Conceptual Model Case Study Series

Aquatic connectivity: Macintyre River

Macintyre anabranches

The Macintyre River from Goondiwindi downstream to Boomi sits in a low relief area of complex geomorphology. The river system comprises a maze of anabranch* channels receiving varied flows depending on their connection to the main river channel. Flows at various levels and times are important to inundate the many channels and drive the region's ecosystem dynamics.

Anabranches are a significant component of the lower Macintyre River. In the 150-km river reach between Goondiwindi and Boomi, there are 69 anabranch channels with a total length of 236 km. Anabranch channel length varies from 0.32 km to 113 km, most being shorter than 1 km. The largest anabranches in the area are Whalan and Callandoon creeks and the Boomi River (see page 4).

There are also many modified and man-made wetlands throughout the reach. Alterations to flow are common in the area. Weirs and other structures regulate flows for irrigation and some anabranch wetlands have been dammed to provide on-farm storage.

Boomi and Goondiwindi town weirs are located at each end of the Macintyre River reach discussed in this case study. Silver perch and Murray cod have been recorded crossing the fishway at the Goondiwindi Weir but the effectiveness of the fishway for other species is unknown. Boggabilla Weir, 8 km upstream of Goondiwindi, is a significant barrier to fish passage. Although this weir is outside the case study reach it is likely to affect the reach. It is an undershot weir, a type shown to cause fish larvae death.

* An anabranch is a stream branching off a river and rejoining it further downstream.

The Integrated Quantity–Quality Model (IQQM), developed by the Department of Land and Water Conservation (DLWC 1996), was used as the source of the flow data for the analysis of connectivity in this wetland guide. The IQQM model simulates flows under natural conditions and under conditions which assume human water use (i.e. water resource allocation) is at a maximum. The term 'developed condition' is used through this guide to refer to the condition under maximum human use. A flow regime analysis was based on the modelled IQQM flow data. The analysis was used to discuss the impacts of changes in water resource allocations on a range of connectivity processes.

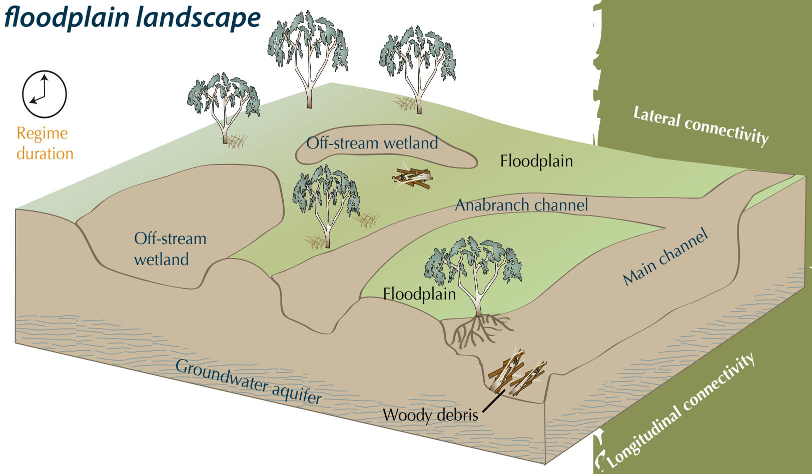
The function of the vertical slot fishway can be compromised if water levels are kept high.

Flow regimes and connectivity

Anabranch ecology varies, depending on connection to the main channel. In high flow, anabranches connect with and function in a similar way to the main channel; when disconnected they are more like off-stream wetlands. As wetting regimes vary across different anabranches, so does categorisation in the Queensland wetland mapping—as riverine, palustrine or lacustrine—depending on geomorphology and water regime. Palustrine and lacustrine anabranches are classed as semi-arid tree swamps and floodplain lakes respectively.

Conceptual diagrams on the following pages demonstrate how different flow regimes influence connectivity at the local scale across a *generalised* river–anabranch–floodplain landscape. Flow regimes are general descriptions of water discharge levels that result in different levels of connection. The diagrams include an indication of the expected duration for each flow regime.

Generic floodplain landscape

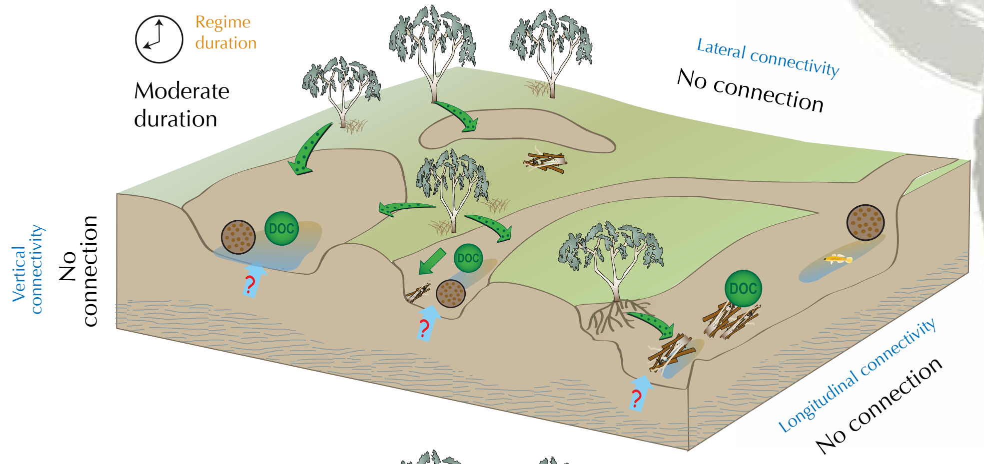


About this case study:

This case study was created by the Department of Environment and Resource Management (DERM) Aquatic Ecosystem Health Science Integration and Capacity Building Team as part of the Queensland Wetlands Program. The study is written for wetland managers. Its purpose is to synthesise and present information about aspects of wetland connectivity. Hydrological, biotic and ecological connectivity are discussed, as well as how these types of connectivity influence each other and how they change over time.

