Sawyer's Meadow near Camden on the Cumberland Plain, Western Sydney, Australia. The meadow is in a Chain of Ponds system, in which water slowly migrates downstream through a soil bed of semi-porous alluvium and surfaces ephemerally in leaky ponds. The surrounding meadows are seasonally to persistently wet, with a structurally diverse micro-topography that has fostered complex biodiversity (image by Penny Allan, August 2025).

LANDSCAPE
REVIEW

Fields of potential: recovering hidden Chains of Ponds in a rapidly urbanising landscape

Penny Allan, Martin Bryant, Peter Ridgeway and Andrew Toland

A Chain of Ponds is an ancient, mostly underground and almost forgotten riparian system that once sustained abundant, biodiverse life in many of the warm and dry regions of Australia. Unlike incised water courses, it forms swampy meadows that detain water and encourage infiltration, which cleans water and mitigates flooding and erosion. It also cools the atmosphere. This critical landscape system was once an extensive and prolific network of slow water movement in the Cumberland Plain in Western Sydney, Australia. It has now, unfortunately, been heavily degraded by colonising agricultural practices and Sydney's inexorable urban sprawl. Drawing on the link between groundwater and a cool environment, this paper looks into the potential for regenerating Chains of Ponds where, due to urbanisation, hard, water-excluding surfaces and the heat island effect are proliferating. The research reassembled a Chain of Ponds history of the Plain from nineteenth-century parish maps and mid-twentieth-century aerial photos, supported by ground truthing and heat analysis. The findings form the basis of a discussion on the potential of this endemic landscape system, with its intrinsic adaptability, to address the vulnerabilities that urbanisation creates for both fragile landscape systems and the increasing population of residents and workers.

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KEY WORDS
Chain of Ponds, heat island; Cumberland Plain; critical mapping; regional landscapes; blue-green infrastructure; water-sensitive urban design

Introduction

On 29 December 2019, during the Australian summer, the city of Penrith in Sydney's far west was named the hottest place on Earth that day, at 48.9 degrees Celsius (McPhee, 2020). The region's geomorphology contributed to this condition: the shallow undulations of the Cumberland Plain, sitting below the surrounding escarpment of the Blue Mountains to the west and the sandstone ridges to the east, create a depression that traps hot air in a rain shadow (Rachwani, 2021). Today's urban surfaces exacerbate the heat and its effects, and will continue to do so. In the coming years, predictions indicate that Western Sydney will experience more extreme heat (Whetton et al, 2012), and that heat will be a major concern to the rapidly increasing number of people who live there and will live there (Resilient Sydney, 2025).

As urban settlement intensifies, one critical and potentially invaluable ecosystem within the Cumberland Plain that may have significant implications for long-term urban and landscape resilience in the region is its Chain of Ponds network. Chains of Ponds, which once occurred extensively across the Plain, are small, ephemeral bodies of water – 'windows in the floodplain water table' (Hawkesbury-Nepean Catchment Management Trust, 1998). Evidence from elsewhere in Australia suggests they can hold and release water according to the fluxes of flood and drought, with the potential to moderate air temperatures and attenuate water flows (Callan, 2018; Mactaggart, Bauer and Goldney, 2007).

Although many in the Cumberland Plain were drained for agricultural purposes and substantially modified due to urbanisation, remnants still exist either as extant Chains of Ponds or as modified farm dams. Many were surveyed and recorded on nineteenth-century parish maps (figure 1), described in historical and botanical records, and designated as a geomorphological River Style (NSW Department of Climate Change, Energy, the Environment and Water, 2023). While Chains of Ponds on the Cumberland Plain in particular have never been formally identified or legally protected as an ecosystem, their specific combination of soil, topography and geomorphology characteristics means such systems are still readily identifiable in the region. On this basis,

Citation: Allan, P.; Bryant, M.; Ridgeway, P.; Toland, A. (**2025**) Fields of potential: recovering hidden Chains of Ponds in a rapidly urbanising landscape. *Landscape Review*, 21(2), pp 4–24.
Received: 03 July 2025
Published: 29 October 2025

we hypothesise, Chains of Ponds exist here as a ‘field of potential’. If society can gain knowledge about them and value them, it may catalyse future development to make adjustments, consider alternatives, or remove or modify certain limiting conditions to encourage Chains of Ponds to recover, re-emerge and regenerate.

(a)

(b)

Figure 1. (a) An 1840 map of the County of Cumberland and its parishes. Outlined in red are the Cumberland Plain study area and, within that, the Parish of Melville (referred to in detail in figure 6). Sydney’s coastline and harbours are to the east, and the Blue Mountains to the west. **(b)** This composite of early nineteenth-century parish map surveys reveals the earliest documented locations of Chains of Ponds on the Cumberland Plain. (Images by Nathan Galluzzo, May 2025, based on County of Cumberland map 1840, and survey drawings from the New South Wales (NSW) State Archives.)

Approach

The broad aim of our research is to understand how modern cities can evolve in place. It builds on research that suggests a correlation between settlement and its adaptive relationship to the local landscape. The focus of this paper is our research on the Cumberland Plain, the site of Sydney’s growing third city and a region that, for geomorphological and anthropogenic reasons, is already dangerously vulnerable to extreme heat. We set out to learn about the Plain’s hyper-specific and fragile Chain of Ponds ecosystems: how extensive they were, what constrains them now and how they work. Because they evolved to adapt to the fluxes of heat and drought, we investigated how their regeneration might offer possibilities for resilient life on the Plain, offset the dramatic loss of biodiversity over the last 200 years and mitigate the heat, floods and drought generated by a combination of climate change and rapidly sprawling urban areas.

Our approach entailed three fields of study. First, we analysed the landscape systems of the Cumberland Plain: its geomorphology, climate, soils and biodiversity; the colonisation of the landscape systems; and the effects of urbanisation. Second, we framed these findings with a review of literature on urban heat. This covered the research already done in Western Sydney, as well as global work on the connection between urban heat and groundwater, blue-green infrastructure and nature-based solutions; and the interplay between cities, landscape and community. Third, we searched for any correlation between the presence of Chains of Ponds and heat levels by mapping the extent of Chains of Ponds and analysing data on their potential to cool the landscape. The concluding discussion draws on these studies to suggest disciplinary mapping practices that can enhance knowledge of local landscape riparian systems and help address urbanisation-related issues such as extreme heat.

