

# Management and conservation of a unique and diverse Australian river type: Chain-of-ponds

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## Key Points

- Many chain-of-ponds have been lost through gullying and sedimentation, or artificially channelised to drain saturated floodplains.
- They are far more diverse in their evolution, structure and maintenance than early work recognised
- Under New South Wales legislation, chain-of-ponds are not recognised as rivers due to their lack of channel- and flow-continuity, nor are they protected under any other Acts
- Knowledge of their ecology and diverse hydro-geomorphic structure and function is required for conservation and rehabilitation
- Due to their lack of legal protection, landholder engagement is critical for conservation where these occur in agricultural settings.

## Abstract

Many chain-of-ponds (steep-sided ponds separated by densely-vegetated valley-fill sediments or shallow ephemeral channels), once common in parts of the Australian landscape, have been modified or degraded since European settlement, resulting in gullies or continuous channels and leaving previously-saturated floodplains disconnected. This degradation resulted mainly from land-clearing and over-grazing, but the intentional drainage of these systems resulted in dewatering and the lowering of water tables across these alluvial floodplains. While there is a broad spectrum of upland discontinuous watercourses (swamps, mires, bogs, dells, etc.), chain-of-ponds have particular hydro-geomorphologic characteristics that may make them unique to Australia; yet unlike other discontinuous watercourse types, little attention has been brought to their conservation, nor are they afforded the legal protection of other 'continuous' rivers. This paper examines examples of chain-of-ponds from the Tablelands of New South Wales as a basis for discussing their hydro-geomorphic structure and function, and the need for better recognition, protection and rehabilitation of these unique Australian river types.