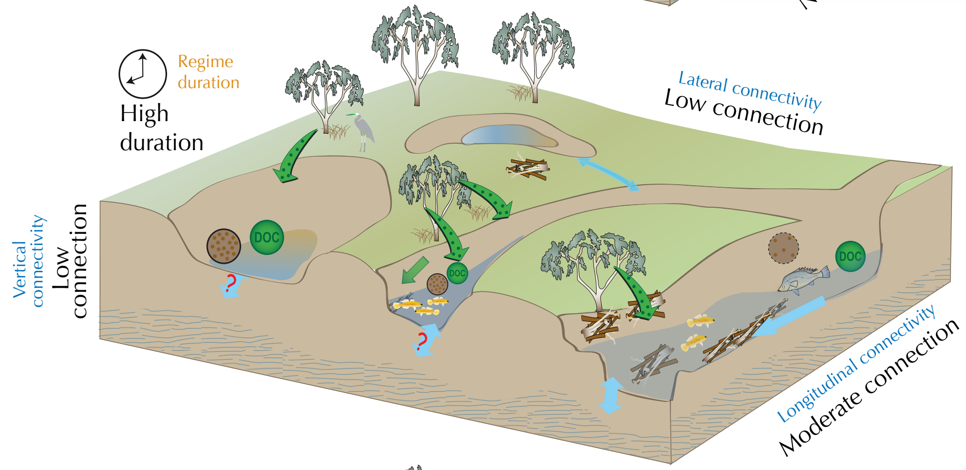
No flow

Though periods of no flow are normal for the Queensland Murray–Darling Basin and plants and animals are generally adapted to cope with it, extended dry periods can stress the system. Dry periods can be advantageous to 'reset' the system and kill off pest fish. Water in disconnected pools tends to be turbid and its quality decreases with time as part of the natural process of drying. If these periods are protracted, biota in these water bodies might suffer and aquatic species can be lost completely until subsequent recolonisation occurs if connected to other populations. Furthermore, ecosystem processes (e.g. decomposition) slow down in the absence of water. Nutrients accumulate after they are deposited from the riparian zone and other terrestrial sources (e.g. leaf litter and woody debris) into the stream bed, off-stream wetlands and onto floodplains. There may be some vertical connectivity between groundwater and surface water; however, this will depend on local geomorphology and the state of the groundwater.