The Cumberland Plain

The geomorphology of the Cumberland Plain's Chains of Ponds

The Cumberland Plain, a small depression in the much larger Sydney Basin, was once part of the delta of a river five times the size of the Amazon. It was thick with swamp forest that flourished and died when the river dropped masses of sediment, which was compressed by advancing and retreating sea, creating layers of mudstone, shale and sandstone that were up to 6 kilometres thick. Then, 200 million years ago, the Pacific and Australian continental plates collided, causing an orographic uplift on the western circumference that defines the Basin, and reversing the tilt of the Plain westwards. In the valley formed by the arc of subduction, the Dyarrubin/Hawkesbury-Nepean River now flows, rising in the high plateau of the Blue Mountains, collecting water for some 350 kilometres as it circumnavigates the rim of the Plain to empty into the drowned valley estuary of Broken Bay.

Despite this geological drama, the landscape of the Plain is strangely subtle. Because it is expansive and relatively flat, it is difficult to 'read'. The vegetation, although diverse, is not spectacular; the terrain is not particularly dramatic; and it is not easy to capture in a photograph. But the layering of sediments and gentle folding of the land, the subsequent differential weathering of rock to create a variety of soils, and the extensive estuarine environments have combined to create a remarkable array of habitat for terrestrial and aquatic life (Karskens, 2020). In the past, these conditions made it one of the most biodiverse regions in the country. Now, however, many of its plant and animal communities are classified as 'threatened' under state and federal legislation (NSW Department of Climate Change, Energy, the Environment and Water, 2009).

While we can imagine what Chains of Ponds looked like, much of what we know of their structure and function comes from:

- a few research papers describing Chains of Ponds in areas beyond the Cumberland Plain (Mactaggart et al, 2007, 2008)
- a document that speaks generally to the geomorphology of the Hawkesbury-Nepean River system (Hawkesbury-Nepean Catchment Management Trust, 1998)
- geomorphological evidence from archaeological excavation (White and McDonald, 2010)
- excerpts from two unpublished BSc Honours theses by geographers from the University of Sydney in the 1980s, which specifically focused on the Cumberland Plain.

Most sources in NSW focus on the Southern Highlands and Tablelands. One of these (Cripps Creek) is in the southern extremity of the Hawkesbury-Nepean catchment, though not on the Cumberland Plain.

Both in the Cumberland Plain (White and McDonald, 2010) and at Cripps Creek (Mould and Fryirs, 2017), the evolution of Chain of Ponds geomorphology began around 22,000 years ago. That was in the late Pleistocene during the last glacial maximum, when dry, cold conditions caused the erosion of gravel and sand, which settled in shallow riparian positions above impermeable clay or sandstone beds. As the climate warmed during the early Holocene, finer clay-loaded silts were deposited among these gravels and sands. These semi-permeable alluvia formed swampy meadows, along with Chains of Ponds – the 'fields of potential'. Chains of Ponds are typically set into broad, low-gradient valleys, which are characterised by irregularly spaced ponds separated by multiple preferential flow paths that do not carry water under low-flow (baseline) conditions (Eyles, 1977; Williams, Fryirs and Hose, 2020). The dense hydrophobic clay substrates act as an 'aquitard' so that water is perched above it in the alluvial deposits that support the lateral flow of subterranean groundwater.

Elliptical ponds may have been formed through surface scouring, although the processes of their formation remain poorly understood. What is better known is how the system degrades: under persistent high-flow conditions, flow paths erode channels, which become deeply incised, creating a feedback loop where groundwater is rapidly released, leading to further erosion (figure 2). But this sequence is known to be reversible in its early stages: if flows are slowed, silt and sediments settle, and the structural diversity of the Chain of Ponds can potentially recover, as can biodiversity (Mould and Fryirs, 2017).

Figure 2. Eroded Blaxlands Creek, formerly a Chain of Ponds, Orchard Hills. The increased flow of upstream runoff, resulting from soil compaction and urban surfaces, has eroded the alluvium layer and left an incised creek bed, which cuts into the underlying clay and will continue to do so. The remnant alluvium of the Chain of Ponds is still present in the flat surrounds, but in this circumstance, it ceases to function as a medium for slowing water flow or encouraging infiltration (image by Martin Bryant, May 2025).

The disturbance of the Cumberland Plain's Chains of Ponds

The meadows and their ponds are likely to have provided a near-permanent water source for First Nations peoples in their campgrounds. This has been evidenced through archaeological excavations at Second Ponds Creek, where considerable stone tool deposits suggest people inhabited reaches of Cumberland Plain's Chains of Ponds (White and McDonald, 2010).

Disturbance of Chain of Ponds landscape systems in the Cumberland Plain began from the earliest days of British colonisation, in 1792, after Governor Philip had granted the first parcels of land to settler convicts on the banks of Dyarrubin (the Hawkesbury River). Hard-hoofed European livestock compacted the delicate upper-soil horizons and scoured the meadow vegetation, both of which were fundamental to hydrological structure and function. The result was less infiltration, more erosion and the incision of free-draining channelised waterways. Some farmers accelerated this degradation by deliberately cutting drains to transform Chains of Ponds into free-flowing channels (figure 3), a practice that continued in some local creeks until at least the late 1940s (Brian Bradley, pers comm, 2012).

(a)

(b)

Figure 3. Agricultural farming practices, Menangle, have (**a**) scoured this Chain of Ponds meadow and (**b**) converted leaky Chains of Ponds to water-fast dams. In so doing, the practices have degraded the structure and function of the Chains of Ponds (images by Nathan Galluzzo, 2024).

The alteration of this natural system, as part of the larger transformation of the Cumberland Plain, was core to the intent of European colonisation to establish a viable agricultural and grazing economy west of the first European settlement in Port Jackson, and thereby to make it possible to consolidate the precarious Sydney colony (Karskens, 2009; Perry, 1963). On the Cumberland Plain, surveying land, subdividing land grants, 'enclosing' private property and modifying the Chain of Ponds systems entailed both procedural and legal abstractions, and a material transformation. The enterprise ultimately identified, possessed and controlled resources, such as soils, vegetation and water systems, giving a measure of its relative success.

Fundamental to this enterprise was how the region's land could, in the language of the eighteenth century, be 'improved'. 'Improvement' was the fulcrum around which the abstraction of 'land' into 'property' turned, naturalising possession and occupation by

Europeans (Bhandar, 2018, p 3), and the dispossession of the Dharawal and Dharug. A perceived absence of 'improvement' founded the claim of *terra nullius*, and the right of the colonial state to appropriate this 'no one's land' (Gascoigne, 2002). Research suggests that, in traditional ecologically based civilisations, how human settlement operated is correlated with local landscape systems (Isendahl et al, 2025). The same correlation does not apply where human settlement involves the establishment of colonial property systems.

