge to escape sudden increases in water velocity.

Fish of the Fitzroy River

Much of the following information is derived from the collaborative Fitzroy Fish Project, undertaken by the people of the Fitzroy River, Murdoch University, the Kimberley Land Council and the Kimberley Language Resource Centre, with funding from the National Heritage Trust.

In the non-tidal fresh waters of the Fitzroy River, 24 freshwater fish species have been recorded, as well as 16 marine/estuarine species that spend some of their lifecycle in fresh water. This diversity is high compared with rivers elsewhere in Western Australia: only 10 species have been recorded in rivers in the south-west and 12 for all the Pilbara rivers.

In other Kimberley rivers, a similarly high diversity of freshwater fish species has been recorded. The number of species recorded is related to factors such as the size of the river catchment (see table below).

Freshwater fish species

River	No. of species	Catchment area (km^2)
Fitzroy River	24	90 000
Ord River	24	53 500
Drysdale River	19	15 670
Carson River	19	1 288
Prince Regent River	18	5 506
Mitchell River	9	2 955
Roe River	7	3 278

* data from Morgan et al 2002

The Aboriginal people who live along the Fitzroy River include the Bunuba, Gooniyandi, Ngarinyin, Nyikina and Walmajarri peoples. Many Aboriginal people have comprehensive knowledge about a river's fish species, and each Aboriginal language may have a different name for the same fish species. Recent studies have found species with no formal English name but several Indigenous names, or vice versa.

Distinct groups of fish species are found in different types of habitat along the river. Populations in the lower, middle and upper reaches of the main channel show significant differences in makeup from populations in tributaries, gorges and large billabongs. Gorges and tributaries typically host smaller freshwater species such as spangled perch, glassfish, rainbow fish and bony bream, while lower reaches of the main channel host sawfish, greenback mullet, whipray and the sought-after barramundi.

Several rare and little-described species such as Greenway's grunter, the speartooth shark and the freshwater sawfish live in the Fitzroy River.

Sawfish

Aboriginal people and the Kimberley rivers

Waterways are an integral part of Aboriginal life and culture in the Kimberley. Aboriginal people have lived in the Kimberley region for at least 40 000 years. Protecting country, maintaining clean and healthy water and preserving areas of cultural and conservation significance are important. For further information please refer to *Water Note 35 – Rivers of the Kimberley.*

Environmental issues of the Kimberley rivers

Wild rivers

In Australia, a 'wild' river is one that has a catchment and watercourse in a natural or almost natural condition. Such rivers and catchments are particularly valuable because of their intact ecosystems, generally high biodiversity, excellent water quality, scientific importance, and aesthetic and spiritual significance, as well as for their increasing scarcity. They are culturally significant, especially to traditional owners, and valuable for environmentally sensitive recreation and tourism.

Wild river catchments in Western Australia were identified through a national project conducted by the Australian Heritage Commission in 1996, which gathered information on the condition of Australia's river catchments. The Australian Heritage Commission and the Government of Western Australia identified 26 catchments in Western Australia in near pristine condition: priority 1 wild rivers. They also found 22 catchments that were only slightly disturbed (priority 2). Of the catchments in near pristine condition, 17 are in the Kimberley, two in the Pilbara, four in the interior of the state, and three in the far south.

Pressures such as tourism, mining, grazing, road building, weeds and feral animals are increasing in some wild river catchments, putting them at risk.

A number of tools exist to better protect wild river catchments, including improved management practices, ranger programs, education materials, and listing as Indigenous protected areas, national parks or Ramsar sites. Work is required as soon as possible to apply the most appropriate tools in partnership with land managers.

Environmental pressures on Kimberley rivers

Kimberley rivers are affected by both natural and human factors. Natural conditions that can stress river systems include unusually long dry periods, very intense rains and fire. Human activities that put pressure on rivers include the introduction of feral animals and stock, exotic fish, weeds, tropical trees, ecotourism, fire, soil compaction, road crossings (such as culverts and raised floodways), aquaculture, irrigation and mining. The effects of these activities can include exacerbated erosion, filling of river pools, pollution, litter, modified flows and declining biodiversity.

River reaches at road crossings and permanent river pools are particularly susceptible to tourism as they are attractive camping/visiting sites. Vehicle tracks disturb vegetation, spread weeds, compact soils and can increase bank erosion. Visitors leave litter at campsites and can pollute waterways with soap, detergent, human waste, sunscreen and insect repellent.