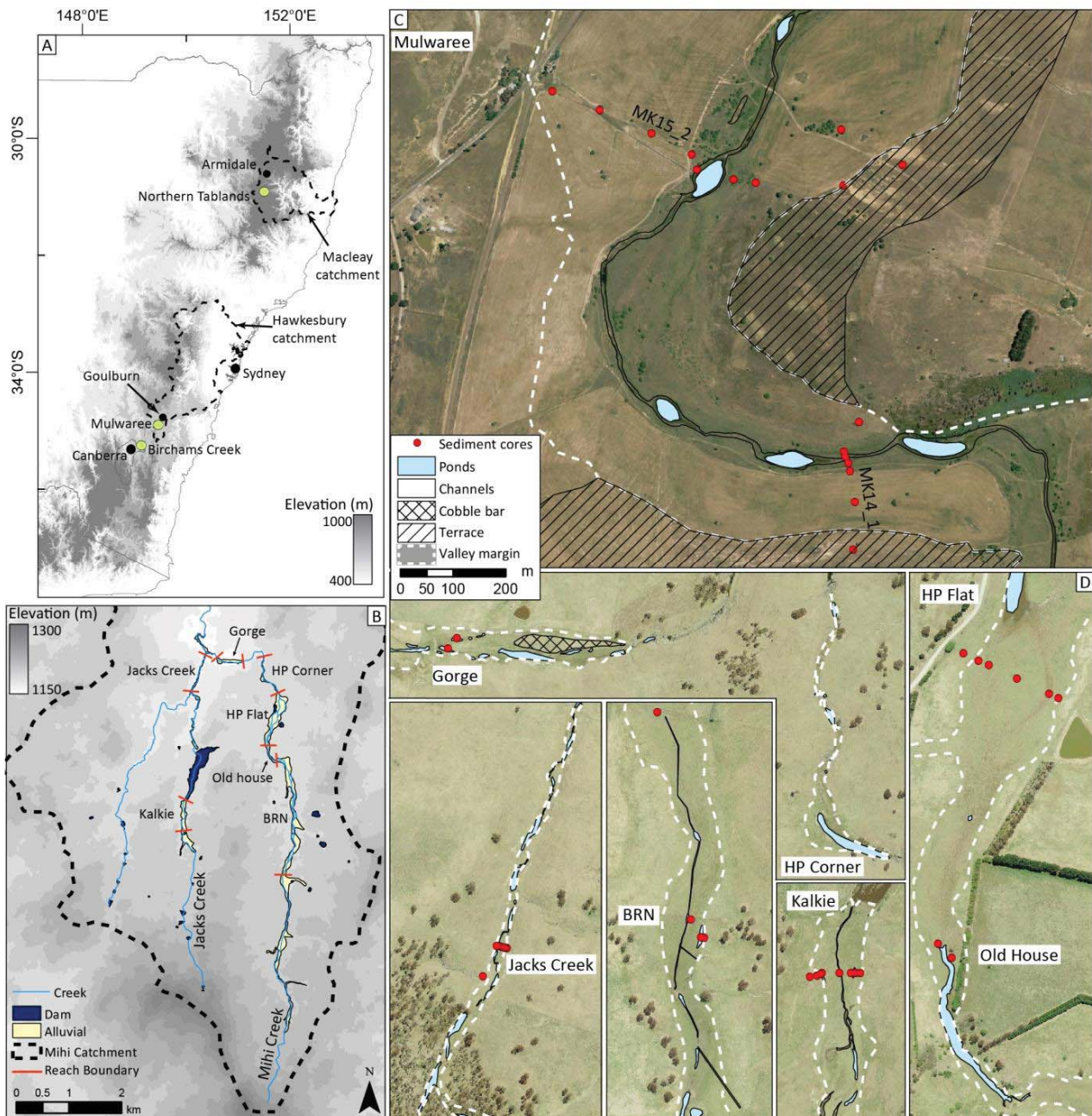
## Keywords

Chain-of-ponds, policy, river management, discontinuous watercourses, legislation

## Introduction

Chain-of-ponds consist of steep-sided ponds separated by densely-vegetated (mostly grasses) valley-fill sediments or shallow ephemeral channels (Eyles, 1977a, Hazell et al. 2001). They form in alluvial surfaces with gentle slopes, such as swampy meadows or broader valley-fills, through scour or deposition (Eyles, 1977a; Prosser, 1991). Land use changes and direct modification has seen the loss of many chain-of-ponds systems that were once common in parts of the Australian landscape (Eyles, 1977b; Prosser et al., 1994). This degradation has resulted mainly from land-clearing and over-grazing, but also from excavating channels along the valley-fill to make saturated floodplains accessible. This resulted in disconnecting the alluvial floodplains, lowering water tables and altering the ecosystems. This exploitation is not surprising as they provided well-watered productive grazing pastures for early graziers and continue to provide identifiable agricultural economic value. The economic values of the land are easier to comprehend, for most people, than the complicated and often intangible value of ecosystem services provided by chain-of-ponds. Chain-of-ponds have been noted as being of (geo)ecological significance because they are representative of pre-European small to medium-sized rivers (Eyles, 1977b; Rutherford et al., 2000) and provide habitat to species dependant

on permanent (or longer-term), lentic water (Hazell et al., 2003). There is some uncertainty of their pre-European distribution, as many early records describe the shape (at single point in time) of the water in the river as a ‘chain-of-ponds’, rather than a full account of the hydro-geomorphic character (Eyles, 1977b; Hazell et al. 2003; Mactaggart et al., 2007). Despite this, understanding of their hydro-geomorphic and ecological diversity remains limited, reducing the capacity of land managers to conserve and rehabilitate these unique systems. This papers seeks to further the scientific understanding of discontinuous rivers, highlighting the diverse structure and function of chain-of-ponds, to inform management practices and legislation to ensure their future protection.



**Figure 1. A) Location of study sites. (B) Mulwaree River at ‘Kelburn’ Mihi and Jacks Creeks on the. C) Location of the Northern Tablelands sites. D) Mihi and Jacks Creeks at ‘Eastlake’ (5 maps).**

## Field sites

The Mulwaree River, a tributary in the Hawkesbury-Nepean catchment, sits atop the Great Dividing Range and drains an area of 790 km<sup>2</sup> where it joins the Wollondilly River at Goulburn, NSW (Figure 1-A). The catchment consists of headwater tributaries in steeper, confined and partly-confined valleys, predominately cut-and-fill or chain-of-ponds, similar to those described by Eyles (1977a). At a catchment area of 73 km<sup>2</sup> the river debouches onto a broad (up to 2 km wide), low gradient (<0.001) partly- to un-confined alluvial valley. The study site, located on the property of 'Kelburn', is a 1.7 km reach consisting of five ponds of varying size, connected by a shallow, ephemeral channel (Figure 1-B).