It is unsurprising, therefore, that the 'improvements' made by the European colonisers demonstrated their lack of knowledge of the land and its ecosystems, including knowledge of how to care for them. The clearing of trees and forests eroded valuable topsoil. The change to endemic grassland ecosystems disrupted foodwebs, microclimates and soil drainage. The alteration of riparian conditions changed flow rates and the environmental health of the water courses. The proximity of the Plain to the Dyarrubin/Hawkesbury-Nepean and Tucoerah/Georges rivers, as well as the ephemeral Wianamatta/South Creek system, had given settlers access to favourable soils and water, but the soils, while initially productive, lost fertility after only one or two seasons of cultivation, and the water resources proved fickle, subject to unpredictable drought and sudden floods (Perry, 1963).

The disappearance of the Chains of Ponds from the land, and from the maps, provides a very specific example of the processes by which colonisation disempowered a functioning ecosystem. In a landscape already prone to unpredictable seasons of wet and dry, the introduction of cultivation and grazing, and the subdivision of natural systems into land grants disregarded hydrological function in these ecosystems. Yet, while the vegetation has been removed and water redirected, the topography and the alluvial soils are, by and large, still there. However, by now they have also been affected by urbanisation.

Today: rapid urbanisation and its effects on Chains of Ponds

The recent rapid growth of Sydney into the Cumberland Plain further fragmented the landscape systems. In 1946, in anticipation of a post-war population boom, Australia's Department of Post-War Reconstruction commissioned 150 square miles (388 square kilometres) of detailed aerial photographs of the Cumberland Plain, which made it 'the most exhaustive survey … for the purposes of town planning ever carried out [in Australia]' (Cumberland County Council, 1948).

Two years later, the County of Cumberland Plan, hailed as the first holistic planning solution to Sydney's urban challenges, was released. The Plan's aerial photos show a flat agricultural landscape largely devoid of trees. Its authors describe the state of the Cumberland Plain landscape in some detail, imagining how its 'even profile and gentle slopes' indicate that it was 'readily lending itself to exploitation'. Moreover, they note how the land presented no obstacles to the location or construction of major roads and railways, and how it could be developed cheaply for housing. Because the lowland rivers and creeks were 'unhealthy and liable to flooding, featureless and monotonous', floodplains were excellent sites for industry or housing, interspersed with treatment to 'make a very desirable open space pattern even though the watercourse itself may eventually become no more than a stormwater channel'. However, the authors did warn that there was 'always the danger of over-exploitation' and that planning required 'sound judgement and careful analysis of natural resources' (Cumberland County Council, 1948, pp 21–23).

The Plan was never implemented, and the newly formed Cumberland County Council was disbanded due to lengthy delays, land ownership battles, political infighting, lack of funds and a cumbersome planning system (Winston, 1957). Nevertheless, Sydney spilled westward into what must have seemed like an endless expanse of available land. In a more recent development, vast tracts of land have been cleared for the construction of Sydney's 'third city' and 20 million cubic metres of earth excavated, with inordinate change to the hydrology, for Sydney's new 'aerotropolis' (Dowling, 2021). Nonetheless, the aerotropolis has been promoted by the NSW government as a high skill jobs hub across aerospace and defence, manufacturing, healthcare, freight and logistics, agribusiness, education and research industries (NSW Department of Planning, Housing and Infrastructure, 2024). Proponents claim its development will involve a 'landscape-led' approach that will create a cooler, greener city for the 300,000 people who are projected to live in the proximity of the airport.

Elsewhere on the Cumberland Plain, the ongoing residential growth and intensity of development, together with a rapidly changing climate, have generated unprecedented problems. These include the poor provision of ecologically functioning open/green space, flood and bushfire risks, urban heat island effects and more biodiversity loss. The ensuing complexities, risks and uncertainties affect the liveability, health and safety of the city (Holemans, 2017).

One factor contributing to this complexity is the trend towards building bigger houses that support fewer people on smaller lots that have minimal setbacks and no room for significant vegetation (figure 4). Because of the proliferation of hard surfaces, and because the interface between riparian corridors and people is poorly managed, the extensive removal of alluvium and the massive increase in stormwater runoff further degrades remnant Chains of Ponds. While green space and trees are desperately needed in Western Sydney (Brunner and Cozens, 2013), most urgently for urban cooling, councils appear to actively discourage them in new housing developments (Allan and Plant, 2022). In the human-centric world of planning for open space, trees are classified as expenses rather than (natural) assets and, in some contexts, councils are forced to cut down trees because they cannot afford to maintain them (ibid). This problematic state of acquisition and investment points to an underlying issue: existing waterways, ecologies and green space are rarely valued, except selectively as an 'ecological service' or 'ecosystem service', and therefore can be easily abandoned if end users of such services lose interest or are unwilling to pay for them (ibid).

Figure 4. Aerial photo of new housing in Marsden Park, which typifies the current approach to housing and water management in urbanised parts of Western Sydney (imagery ©2025 Airbus, Maxar Technologies, Vexcel Imaging US, Inc, map data ©2025 Google, accessed June 2025).

The landscape of urban heat

Heat on the Cumberland Plain

All of the human activity described above has led to extreme heat events on the Cumberland Plain. This represents a serious threat into the future. Heatwaves have killed more Australians since 1890 than bushfires, cyclones, earthquakes, floods and severe storms combined. Moreover, in its most recent assessment, the Intergovernmental Panel on Climate Change predicts 'species extinction, more widespread disease, unliveable heat, ecosystem collapse, cities menaced by rising seas' (Jackson, 2021). Yet, until recently, the problem of extreme heat has not attracted much attention. Perhaps the reason is that, as Tom Vanderbilt suggests in reflecting on Chicago's 1985 heatwave, it doesn't *look* like a disaster: it offers no dramatic aerial views such as bushfires bearing down on houses, flood-submerged suburbs or earthquake-flattened cities (Vanderbilt, 2002). Or perhaps it is because of the perception that extreme heat happens 'somewhere else', like New Delhi in 2022, when the temperature reached 49 degrees Celsius and satellite imagery from NASA's Ecosystem Spaceborne Thermal Radiometer (Ecostress) revealed 'fiery red pockets dispersed evenly over the city' for days (Thomas, 2022).

The concept of Penrith as the hottest place on Earth on that December day in 2019 is shocking, but not unexpected. Heat scientist Dr Sebastian Pfautsch of Western Sydney University says that black suburban roofs and synthetic playground surfaces in Western Sydney can reach up to 80–100 degrees Celsius in summer. Pfautsch, whose media profile on this issue has reached more than one billion readers with 350 headlines in five languages and 21 countries, has publicly expressed his grief that even the simplest strategy, such as changing the colour of roofs, had been ignored (The Project, 2022).

