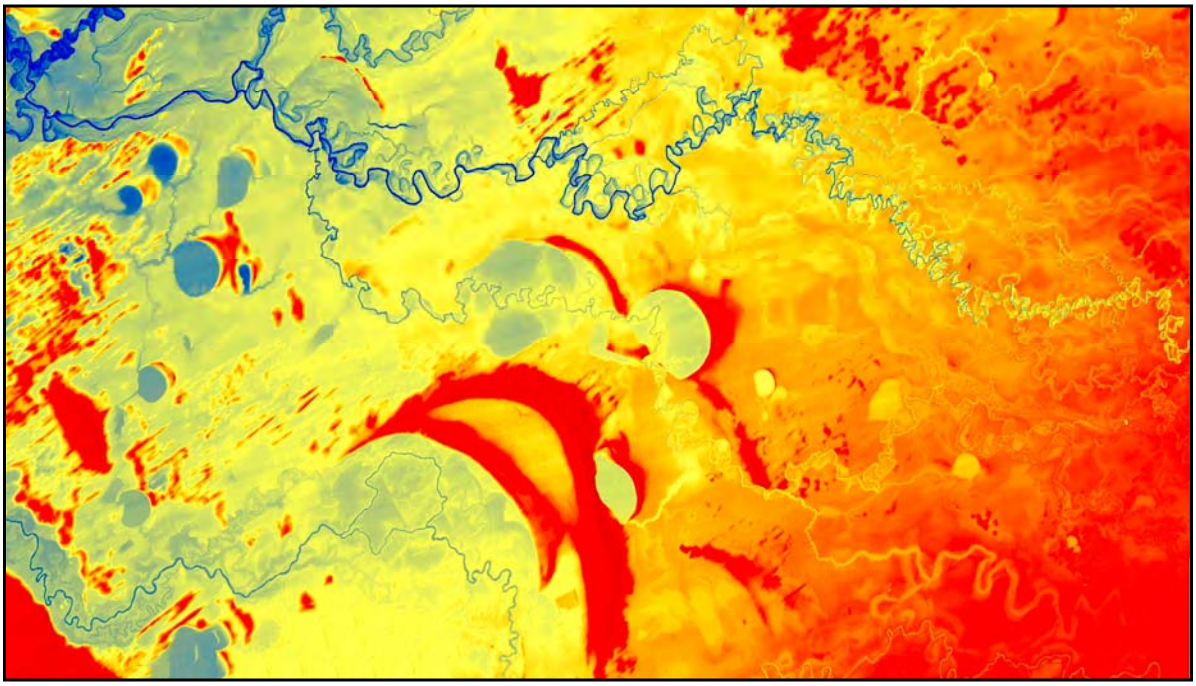
Aspects of Quaternary geology, geomorphic history, stratigraphy, soils and hydrogeology in the Edward–Wakool channel system, with particular reference to the distribution of sulfidic channel sediments



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NSW Office of Environment and Heritage

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Photo credits

Cover image: LiDAR image of the western part of the study area (see Figure 16)

Plates 1, 4: Panoramio photo collection, Google Earth
Plates 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15: Mitch Tulau, OEH
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Introduction

The aim of the overall project, 'Distribution and hazard of sulfidic sediments in a river and creek channel system of the Murray–Darling Basin: Edward–Wakool channel system case study', is to examine the distribution and nature of sulfidic sediments in the Edward–Wakool channel system in order to understand the accumulation and potential mobilisation of these materials.

This project has two specific goals, to:

- quantify the spatial occurrence of sulfidic sediments in the channels of rivers and creeks of the Edward–Wakool channel system
- develop appropriate sampling strategies to assess the occurrence of sulfidic sediments in inland waterways.

This report forms part of Research Component 1, a broad spatial assessment of the distribution of sulfidic sediments throughout the Edward–Wakool channel system.

This research component explores the spatial extent of sulfidic sediments in the Edward–Wakool channel system in relation to their geomorphic, hydrogeologic and geochemical settings. The principal outcomes are:

- an assessment of potential landscape factors contributing to the occurrence of sulfidic sediments
- preparation of a detailed report describing these relationships.

Study area

The Edward–Wakool alluvial channel system (Figures 1, 2) is a major inland distributary-anabranch-confluent system that forms part of the Riverine Plain (Butler 1950), an extensive (77,000 km^2), complex alluvial plain deposited and traversed by generally westerly-flowing watercourses, including (from north to south) the present day Lachlan, Murrumbidgee, Edward and Murray rivers, and, in Victoria (from east to west), the Goulburn, Campaspe, Loddon and Avoca rivers. The Riverine Plain in turn lies within the geologic Murray Basin (Pels 1962), a large (320,000 km^2) intracratonic structural basin located to the west of the Eastern Highlands, and extending into northern Victoria and South Australia.

The Edward–Wakool channel system is located between Deniliquin in the east, where the system begins to distribute, and Kyalite, ~145 km to the north-west, where the Edward and Wakool rivers converge once again (Figure 2). The Murray and Murrumbidgee rivers re-enter the system ~16 km and ~35 km further downstream respectively. The study area is bounded by the diffluence of the Wakool from the Edward River near Deniliquin, the Edward River in the north, the Wakool River in the south-east, the Murray River in the south-west, and the confluence of Merran Creek and the Wakool River near Kyalite in the west (Figure 2).

Figure 1. Location of the Edward–Wakool channel system study area

Geology

Sedimentation in the Murray Basin commenced in the Palaeocene, with deposition of Renmark Group sediments (Macumber 1969; Brown and Stephenson 1991), comprising a lower Warina Sand, and upper Olney Formation carbonaceous silty clays, sands and lignites (Lawrence and Goldberry 1972; Lawrence 1975; Brown 1985; Brown and Stephenson 1991) (Figure 3).


Deniliquin
Colligen Ck
Yallakool Ck
Wakool R
Cockran Ck
Jimaringle Ck
Barber Ck
Murray River
Barham
Niemur R
Edward R
Yarrein Ck
Merran Ck
Murray R
Kyalite
10 km

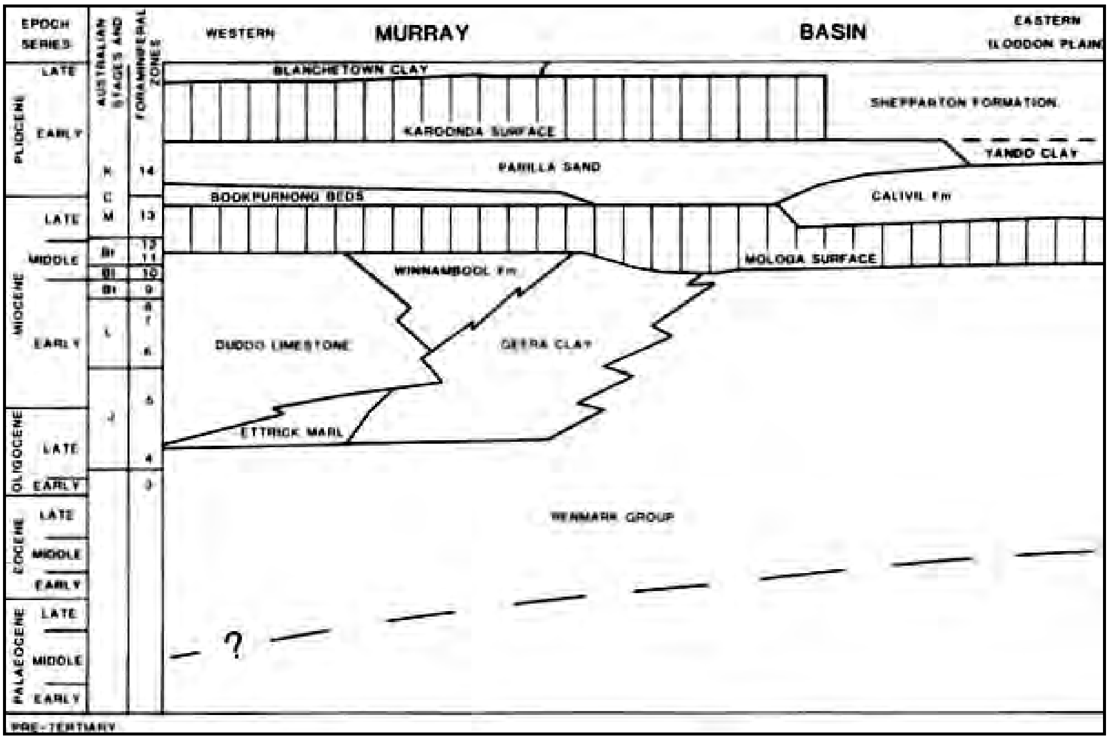


Figure 3. Stratigraphy of the south-western Murray Basin

Source: Macumber (1991)

In the late Miocene to early Pliocene, a rise in base level and marine transgression into the Murravian Gulf (Gloe 1947) resulted in deposition of Calivil Formation (Macumber 1973; Brown and Stephenson 1991) fluvial quartz gravels and pebbles, and aeolian, lacustrine and fluvial Parilla Sand (Firman 1966; Cramsie 1969; Brown and Stephenson 1991). The limit of marine transgression is believed to have been near Barham, with the sea retreating in the early Pliocene. The uppermost surface of the Parilla Sand is silicified and/or ferruginised and is known as the Karoonda Surface (Firman 1966, 1973; Lawrence 1966; Macumber 1991).

Geomorphic and stratigraphic evidence suggests that until the mid-Pliocene the palaeo-Murray River flowed south through the Douglas Depression (Figure 4), to exit to the sea in far western Victoria, near Cape Bridgewater (McLaren et al. 2011). However, uplift of the Pinnaroo Block and Padthaway Ridge (Hills 1939; Sandiford 2003), to the west of the present study area, led to the defeat of the lower Murray River at ~2.4 Ma, and the formation of a huge freshwater lake, Lake Bungunnia, to the immediate west of the study area (Stephenson 1986). At its maximum extent the lake covered more than 50,000 km^2, and within it the Blanchetown Clay (Brown and Stephenson 1991; An Zhisheng et al. 1986) was deposited. After ~800 Ka, the dammed Murray broke through to the sea along its present course in South Australia, and the lake drained, fragmenting into several smaller basins, of which Lake Tyrrell in Victoria is the largest surviving remnant (Page and Nanson 1996).

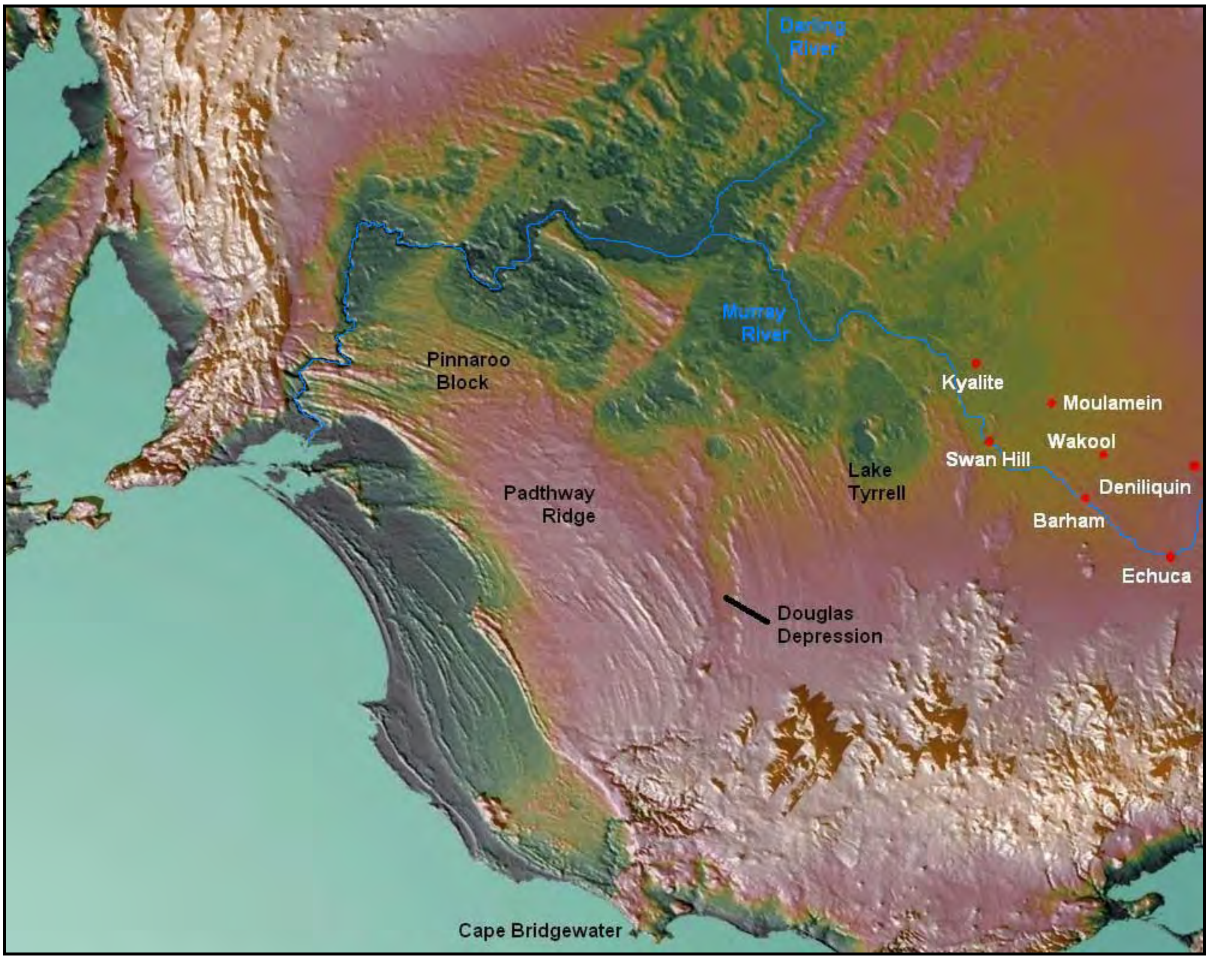


Figure 4. Murray Basin, SRTM 30 arcsecond DEM

Source: Adapted from http://jaeger.earthsci.unimelb.edu.au/ImageLibrary

The Shepparton Formation (Lawrence 1966; Brown and Stephenson 1991) was deposited by large rivers flowing out of the highlands from the late Pliocene–Pleistocene, and consists of a thick (20–80 m) sequence of fluvial and lacustrine reddish-brown and grey mottled clays and silts comprising a lower Yando Clay Member (Kotsonis and Joyce 2003), and several later depositional phases identified in the southern part of the Riverine Plain. Butler (1958) recognised the Pleistocene Katandra Member, a complex of riverine and parna layers, which underlies the Riverine Plain at a depth of up to 3–4 m (Plate 1) overlain by later Quaternary Quiamong and Mayrung materials. See also Pucillo (2005).