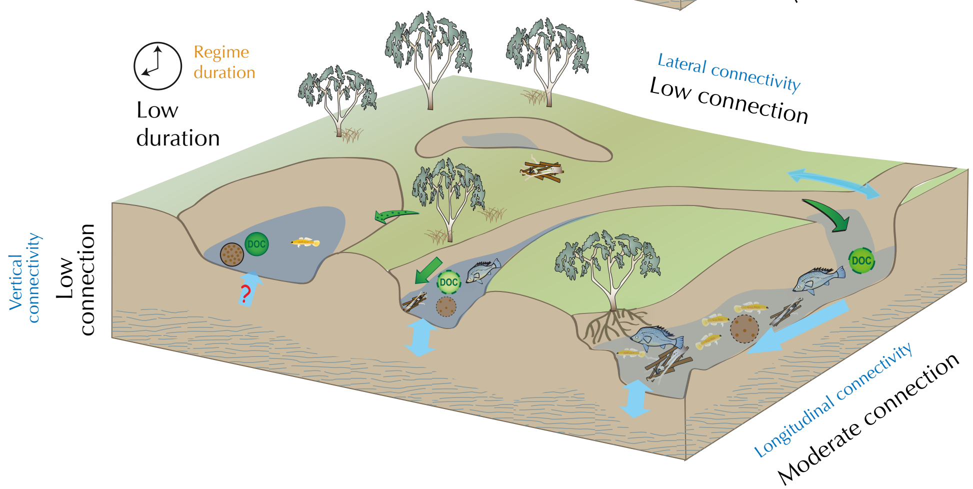
Low flow

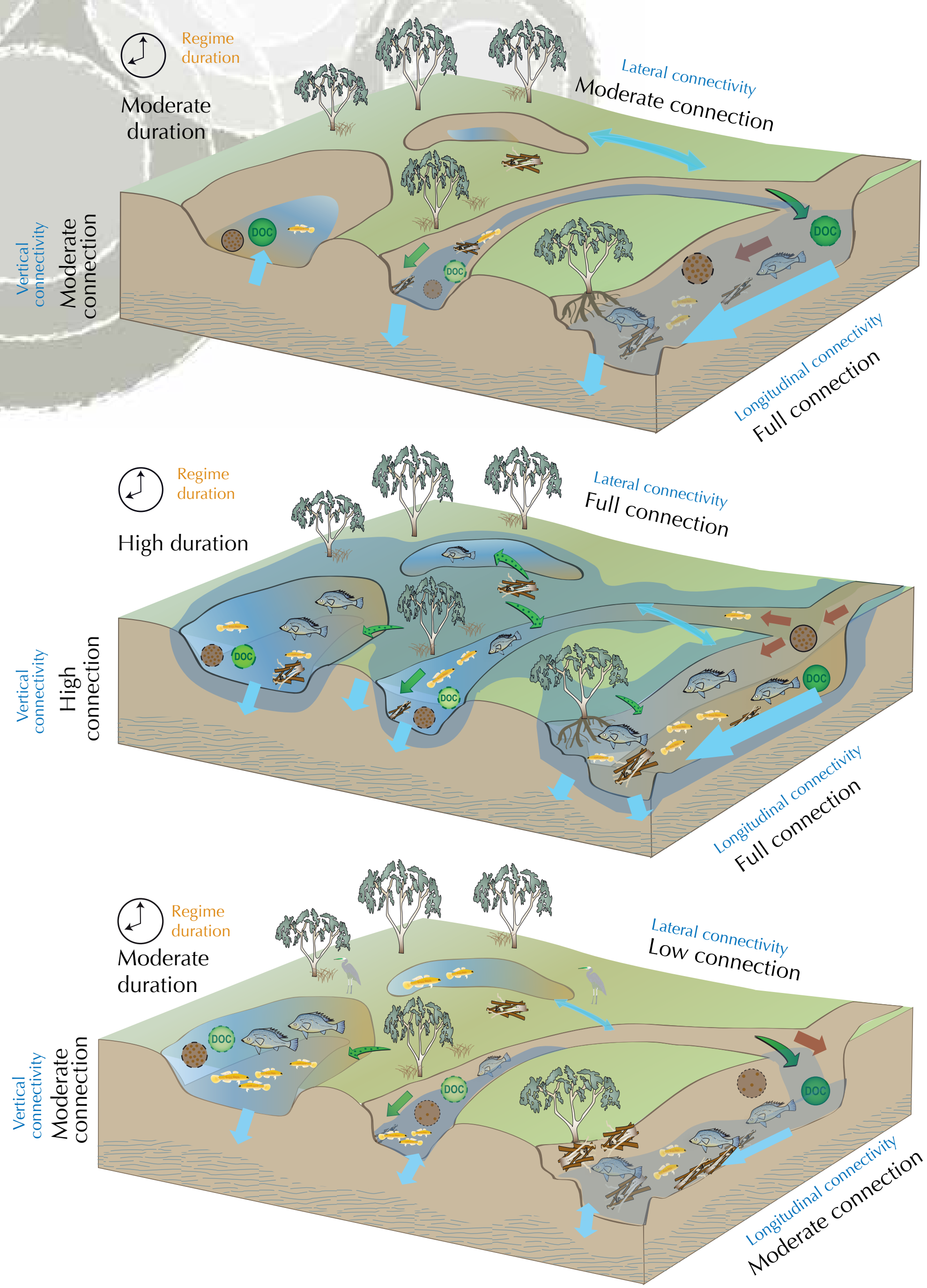
Compared with no flow, low flow benefits fish populations by helping maintain water quality. Low flows link in-stream habitats, sustain longitudinal connectivity for movement of biota, raise water levels increasing available habitat and refresh in-channel pools improving water quality. Connection to groundwater can occur in either direction, depending on the local geomorphology. In some cases the low flows of surface water may be provided entirely by the groundwater (this is known as baseflow) or low flow may seep into the earth and recharge the groundwater. Groundwater recharge during low flow is likely to be limited because hydraulic pressure from the stream will be low.



Flow pulse

Short flow pulses cause rapid changes to physicochemical aspects of water quality. These may be used as biological triggers, e.g. flow pulses bring food sources into an area, followed by low flows to maintain water quality. Pulses can briefly connect anabranches and off-stream wetlands, depending on the size of the flow pulse and the local topography, resulting in improved water quality and therefore improved health of aquatic habitats. Nutrients accumulated in the channels of anabranches can mobilise as a result of these pulses and sediments can be flushed out, resulting in reduced turbidity.





High flow

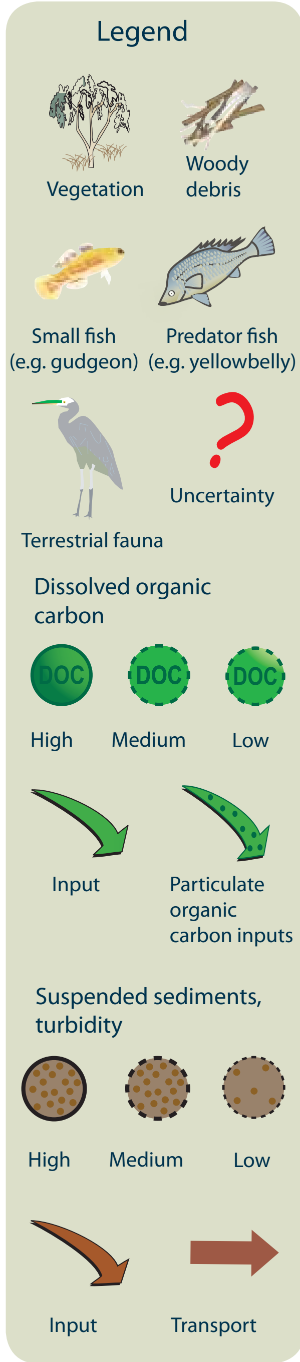
High flows inundate or mobilise organic material accumulating in dry stream beds, increase turbidity in channels by increasing sediment transport and allow fish to migrate. High flows provide connectivity to additional habitat and will result in connection to anabranches and secondary channels (depending on flow level and channel shape). High flows can benefit fauna by inundating benches (flat areas of sediment deposited in stream channels above the bed but below the banks) providing more habitat. During summer, this is especially important for breeding. Higher water levels increase water flow vertically into the groundwater. The increased hydraulic pressure in the groundwater aquifer can result in lateral movement of water to off-stream wetlands and anabranches through subsurface flows, depending on local geomorphology.