Pfautsch and colleagues released the report *Benchmarking Summer Heat across Penrith NSW* (Pfautsch, Wujeska-Klause and Rouillard, 2020) in the year after the hottest day, documenting the near-surface air temperatures at various locations across Penrith (figure 5). The report highlights the risks of building a city on a plain already geographically compromised, with no sea breezes, low rainfall, very little surface water and fragmented vegetation. It blames the recent rapidly rising temperatures on 'human activity' or, in other words, continuing to build in a way that exacerbates heat. It concludes with 10 key recommendations, including to implement specific policy and monitoring initiatives, reduce hard surfaces, increase canopy cover and introduce nature-based cooling initiatives in those suburbs that regularly record the hottest temperatures. The report further notes that while blue-green infrastructure is an important cooling strategy, large water bodies actually contribute to the urban heat island effect by holding heat and then re-radiating it overnight into the atmosphere.

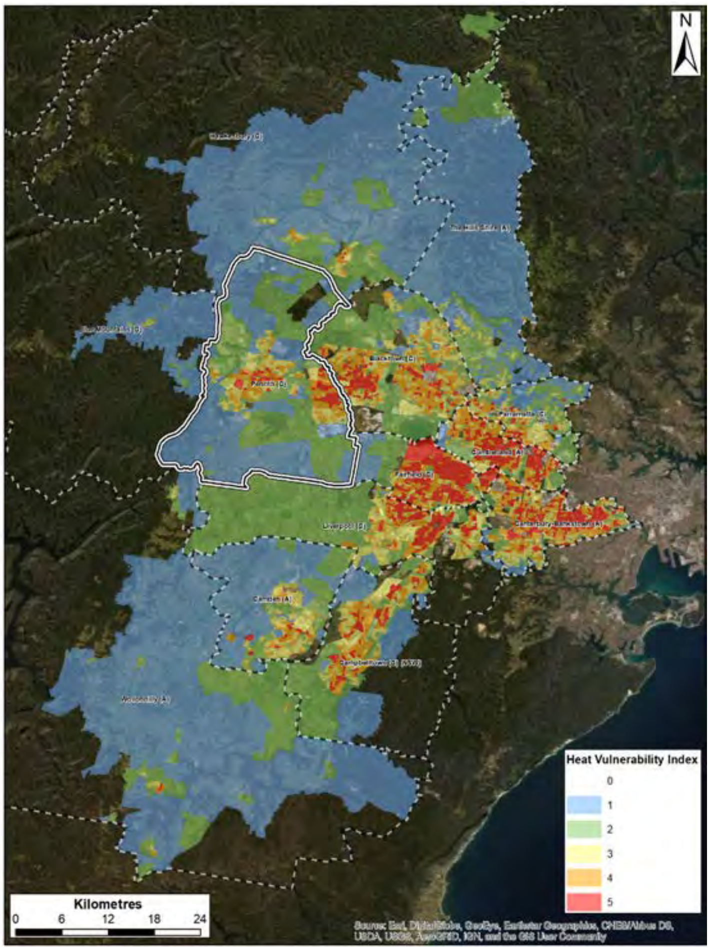


Figure 5. The map shows heat vulnerability in the summer of 2015/16 in Western Sydney, with Penrith outlined top left. The unfragmented red areas trace the intense areas of extant urbanisation. As urban areas expand in the future, so too will heat vulnerability (image by Pfautsch et al, 2020; published with permission).

Urban heat solutions: blue-green infrastructure and water-sensitive urban design

Blue-green infrastructure, a design strategy using trees to shade hard surfaces and environmental water to cool ambient temperatures, can have a cumulative mitigating effect on conditions of extreme heat. Networks of blue-green infrastructure act like a refrigerator coil, spreading the benefits of cooling across a city as they encourage cooling air flow to permeate across the hot surfaces of a city. Integrating green spaces and water to form a network in urban areas can provide significant environmental, economic and social benefits (Drosou et al, 2019).

Groundwater, including the groundwater associated with Chains of Ponds, makes an important contribution to this network effect in many ways. Approximately 34 per cent of land areas in Australia has the potential to have groundwater-dependent ecosystems (Mengyuan et al, 2022). Although studies on the relationship between groundwater and heatwaves are rare, emerging evidence suggests the role of groundwater can be beneficial. One study showed that shallow groundwater moistens the soil and supporting vegetation, which in turn cools and moistens 'the lower atmosphere via evaporation, slowing the accumulation of heat … and potentially suppressing heatwave intensity' (ibid). Another suggests that groundwater associated with wetlands and marshes in temperate climates has a more pronounced impact on heat at higher temperatures, making a significant contribution to regional cooling (Gohr et al, 2021). In addition, recent studies in China indicate that a *network* of wetland fragments (much like a Chain of Ponds) can greatly enhance hydrological connectivity and, therefore, the spatial extent of heat mitigation because their surface water and groundwater rely on heat exchange and local circulation to cool the atmosphere (Xue et al, 2019; Zhang, Shen and Lin, 2021).

Water-sensitive urban design is a type of blue-green infrastructure where nature-based principles are abstracted and applied in urban areas, typically when ecosystems have been damaged or completely destroyed. Emerging in the late 1980s as a land development approach (Coutts et al, 2013; Zhang et al, 2021), it employs the hydrologic processes of retention, infiltration, storage and evaporation to replicate a site's pre-development hydrology (Ahiablame and Shakya, 2016; Davis et al, 2009; Dietz, 2007). Its biotic components help promote natural filtration, improve water quality, enhance biodiversity and reduce the volume and velocity of stormwater runoff (Sayers et al, 2015).

The best examples of projects using water-sensitive urban design have been highly influential in urban planning. One is China's Sponge City programme for wetlands and wet gardens to capture, store and retain rainstorm water in urban areas to prevent flooding (Li, Li and Wu, 2016; Sallustio et al, 2019). Australia's Water Sensitive Cities strategy, designed to enhance adaptability and resilience to broad-scale climate changes, is another leading example (Wong and Brown, 2009; Wong et al, 2013). But the effectiveness of the design can be limited by the tendency, especially in urban environments, to repeat the engineering pattern and blue-green infrastructure componentry without much reference to local conditions.

Another way of thinking about blue-green infrastructure is as an already existing hyper-specific, living, life-support system that is characteristic of a bioregion and fundamental to its resilience. Close attention to these systems can provide clues on how to live with natural landscape systems rather than in spite of them. The focus here is on an adaptive balance among environment, city and community, with the needs of the environment guiding the way. It is a subtle reversal of the ecosystems service-to-humans approach, where characteristics are extracted and deployed elsewhere without understanding how integral those characteristics are to the ecosystems of a place. Conversely, in the hyper-specific approach, humans care for the environment because they understand its critical role in the long-term survival of themselves and the planet.