The Shepparton Formation forms much of the residual land surface in the Edward–Wakool channel system. Modern Coonambidgal Formation (Butler 1958) alluvial sediments overlie older surfaces in areas of active or ancestral fluvial deposition. The total depth of Cainozoic sediments in this section of the Murray Basin is generally less than 200 m (Brown and Stephenson 1991).

Plate 1. Probable Katandra layer exposed on lower banks of the Wakool River at the Kyalite Bridge

Geomorphology

The Cadell Fault

The Edward–Wakool channel system owes its formation to tectonic movement along the Cadell Fault, located between Deniliquin and Echuca. Displacement at the fault and across the flow path of the palaeo-Murray commenced by ~65 Ka, and eventually resulted in vertical displacement of the Cadell Tilt Block (Harris 1939), to the immediate west of the fault, of up to 14 m (Page et al. 1991, 2009; McPherson et al. 2012). The palaeo-Murray River was diverted at the fault to the north, resulting in the abandonment and preservation of relict channels to the west of this feature, such as Green Gully (Figures 5, 6). Towards the southern end of the fault, the flow of the palaeo-Goulburn River was deflected to the south-west (Stone 2006a). Lake Kanyapella, with its associated beach and lunette system along its north-eastern shore, developed to the east of the southern section of the block, near Echuca, by ~34 Ka. The lake was sustained by flows from the palaeo-Goulburn River (Stone 2006a) until it dried out by ~14 Ka, with the Goulburn re-establishing a course across the floor of the lake.

In more recent times, thought to be ~8 Ka (Bowler 1978), but possibly as recently as only ~550 years ago (Stone 2000b), the Murray River also diverted to the south through the Barmah Sandhills (the Kanyapella lunette) and across the floor of the Kanyapella Depression (Bowler 1978), where it is joined by the Goulburn River, flows around the southern part of the block, and turns to the north-west near Echuca, flowing into the valley of the palaeo-Goulburn River.

The remainder of the upper Murray's flow is directed to the north as the Edward River, and at Deniliquin it rounds the northern end of the block and returns to a generally westerly direction.

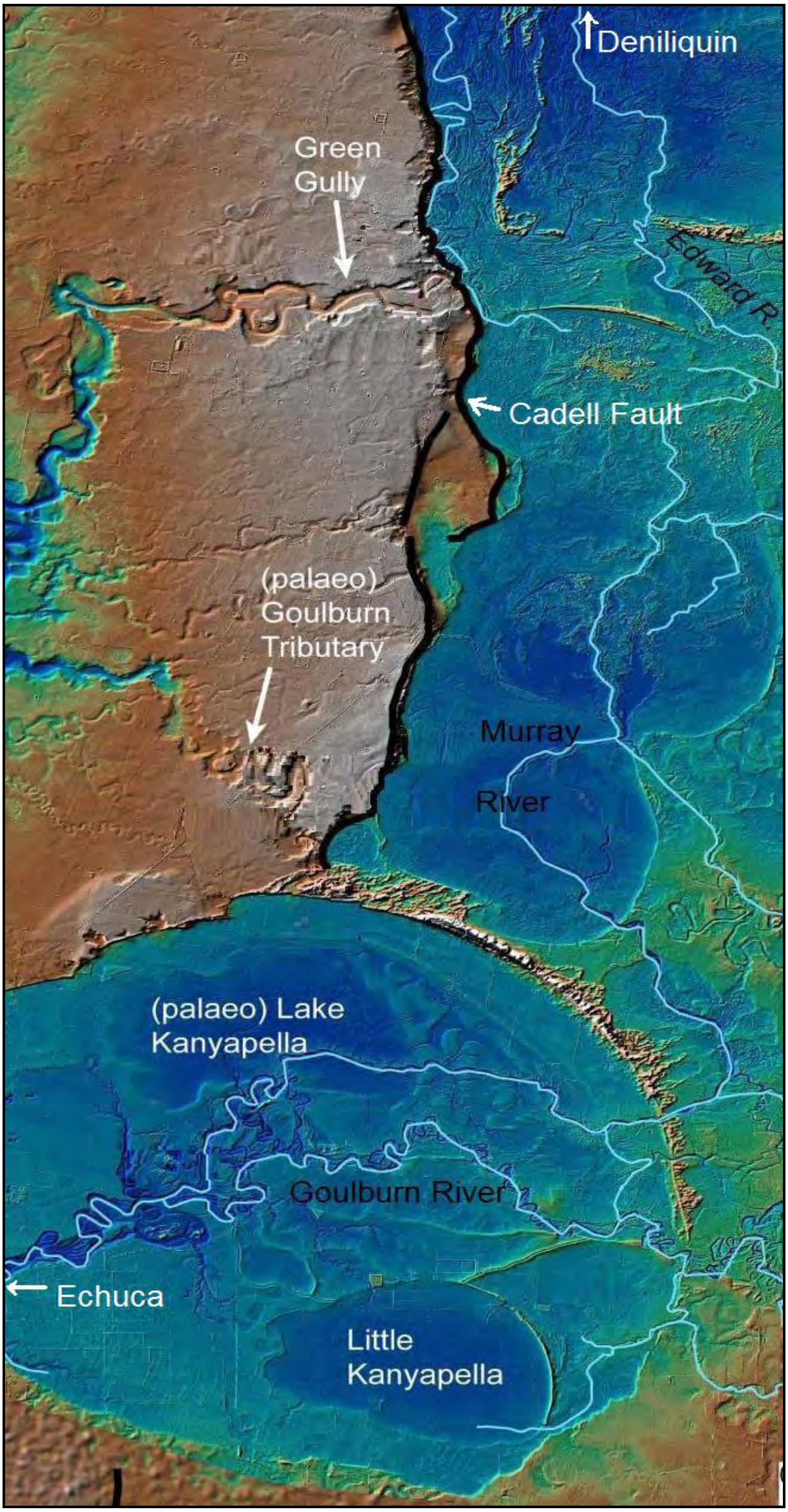


Figure 5. Green Gully, palaeo-Murray River, at the Cadell Fault

Source: Adapted from McPherson et al. (2012)

Figure 6. Green Gully, palaeo-Murray River, at Thule

Fluvial geomorphology

The study of fluvial geomorphology has been the key to understanding the distribution of sediments and soils of the Riverine Plain, their physical and geochemical properties (including their suitability for irrigation), and of groundwaters associated with them, since the 1940s (see e.g. Butler 1950, 1956, 1958; Butler and Hutton 1956; Pels 1964a, 1964b, 1966, 1969; Butler et al. 1973; Firman 1973). Much of the scientific debate in the 1950s and 1960s focused on stream patterns and morphologies and concerned the relationships between sedimentation and Quaternary climates (Butler 1950, 1958, 1960; Langford-Smith 1959, 1960a, 1960b, 1962; Pels 1964a, 1964b, 1966, 1969).

Butler (1950) described a system of 'prior streams', being very long wavelength, low sinuosity bedload channels, remnants of which are still visible in many areas (Figure 7). These materials are considerd to be the youngest deposits of the Shepparton Formation (Pucillo 2005). Butler also recognised a system of more recent fluvial deposits and terraces formed by a later phase of palaeo-channels, after the abandonment of prior streams. Compared to the prior streams, these 'ancestral streams' had shorter wavelengths, were more sinuous, and carried a higher proportion of suspended load. The ancestral stream channels were formed by incision into the existing alluvial-aeolian Shepparton materials (Figure 8), and were the immediate precursors of the modern drainage pattern. Butler (1950) termed these deposits the Coonambidgal, differentiated from the Shepparton Formation, and established as a more recent formation in its own right, on the basis of a lack of weathering.

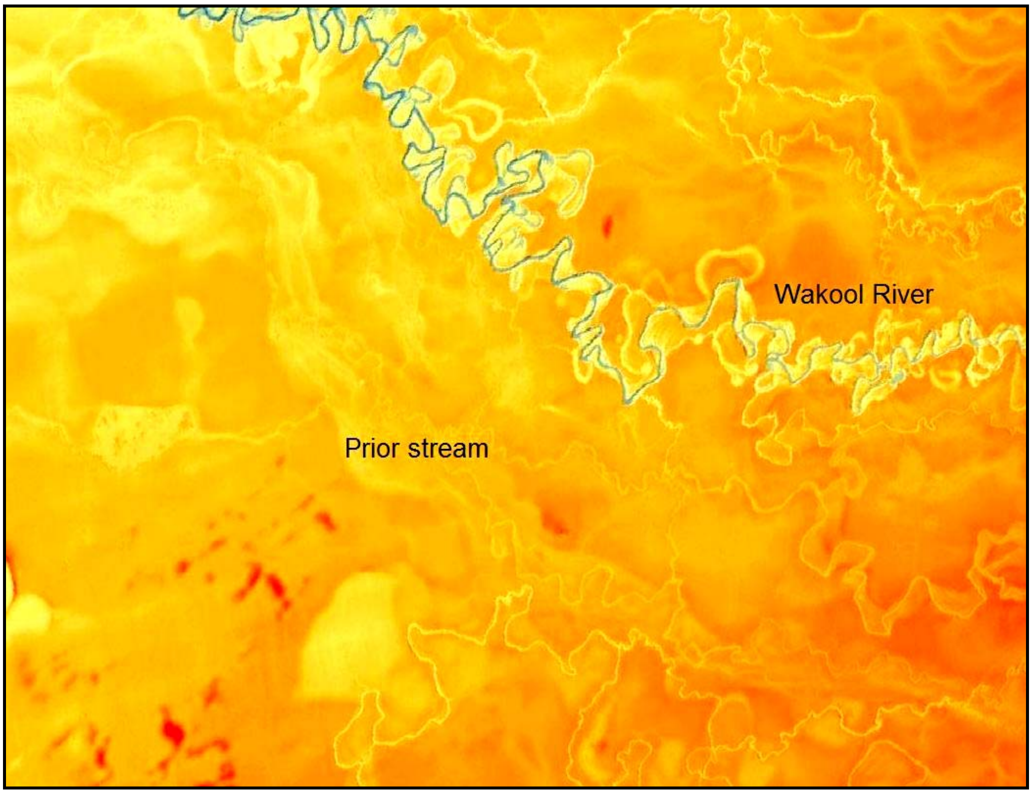


Figure 7. Trace of a prior stream visible using LiDAR, near Noorong

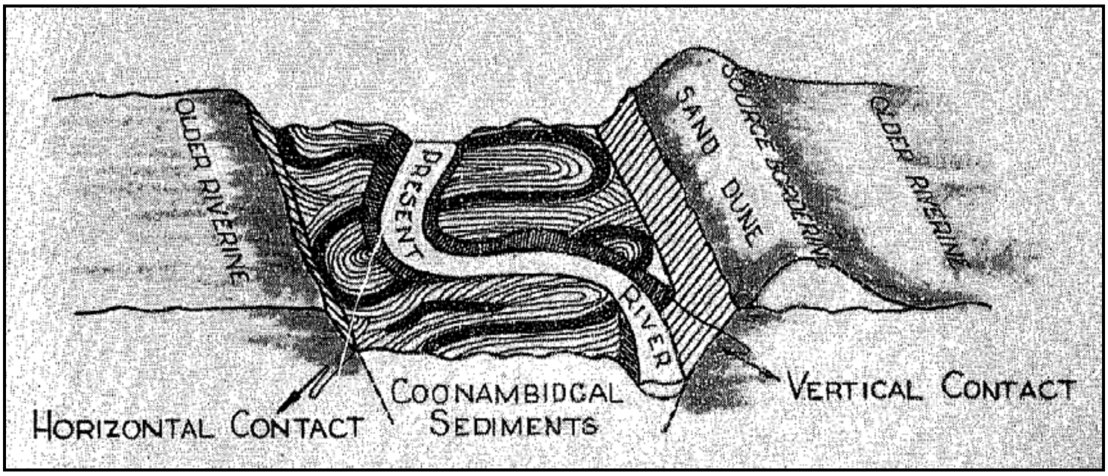


Figure 8. Relationship between older riverine Shepparton and Coonambidgal sediments

Source: Pels (1964b, p 112)

However, Pels (1964a, 1964b) recognised that Butler's Coonambidgal unit was more complex than originally understood, and on the basis of fieldwork near Deniliquin, where faulting had separated different episodes of stream activity, Pels identified three distinct phases of ancestral riverine deposition – Coonambidgal I, II and III, each phase thought to have been initiated during wetter periods and channel incision, and ending with aggradation as the climate dried and discharge waned. The prior streams and Coonambidgal I were beyond the ^{14}C limit, but Coonambidgal II sediments yielded a date of 24 Ka.