The Northern Tablelands sites, on the property 'Eastlake' (near Uralla NSW) in the upper Macleay catchment, are reaches on the adjacent Jacks and Mihi Creeks, each with catchment areas of 19 km<sup>2</sup> at their confluence (Figure 1-C, D). These reaches cover a range of chain-of-ponds morphologies with varying sedimentology, valley confinement, slope and geology. Both sites are located on tableland plateaus with temperature ranging from 12 to 27 °C in summer and 0 to 12 °C in winter. They receive highly variable rainfall with approximately 800 mm and 550 mm annually for the Northern Tablelands and Mulwaree, respectively.

## Methods

A digital elevation model (DEM) was created by combining filtered surface scans (using a Leica C10 laser scanner) and bathymetric surveys (CeeScope 200 echo-sounder). The Mulwaree chain-of-ponds stratigraphy was revealed through examination of surface pits, bank exposures and 17 sediment cores across two valley-wide transects. Five cross-sections, each with 3-9 cores, along bank exposures, were used for Jacks and Mihi Creeks (Northern Tablelands). Site flood discharges and stream power values were calculated from a regional slope-area-discharge recurrence interval curves (see figure 2).

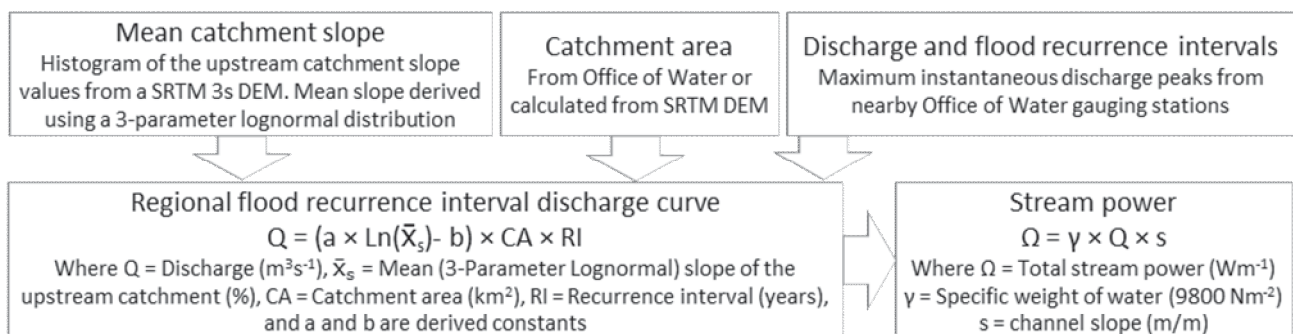


Figure 2. Flood discharge-recurrence interval and stream power calculation method.

## Results and Discussion

### Geomorphic variability

The lower Mulwaree River has layers of gravel and cobble clast-supported sediments (filled with a matrix of sands and silt) that dominates the stratigraphy from bedrock at a depth of ~18-30 m (Office of Water, 1981) (figure 3 and table 1). These coarse-grained layers are from 0.1 m to >1.5 m thick and separated by silt/sand deposits ranging from 0.02 m to 0.7 m. However, these fine-grained layers are rarely homogenous with distinct layers usually thinner than 0.1 m. Atop, finer sediments (mostly silt and fine sand) extend to a depth of 3 m in the centre of the existing channel and inset floodplain, and between 1 and 3 m on the more distal parts of the floodplain. The ponds, which sit into this valley-fill, are much larger (1000-4000 m<sup>2</sup> and up to 8 m deep) than those described by Eyles (1977b) and Prosser et al. (1994), and are relic forms from a much larger and more energetic gravel-bed river that have not infilled with the fine drape seen across the floodplain. A shallow ephemeral channel (~1 m deep) links the ponds and, with the exception of approximately 100 m

where the banks are exposed and subject to erosion, is densely vegetated, impeding flows and encouraging sediment deposition.

The low slope of the Mulwaree River that persists from the point where it debouches near Tarago to its confluence with the Wollondilly at Goulburn plays a critical role in the maintenance of these very deep ponds. As documented by Rustomji et al. (2006) the large (>3x) increase in sediment yield since European settlement has not been transported through the system, but deposited in lobes near the point of unconfinement. Combined with the broad floodplain that creates a buffer (Fryirs et al., 2007) from tributaries and adjacent hillslopes, the transfer of anything other than suspended load is limited to extreme floods. Fine silts and clays that have settled in the ponds post-flood or during low-flow remain dispersible likely due to the constant pore pressure from subsurface flow through the coarse palaeochannel sediments. This lack of cohesion makes it easier for higher flows to re-mobilise finer sediments thereby limiting in-filling and maintaining the deep ponds. The Mulwaree River is unique due to its scale and stratigraphy, and while it is not scouring new ponds through the coarse substrate, it still relies on the highly variable discharge, low slope and dense vegetation, typical to chain-of-ponds, to maintain them.