Traditional ecologically based knowledge-holders already understand this reciprocal relationship. Indigenous Peoples worldwide are stewards of more than 80 per cent of the world's biodiversity, with knowledge systems that span millennia (Garnett et al, 2018; Reihana et al, 2021). In Aotearoa New Zealand, for example, kaitiakitanga, the guardianship of natural landscapes, is grounded in the interrelationship of humans and nature. Attuned to the rhythms and pulses of the environment, humans enact kaitiakitanga through practices of responsibility and reciprocity (Marras Tate and Rapatahana, 2023). Potawatomi botanist and author Robin Wall Kimmerer foregrounds this reciprocity in her latest book, *The Serviceberry* (Kimmerer, 2024). She begins with the words 'all flourishing is mutual', and defines the production of a bountiful harvest of berries not as a natural resource or ecosystem service, but as a 'gift'.

The notion of mutual flourishing might be a good place to start when considering how best to live in many places that are becoming hostile environments. However, this is not yet part of urban planning scholarship and practice. A recent survey of literature on urban blue-green infrastructure between 2001 and 2024 found an overwhelming emphasis on its ecological, technical and economic dimensions, and much less on its sociological aspects. The focus is beginning to change, driven 'by the challenges of urbanization, industrialization, pollution, and growing awareness of how environmental issues, such as climate change, affect social well-being' (Suárez, García and Leiras, 2025). Some approaches that might precipitate the shift include: undertaking interdisciplinary research and practice to better understand how urban blue-green infrastructure influences community dynamics, social cohesion and wellbeing (ibid); identifying multiple, locally derived values and incorporating them into green infrastructure planning (Kati and Jari, 2016; Orantes, Kim and Kim, 2017); and developing educational materials to foster broader social and environmental awareness and advocacy (Suárez et al, 2025).

Remapping the Cumberland Plain's Chains of Ponds

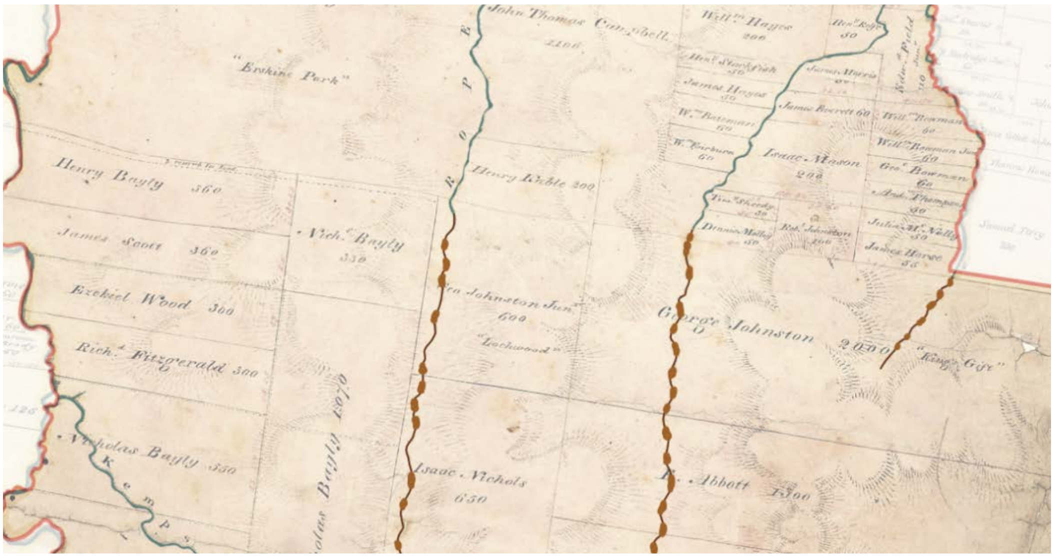
Archival maps; historical aerial photos

Despite the scarcity of information on Chains of Ponds on the Cumberland Plain, we have developed a chronicle of their pervasiveness by reassembling and matching historical maps with aerial photographs and Geographic Information System (GIS) analysis. While research into First Nations histories will take more time and will be a focus for the future, in this research archival maps revealed the whereabouts, the extent and the configuration of some of the ancient hydrological pattern and hinted at the contextual correlations between water and landscape, topography, vegetation, property lines, road alignments and built form. These findings lead to a position on the value of regenerating Chains of Ponds in the rapidly urbanising context of Western Sydney.

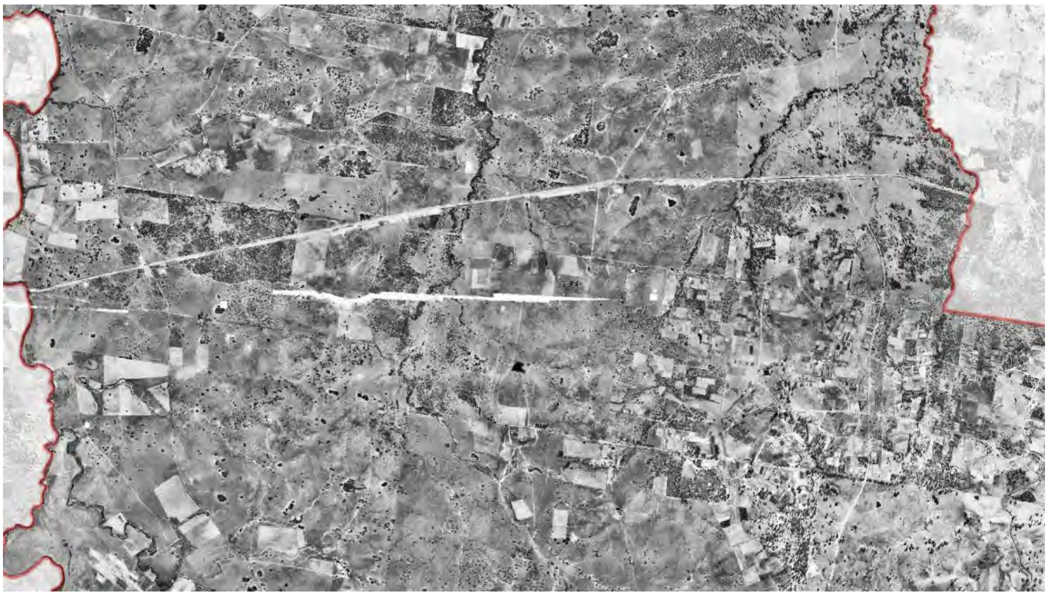
The earliest recorded data are the parish maps, which follow the British land management system of counties and parishes. The County of Cumberland was the first county established following British colonisation in 1788. The first map of the county, published in 1840, contains two primary catchments divided by a north–south ridge. The hand-drawn parish maps, dating from the 1830s to early 1900s, clearly depicted water lines, roads and property boundaries and, sometimes, gave scant indications of topography via relief mapping, though contours were never used. Undoubtedly, there would have been multiple surveyors doing this work across the Cumberland Plain, and their primary goal would have been to 'render … property and topography commensurable' (Pottage, 1994, p 362). On the maps, property boundaries of land holdings and road alignments are clear. The gently undulating topography would have been hard to measure and depict, as well as being information that was probably less important for the farming community audience. But geolocating water courses would have been essential in this dry region intent on agriculture, and simply done by identifying grass meadows with Chains of Ponds surrounded by woodland.