Plant and animal pests also threaten Kimberley waterways. Unmanaged animals, such as feral pigs, donkeys, horses and cattle, tend to concentrate along rivers – their source of shade, food and water. These animals can foul river pools, erode banks, destroy riverside vegetation and cause soil compaction. The immanent invasion of the cane toad represents a significant threat to waterway ecosystems in the Kimberley. The weed Noogoora burr is widespread along the Fitzroy River and other weeds, such as Parkinsonia (*Parkinsonia aculeata*), rubber bush (*Calotropis procera*) and some leucaena (*Leucaena leucocephala*), threaten native riverside vegetation.

Local extinctions of fish species can occur where barriers such as dams, weirs, floodgates, waterway crossings and culverts stop fish from migrating upstream. For example, the dams in the Ord River and barrage on the Fitzroy River hinder the migration of barramundi – a fish that needs to migrate from salt water to fresh water to breed.

Altered fire patterns can significantly change and degrade riverside and floodplain vegetation. This can threaten the waterways' condition and water quality, such as by increasing sediment and nutrients (which can feed excessive algae growth) in the rivers and increasing weeds along the banks.

Runoff from the Ord River irrigation area can increase the amount of sediment, nutrients and pesticides that enters the Ord and Dunham rivers. Smaller irrigation developments, as at Camballin near Fitzroy Crossing, may also bring a threat of pollutants.

Managing Kimberley rivers

Kimberley rivers have some protection from the effects of commercial and recreational use through the statutory functions of several government departments, and some landholders have adopted methods of managing land that are sensitive to river health. Kimberley rivers are still not well understood or recognised. The *Kimberley Natural Resource Management Plan* (2005) highlights the need for further research and education, with greater participation from the local community. Long-term sustainability of the rivers depends on the broader community, including landholders, Indigenous people, government agencies and scientists, working together to identify and implement practical approaches to better manage and monitor the waterways.

Caring for Kimberley waterways – tips for visitors

The watercourses, spectacular gorges and permanent pools of the Kimberley are valuable tourist attractions. Most campers choose to stay beside rivers for the scenery and for access to water for swimming, fishing, cooking and washing. When enjoying Kimberley rivers, help to protect them by taking the following actions.

1. Stay on existing tracks. New tracks destroy vegetation and cause erosion.

2 Park well away from waterways and use established campsites, trails and picnic areas. Tyres and trampling cause vegetation damage and soil erosion.

3 Take all rubbish out with you and dispose of it appropriately. Follow the mantras 'pack it in, pack it out' and 'leave nothing but footprints'.

4 Use toilets where provided, or plan ahead and take a spade or trowel with you to bury faeces and toilet paper at least 100 metres from watercourses. This will minimise contamination of water supplies.

5 Do not urinate in waterholes or creeks: this can spread disease.

6 Slip, slop, slap – but don't slop excessively just before swimming: sunscreen chemicals can contaminate water holes, leaving a toxic surface scum.

7 Ensure your boat is well serviced. Poorly maintained engines leak fuel and oil, which contaminate waterways.

8 Wash dishes and yourself at least 50 metres from watercourses, use minimal soap, detergent or shampoo, and scatter used water. Even the best biodegradable soap can take years to break down and any soap product introduced into fresh water can severely affect plants and aquatic animals.

9 Use only fallen, dead wood for fires or bring your own and keep fires small. Breaking standing trees or cutting down branches leaves obvious scars and destroys animal habitat – it is also illegal in some areas.

10 Think before you dump anything near a river.

11 Drive slowly through natural creek crossings. Wash from water can increase erosion and silting downstream.

12. Fish for the future – take home all tackle and only catch what you can eat. Size and bag limits apply.

13 Regularly check all your equipment for seeds. Weed seeds are easily spread.

14 Leave rocks, shells, plants, feathers, fossils, artefacts and other objects as you find them. Pass the gift of discovery on to those who follow. It is illegal to move fossils and artefacts.