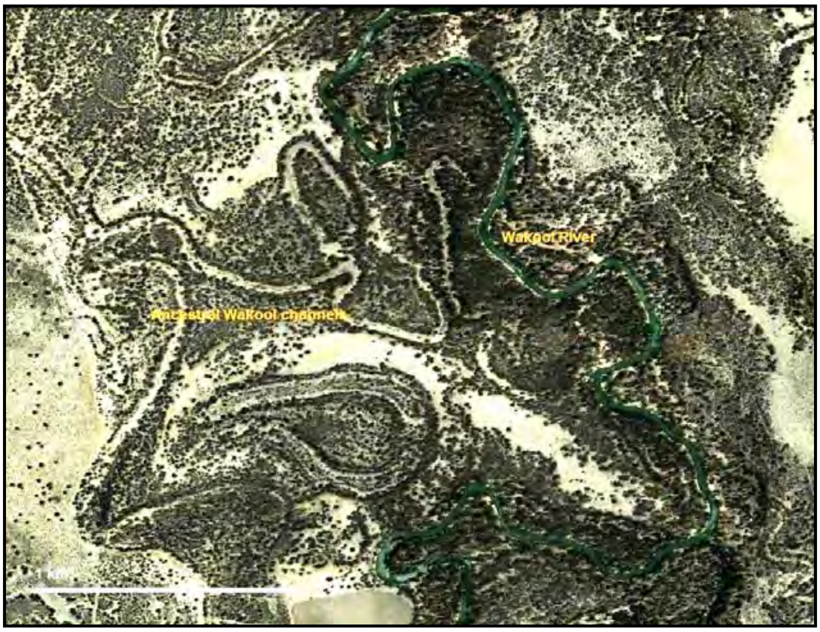
In the Goulburn River valley, Bowler (1978) recognised two larger ancestral river systems, the Green Gully–Tallygaroopna and Kotupna channel systems, occupying a valley incised into Shepparton Formation sediments. The Tallygaroopna channels had much larger dimensions than the present Murray, and carried a predominantly sandy bedload, with much greater discharges. They were formed between ~50–20 Ka, in the period prior to significant tectonic rise along the Cadell Fault. The Tallygaroopna meander belt ridge is visible beneath the floor of Lake Kanyapella on LiDAR imagery (Figure 5); further downstream it follows the course of Gunbower Creek (Stone 2006a). Around 25–15 Ka, Kotupna channels were formed, with a narrower meander belt and smaller dimensions; these carried more suspended load, with lower discharges. Goulburn-type channels formed ~14–11 Ka, and are typically narrow, sinuous, suspended load channels.

With the advent of thermoluminescence dating, absolute ages beyond the ^{14}C limit could be determined and the chronology more fully described. On the Murrumbidgee plain, Page et al. (1991, 2009) identified and dated four distinct phases of palaeo-channel activity. The first of these was the Coleambally phase, dating from about 110 Ka, when the plain was crossed by low sinuosity, bedload-dominated (prior) streams which declined in activity after ~ 5 Ka. There was a hiatus in alluvial deposition, with enhanced aeolian deposition until ~55 Ka. The Kerarbury phase (Page et al. 1991, 2009) was a renewal of fluvial activity from 55 Ka to 35 Ka, and this was followed by deposition of Gum Creek system sediments until 25 Ka (Figure 9). The Glacial Maximum Yanco system phase (Figure 10) was marked by broad, bedload-dominated streams with high discharges caused by increased snowfall in the high country to the east and very low evaporation rates, with consequently high lake levels throughout the Riverine Plain. Yanco system sedimentation lasted until ~12 Ka (Page et al. 2009).

The modern drainage system has continued to undergo change, with the abandonment of some channel reaches and, conversely, capture of other flow paths. Channel patterns may be distributary, anabranching, anastomosing, convergent or braided, often depending on flow, with abandoned river channels common. In this geomorphically complex and dynamic area, modern channels are often a combination of channel reaches of different ages and morphologies and flowing through various surfaces and materials.

Like much of the Riverine plain, channel systems in the study area are currently undergoing a phase of incision as the rivers adjust to current discharge and climatic patterns. In the Edward–Wakool channel system, reduction in climate-controlled discharge has been exacerbated by geomorphic change occasioned by the avulsion of the Murray River to the south. River regulation has also affected the relationships between channel morphology and flow. As a result, many channels in the study area are underfit in relation to their current stream discharges, and generally have low width to depth ratios.

Many modern channels have adjusted their morphology within earlier Coonambidgal sediments. However, due to fluvial avulsion across the extremely low relief plain, many modern channels have established within older Shepparton Formation materials. It is these channels that are the focus of this study.



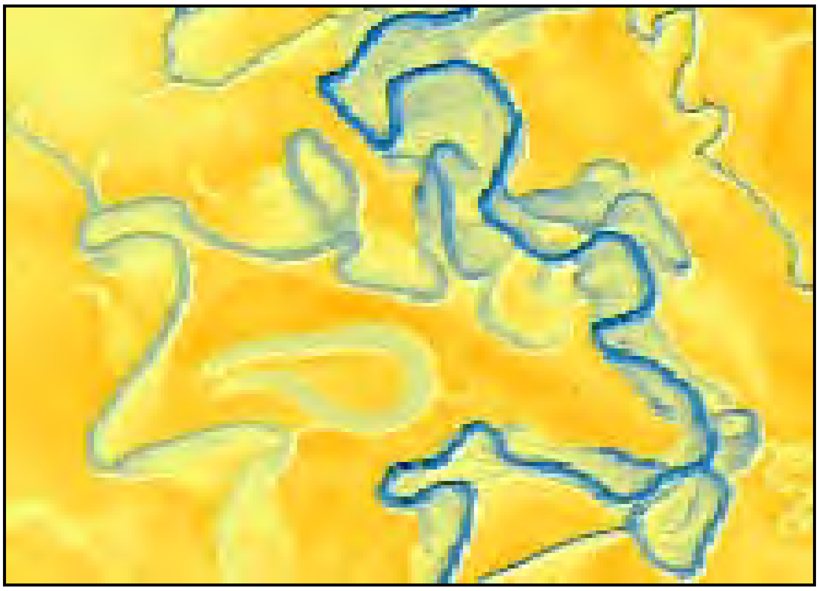


Figure 9. Ancestral gum creek phase and modern Wakool channels, satellite and LiDAR images

Note the much larger meander belt width and width to depth ratio of the ancestral river remnants.

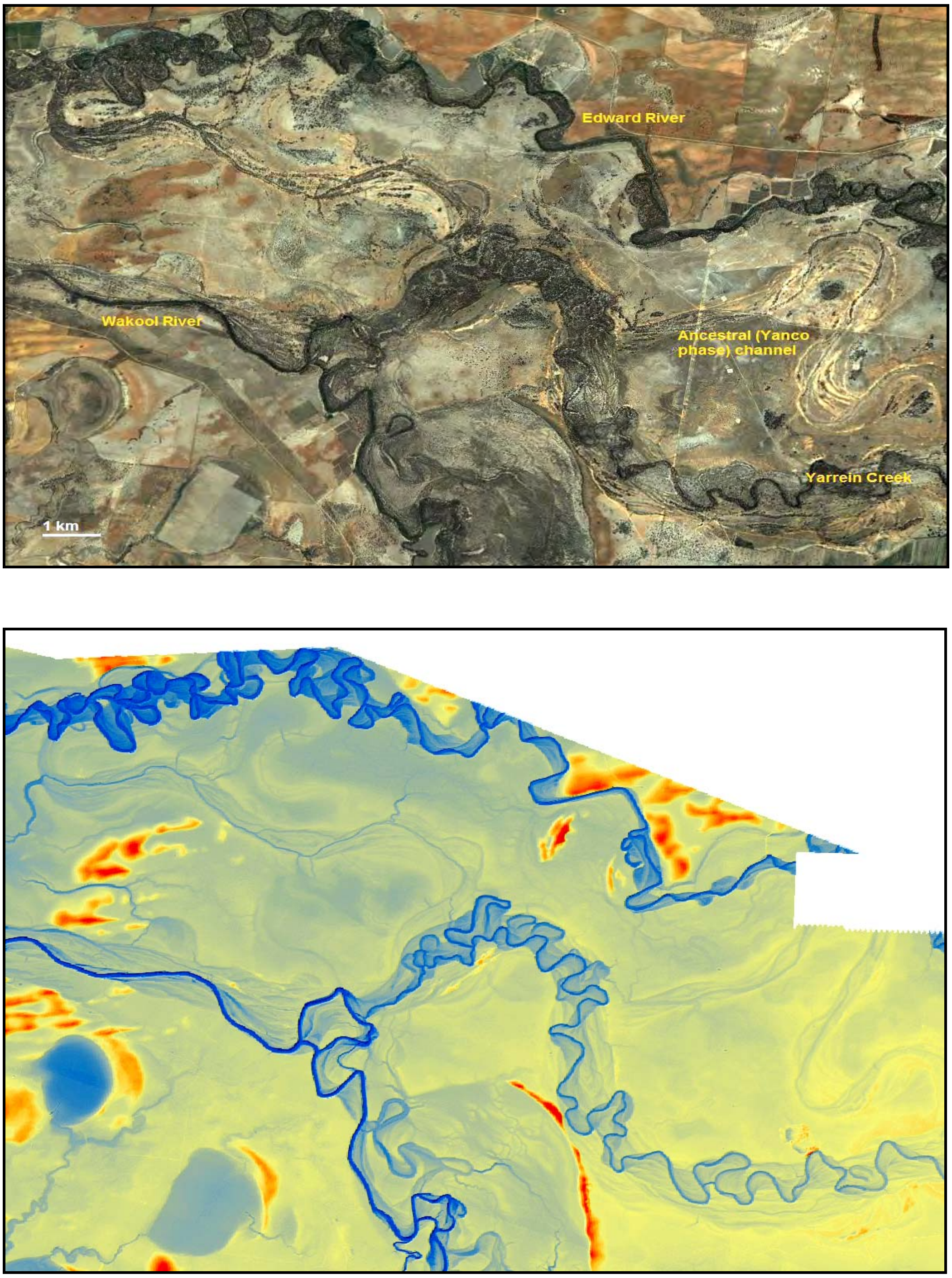


Figure 10. Ancestral Yanco Phase channels, satellite and LiDAR images

Note that Yarrein Creek occupies an ancestral Yanco Phase channel of a much larger width to depth ratio.

Aeolian deposition

Aeolian materials are also widespread in the study area, and fall into six types:

- linear dunes and associated sand sheets
- isolated sub-linear remnants
- parna
- source bordering dunes, including:
  - riverine source bordering dunes
  - lunettes.

Linear dunes and associated sand sheets define the Mallee region (Bowler and Magee 1978; Bowler et al. 2007), and these mark the western boundary of the Riverine Plain, and of the present study area (Figure 11). South of the Edward and Wakool rivers, extensive linear dunefields are confined to an area west of Merran Creek. North of the Edward, linear dunefields dominate the landscape further east, almost to the Moulamein–Balranald Road.