We found 24 parishes in the study area, sourced hundreds of maps from the NSW Land Registry Services and downloaded their corresponding digital records in an Excel file to account for each map we surveyed. To catalogue Chain of Ponds features within each parish, we prepared an index of indicators, such as place names, geology, terrain and water bodies. We documented the range of terms for water courses that our sources used: what we, in this research, collectively call Chains of Ponds were labelled variously in the parish maps as 'Chains of Ponds', 'swampy meadows', 'swamps', 'dells', 'mires' and 'marsh'. It is difficult to know whether the differences arose because these terms had nuanced interpretations, or whether the nomenclature was a result of the wet or dry season in which the nineteenth-century fieldwork took place, or whether surveyors used different terms based on their own personal and professional background. The graphic used for the Chain of Ponds also varies from map to map: solid lines, dashed lines (perhaps ephemeral?), or solid lines with a sequence of pond outlines. But certain consistencies in the recurrence of Chains of Ponds across the Plain confirm that the maps provide the foundational material for the research.

We combined data from two or three maps for each parish, selecting those that contained the most comprehensive Chain of Ponds data, and then stitched them together. Using Photoshop, we realigned and rescaled each parish map to modern geospatial coordinates (GA94), by overlaying them with GIS layers that included key landscape markers such as roads, rivers and contours. The composite collage was then imported into computer-aided design (CAD) software (Rhino), where digital layers were extracted to isolate historical hydrological features, including major rivers and their tributaries. The digitised layers were overlaid with the earliest available (1947) aerial imagery. Each hydrological line was examined in high resolution to identify Chain of Ponds characteristics in as much detail as possible. Many permanent dams appeared on the 1947 imagery, but, more significantly, there were strong clues that the presence of Chains of Ponds was more extensive than the parish maps had suggested (figure 6).



(a)



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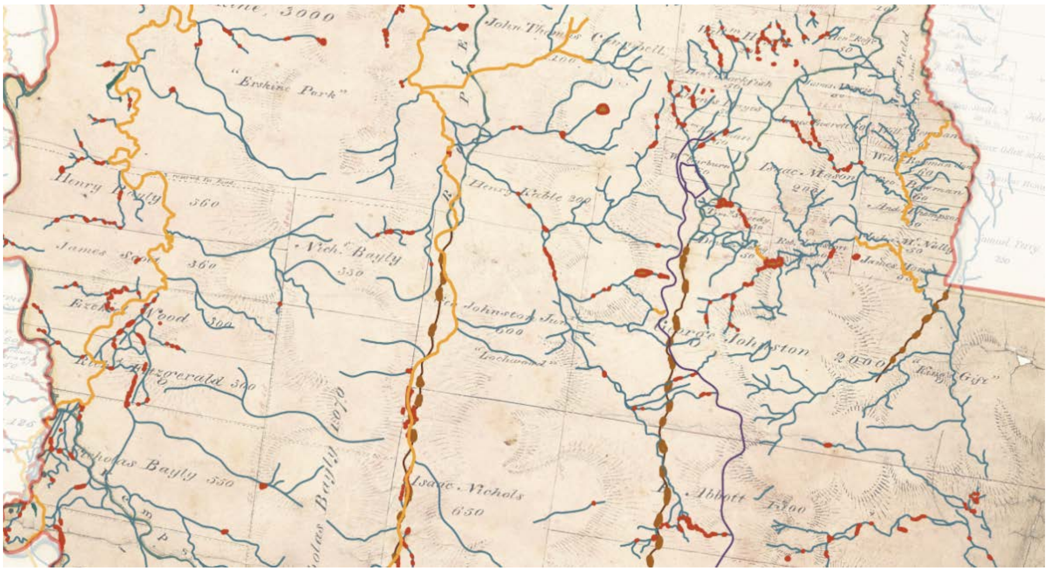


(c)

Figure 6. Mapping historical Chains of Ponds using the Parish of Melville as an example (see figure 1). The composite **(a)** is a combination of parish maps. The 1947 aerial **(b)** is similarly a composite of combined aerial photos. The two data sources were combined. The combined product **(c)** showed that many smaller Chains of Ponds (still present in 1947) were overlooked in the original parish maps. (Images by Nathan Galluzzo, 2025.)

We estimate that at the time the aerial photographs were taken, each parish contained up to 30 times more Chain of Ponds systems than indicated in the early hand-drawn maps. We attribute this discrepancy to the scope and context of the surveying. Perhaps only some hydrological systems were apparent at the time of survey, perhaps only major lines were surveyed, and so the extensive networks of smaller Chains of Ponds ephemerally present throughout the landscape were omitted.

What is distinctive about them, as evident from the mapping, is that Chains of Ponds operated upstream from the main waterways, such as Wianamatta/South Creek, the Nepean River and their lagoons. The Chains of Ponds are thus first- and second-order Strahler water courses, dendritically arranged, and invariably long and meandering, which reflects the nature of the vast Plain with its low-lying undulating terrain. These characteristics contrast with the nature of the first- and second-order creeks in the sandstone geology to the east and west, where the first- and second-order creeks are short, direct and incised into the valleys.

Heat mapping correlations

We concurrently investigated heat to find correlations with water in the landscape. We undertook a limited investigation to measure temperatures around water corridors in Western Sydney. Drawing from LandSAT land surface temperature (LST) data collected during the 2022/23 summer, we were able to correlate the surface temperatures adjoining different river styles during a heatwave season. The 10-metre grid resolution was coarse, but sufficient to provide an indication of the contribution of different river styles, including Chains of Ponds, to adjoining LSTs.