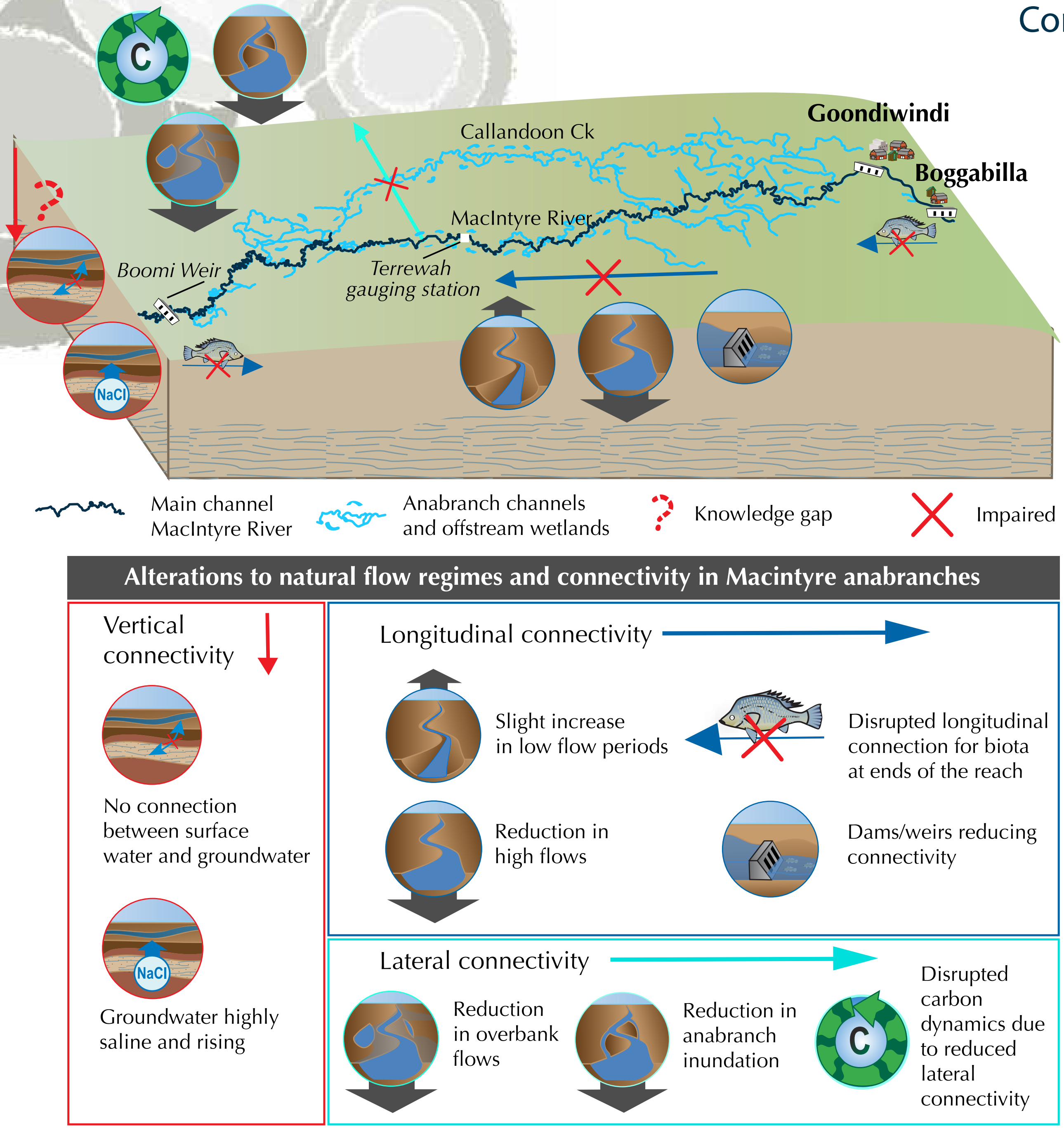
Overbank flow

Overbank flows inundate the floodplain and refresh water supplies in off-stream wetlands, improving water quality. Floodplains can be accessed by biota; organisms and seeds can move into off-stream wetlands, and nutrients accumulated in the floodplain can shift into the channel ecosystem. Vertical water movement into the groundwater is at its greatest rate.