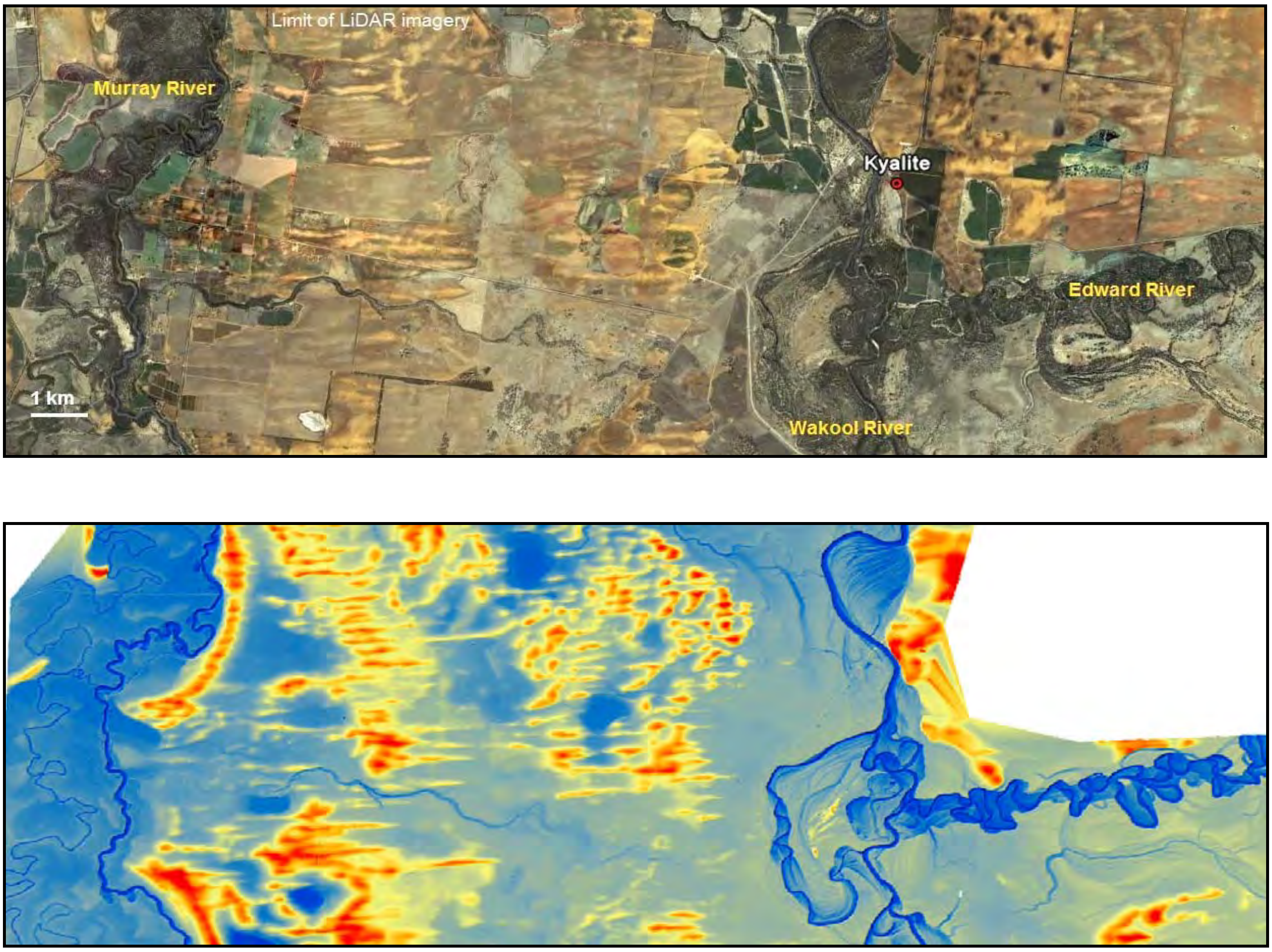


Figure 11. Aeolian linear dunefield in the vicinity of Kyalite, satellite and LiDAR images

The Mallee dunefields became established by about 0.5 Ma (An Zhisheng et al. 1986), and became active again during the Last Glacial Maximum between 35 Ka and 8 Ka (Gardner et al. 1987). The dunes comprise clayey sand, and contain abundant gypsum and carbonates (Gardner et al. 1987), which often form a subsurface pedogenic hardpan. Surficial fragments of the calcareous hardpan occur in areas of dune erosion or mobility.

More isolated sublinear dune remnants extend further to the east (Figure 12), with a particularly large dunefield outlier located on either side of the Niemur River in the vicinity of Lake Nangtree (Figure 13). This outlier dunefield may be a significant influence on groundwater recharge and flow paths, with the majority of saline and sulfidic sites located between the main Mallee dunefield and this dunefield outlier. The occurrence of a shallow ferruginised hardpan in this part of the study area may also be related to this setting.

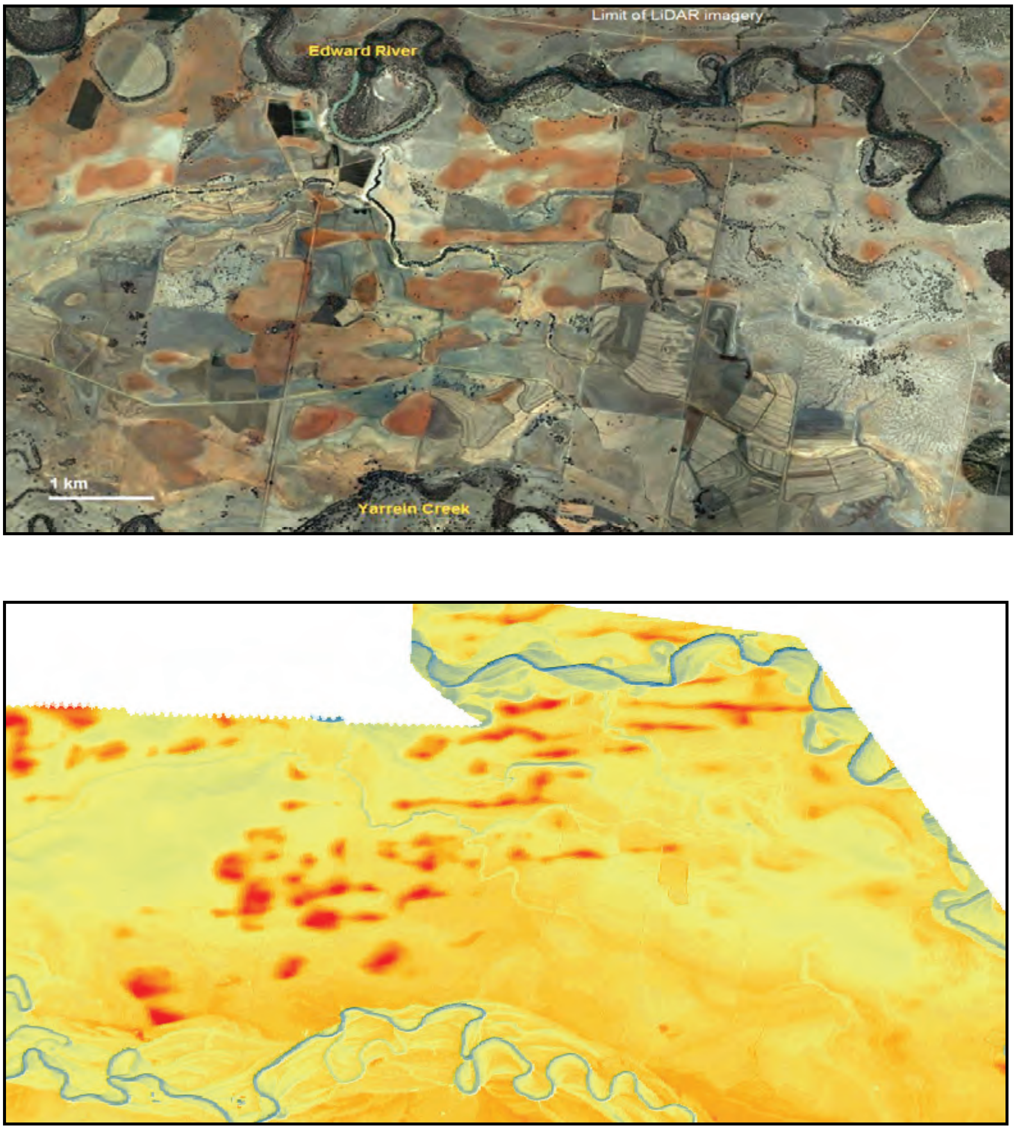


Figure 12. Localised sub-linear dune remnants, satellite and LiDAR images

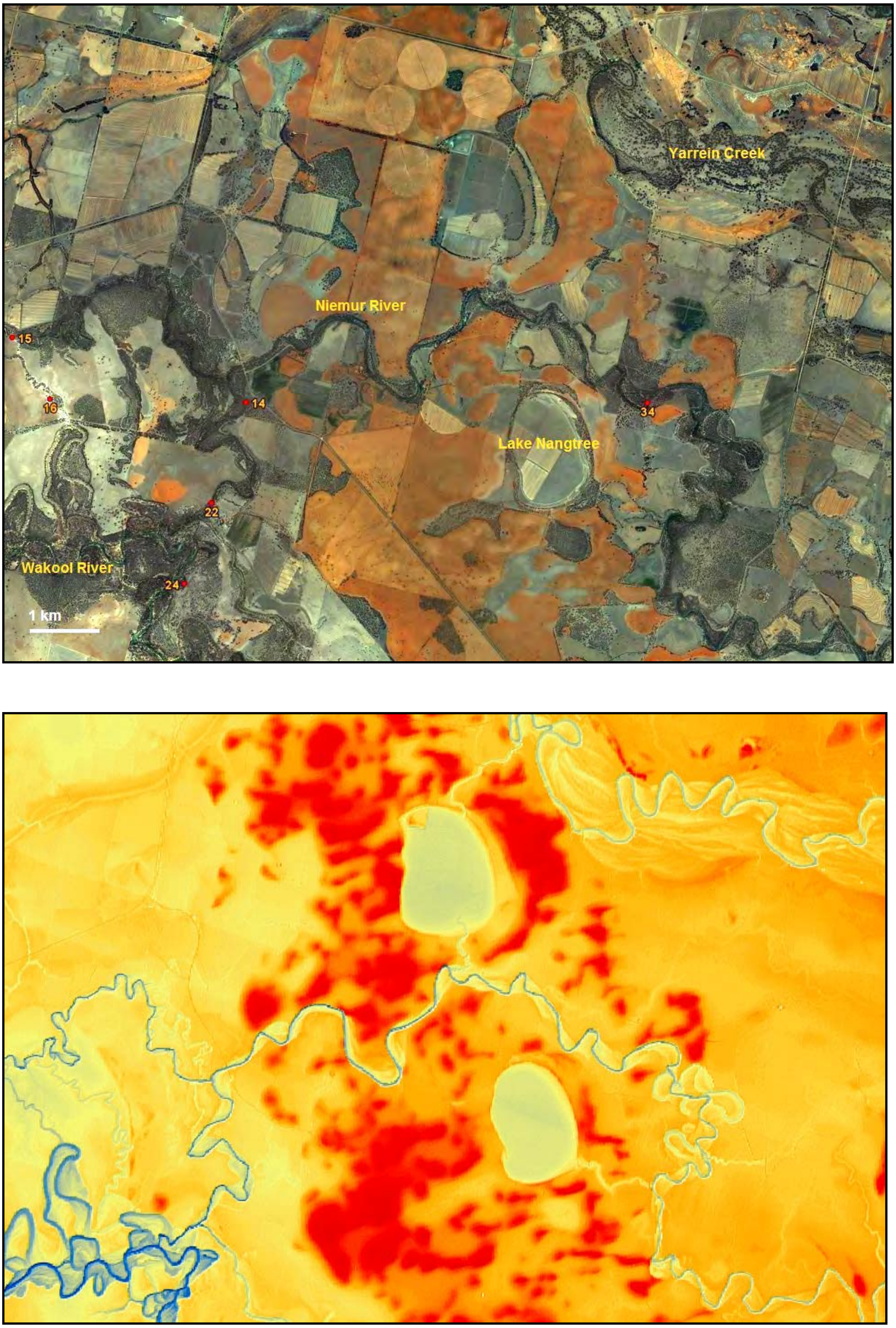


Figure 13. Dunefield outlier at Lake Nangtree, intersected by the Niemur, satellite and LiDAR images

The most extensive aeolian material in the study area is parna (Butler 1956, 1958), which occurs either as a surficial layer in its own right, or as a constituent of otherwise alluvial layers over most of the study area. Parna is so ubiquitous that Butler (1958) defined areas without it as ‘parnaless zones’, the major such zones being to the north and west of Deniliquin. Linear dunefields, sublinear remnants and parna sheet materials in the study area are all calcareous.

Source-bordering dunes are associated with relict bedload-dominated streams, and are common along the palaeo-Murray Green Gully-Thule Creek system, along the palaeo-Edward River north and north-west of Deniliquin, near Wakool and Noorong, and elsewhere.

The earliest evidence for aridification along the Murray River is an episode of riverine source-bordering dune formation ~72 Ka. Further episodes of riverine source-bordering dune formation occurred ~40 Ka, and at the end of the Kanyapella lacustrine period, ~24 Ka (Stone 2006a).

Lake–lunette associations are especially common in the western part of the study area, towards the interface between the residual Cainozoic mallee surfaces in the west and more recent alluvial materials. Some of these lake–lunette associations are overlapping, indicating multiple phases of lacustrine conditions and lunette dune formation. The largest of these palaeolakes was the giant Swan Hill palaeolake, the lunette of which confines the Murray River for 40 km downstream of Swan Hill (Figure 14).