The data in table 1 show the average LSTs beside each major geomorphic creek type in the Cumberland Plain, based on the Interim Biogeographic Regionalisation for Australia subregion ('Western Sydney'). Large bodies of water are the best ways of cooling, but what is not evident in this table is that they would inculcate problems in maintaining storage and they may emit heat at night. Of all the other ephemeral types of water bodies, the intact Chain of Ponds significantly reduces heat relative to degraded (incised/channelised) streams or urban streams. Note also that the data belie the benefits that a Chain of Ponds brings in terms of biodiversity and water quality, compared with other types of water bodies.

Table 1. Average land surface temperatures (LST) in degrees Celsius

Geomorphic creek type/river style	LST (degrees Celsius)
Water storage (dam or weir)	30.3
Chain of Ponds	31.1
Channelised stream in a degraded Chain of Ponds	31.9
Planform controlled, low sinuosity, natural surface	32.2
Urban stream – highly modified, concrete	35.9

Source: LandSAT 2022–2023

Ground truthing

Current cartographic and aerial photographic data offered clues on the most appropriate locations for intensive case studies of relatively intact systems that might provide, at a later date, a more detailed inventory of exemplar sites across the Plain. But the Cumberland Plain is notoriously gridlocked by private landholdings, the legacy of some of the first land grants by Governor Philip in the late 18th century (Rogers et al, 2025). So when, as a preliminary exercise, we ground-truthed three local systems, we chose locations not only because they were meadow-like, but also because they were readily accessible. These three examples served as the starting point for examining the condition more broadly.

Within the Defence Establishment Orchard Hills, an ephemeral 'gilgai meadow' was evident as a 1-hectare meadow of grass species ringed by Cumberland Plain Woodland of *Eucalyptus tereticornis* and *Eucalyptus amplifolia*. While not a Chain of Ponds, the meadow has vertosolic soils that perform a similar function by absorbing and holding water during wet seasons, a process that naturally prevents the establishment of trees and shrubs. This environment also shares many of the wetland flora native to Cumberland Chain of Ponds meadows, including *Eleocharis cylindrostachys*, *Craspedia variabilis*, *Isotoma fluviatilis* and *Lachnagrostis aemula*.

Nearby was a section of Blaxlands Creek that was formerly a Chain of Ponds meadow but is now incised (figure 2). Erosion has exposed the soil profile, which reveals the semi-porous alluvium material above the dense clays derived from Wianamatta shale, suggesting that this place once supported a Chain of Ponds meadow.

The interrogation turned to a functional Chain of Ponds, which had recovered after urbanisation. An excellent example is at Harrington Grove (figure 7), a new suburb developed in 2015, where residential houses have been built in a configuration that retains a 150-metre-wide buffer of regrowth woodland and forest along Cobbitty Creek. Residential runoff is fed into a 1.5-megalitre bioretention basin, which releases filtered water slowly into the creek. As a result, the historically incised Cobbitty Creek has begun a process of natural recovery toward a Chain of Ponds function, structure and character. Notably, silts are gradually re-sedimenting, ponds are re-forming, *Eleocharis cylindrostachys* and other Chain of Ponds meadow flora are colonising the creek, and natural dieback of regrowth sapling trees is occurring on grounds that have rehydrated.

Protected by bioretention basins from any urbanised concentrations of water flow, and with minimal human-led deterministic design, Cobbitty Creek is therefore a passively recovering Chain of Ponds system. This is a harbinger of what may be possible, indicating how ancient in-place systems have a tendency to adapt and why the regeneration of Chains of Ponds might be possible in urbanised areas and specifically in the Cumberland Plain. But it is only one small example. For such recovery to be effective in addressing the much more widespread issue of urban heat, further work is needed to investigate how this might recur across a network, and how the cooling effects can influence nearby urbanised precincts.

Figure 7. The recovering Chain of Ponds meadow at Harrington Grove is identifiable by its clean, shallow water, diversity of ground-cover plants, and the dieback of trees caused by the elevation of the water table. The tracings of mist in the background indicate the relationship between groundwater and a cool atmosphere (image by Penny Allan, 2025).

Discussion

Two main discussion points from this work may be salient to regenerating Chains of Ponds as part of Western Sydney's urban expansion.

Critical mapping

While we recognise that mapping is an instrument of those charged with acting in geospatial terms, critical mapping is a way of reading a landscape and its systems. By piecing the parish maps together (something that the nineteenth-century surveyors did not or could not do) and then re-interpreting them with later geospatial information, we could gain a new understanding of the whole landscape. Just as the nineteenth-century maps appear to be, our reassembled and collated remapping is objective. However, it is also inherently critical of the piecemeal mapping of parishes, which served to atomise the landscape through land division. With LandSAT data and GIS, we are using new tools to map old systems. The approach belies the idea that new technologies catalyse new solutions. To the contrary, what this work shows is the potential for new tools to re-read landscapes as their own broad network.

The mapping shows the value of having a deep understanding of the story of a landscape system that is inherently fragile and unfortunately smothered by the processes of colonisation and urbanisation, which is so commonly evident in the Antipodes. Re-making the composite parish maps and then ground-truthing reveal both the detailed and the broad-scaled landscape systems that operated and might continue to operate here. This mapping process is a powerful tool to reimagine this landscape's role in urbanisation. It enables a rekindling of landscape systems, not for some nostalgic revival, but to respect their intrinsic resilience and adaptability, and what that might offer to future urbanisation and the liveability of Western Sydney.

Making space to cool down

Our literature review revealed that connected networks of blue-green infrastructure are an effective way to mitigate heat. Our mapping shows that networks of Chains of Ponds are dispersed throughout the Cumberland Plain, and our ground truthing at Harrington Grove shows their regeneration is possible. These pieces of evidence can be connected in a place where urbanisation is inevitable, and that experiences some of the worst heat effects in Australia, to show that the role of Chains of Ponds as a heat-mitigating performative entity is compelling. But to focus only on regenerating Chains of Ponds may be overlooking other hurdles that must be addressed if this is to be a sustained solution to urban heat.

One of the significant hurdles that faces any regeneration of Chains of Ponds is that most of them exist on privately owned land, and different authorities manage or own different parts of the system, creating an uncoordinated approach to managing any regeneration. Another issue is that local development codes and town planning instruments prescribe floor to space ratios (FSR), which usually limit built area in relation to site area, and deep soil percentages where soil profiles connect with the ground plane on a lot-by-lot basis. Herein is little nuance about the land's potential to integrate water systems that could feed Chain of Ponds systems. FSRs leave the management to individuals, who may not act on landscape in community-minded or ecosystems-centric ways. Moreover, economies of scale in building encourage a business-as-usual approach to housing and factory, which invariably results in large-format buildings with some left-over deep-soil landscape. This suggests that an effective approach to regenerating Chains of Ponds must involve all the actors and institutions in Western Sydney.