Receding flow

As flow drops back, off-stream wetlands retain water and can become hot spots for biological processes (e.g. decomposition, habitat for fish populations). Animals leave the receding floodplains and their associated wetlands or remain in off-stream wetlands. Nutrients and sediments drain from the anabranches back into the main channel or off-stream wetlands. Over time, the disconnected pools dry either partially or completely through evaporation or seepage into the groundwater, returning the system to no flow or low flow.





Connectivity in Macintyre anabranches

Hydrological connectivity

Longitudinal connectivity

This section refers primarily to the main channel of the Macintyre River. The hydrological connectivity of the anabranches is discussed in the section on lateral connectivity.

In its natural state, the Macintyre River around Goondiwindi is expected to have more or less continuous flow, with the no-flow state occurring less than 1 per cent of the time. This is significantly different from the rest of the Murray–Darling Basin in Queensland, where, on average, there is no flow 40 per cent of the time. With water resource development, continuity of flow has increased and no-flow periods occur with even less frequency. Longitudinal connectivity is slightly higher along the reach than would be expected under natural conditions, though the change is small and is unlikely to have much influence on the system dynamics.

Under natural conditions there are approximately 20 per cent more high-flow events along this reach of the Macintyre River than in the Queensland Murray–Darling basin as a whole. The seasonal distribution of high-flow events is also different from the rest of the basin, with more events in the dry season (June to December) than in the wet season. Development has reduced these flows; at Goondiwindi these have dropped from an average flow of 26 000 to 20 000 ML and at the Terrewah gauging station, from 15 000 to 10 000 ML.

Lateral connectivity—anabranches

Hydrological connectivity to the Macintyre anabranches varies with channel geomorphic form.

How an anabranch connects to the main river depends on the amount of flow it receives and how its entry and exit points intersect with the river. There are four phases of connection—disconnection, partial connection, complete connection and draining (McGinness and Arthur 2011). The relationship of connection phase to flow regimes depends to some extent on local geomorphology, but in general:

- anabranches are disconnected from the main channel during no flow
- as flow increases to the low-flow regime, partial connection occurs in some anabranches and complete connection may occur in those with low-commence-to flow (CTF) values
- when high flow is reached, almost all anabranches will have partial connection and most will be completely connected
- flow pulses will typically bring partial connection, followed by receding of waters into the anabranch, depending on the size of the pulse
- all anabranches will be completely connected with overbank flows
- the draining phase will occur with receding flow.

When fully connected, water typically flows from the upstream to the downstream end of an anabranch channel. However, when partially connected, flow may inundate the channel from either end, depending on the layout of the anabranch relative to the main river. In some river systems, subsurface flows increase connectivity to the anabranches during partial connection, however, there is little or no groundwater interaction between the main channel and the anabranches of the Macintyre River. Connection is primarily driven by surface flows. As a flood recedes, water can drain out either end of the channel.

The levels at which anabranch channels of the Macintyre River commence to flow (CTF levels) range from 1200 to 48 000 ML per day. Inundation can occur at many times during the year, or as infrequently as every five years.

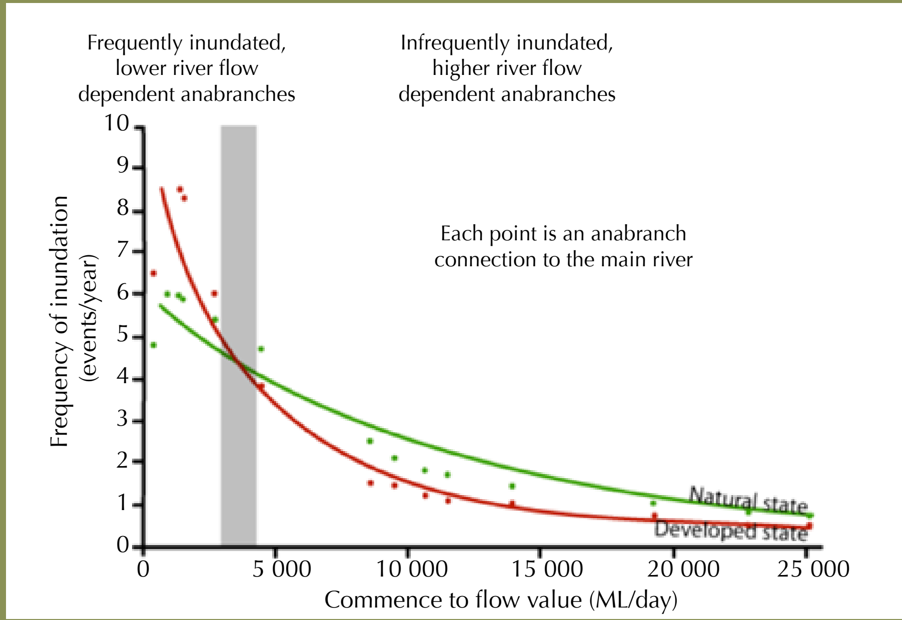
While most anabranches would experience repeated partial connection throughout the year (i.e. at least one intersection point inundated), some intersections with the main river experience flows at a frequency of less than once per year.

Similarly, while most anabranches are completely connected to the main channel several times a year—though less often than they are partially connected—some anabranches rarely reach the complete connection phase. They progress from partial connection directly to draining which influences ecosystem processes (e.g. carbon dynamics, habitat availability, water quality).