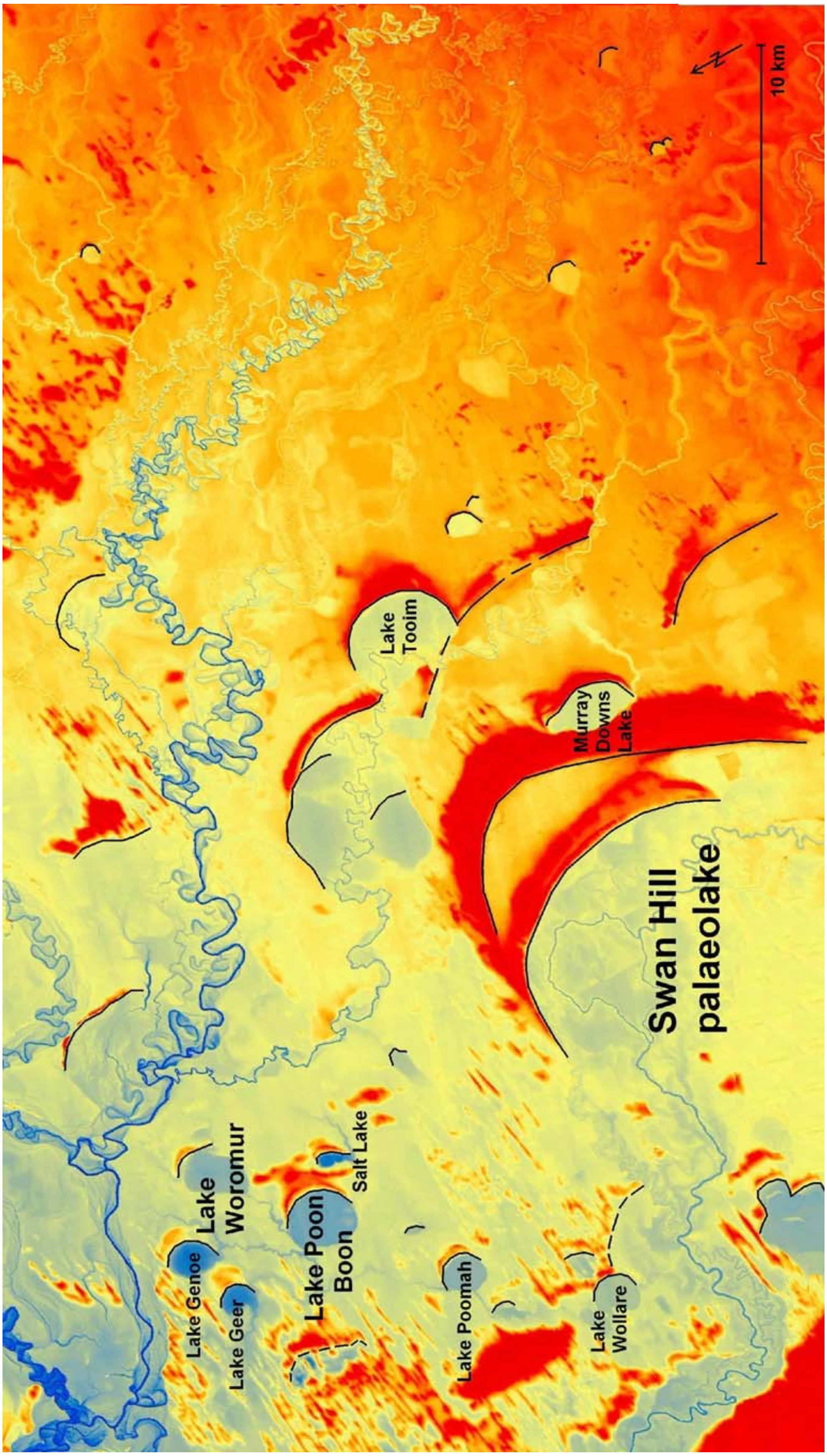


Figure 14. Lacustrine–lunette associations in the western part of the study area, LiDAR image

Note that leading edges of lunettes are marked in black.

Landscapes and soils

As a consequence of these geomorphic events, combined with the effects of climate change over the late Quaternary, the Edward–Wakool channel system comprises a complex pattern of residual alluvial, aeolian and modern alluvial materials (Smith et al. 1943; Butler 1950).

A geomorphic map for the entire Riverine Plain, showing stream traces, plains, channels and depressions, dunefields and lakes, was produced by Butler et al. (1973).

Broad-scale reconnaissance soil-landscape mapping of the study area was undertaken by Davy (2005), as part of a wider project, using aerial photo interpretation and radiometrics data (Figure 15). In the present study area, 22 landscapes and 5 variants were distinguished. These data have been processed using ArcGIS and interpreted using additional soil-landscape descriptions held by the Office of Environment and Heritage with reference to the dominant soil types and landscape features. To assist interpretation, the 27 units have been reduced to four basic types:

- landscapes with residual surfaces, shown in yellow
- landscapes dominated by alluvial materials, in grey
- landscapes dominated by aeolian materials, in orange
- landscapes of lacustrine sediments, in light blue.

This map reveals the large area of residual landscape of the Cadell Tilt Block west of Mathoura, intersected only by the palaeo-Murray Green Gully landscape. The large area of alluvial and lacustrine materials in the centre of the study area, north-west to north-east of Barham, is interrupted only by the slightly elevated Wakool plain, aeolian ridge remnants, and other features associated with relict streams.

Further towards the west, in the area north to north-east of Swan Hill, the soil-landscape data reveals an emergent residual, slightly elevated surface, with landscapes and soils largely formed from the Shepparton Formation, the surface in part overlain by recent aeolian linear dunes from the west. In this fluvially convergent part of the study area, Merran Creek, Wakool River, Niemur River and Edward River become increasingly confined and therefore incised into this residual surface, the changing morphology of stream systems as they progress downstream confirmed by LiDAR analysis (see also Clarke et al. 2010).

A 10 m digital elevation model (DEM) of the western, lower part of the Edward–Wakool plains has been prepared for this study (Figure 16). It reveals the generally flat, even gradient of the area sloping to the west. Outstanding from this general surface are dunefields and lunettes, particularly the large double lunette of the Swan Hill palaeolake. Also visible on the left land margin of the image is the edge of the raised surface on the western side of the Avoca Fault.

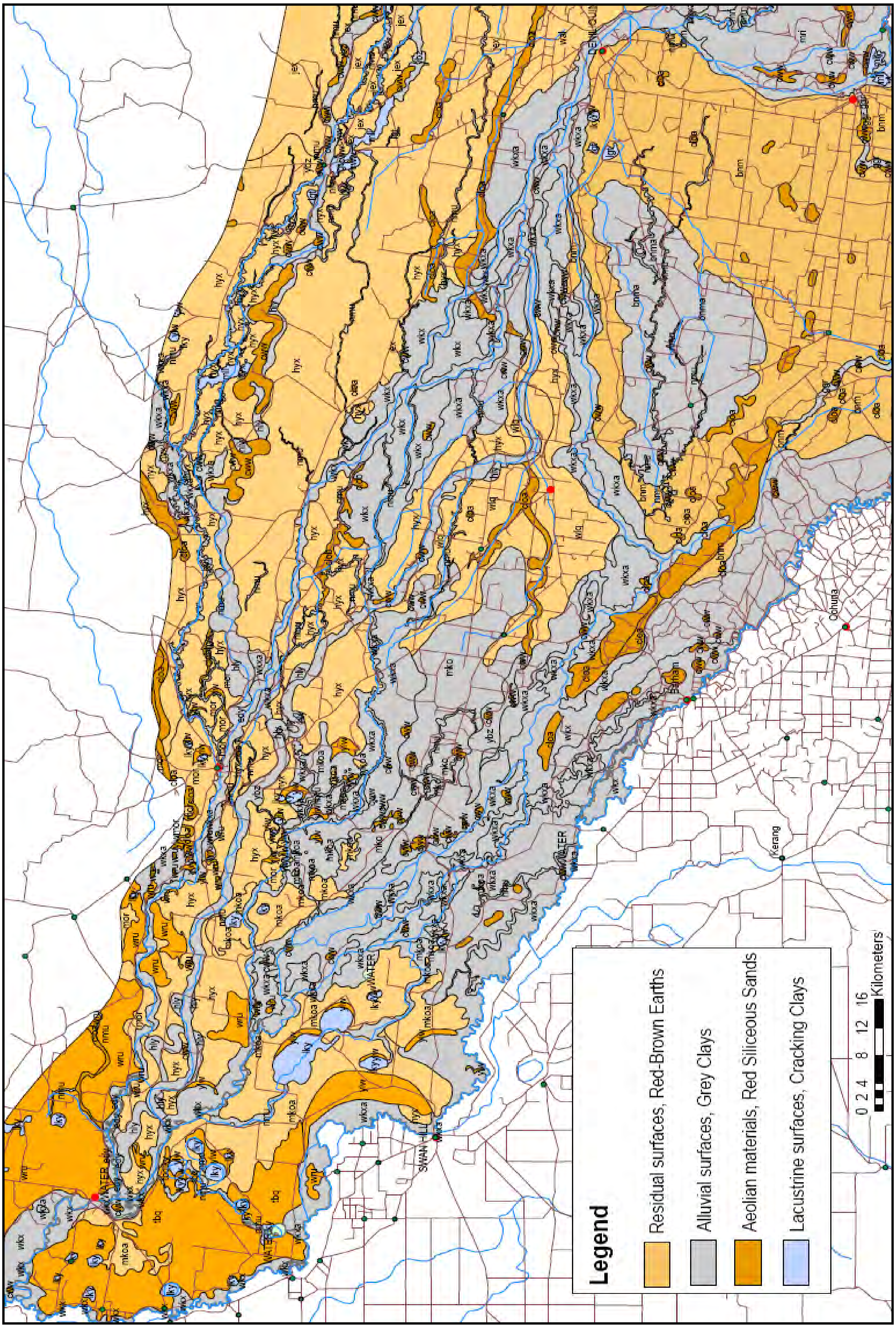


Figure 15. Soil landscape map

Adapted from Davy (2005)

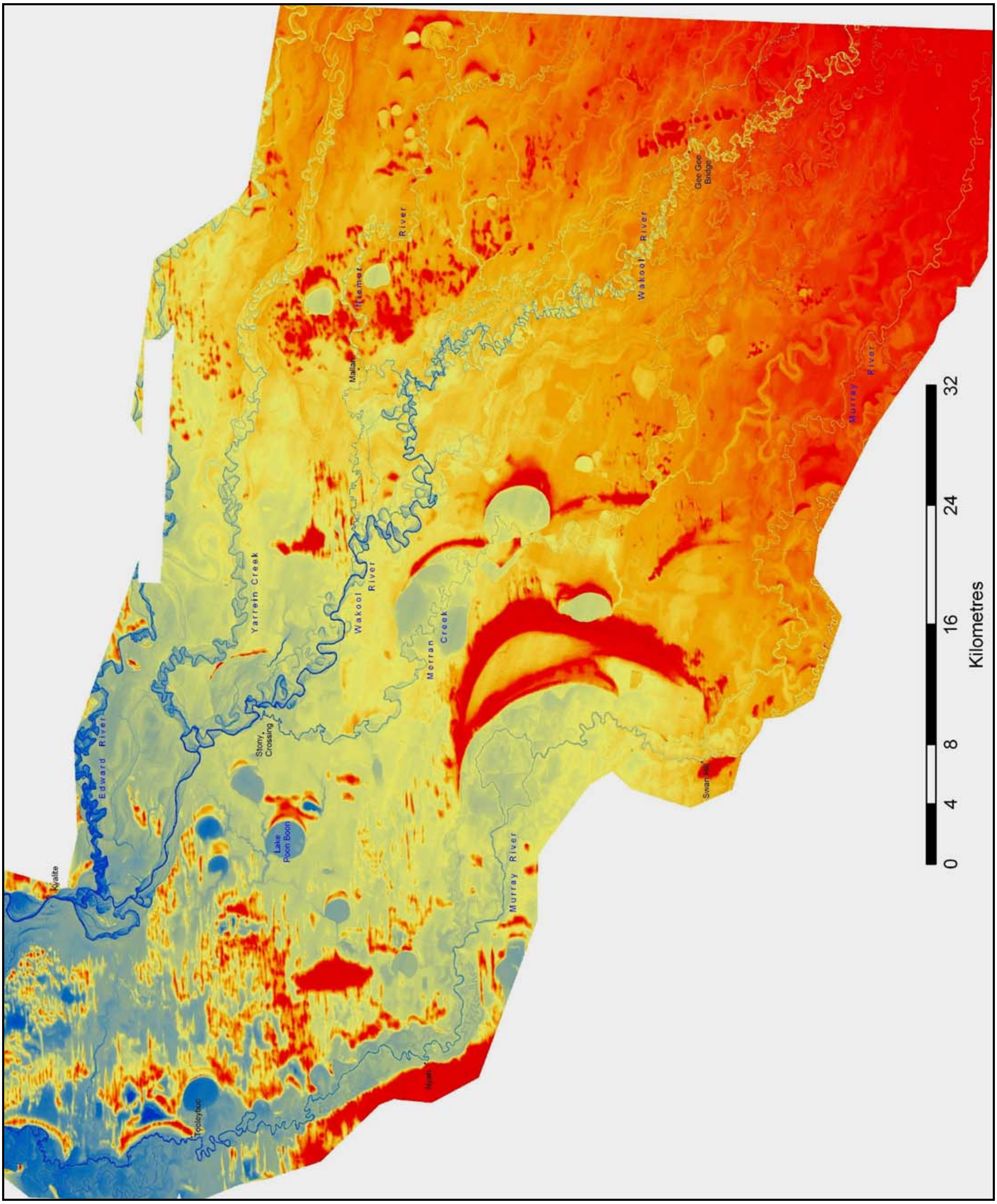


Figure 16. LiDAR image of the western part of the study area

Conversely, depressed into the general land surface are lake basins and channel systems, the LiDAR data revealing stratigraphic and morphologic differences between the various channel system types. The broad, low sinuosity channel occupied by Yarrein Creek is visible coursing across the top of the image. This can be contrasted with the incised high-sinuosity meander belt occupied by the Wakool River, and Merran Creek, with no meander belt, rather incising directly into the older Shepparton land surface.