In the subtleties of the fragile Cumberland Plain, a landscape-led approach is unlikely to be productive if landscape systems are not fully understood for their regenerative potential. What may be apparent is that the optimum approach to landscape and urbanisation needs to involve the whole catchment. Because Chains of Ponds were once a widespread network across the Plain, and because they sit in a delicate balance that may not necessarily accommodate generic solutions, they present a case for acting differently. Perhaps there is a need for different development policies to support the regeneration of Chains of Ponds, or different building designs that involve less slab on ground, and more water-sensitive built-form articulation. And perhaps there is a need for a recognised planning instrument that gives space to a Chain of Ponds. Making space allows a Chain of Ponds to exist in its own right.

Conclusions

Peter Andrews, in his seminal book *Back from the Brink* (2006), describes Chains of Ponds as fundamental to the resilience of the Australian rural landscape. Charles Massy (2017) explains that, because the country is often prone to drought and flood, and the soils have compacted over time, Chains of Ponds in water corridors have co-evolved in a natural sequence with the flora and fauna to keep the land moist and habitable. Both these authors write with knowledge of Australia's inland climate, soils and hydrology in order to reconfigure Australian farming practice. In doing so, they share knowledge that Chain of Ponds systems are inherently adaptive and, if healthy, can generate resilience for the landscape.

This paper suggests that this knowledge may also be inherently applicable to the landscapes of cities. The hypothesis that we put forward is that, rather than inventing new engineered systems of water management, and rather than trying universal technologies to deal with heat and water, there is potential in endemic geomorphic water systems in places like the Cumberland Plain that can not only contribute to urbanisation, but also care for the landscape systems themselves. Through this adaptive coupling, a healthy landscape and a healthy city can each make the other more resilient.

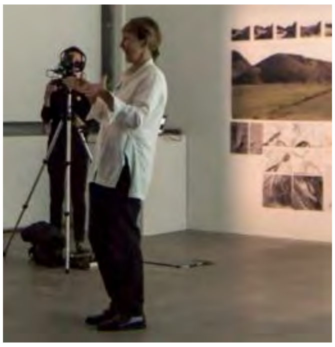
In this research, we have described how European land-use practices have degraded Chains of Ponds. We have seen through the mapping of the Cumberland Plain that its historical Chain of Ponds system was both extensive and prolific, and that by remapping we can look at this landscape as a regional working system, rather than one threatened by its geomorphic basin and anthropogenic acts. Further, through some grounded evidence we have shown that it has potential to be re-established as a working system, as long as it has the space needed for ecological function. This suggests that rather than interpreting the regeneration as a discrete component of land development on a distinct parcel of land, what is needed is a whole-of-place concept. If Western Sydney's future urbanisation is to be landscape-led, it is necessary to ensure that landscape is not just a spatial concept, and not just a structural device, but also one that encourages a landscape ecosystem to function effectively.

But there is more to do. We know the research reported here is at the tip of what needs to be explored. We know that a remit to expedite development means that time is running out to address the social-equity demands for housing and the industry demands for the new aerotropolis. Addressing these demands presents a need to learn more about this landscape from the stories and archaeology of the campgrounds of First Nations peoples in the Cumberland Plain. There is a need to interrogate further the evidence of surveyors who developed the parish maps and, concurrently, the flaws in the persistent colonial knowledge constructs of these systems. There is a need for further on-ground studies and piloting to determine how Chains of Ponds adapt to the diverse soil conditions and microclimates across the Plain, and how they might regenerate and redevelop biodiversity. Further, we need to model how Chain of Ponds systems can generate cooling effects that operate across the region.

This list of urgent needs may be long, but perhaps even more pressing is the need to recognise and protect Chains of Ponds in the Cumberland Plain. As yet, there is no official policy to protect them. A key barrier to protection is the current lack of any official classification of this ecosystem. No government programme has mapped Cumberland Plain Chain of Ponds meadows or officially categorised this ecosystem, and they are not included in the official NSW plant community types database (NSW Department of Planning and Environment, 2023), which is used to assess land clearing proposals and biodiversity offsets. Similarly, while Cumberland Plain Chain of Ponds meadows clearly meet the International Union for Conservation of Nature criteria for a listing as a Critically Endangered ecological community (Bland et al, 2017) and associated NSW and Commonwealth Biodiversity Conservation Act listings, no application for a protection listing has been made under any biodiversity protection schemes.

Official classification and a Critically Endangered listing would significantly assist efforts to conserve and restore this ecosystem. Such recognition would lead to work that is fundamental to urban resilience. Seeing Chain of Ponds networks as integral components of urban development might enable their wet meadows to mitigate urban heat. Moreover, the beauty of these landscapes might encourage urban communities to connect with and care for them.

About the authors and collaborator



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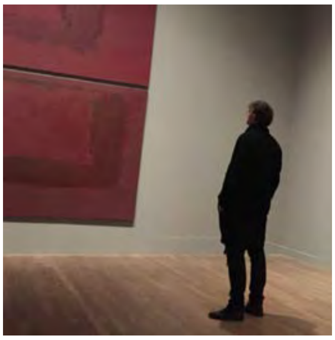

Martin Bryant is Professor of Landscape Architecture at UTS and an architect, urban designer and landscape architect who has expertise in connecting building, urban and landscape design with ecological principles and the characteristics of resilience. His knowledge draws on four decades of experience in award-winning research and professional projects, as both an academic and a practitioner. He is currently Director of the UTS Green Infrastructure Lab and is working with the Living Lab Northern Rivers on numerous projects in the flood-affected region.

Peter Ridgeway is a conservation ecologist specialising in conservation and restoration of the Cumberland Plain. He has led over 200 on-ground restoration projects in Western Sydney and dozens of government–industry partnerships, as well as providing professional advisory services to local, state and federal agencies. Since 2020 Peter has been leading partnerships to further the understanding and recognition of Cumberland's unique Chain of Ponds meadow ecosystems. He is a research fellow at UTS, is a partner in a University of New South Wales School of Ecosystem Science grant investigating the paleoecology of Cumberland Chains of Ponds and, with the Soil Science team in the Department of Climate Change, Energy, the Environment and Water, is investigating soil properties of Cumberland Chains of Ponds.

Andrew Toland is a senior lecturer in landscape architecture at UTS. As a transdisciplinary scholar of the natural and built environment, he focuses his research on the capacity of architecture to change how we view and understand our environmental realities. Andrew's work explores the cultural dimension of technological practices, large-scale landscape modification and infrastructure, and their normalisation in our everyday urban and natural surroundings. Collaborator Nathan Galluzzo is a research assistant and PhD student at UTS School of Architecture.

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