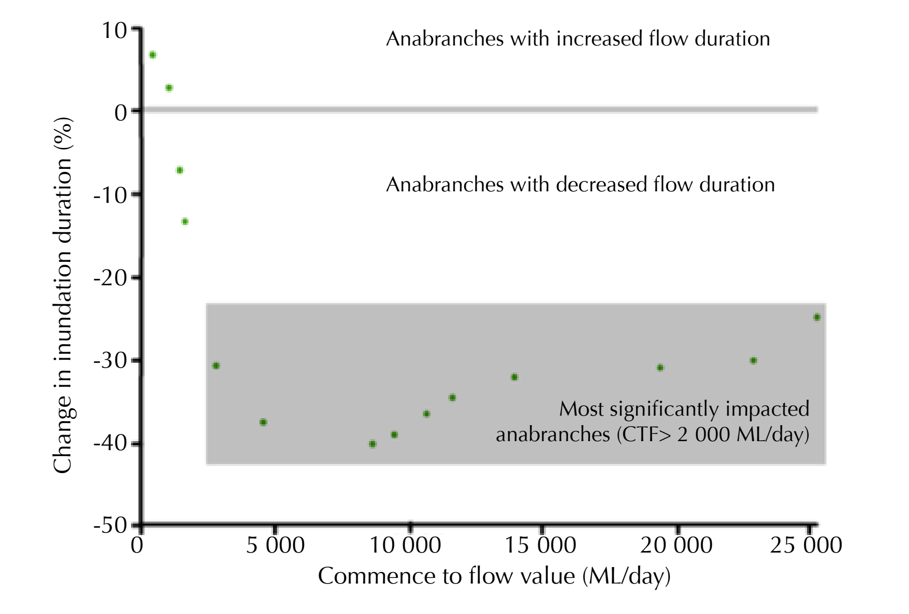
*ARI: The average recurrence interval (ARI) refers to specific flow levels and the average frequency at which they are expected to occur (e.g. a flood of ARI=5 yrs would be expected to occur every five years on average).

Flow management in the region of the Macintyre anabranches has increased low-flow longitudinal connectivity. This is reflected in the inundation frequency and duration of anabranch openings with low CTF values. When changing from the natural state to the development regime, anabranch openings with low CTF ratings (<3000 ML per day) tended to show an increase in their inundation frequency (Graph 1). Not all anabranches showed an increase in their inundation duration; this was limited to anabranches with CTF values <1000 ML per day (Graph 2).

Anabranch openings with CTF values >2000 ML per day showed the greatest reduction in their inundation durations (average reduction in inundation of 32.8 per cent). Thus anabranches that inundate less frequently will suffer the greatest changes to their inundation recurrence from an Average Recurrence Interval (ARI)* of two to three years as shown in Graph 2. This would be expected to reduce anabranch water quality and change subsequent ecosystem dynamics.



Graph 1: Frequency of anabranch inundation based on commence-to-flow value



Graph 2: Change in duration of anabranch inundation, due to development, based on commence-to-flow value

Lateral connectivity in Callandoon Creek anabranch

Callandoon Creek is one of the major anabranches in the region and runs alongside the Macintyre River for almost the entire distance from Goondiwindi to Boomi. Based on its CTF value of 6245 ML per day the creek would connect more frequently and for longer durations under natural conditions than in developed conditions (see Table 1).

Table 1: Connectivity frequency and duration metrics for the Callandoon Creek anabranch under natural and developed conditions.

Type	Natural state	Developed conditions
Connection frequency per year	4.4	3.9
Time connected (%)	8.4	6.3
Mean time between connections (days)	76	87
Longest period without flow (years)	2.2	3.0

Vertical connectivity

Groundwater level in the area is about 10–20 m below ground and is disconnected from the surface. Current studies suggest it is rising in some irrigated areas at up to approximately 0.5 m per year and is estimated to intersect with the surface water in 5–15 years. As the groundwater in the region is extremely saline, this would result in significant declines in ecosystem health.

Ecological connectivity

Abiotic connectivity: carbon case study

The distribution of carbon across the landscape (carbon patchiness) depends on a number of factors. These include local factors, such as presence of riparian vegetation, bird populations in larger wetlands and benthic metabolism. As well, transportation factors such as sediment and litter deposition influence carbon patchiness. Processes occurring within a stretch of stream, such as benthic metabolism, can indicate whether the local system produces enough carbon to sustain itself through photosynthesis (autotrophy) or whether external sources are being used (heterotrophy). Carbon mobilisation and accessibility to the riverine ecosystem relies on spatial and temporal aspects of hydrological connection. Landscape types considered are the main river, a series of anabranches and the floodplain.

Macintyre River in high flow. Photo: DERM

Carbon can be grouped into two broad categories depending on its accessibility to the ecosystem:

- Refractory carbon—refers to material made of dense, complex chains of carbon (e.g. leaf litter and bark) or to dissolved organic carbon (DOC) derived from terrestrial sources such as sediments. These forms of carbon are broken down relatively slowly and used by few organisms.
- Labile carbon—refers to chains of carbon that are shorter and less complex than refractory carbon and so are able to be broken down relatively quickly and used by many organisms (e.g. algae, DOC from leaf and carcass leachates).