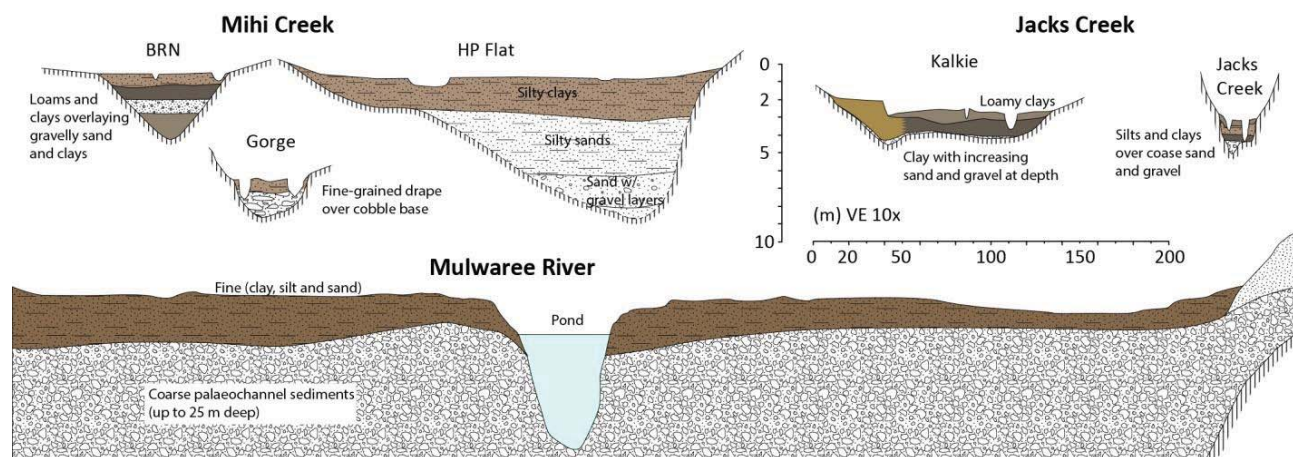


Figure 3. Cross-sections of 3 reaches on Mihi Creek at and 2 on Jacks Creek at ‘Eastlake’ on the Northern Tablelands and the Mulwaree River at ‘Kelburn’ on the Southern Tablelands. See figure 1 for locations.

Table 1. Chain-of-ponds study sites and metrics.

Site (River)	Location		Site					Discharge* ( $m^3 s^{-1}$ )			Stream power ( $Wm^{-1}$ )		Ponds		
	Latitude	Longitude	Catchment area ( $km^2$ )	Mean catchment slope (%)	Valley width (m)	Alluvium depth (m)	Slope (m/m)	$Q_5$	$Q_{20}$	$Q_{100}$	$\Omega_5$	$\Omega_{100}$	Area ( $m^2$ )	Depth (m)	Bed material
Kalkie (Jacks)	-30.82	151.62	4.3	5.09	40-150	2	0.013	2.2	4.4	7.0	284	894	141	0.3	Fine-grained/vegetated
Jacks Creek (Jacks)	-30.80	151.63	18.8	4.26	15	1-2	0.009	8.8	17.5	27.6	772	2431	120	0.7	Fine-grained
BRN (Mihi)	-30.82	151.64	12.5	3.67	40-100	2-4+	0.0043	5.2	10.4	16.4	219	691	171	0.3	Fine-grained/vegetated
Old House (Mihi)	-30.81	151.64	14.6	3.56	23	0-2	0.0035	6.0	11.9	18.8	70	221	4589	1	Fine-grained drape on bedrock
HP Flat (Mihi)	-30.81	151.64	15.3	3.52	100-200	2-7+	0.002	6.2	12.3	19.5	200	629	40	0.3	Fine-grained/vegetated
HP Corner (Mihi)	-30.80	151.64	17.7	3.51	25	?	0.005	7.1	14.3	22.5	385	1213	116	0.5	Fine-grained/vegetated
Gorge (Mihi)	-30.80	151.63	19.2	3.59	50	0.5 to cobbles	0.01	7.9	15.7	24.8	772	2430	172	0.8	Armoured - flat cobbles
Kelburn‡ (Mulwaree)	-34.88	149.65	462.0	6.56	250-700	1-3 fine 18+ coarse	0.0007	58	187	292	399	2004	1816	3.5-8	Fine-grained drape over cobbles
Birchams Creek†	-35.26	149.31	4.4	4.26	25-50	1-2	0.02-0.07	2.3	4.5	7.1	454	1400-4800	179	0.5-2	Fine-grained