In places, modern streams are incised into former lake basin sediments. Merran Creek, for example, flows through two such lake basins (Figure 17). Saline and sulfidic conditions are significant downstream of these basins.

Early soil surveys were carried out in the Murrumbidgee Irrigation Areas by Taylor and Hooper (1938). The first detailed soil and land use survey in the study area was that of Smith et al. (1943), who carried out a study of the Wakool Irrigation District, which approximates the present study area. Soil types were classified into three main groups: Red-Brown Earth Soils; Grey and Brown Soils; and mallee soils. A range of physicochemical analyses was carried out. Further soil surveys were undertaken by van Dijk (1958, 1961) and Stannard (1970). It was found that the soils could generally be grouped into five broad soil groups: clays; red brown earths; transitional red brown earths; sands over clay; deep sands. These approximately correlate with the later geomorphic map by Butler et al. (1973) and the soil landscape groupings of Davy (2005), who identified the following soil types:

- Red-Brown Earths and Grey and Brown Cracking Clays (Red and Brown Chromosols and Sodosols and Grey and Brown Vertosols) (in landscapes with **residual** surfaces, including ancient alluvium and parna)
- Grey and Brown Cracking Clays or Solodic Soils (Grey and Brown Vertosols or Sodosols) in backplain locations, with silty or sandy Alluvial Soils or Earthy Sands (Tenosols) near current channels (in landscapes dominated by **alluvial** materials including the Coleambally through to Yanco phases and modern channel systems
- reddish Siliceous Sands, Red Earths and Calcareous Soils (Arenic Rudosols, Red Kandosols and Calcarosols) (in landscapes dominated by **aeolian** materials)
- Grey, Brown and Black Cracking Clays (Vertosols) (in landscapes comprising **lacustrine** sediments).

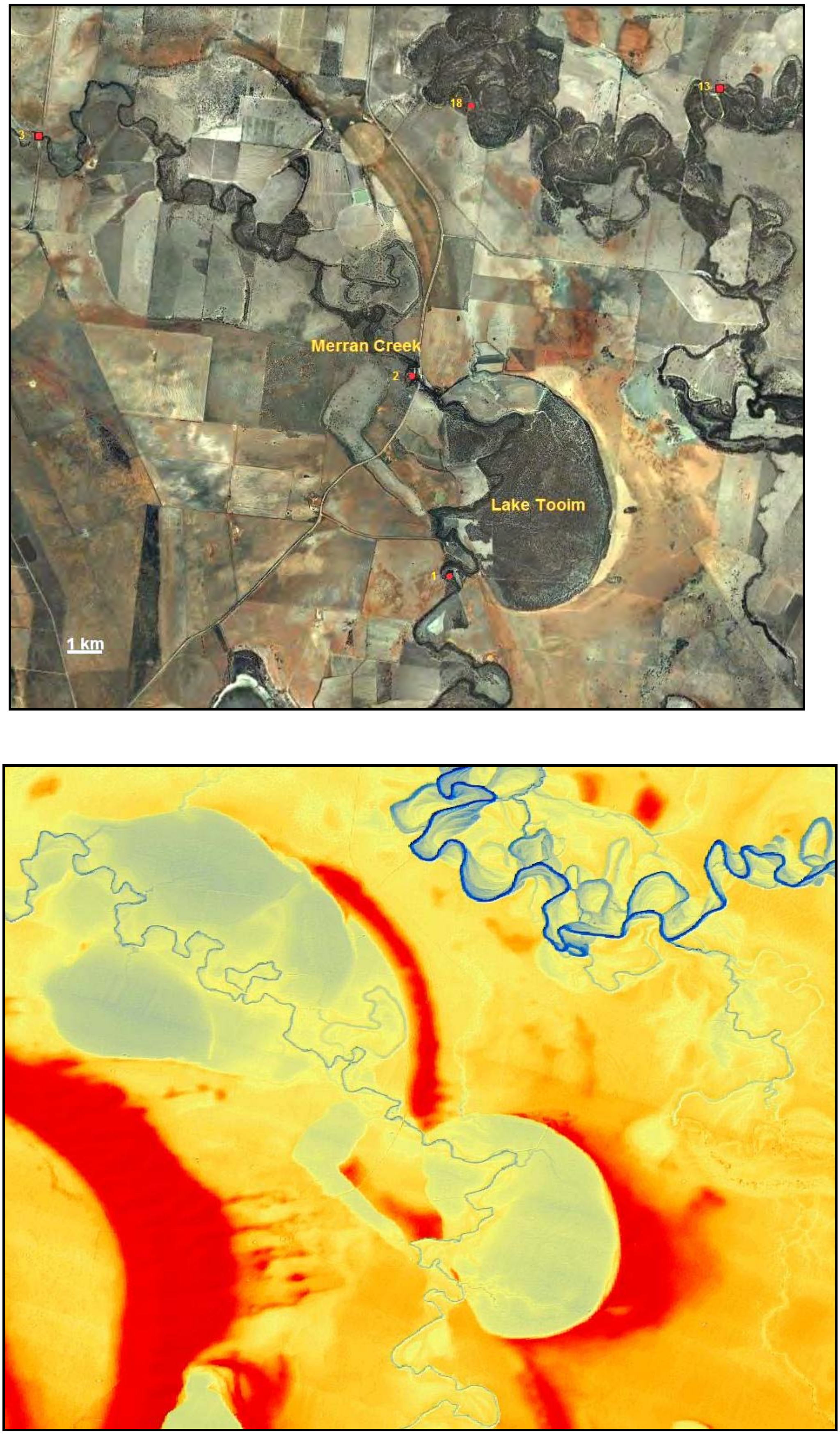


Figure 17. Merran Creek flowing within two former lake basins, satellite and LiDAR images

More recently, Hornbuckle et al. (2008) and Thacker et al. (2008) examined the physical and chemical properties of the soils of the Murrumbidgee, Coleambally and Murray Irrigation Areas. Intensive fieldwork was also carried out by Jenkins et al. (2006) and Vaze et al. (2010) across the Koondrook–Perricoota Forest for a hydraulic model. Soils information generated included the spatial distribution of soil types, soil stratigraphy, soil hydraulic properties, soil salinity and soil organic matter. It was found that most of the floodplain soils were grey clays, although the study also highlighted the importance of shallow, often coarse-grained, palaeo-channel deposits as fluvial aquifers in influencing groundwater movement (see also Pucillo 2005; Vaze et al. 2010).

Ferruginous hardpans are also commonly observed, especially in the lower, western part of the study area, particularly in the Coobool Island and surrounding district. These concretionary layers are generally massive vesicular or pisolitic, above a mottled red and white pallid zone clay or sandy clay (possibly having affinities with the Merriwagga Surface of Butler (1958; see also Butler and Hutton 1956). Modern streams, such as the Niemur River (Plates 2 and 3) either incise into or may be perched on this surface. Stony Crossing is an example of the latter, where a recent meander cut off remains perched on the hardpan, with hardpan and mottled-pallid zone remnants exposed nearby (Plate 4).

Plate 2. Niemur River, near Site 34, showing river perched on ferruginous hardpan

Plate 3. Niemur River, near Site 14, showing incised pallid zone

Plate 4. Ferruginous hardpan remnants and mottled zone exposed near Stony Crossing

The Edward–Wakool rivers

Wakool River

Wakool River is the major southern distributary of the Edward–Wakool alluvial system. The Wakool branches from the Edward ~8 km downstream of Deniliquin, and for the first ~10 km it follows the course of the palaeo-Edward River, within a broad, complex meander belt, the modern Edward having avulsed to the immediate north along this section. However, the Wakool then leaves this palaeo-valley, which continues to the north-west (the palaeo-channel being occupied ~7 km further on by Colligen Creek). The Wakool then flows across a Shepparton Formation surface, along the northern edge of the Cadell Tilt Block. Guided by the edge of the Block, the Wakool has a fairly straight planform until ~30 km downstream, where the Wakool falls into a broad Coonambidgal Formation meander plain, and becomes highly sinuous. The river is narrow and of relatively insignificant dimensions until a further 10 km downstream, where the Wakool is joined from the north by the morphologically larger anabranch Yallakool Creek. The Wakool, now having a substantial channel with large meander wavelengths, and situated within a broad meander belt, continues in a south-westerly direction towards the Murray and Barham rivers until, at ~60 km downstream, the Wakool falls into the Thule Creek–Green Gully meander plain, being the palaeo-Murray River valley. The Wakool, along with a number of other modern anabranching and anastomosing channels and palaeo-channels, follows this palaeo-meander belt towards the north-west, being joined on the way by Barbers Creek from the south, flowing from the Koondrook-Perricoota forest near Barham. The Wakool River continues for another ~70 km across a highly complex alluvial plain, until it reaches Coobool Island. The ‘island’ is surrounded on all sides during higher flows by the Wakool (southern and western sides), Mallan Mallan Creek (northern side), and the Niemur River (eastern side). Mallan Mallan Creek joins the Wakool ~12 km further on from the north and, after another ~13 km, by Merran Creek from the south, with Yarrein Creek coming in ~5 km later from the north. At this point all the major channels, with the exception of the Edward, have flowed back into the Wakool, which now assumes the proportions and morphology of the palaeo-Murray River, with channels widths, meander wavelengths and widths generally in excess of that of the modern Murray. The Wakool is joined ~12 km later by the Edward River from the north, just before Kyalite.

Wyam Creek

Wyam Creek is an anabranch channel of the Wakool in its middle reaches. Wyam Creek has several offtakes from the Wakool, with the main offtake channel ~21 km north of Barham. The creek flows for another ~22 km in a generally north-westerly direction, in an anastomosing pattern with many tributaries and distributaries, part of the way adopting an almost braided pattern within a Yanco phase channel (Page et al. 1991, 2009), before incising into an older land surface and joining the Wakool River near Gee Gee Bridge.

Yallakool Creek

Yallakool Creek diverges from the Edward River ~21 km downstream of Deniliquin, and just 1 km upstream of the diffluence of Colligen Creek from the Edward. Yallakool Creek begins by flowing back upstream along a meander reach of the palaeo-Edward, before leaving this meander belt and heading in a westerly direction and incising into an older Shepparton surface. Approximately 19 km downstream, the Yallakool is joined by tributaries from the north and flows across a more recent alluvial surface, with some forested areas with incompetent and deranged drainage before, ~34 km from the start, joining the Wakool with which it has gradually converged over its course.

Colligen Creek

Downstream of Deniliquin the Wakool diverges from the Edward River, and 12 km further, Yallakool Creek diverges, also to the south. Approximately 1 km further, Colligen Creek, a major anabranch of the Edward, diverges to the south, just above Stevens Weir on the Edward. Colligen Creek flows generally parallel to the Edward, rejoining it ~30 km downstream in the Werai forest. Morphologically however, Colligen Creek is the major channel, with a broad, complex Coonambidgal meander belt with numerous ox-bow cutoff meanders, in contrast to the Edward, which lacks such in this section.

Cockran Creek

Cockran Creek diverges from Colligen Creek at a point where the Colligen departs from a broad, low sinuosity ancestral channel and turns generally to the north-west. Cockran Creek remains within this ancestral channel, and is the name given to the most obvious of the modern channels, usually dry, in a braided system occupying the breadth of this ancestral belt, which heads in a generally westerly direction for ~24 km. This ancestral channel then turns towards the north and north-west and, ~10 km later, is joined by a tributary from the east as the dominant modern channel leaves the ancestral channel and turns to the west, in the process changing its form to a low sinuosity single channel known as Jimaringle Creek.

Jimaringle Creek

The commencement of Jimaringle Creek is marked by its departure from the ancestral stream channel of Cockran Creek. Jimaringle Creek flows in a generally north-westerly direction through an older Shepparton land surface for ~27 km before joining Niemur River.