The benthic metabolism of the system is affected by hydrological connectivity. Benthic metabolism refers to the processing of carbon through consumption (e.g. decomposition) and production (e.g. photosynthesis) by organisms such as bacteria and algae living on the substrate. Benthic metabolism is a key process underlying carbon dynamics in aquatic systems. It is influenced by local factors, such as light levels and carbon abundance. These factors interact with flow and its associated attributes and processes. For example, flow affects carbon abundance by moving carbon in and through the system; it affects the aquatic light levels by creating different amounts of turbidity. Benthic metabolism depends on interactions between the abiotic and biotic components of the ecosystem and the influence of connectivity on these (McGinness and Arthur 2011).

The following sections focus on the role of hydrological connectivity in the carbon dynamics in the Macintyre River anabranch system. This includes the quantity, quality and distribution of carbon through the system and how scale influences the mechanisms of carbon distribution and the patterns observed.

Carbon quality and distribution

The landscape around the Macintyre River comprises three components: the main river channel, its associated anabranches and the surrounding floodplain. When disconnected, the main channel contains the least carbon, followed by the anabranches, then the floodplain. Different carbon types dominate each of three terrain types—river bank, anabranches or floodplain—depending on local processes and connectivity regimes. Table 2 summarises the carbon distribution, the associated connectivity processes and the role of the terrain type in the broader ecosystem.

Depositional processes

Different amounts of sedimentary carbon and litter are distributed within anabranches depending on specific aspects of the local geomorphology and hydrology, as follows: in simple channels, which flow predominantly

Table 2: The influence of connectivity on carbon distribution in the landscape of the Macintyre River (summarised from McGinness 2007)

Terrain	Carbon quantity/quality	Connectivity processes	Role in ecosystem function
River bank	Lowest abundance of carbon overall.	Highest connectivity. Flow dilutes carbon pools. Carbon is primarily produced in situ (autotrophy).	Carbon production is at the lowest viable level (baseline) for ecosystem function. Enough carbon is produced to keep ecology viable during 'bust' periods. Local areas of carbon production sustain benthic communities.
Anabranch	Highest abundance of labile carbon. Primarily dominated by DOC and phytoplankton (chlorophyll *a*).	Medium connectivity. Disconnected wetland pools are hot spots for carbon processes and metabolism. Connection to the main river channel occurs at varying intervals, up to several times per year. When connected, anabranches deposit large quantities of labile carbon into the river system.	The anabranches act as a sink of sedimentary (refractory) carbon, with significant deposition occurring during flow events. They also act as a significant source of labile carbon, connecting frequently enough to have a major influence on the carbon dynamics of the floodplain–anabranch–river ecosystem.
Floodplain	Highest abundance of refractory carbon. Primarily composed of litter and sedimentary carbon.	Primarily disconnected (dry). Allows for significant accumulation of carbon from local processes (e.g. leaf falls from trees). Dry state means carbon breakdown is slow.	Unknown—either intermittent carbon source (possibly associated with boom bust cycles) or run-off/wind-based connectivity could allow this to function as a lower input but more consistent carbon source.

in the same direction as the main channel, carbon pools increase from entry to exit points. In anabranches with multiple channels, or channels that tend to flow in the opposite direction to the main channel, carbon pools are greatest in the middle of the anabranch.

Sediment distribution processes are well understood (as water velocity decreases, larger sediments fall out first) and appeared to be the primary determinant of the carbon distribution observed in anabranch channels with a simple layout, i.e. one entry and exit, flowing in the same direction as the main channel. Deposition in these channels follows the standard pattern with coarser sediments found at the entry points and finer silts and clays toward the exit. In general, fine sediments have a higher carbon content and have more influence on total carbon distribution than does litter.

Macintyre River

Deposition of litter is less consistent with the observed carbon distribution. It is primarily driven by vegetation distribution and density, but partially influenced by flow dynamics. Flow determines whether litter is buried or transported. In the case of transportation, flow determines the type and size of litter transported, the distance moved and where it is deposited. In general, accumulations of large woody debris and leaf packs seem to increase in frequency and size with distance down the anabranches.

Carbon deposition is ultimately determined by the specifics of connectivity, including flow path and regime. If an anabranch is only partially connected, regions beyond the reach of the connection, along with the carbon and nutrients they contain, will not be available to the broader river ecosystem. This was demonstrated in a channel that had only one physical connection to the main river and the lowest sedimentary carbon and litter loads of all the anabranches studied.

Connectivity is a question of scale

Connectivity influences processes across multiple spatial and temporal scales. Carbon distribution was examined by McGinness and Arthur (2011) at three spatial scales:

- habitat patch—focusing on differences between the three types of terrain: the anabranch, floodplain and river bank
- individual anabranch—examining differences in carbon distribution between anabranches
- site scale—examining differences in carbon distribution within the anabranches, at the entry, exit and mid points of the channel.

Scale influenced the variability observed in carbon distribution. At the habitat patch scale there were differences in the quantity and quality of carbon found between the main channel, the anabranches and the floodplain. The distribution of carbon appeared to be primarily linked to the flow regime, and to periods of hydrological connection (mobilisation of carbon) and disconnection (accumulation of carbon).

At the individual anabranch scale, while anabranches differed slightly in the composition of their dissolved (i.e. more mobile) carbon pools, these differences were not significant in the McGinness and Arthur study. At this scale there was no effective difference between the anabranches.