\*Discharge ( $Q_x$ ) and Stream power ( $\Omega_x$ ) subscript denotes flood recurrence interval

*Williams and Fryirs - Management and conservation of chain-of-ponds*

\*Mihi and Jacks Creeks  $Q = (0.2305 \times \ln(\text{Mean Catchment slope}) - 0.05) \times \text{Catchment Area} \times \text{Recurrence Interval}$

\*Birchams Creek  $Q = 0.1909 \times \ln(\text{Mean Catchment slope}) - 0.0272) \times \text{Catchment Area} \times \text{Recurrence Interval}$

‡Discharge estimates from flood discharge recurrence intervals values in Rustomji et al. (2006)

†Pond and alluvial depths, and sediment description from Eyles (1977a)

The Northern Tablelands sites are similar to those of Birchams Creek (Eyles, 1977a), but with a diverse range of stratigraphy and planforms. The two upper sites on each creek (BRN and Kalkie) have wide valley margins (~70-200 m), with little elevation change across the valley bottom. The stratigraphy of Kalkie (Jacks Creek) shows weathered bedrock at a maximum depth of 1-2 m, overlain with sandy clays with occasional small gravels (0.1-0.5 m) below silty clays and loams. The depth is controlled by outcrops of the steeply dipping meta-sedimentary bedrock as the valley margin narrows 0.15 km downstream, 1.5 m lower in elevation). The valley-fill sediments at the BRN site (Mihi Creek) are much deeper (>4.5 m at points) as the monzo-granite bedrock control-point is 5 m lower and 1.6 km downstream. Both sites have a dense covering of pasture grasses with tussocks dominating the lower (wetter) areas and a small (0.3 m deep) vegetated artificial channel. Many of the ponds are shallow and concave and only maintain water for a short time after heavy rain. Along the upper parts of Kalkie there are deeper ponds (1.5 m) that have eroded through headcuts and bank slumping from stock ingress. Downstream on Jacks Creek the valley narrows to 10-25 m with steep valley sides. Weathered bedrock is 0.5-1.5 m below gravelly sediments (only in the centre of the valley) and silty-clays, with tussocks covering the width of the flat valley bottom. These deeper ponds (~1 m) are steep sided and maintain water, except during extended dry periods, and many have narrow head cuts that are forming small channels between the ponds.

Below BRN on Mihi Creek there are four distinct pond and valley morphologies. The first pond (Old House) is steep-sided and bedrock (monzo-granite) confined as the creek moves between unconfined valleys. The pond has formed due to sediment deposition of levies and a floodout as the creek again debouches on to the broad valley where the next site is located. HP Flat is a broad (100-200 m) valley-fill, controlled by bedrock at the downstream point. Over the 1 km length of this reach, the elevation drops by 2 m (much less than the unconsolidated sediments that are over 7 m deep) and only holds two ponds; one small (50 m<sup>2</sup> and 0.5 m deep), and one large – estimated to be up to 2000 m<sup>2</sup> before it was extensively modified to hold water for stock. The stratigraphy is unlike any other reaches as the valley-fill is mostly silty-sands from >7 m to 2.5 m; the upper level being the same elevation as the bedrock outcrop downstream. Between 2.5 m and 1.8 m are loams with occasional gravelly flood deposits and then the more typical fine-sandy loams to the surface. The third reach (HP Corner) is a series densely-vegetated alluvial sediments built up behind bedrock control points. Unfortunately there are no cores to confirm the depth or stratigraphy. The last reach (Gorge) has ponds with an armoured base of cobbles that have been deposited after the creek exits a steep gorge. These cobbles also form a large (~4000 m<sup>2</sup>) clast-supported bar with a fine-grained matrix, bordered by a near-flat valley floor 15-20 m either side. The ponds sit 0.5-0.8 m into the complex stratigraphy that moves from clast-supported to matrix-supported with a 0.2-0.5 m drape of fine-sands to clays. This surface is covered with large tussocks and pasture grass, and much like the nearby site of Jacks Creek maintains water except in extended dry periods and many of the ponds have head cuts. Notably, a ponds that is no longer active (but was less than 50 year ago) shows no evidence of incision. The steep sided ponds (all except the small pond in HP Flat) have bank slumping from livestock accessing water. All of the reaches have seen a modification to their flow variability with the construction of many small farm dams, but since the 1960s, the lower Jacks Creek reaches have seen a decline in the magnitude of high frequency discharges due a third of its catchment flowing into a ~500 ML dam. This has also reduced the sediment inputs, which are critical for balancing scouring from larger discharges.