Niemur River

Niemur River begins as several distinct overflow channels off Colligen Creek immediately above the confluence of that creek and the Edward River in the Werai forest, a large area of incompetent and occasionally deranged drainage. The incipient upper Niemur channels gradually form into one main channel as it leaves the Werai forest, and is joined by several more from the Edward to the north as it heads in a generally westerly direction. Approximately 29 km downstream it is joined by another branch of the Niemur, which meanders within a broad, low sinuosity ancestral channel coming from the south-east. The Niemur crosses this ancestral valley at right angles as the two branches converge, and ~5 km further on is joined by Jimaringle Creek from the south. A larger channel at this stage, the Niemur meanders through a low elevation forested area with areas of incompetent, deranged drainage, before turning generally towards the north and north-west and becoming more confined within a large area of former lake basin, lunette remnants and dunefields, and passing through these north of Lake Nangtree before emerging at Coobool Island. The Niemur avulsed in the geomorphically recent past through Shepparton materials in a southerly direction into the Wakool, leaving its partially abandoned former lowest reach as Mallan Mallan Creek. This avulsion may have been caused by the development of a lunette formed from a deflation basin in the eastern part of Coobool Island.

Mallan Mallan Creek

Mallan Mallan Creek is the lowest ~12 km of the palaeo-Niemur River. Consequently, Mallan Mallan Creek is an incised, overfit, partially abandoned channel that flows through a Shepparton land surface into the Wakool, the resulting arrangement of channels forming Coobool Island.

Pissen Creek

Pissen Creek is a short, ~6.5 km long, but apparently highly polygenetic, channel that flows across Coobool Island. It appears to receive overflows at a point at which it comes close to Mallan Mallan Creek, ~1.5 km from the easternmost end of Pissen Creek. From this point, the creek channel increases in width as it flows in a south-easterly direction across a deflation basin in the eastern part of Coobool Island to connect with an abandoned ox-bow of the Wakool on the southern side of Coobool Island. The western part of Pissen Creek connects with the Wakool ~2.7 km above Mallan Mallan Creek. Pissen Creek has fluvial features suggestive of flow in both directions, flow direction possibly having reversed when direct connection with the main river at the upstream end was cut off by ox-bow formation.

Yarrein Creek

The upper reaches of Yarrein Creek receive flow from the Edward River at two points ~10 km and ~14 km upstream of Moulamein where a major ancestral channel approaches the Edward from the south. Shortly downstream, a connecting channel diverts some flow to the Niemur River, with Yarrein Creek meandering in a generally north-westerly direction within the ~1.5 km wide Yanco Phase channel. Yarrein Creek continues for another ~55 km, confined within the Yanco channel, until its confluence with the Wakool River ~15 km upstream of Kyalite.

Barbers Creek

Barbers Creek emerges as the dominant channel of a large area of interconnected drainage from the Koondrook-Perricoota forest. Shortly before leaving the forest, Barbers Creek is joined by Cow Creek, also coming from the forest, and then flows past Pollack Swamp north of Barham. The creek continues to meander in a generally north-westerly direction across a broad ~14 km wide alluvial distributary belt including the Wakool River, Barbers Creek, an upper reach of Merran Creek, Little Murray River and the Murray itself. Barbers Creek flows into the Wakool some ~30 km downstream of Barham Road.

Merran Creek

Merran Creek is connected in its upper reaches to Eagle Creek, which originates in the area to the immediate east of Barham. Eagle Creek is supplemented by an offtake canal from the Murray River at Barham, and then meanders in a generally north-westerly direction. Approximately 10 km north-west of Barham, artificial canals offtake from the Murray and deliver water to Eagle Creek, from which it can be delivered into Barbers Creek to the north via a small natural connecting channel at a point where the two creeks come to within 570 m of each other. Downstream of this point the system is known as Merran Creek, and it continues to meander in a generally north-westerly direction, with a number of major meander cut offs. This part of the Edward–Wakool rivers system is fluvially complex and anastomosing, and Merran Creek is connected to the Wakool via a number of natural channels along this section, at one point coming within 1 km of the river. Approximately 34 km north-west of Barham the creek diverges, the northern channel being Coobool Creek. Approximately 45 km north-west of Barham, and ~23 km east of Swan Hill, Merran Creek redirects towards the west into an area marked by sand dunes, deflation basins and lunettes. After being joined by Waddy Creek from the south, the Merran rounds the southern end of a major lunette remnant and flows along its western side before flowing through a break in this lunette remnant and across the floor of a more recent lake/deflation basin, Lake Tooim. After leaving the bed of this lake, Merran Creek flows in a generally north-westerly direction across the bed of another, larger basin, before turning to the north and incising into an older Shepparton surface before finally flowing into the Wakool at Stony Crossing, itself flowing through a large basin in this area.

Methodology

Fieldwork

Sixty sites were selected, approximately evenly spaced along each channel (depending on access), with the number of sites per channel weighted according to the length of the river or creek system (Table 1; Figure 18). At each site, a single core up to 90 cm was taken from the deepest part of each reach sampled. Sediments were sampled and analysed using the Phase 1 Detailed Assessment Protocol for Acid Sulfate Soils (MDBA 2010).

Table 1. Channels surveyed and number of sites

Stream	No. of sites	Site numbers
Wakool River	17	9, 11, 12, 13, 18, 19, 21, 23, 24, 26, 28, 39, 46, 53, 55, 57, 58
Wyam Creek	2	10, 20
Yallakool Creek	2	47, 54
Colligen Creek	5	48, 50, 51, 52, 60
Cockran Creek	4	38, 40, 41, 59
Jimaringle Creek	4	36, 37, 44, 45
Niemur River	10	14, 22, 29, 30, 31, 34, 35, 43, 49, 56
Mallan Mallan Creek	2	15,17
Pissen Creek	1	16
Yarrein Creek	2	32, 33
Barbers Creek	3	25, 27, 42
Merran Creek	8	1, 2, 3, 4, 5, 6, 7, 8

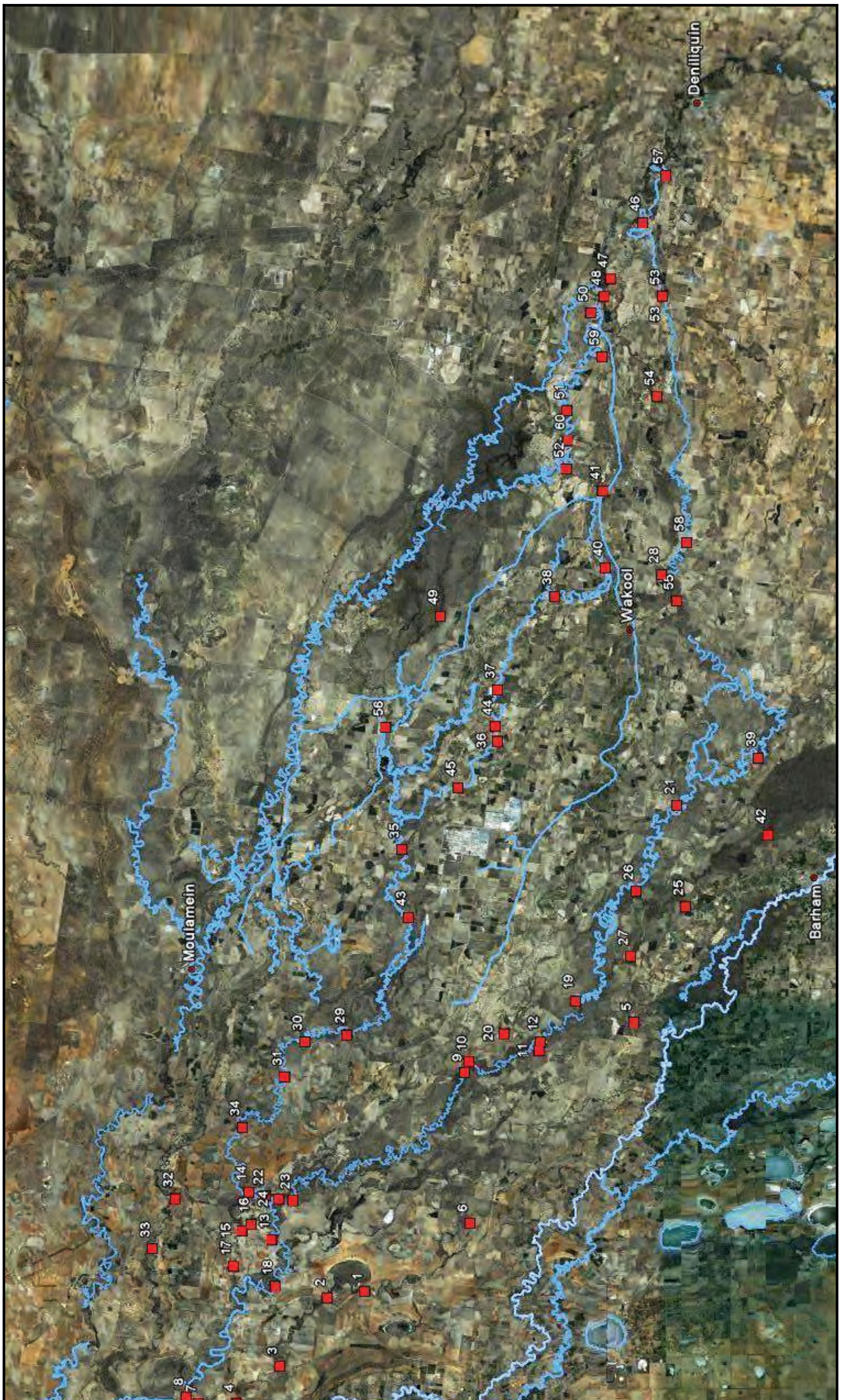


Figure 18. Study area showing site locations

The materials and geomorphic setting at each site were described in detail to contextualise the spatial attributes and their potential relationship with sulfidic accumulations. This information was entered into the NSW Soil and Land Information System (SALIS) (Milford et al. 2001). Water quality parameters were also recorded in accordance with the Protocol, using a Hach HQ40d meter. Photographs were taken of the site, with in situ core and chip trays at each site. Sediment samples were collected in chip trays and 70 ml containers, the latter frozen in the field and dispatched to the Southern Cross Geoscience laboratory in Lismore.

Spatial analysis

Integration of site-specific sediment and landscape data to the broader channel system was achieved using a range of materials, including:

- review of published information on geology, geomorphology and soils
- air-photo interpretation
- soil-landscape data
- various GIS data
- the results of previous acid sulfate soil investigations.

In addition, LiDAR DEMs were used to further refine and confirm geomorphic concepts relevant to the study area. A 10-m DEM was used to provide broad spatial coverage of the western, lower part of the study area. A high resolution 1-m DEM was used to examine geomorphic factors at specific sites.

Distribution of sulfidic sediments within the study area

Each channel system studied is listed in Table 2. The sites have been arranged with those nearest the Deniliquin diffluence towards the left, and those nearer the Kyalite confluence towards the right. The Edward–Wakool channel system was divided into 20 equidistant sections transverse to a line between these two points, each section represented by a column, and the sites allocated to the relevant column. Sites where all samples or all but one sample from the profile returned sulfidic or sulfuric materials are shown in red. Sites where at least one sample was sulfidic or sulfuric, but between 2 and 4 layers were not sulfidic or sulfuric are shown in orange. Sites with monosulfidic materials are shown underlined. Sites where no samples from the profile returned sulfidic or sulfuric materials are shown in green. Sites where the soils expressed saline discharges, or otherwise had a saline/sodic appearance are shown in **bold**. Other environmental indicators, such as precipitation of iron compounds or extensive riparian tree dieback, were also taken into account where soil test results were inconclusive, borderline, or at variance with environmental indicators. Variations from the above scheme are explained in footnotes.

Commonly, the deeper pools occurred at locations where the modern channel and associated Coonambidgal sediments abutted older, more consolidated and often indurated Shepparton Formation sediments, forcing the stream to expend its hydraulic energy downwards, in scour. Sites that were located with one bank abutting Shepparton sediments are shown with an asterisk following the site number, thus: 57*. Sites where the channel was incising into Shepparton sediments, with both banks comprising such materials, are shown with an asterisk before and following the site number, thus: *53*.

The spatial distribution of these classified sites is shown in Figure 19. In addition, in Figure 20, these data are supplemented with channel data from the Murray–Darling Basin Acid Sulfate Soils Risk Assessment Project, classified according to pH_f, pH_{incub}, SO_4^{2-} and EC , and shown as circular icons.

Table 2. Channels surveyed and classified sites from upstream to downstream

Stream	Site numbers																			
Wakool R	57* 46	*53*[1]			58* 28 55		39*	21*	26		19*	12 11*	9			23	*24*[2] *13*	18*		
Wyam Ck												*20*	*10*							
Yallakool Ck		*47*	54																	
Collligen Ck		*48* 50*		51 60 52																
Cockran Ck			59*	41	40	38														
Jimaringle Ck							*37*	*44* *36*	*45*											
Niemur R							49	56		35	43		29*	30*	*31*[3]	34*	*14* *22*			
Mallan M. Ck																	*15*	*17*		
Pissen Ck																	*16*[4]			
Yarrein Ck																	32*[5]	33		
Barbers Ck								42	25	27										
Merran Ck											5					*6*	*1*	*2*	*3*	*4* *7* *8*

[1] All layers at Site 53 were hypersulfidic; however there were no other soil or environmental indicators normally associated with sulfidic sediments.