At the site-scale, distribution patterns of carbon are more random. Labile carbon showed no real patterns of distribution through the anabranch channels. Closer inspection showed discernable patterns in the distribution of refractory carbon within the anabranches. These patterns depended on specific attributes of the channels (e.g. CTF value, riparian condition, geomorphology and flow paths/regimes) and the influences of these attributes on fluvial dynamics. The specifics of the flow regime affect the material transported and the deposition patterns, and demonstrate how connectivity interacts with flow to influence carbon patchiness at the site level. All three spatial scales interact with connectivity in a different way, demonstrating how different processes mesh to create observed patterns.

Biotic connectivity

At the upstream end of the reach are two dams, Goondiwindi and Boggabilla, whose impact is not fully known. While the Boggabilla Weir is 8 km upstream of Goondiwindi and technically outside the reach, it is a significant barrier to fish and larvae. Its fishway was designed to operate with the weir pool at 50 per cent capacity. However, current management practices keep the weir pool at close to full capacity, compromising the efficacy of the fishway. Additionally the weir is an undershot weir, a type demonstrated to increase yellowbelly and Murray cod larvae mortality.

The effectiveness of the fishway at Goondiwindi Weir has not been fully explored. Tagged silver perch and cod have passed through, but the movement of other fish is unknown.

Boomi Weir is at the downstream end of the reach, 120 km away. Fish pass through this structure only when it is significantly flooded every year or two (i.e. ARI of one to two years). The Boomi Weir has been identified as an important location in the Murray–Darling Basin for a fishway. In the larger landscape context, movement of fish into and out of the region is limited.

Within the reach, the main impact on biotic connectivity comes from reduced flow to the anabranches and other off-stream wetlands. This limits the carrying capacity of the environment by reducing habitat quantity and quality. Lower flows inundate a smaller area and bring longer disconnection periods for wetlands. Disruptions to anabranches may result in reduced ecosystem function due to disruption of processes such as carbon dynamics.

The abiotic connectivity case study, along with a significant amount of the data for the other analyses, is modified from McGinness and Arthur's extensive study of carbon dynamics in the anabranches of the Macintyre River (McGinness and Arthur 2011). This three-year study highlights the interaction between carbon dynamics and hydrological connectivity. It explores how differing levels of lateral connectivity interact with environmental processes (e.g. turbidity, flow, inputs from outside the system) and how this interaction impacts on the carbon dynamics of the local ecosystem (e.g. distribution, accumulation and carbon production and consumption processes).

Synthesis

Low-flow hydrological connectivity along the length of the main channel has not been greatly affected by human activity; however, weirs at either end of the reach act as barriers to fish passage, limiting biotic connectivity to the extended stream and anabranch network. Reduction in high flows in the main channel will reduce inundation of anabranches (especially those that inundate at high-flow levels). This can have a significant effect on carbon dynamics of the system with consequential effects on the health of populations of fish and other biota. The groundwater table in the region is highly saline and, though not currently connected to the surface, it is rising in some areas. Connection to the surface water would have a negative impact on the ecosystems.

Longitudinal connectivity

- Low flow is slightly higher than under natural conditions.
- High-flow events have lower magnitudes.
- Biotic connection to the rest of the stream network is limited due to weirs at the ends of the reach. This lack of biotic connection is likely to negatively impact fish population health and resilience.

Lateral connectivity

The complexity of the anabranch network makes lateral connectivity especially important to the ecosystem dynamics of the Macintyre system.

- Reduction in high flows has reduced the frequency of connection of numerous anabranches, notably those with the highest commence-to-flow (CTF) values.

The fishway at Goondiwindi Weir allows movement of silver perch and cod but its effectiveness for other fish species is unknown. Photos: DERM

- Reduction in anabranch inundation frequency influences carbon dynamics and its accumulation and distribution patterns.
- Reduction in high-flow magnitude influences the area of anabranch inundated and the quality of waterholes.
  – Flow level interacts with channel layout to influence abiotic connectivity, affecting distribution patterns of nutrients, sediments and debris, and consequently the processes of benthic metabolism.
- Reduction in high-flow peaks reduces lateral connectivity to the floodplain
  – This may influence nutrient dynamics and ecosystem function.
  – High-flow peaks are important to biota. They are used by fish but the detials of how they are used are unknown.
- There does not appear to be any subsurface flow from the main channel to the anabranches.

Further research will provide better understanding of the function and role of lateral connectivity across the floodplain such as:

- the mechanisms that contribute to population success. This may be due to enhanced access to habitat or to mobilisation of accumulated nutrients
- the specifics of how the timing of connections allows for the accumulation and mobilisation of nutrients.

Vertical connectivity

In its natural state there is no connectivity between groundwater and the surface.

- The groundwater is highly saline and is rising in some areas.
- Rising saline groundwater resulting in groundwater–surface connection is likely to have negative consequences for biota.

Recommended reading and references

Biggs A, Silburn M, Free D and Power E 2006, *The Border Rivers catchment—Still fresh as a daisy?—five years on*. 10th Murray–Darling Basin Groundwater Workshop, Canberra ACT, pp 62–63.

McGinness HM, Thoms MC and Southwell MR 2002, Connectivity and fragmentation of floodplain-river exchanges in a semiarid, anabranching river system, In Dyer FJ, Thoms MC and Olley JM (eds), *The structure, function and management implications of fluvial sedimentary systems*, International Association of Hydrological Sciences, Wallingford UK, pp 19–26.

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