Birchams Creek and other small chain-of-ponds in the Murrumbidgee catchment have been severely degraded by gullyng or infilling (Eyles, 1977a; Prosser, 1991) but Mihi and Jacks Creeks (along with many small neighbouring catchments) remain relatively intact. Both regions have been extensively cleared for grazing during the late 19<sup>th</sup> and early 20<sup>th</sup> centuries and have similar topographic settings, rainfall variability, temperatures, catchment slopes and area-discharge relationships. The factor that puts Birchams Creek at

greater risk is a channel slope from 2 to 5 times that of any of the study reaches (Table 1). This erosive power is also apparent when stream power values are compared (table 1), showing Birchams Creek up to 5 times greater, in a catchment of similar size. As Eyles (1977a p.151) comments, "In any chain of ponds where ponds are close together along a valley floor of appreciable slope... there is probably a very delicate equilibrium, with any disturbance triggering erosion and the development of active ponds or discontinuous gullies".

All small scale chain-of-ponds on the Northern Tablelands form through scour or deposition, similar to the processes described in Eyles (1977a). The ponds in upper reaches of Mihi and Jacks Creeks are scoured into fine-grained sediments, but the risk of gullying is reduced by the low slope and broad floodplains that are rapidly inundated because of the lack of channel. Downstream, floods are confined by narrower valley margins, however pond expansion is hampered by the very coarse (large gravel and cobble) substrate. Along the ponded reaches of Mihi and Jacks Creek, the low slope results from bedrock control points below, often deep, valley fill. On some reaches (e.g. HP Corner or Jacks Creek) this will limit the slope but also provide a 'break' in the event of gully initiation. These physical properties, of low slope, minimal or no channel, and a readily inundated floodplain combined with highly variable flows are critical for chain-of-ponds.

### *Management of chain-of-ponds*

There is a well developed process for prioritising reach scale projects and rehabilitation techniques that are suitable for most chain-of-ponds (e.g. Brierley and Fryirs, 2005; Rutherford et al., 2000). However, an increase in the understanding of the ecological and geomorphic diversity of this important Australian river type is required to inform these processes and manage the remaining chain-of-ponds. Conservation must be based on four key areas; intrinsic properties, extrinsic properties, value and landholder engagement. Intrinsic properties including the channel and pond morphology, slope, sedimentology, valley width, vegetation, and discharge are key in assessing a reaches resistance to degradation. As discussed, the morphology of chain-of-ponds can vary greatly between sites and therefore need to be interpreted to identify its risk of degradation or recovery potential. While the reach may appear resilient, upstream changes may push the ponds past thresholds. Extrinsic factors such as upstream catchment morphology, land use and vegetation impact discharge through a number of processes. Some chain-of-ponds may carry greater value than others, be it (geo)ecological, social, cultural, or economic. For example, the Mulwaree River chain-of-ponds are unique and therefore have high geomorphic and ecological value, but also have cultural significance to indigenous Australians and economic benefit as a permanent water source to farmers. Engagement of stakeholders is critical as most chain-of-ponds are located on agricultural land, therefore requiring the landholder to be invested in the process to achieve appreciable and long-term outcomes. Before these systems can be adequately conserved or managed it is required that they are recognised in legislation.