15 Never touch Aboriginal rock art or disturb sites of significance.

Glossary

alluvial	(of soil, sediment, etc.) transported or deposited by flowing water
anabranch	a branch of a river or stream that leaves the main stream and then re-enters it further downstream
backplain	an area of floodplain far from the main channel, where very fine sediment settles slowly out of still or falling floodwater
backwater	a slowly flowing or still area within a river and creek (also edgewater)
bar	a deposit of sand or silt, usually formed across a river or river mouth
barrage	an artificial obstruction, such as a dam or irrigation channel, built in a watercourse to increase its depth or to divert its flow
biodiversity	the variation of life forms within a given ecosystem; often used as a measure of the health of biological systems
braided	dividing and reuniting to form a network of channels
catchment	an area of land that catches rainfall and drains the collected water into streams, rivers, wetlands or underground
cut bank	a steep or nearly vertical eroded bank, typically occurring on the outer bend of a river.
discharge	an outflow of water, often measured in cubic metres or litres per second
duplex soil	soil consisting of two types mixed together
ecology	the study of the interactions between living organisms and their environments
edgewater	a slowly flowing or still area within a river and creek (also backwater)
flood	an overflow of a river from the main channel onto the floodplain
flood pulse	the regular annual flushing by floodwater that is necessary for health of river systems
hydrology	the scientific study of the properties, distribution and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere
hyporheic zone	an area of water-saturated soil or sediment that is beside and beneath a stream channel
macroinvertebrate	an animal without a backbone that is large enough to be observed without the aid of a microscope or other magnification

macrophytes	rooted aquatic plants such as rushes and sedges
meander	to follow a winding and turning course; a bend
peak	the maximum level or flow rate during an event such as a flood
Ramsar Convention	The Convention on Wetlands, an international treaty signed in Ramsar, Iran in 1971, under which internationally important wetlands are identified for protection
Ramsar site	site identified under the Ramsar Convention as an internationally important wetland
reach	a stretch of water visible between bends in a river or channel
riparian	related to, living on or growing along the banks of rivers, streams and wetlands
river	a large natural stream of water emptying into an ocean, lake or other body of water and usually fed along its course by tributaries
runoff	water that flows over a surface from a catchment area, including waterways
sediment	sand, clay, silt, pebbles and organic material carried and deposited by wind and water
step fall	a waterfall dropping over stepped rocks
tributary	a stream, creek or small river that flows into a larger stream, river or lake
water resources	water in the landscape (above or below ground) with current or potential value to the community and the environment

Appendix 1 — River features

River forms common in floodplain and rocky country

Main channel	A channel that is usually wider and deeper than other channels, with longer-lasting flow and more established vegetation along its banks.
Low-flow channel	A deeper channel within the bed of the main channel, containing a base, or dry-season, flow.
Headwater creek	A small, ephemeral or intermittent waterway in the upper part of a catchment. Headwater creeks may be poorly defined where flow is infrequent, for example, at their extreme upstream end.
Waterhole, pool or billabong	A low point in the channel bed where water pools and remains through all or part of the dry season. Such pools are important refuges for fauna and flora.

Sediment bar	A raised sediment deposit within a channel where the shape and and size varies with flow conditions and sediment supply. A bar can be made up of sand, clay, cobbles or a mixture of these. Common bar types include point bars, lateral bars and transverse bars. A point bar is an accumulation of sediment on the inside of a river bend; lateral bars form down the sides of a channel; transverse bars cut across channels.
Bedrock bar	A bar of solid rock that rises above the channel floor. Bedrock bars can create rapids and/or trap sediment.

River forms common in floodplain country

Secondary channel	A channel that is narrower and shallower than the main channel and carries a smaller volume of water and/or flows less frequently. (Also known as a flood channel.)
Chute channel	A short, straight channel formed on the inside of a bend.
Floodplain	Relatively flat sedimentary land that is prone to flooding. A floodplain can be defined in several ways, including topographically (height of land) or hydrologically (frequency of inundation).
Floodway	The main flow path of minor floods. Floodways are usually colonised by denser vegetation than the floodplain and surrounds.
Backplain	An area of floodplain far from the main channel, where very fine sediment settles slowly out of still or falling floodwater.
Natural levee	A raised sediment deposit at the top of a riverbank, formed when sand, silt and mud drop out of floodwater as it slows when moving from the channel to the floodplain.
Floodplain billabong	A pool, usually elongated, holding permanent or semi-permanent water. Such pools are formed by the partial infill of an old channel or by scouring from floods.

River forms common in rocky country only

Gorge	A river valley with nearly vertical rock walls.
Rocky run, confined channel	A section of river where rock makes up the base and sides of the channel.

River forms in coastal or saltwater country

Tidal reach	A section of river strongly influenced by tidal flows. It typically meanders over flat, muddy country and its ecology is dominated by salt-tolerant species.
Estuary	A semi-enclosed coastal body of water where fresh water that drains from the land mixes with seawater.

For more relevant terms, read chapter 3 of *Recognising channel and floodplain forms* (Water and Rivers Commission, 2002).

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Lakes	AUSLIG	Dec 1998
Hydrography, linear (hierarchy)	Department of Water	Nov 2007
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WA coastline	Department of Water	Jul 2006
Hydrographic catchments	Department of Water	Jun 2007

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Disclaimer

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