In NSW, the definition of a 'river' has been discussed in relation to rulings on development applications, while highlighting the inadequacy of the definition for Australian rivers (Lamaro et al., 2007; Taylor et al., 2011; Taylor and Stokes, 2005). The *Water Management Act 2000* (NSW) (WM Act) provides an update from the repealed Rivers and Foreshore Improvement Act 1948 (NSW), but remains an ambiguous definition;

*river includes:*

*(a) any watercourse, whether perennial or intermittent and whether comprising a natural channel or a natural channel artificially improved, and*

*(b) any tributary, branch or other watercourse into or from which a watercourse referred to in paragraph (a) flows*

While this is an improvement, as it allows for greater flexibility in interpretation, there is still the omission of 'ephemeral' as a flow type. A decision in the NSW Land and Environment Court (Lloyd, 2010) concluded that intermittent and ephemeral are synonymous, expanding on the WM Act definition of a river. However, it is contended that this ruling is based on incomplete evidence as the terms are understood and used by geomorphologists to differentiate river types and function (Davies et.al, 2011). Further uncertainty remains

### *Williams and Fryirs - Management and conservation of chain-of-ponds*

as 'watercourse' is not defined in the WM Act, but, relies on the High Court ruling by Barwick (1968), which in turn relies on a definition from Anglo-American law from the mid-nineteenth century (Angell, 1854 p.2).

*...the watercourse, in my opinion, must exhibit features of continuity, permanence and unity, best seen, of course, in the existence of a defined bed and banks with flowing water.'* (Barwick, 1968 18)

This High Court ruling has flowed down the legal channels and the question of whether chain-of-ponds are defined as a river, and therefore protected, was answered by Bannon (1996);

*At best it can be classified as a drainage line with gullies to the East and West, together with intermittent ponds and flood plane [sic] where water flows are rare intervals, under the influence of rain.*

Who also noted an expert witness (Dr E.M. O'Loughlin, previous Chief Research Scientist with CSIRO)

*...thinks of waterbodies in a scientific way, which includes waters such as Coopers Creek, but does not fit the definitions given by the Courts, taken as they are, from European conditions*

Considering the changes in understanding of (Australian) rivers since 1850, this definition is outdated. As Mactaggart et al. (2008) note, discontinuous systems, such as swampy meadows and chain-of-ponds, are not protected due to their lack of channel continuity; this is until (ironically) they become degraded by gullying and acquire the necessary geomorphic features of bed and banks. Some chain-of-ponds may have protection through the WM Act's definition of a lake being '...any collection of still water, whether perennial or intermittent...'; however, like the definition of a river, it excludes the term ephemeral.

While they do not meet the conditions of permanence of flow, or continuity of (the legally defined) bed and banks of a channel, the process by which they form are evidently fluvial and result from Australia's highly variable rainfall and streamflow conditions. Combined with their unique geomorphology, ecological value and documented decline in number (Eyles, 1977b; Prosser et al., 1994) this should be enough to ensure protection under a precautionary approach. Limited knowledge of the ecological communities may restrict their inclusion under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) or Threatened Species Conservation Act 1995 (NSW) (TSC Act). Unfortunately no chain-of-ponds are listed, nor are they afforded under any other protection (e.g. Directory of Important Wetlands in Australia) or acknowledged as groundwater dependent ecosystems (Bureau of Meteorology, 2016). Amendments to the definition of a *river* under the WM Act to include discontinuous and ephemeral rivers is unlikely. Therefore, to ensure their prolonged existence they may need to be included as endangered ecological communities, which will require greater ecological understanding to compliment the ongoing hydro-geomorphic research.

## Conclusions

Once common across the Tableland headwaters, many chain-of-ponds have been lost due to land use changes since European settlement. Chain-of-ponds are a uniquely Australian river type, yet little is known of the diversity, or hydro-geomorphic processes, that are vital for developing management practices. To ensure the long-term conservation of these characteristically Australian rivers, they must be granted the legal protections that our current Anglo-American definition of a river withholds. As the last update to the statutory laws that govern their use took 52 years, with little change (or appreciation for the enormous increase in our understanding of Australian rivers), then other avenues of protection need to be pursued. This paper begins to inform on the hydro-geomorphic processes, but more is needed with additional ecological research. Until such time, those involved in river management will have to continue to engage land holders to conserve of the diversity of Australia's chain-of-ponds systems.

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## **8ASM Full Paper**

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Taylor, M.P., Stokes, R., 2005. When is a River not a River? Consideration of the legal definition of a river for geomorphologists practising in New South Wales, Australia. *Australian Geographer*, 36(2), 183 - 200. Threatened Species Conservation Act 1995 (NSW).

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