[2] Not all layers at Site 24 were sulfidic; however the site exhibited strong evidence of other soil and environmental indicators normally associated with sulfidic sediments, including vegetation dieback, and precipitation or iron compounds and halite.

[3] Sulfidic materials were not detected at Site 31; however sulfidic materials were found at this site during the previous Assessment Project. Furthermore, the site exhibited strong evidence of other soil and environmental indicators normally associated with sulfidic sediments.

[4] Sulfidic materials were not detected at Site 16; however the site exhibited strong evidence of other soil and environmental indicators normally associated with sulfidic sediments.

[5] Not all layers at Site 32 were sulfidic; however the site exhibited strong evidence of other soil and environmental indicators normally associated with sulfidic sediments. The site was also rated at high risk of acid sulfate soil in the Murray–Darling Basin Acid Sulfate Soils Risk Assessment Project.

Figure 19. Distribution of sulfidic sediments in the study area

Figure 20. Distribution of sulfidic sediments, supplemented with rapid assessment data

Factors affecting the deposition of sulfidic materials

The general distribution of sulfidic sediments

Table 2 and Figures 19 and 20 indicate that sulfidic sediments occur in various locations throughout the Edward–Wakool channel system. However, the incidence of sulfidic sediments also appears to generally increase in a downstream direction within the study area. The greatest number, and concentration, of sites with sulfidic sediments occurred in the lower part of the study area, the majority of these within an ~10 km radius of Coobool Island. Further sulfidic sites occurred along the middle reaches of the Wakool River at Wyam Creek and on Barbers Creek, with a separate group in the vicinity of the Wakool irrigation district near Wakool township, including Jimaringle Creek.

The incidence of sulfidity and salinity

In this part of the Riverine Plain, sodium chloride tends to be the most common salt present in soils, with sodium the main cation (Butler 1958). Sulfate is generally present in moderate amounts, except for gypseous soils where it may be the most common anion (Smith et al. 1943). Butler (1950, 1958) considered an overall model for the deposition of soluble salts in the Riverine Plain, and found that salinity increased with distance downstream and with distance transverse from the depositing channels. Furthermore, the more saline soils were found in the lower rainfall areas, because leaching was less effective in these areas.

The present study suggests that there is a correlation between halite precipitation and sulfidic sedimentation. In virtually every site where severely sulfidic sediments were recorded, halite, occasionally with gypsum, occurred in combination. Monosulfidic sediments in particular appear to be highly correlated with expressions of halite salinity. With the exception of sites on Jimaringle and Barbers creeks, all fully sulfidic profiles were always associated with monosulfides, and monosulfidic sites were always associated with the expression of saline discharges. The common sequence is illustrated in Plate 5, where an iron precipitate, possibly schwertmannite, is expressed on the lower stream bank, with halite at a lower level and as a crust coating the sediment surface, below which monosulfidic black ooze occurs.

Plate 5. The sequence of iron, halite and monosulfidic black ooze at Wyam Creek

The role of fluvial incision and hydraulic head

Groundwater naturally expresses at low points in the landscape, including in wetlands and channels. Furthermore, groundwater geochemical properties change with depth. Studies from Smith et al. (1943) to Vaze et al. (2010) have confirmed the expected trend in groundwater geochemical properties at sites within the present study area, finding non-saline topsoils, slightly saline subsoils at ~1.0 m, with moderately saline soils commonly below ~3.0 m. That is, all other things being equal, the deeper the channel, the greater is the potential for the expression of groundwaters with higher solute concentrations. Stratigraphic and textural differences, including deep sand layers such as those identified by Vaze et al. (2010), can also have a large impact on hydraulic conductivity and groundwater expression.

However, there is considerable spatial variability in the manifestation of salinity and sulfidity. Analysis of the occurrence of these conditions within the different channel systems of the study area reveals that broad, shallow, meandering, bedload-dominated relict stream channels do not appear to be associated with major salinity or sulfidity issues. The palaeo-Murray Green Gully system, where Kulatunga (1992) identified salinity and waterlogging, appears to be an exception, although sulfidic materials were not noted.

Rather, sulfidic and saline materials appear to be more common in deeper, more incised, low width–depth ratio systems. In the western, lower part of the study area, severely sulfidic sites all occurred within modern incised streams. At Merran Creek, upper catchment sites did not exhibit salinity or sulfidic sediments (Plate 6). Conversely, sulfidic sites all occurred in the lower reaches of the creek, where the level of stream incision has increased relative to the surrounding land surface, as the lower creek has incised into the western margins of the residual land surface (Plate 7). At Site 8 for example, one of the sites most severely affected by sulfidity, the creek has incised ~4–5 m below the level of the surrounding land surface.

Plate 6. Upper Merran Creek (Site 1)

Plate 7. Lower Merran Creek (near Site 7)

Steep hydraulic gradients are especially associated with deep channels where streamflows are underfit due to natural channel change, or within which flows are otherwise reduced by regulation and irrigation. Lower Merran sites, for example, also appeared to suffer from low flows, possibly pointing to water extraction as a contributing factor.

Deep pools can be formed by particular fluvial geomorphic situations, such as at the locally atypical 'Rusty Waterhole', an ox-bow channel cut off from the main Wakool (Plate 8). Here, hydraulic energy through this former channel has been laterally constrained by an indurated Shepparton Formation layer ~3 m below the natural land surface, with the stream forced to express its flow by locally incising a deep hole. Monosulfidic black ooze and iron preciptation affects this deepened site during drought.

Plate 8. 'Rusty waterhole', an abandoned ox-bow lake of the Wakool River (Site 11)

Hydraulic head may also be affected by drought. The Murray–Darling Basin has recently experienced a multiyear drought that led to the almost complete drying of surface water resources and lowering of groundwater levels (Leblanc et al. 2009). Drought conditions tend to coincide with saline expression and the precipitation of sulfidic sediments, a relationship that has been recognised and understood for some time (e.g. Sturt 1833, quoted in Butler et al. 1973).

The relationship between this suite of precipitates and groundwater expression is further underlined by the condition of stream banks at such sites. At virtually every site where sulfidic materials were identified, active and commonly severe tunnel erosion was also evident (Plate 9). Bank soil materials also typically displayed a sodic or saline appearance.

Plate 9. Tunnel erosion at Merran Creek (Site 7)

Groundwater hydraulic gradient is also influenced by the level of surface water in the channel. Both the level of water in the channel and the nature of sedimentary strata within which the stream flows, particularly the hydraulic conductivities of such layers, determines the nature of river–groundwater interaction. Depending on the spatial and vertical distribution of these factors, streams may alternate both spatially and temporally between losing water to surrounding materials, and receiving groundwater (Cartwright et al. 2010). However, while these factors may be critical in controlling the expression of groundwater solutes and precipitates, it has not been possible to examine these in detail within the context of the present study.

The sandhills common in the lower part of the study area appear to operate as areas of high infiltration and groundwater recharge. Groundwater tends to conduct vertically until the boundary with the very low hydraulic conductivity basal clays is met. Water moves laterally above this layer and seeps out into areas adjoining the sandhills (Vaze et al. 2010; Kulatunga 1996). Aeolian materials provide a source of solutes, including iron, and operate to steepen groundwater hydraulic gradients in the vicinity of streams.

The effect of aeolian materials may operate at multiple scales, from regional to local. At the regional scale, all the severely sulfidic and saline sites in the lower Edward–Wakool plains are located between the main Mallee region and the Lake Nangtree sand outlier. At a more local scale, the hydraulic and possibly the geochemical effects of sandhills appear to be factors on the Niemur River, where a single reach of the river is affected by salinity, sulfidic sediments and tree dieback (Plate 10; Figure 21).

The role of Quaternary stratigraphy

The incidence of sulfidic sediments also appears to be highly correlated with Shepparton Formation materials. All 15 fully sulfidic profiles were associated with such materials.[6] Conversely, only one site (Site 1 on Merran Creek) appeared to be fully incised in Shepparton Formation sediments, and yet returned no evidence of sulfidity.

Shepparton Formation sediments are also commonly underlain by ferruginous hardpans, which act as groundwater aquicludes. At Site 34, the river is confined vertically by a pedogenic ferruginous hardpan, which may provide an additional source of iron, while operating as an aquiclude causing a perched groundwater table (Plate 2).

Plate 10. Niemur River upstream of Site 34

[6] Site 42 on Barbers Creek, in Koondrook forest, is associated with surficial Coonambidgal sediments. However, according to Vazet et al. (2010), these are underlain at shallow depths by Shepparton Formation materials.

Figure 21. Niemur River upstream of Site 34, showing proximity to an aeolian dune

At Pissen Creek, on Coobool Island, the hydrogeologic effect of this hardpan is clearly illustrated. The creek itself is perched on the hardpan, and has adjusted morphologically by adopting a high width–depth ratio (Plate 11), assisted over geomorphic time by the effects of salinity and sodicity on the structure and stability of bank materials. The watertable is also presumably perched on this pan, and the creek is consequently severely affected by saline discharges, the effects being particularly striking in the lower reaches (Figure 22).

Plate 11. Pissen Creek (Site 16)

Figure 22. Pissen Creek (Site 16) aerial view showing saline impacts

The impact of land management

A disjunct group of sulfidic sites occurs in the central part of the study area around the township of Wakool. Watertables in the Wakool area rose as a result of irrigation and clearing. By 1981 there were 19,200 ha in the Wakool area affected by watertables within 1.5 metres of the surface. The Wakool Tullakool Sub Surface Drainage Scheme was constructed between 1978 and 1992 in order to lower watertables (Murray Irrigation Limited n.d.), although much of the near-surface soils continue to reveal the effects of salinity.

Jimaringle Creek is the stream that is most severely affected by sulfidity in the Wakool district (Plate 12), with the channel affected for at least 10 km along its length. Jimaringle Creek is a shallow, high width–depth ratio channel that has largely been abandoned, and has not flowed for several years. Any water within the creek is supplied from groundwater. It appears that in such cases, watertables remain sufficiently elevated so that saline groundwater expression and sulfide deposition may occur within even shallow channels. Deep incision is not necessary, although the geomorphic context of Jimaringle remains relevant, incised into Shepparton Formation materials.

Plate 12. Jimaringle Creek (Site 36)

Case studies

Analysis of LiDAR data has been used to illustrate many of the factors outlined above. The roles of channel morphology and relationships of the channel to sedimentary formations are illustrated with respect to:

- the lower Merran Creek
- Mallan Mallan Creek
- Wyam Creek
- Yarrein Creek.

Lower Merran Creek

At Merran Creek, the degree of incision of the lower section of the creek is illustrated in Figure 23. Merran Creek is incised into a relatively raised Shepparton Formation surface, indicated by the fact that there is virtually no significant lateral channel movement. The lower section of Merran Creek, in particular, which corresponds with the geomorphic factors above, was found to be in extremely poor condition. In contrast, the broad Wakool River, on the right hand side of the image, sits within complex multi-aged Coonambidgal sediments.

Mallan Mallan Creek

At Mallan Mallan Creek, natural channel change has been an additional factor contributing to the current state of the stream. Formerly, the Niemur River flowed from the east through the deep sinuous channel that is now Mallan Mallan Creek (Figures 24, 25; Plate 13). At some point in the geomorphically recent past, the Niemur has undergone avulsion to the south, joining the Wakool at a point some 28 km upstream of the former confluence, now the confluence with Mallan Mallan Creek. The land resulting from this process, now surrounded by deep high order channels, is known as Coobool Island (Figure 24).

The result is a particularly striking example of an underfit, reduced flow stream occupying a much larger channel. Again, it is noted that Mallan Mallan Creek, as with the lower Niemur, is a modern channel deeply incised into Shepparton Formation sediments. The whole Mallan Mallan system is severely affected by both salinity and sulfidic sediments (Plate 13).

Figure 25 also reveals a large lake deflation basin in the lower right corner of the image, through which both Mallan Mallan Creek and Pissen Creek flow, the latter creek being severely affected by salinity, the extent of which is clearly visible in the lower right of the aerial image.

Wyam Creek

This effect of modern stream incision into Shepparton Formation surfaces is again illustrated at Wyam Creek, which flows into the Wakool at Noorong (Plate 14; Figure 26). Wyam Creek is affected by sulfidic precipitation in groundwater pools along its length.

Yarrein Creek

The only site identified in the western Edward–Wakool plains where sulfidic sedimentation has affected a stream of higher width-depth ratio is Site 32, on Yarrein Creek (Plate 15). Here, the modern channel has incised within a much larger ancestral Yanco phase system, already below the main residual land surface (Figure 27). However, sulfidic sedimentation only affects those reaches that have incised laterally into the adjacent Shepparton Formation surface, and from which groundwater is received. The remainder of the channel, both upstream and further dowstream, appears healthy.

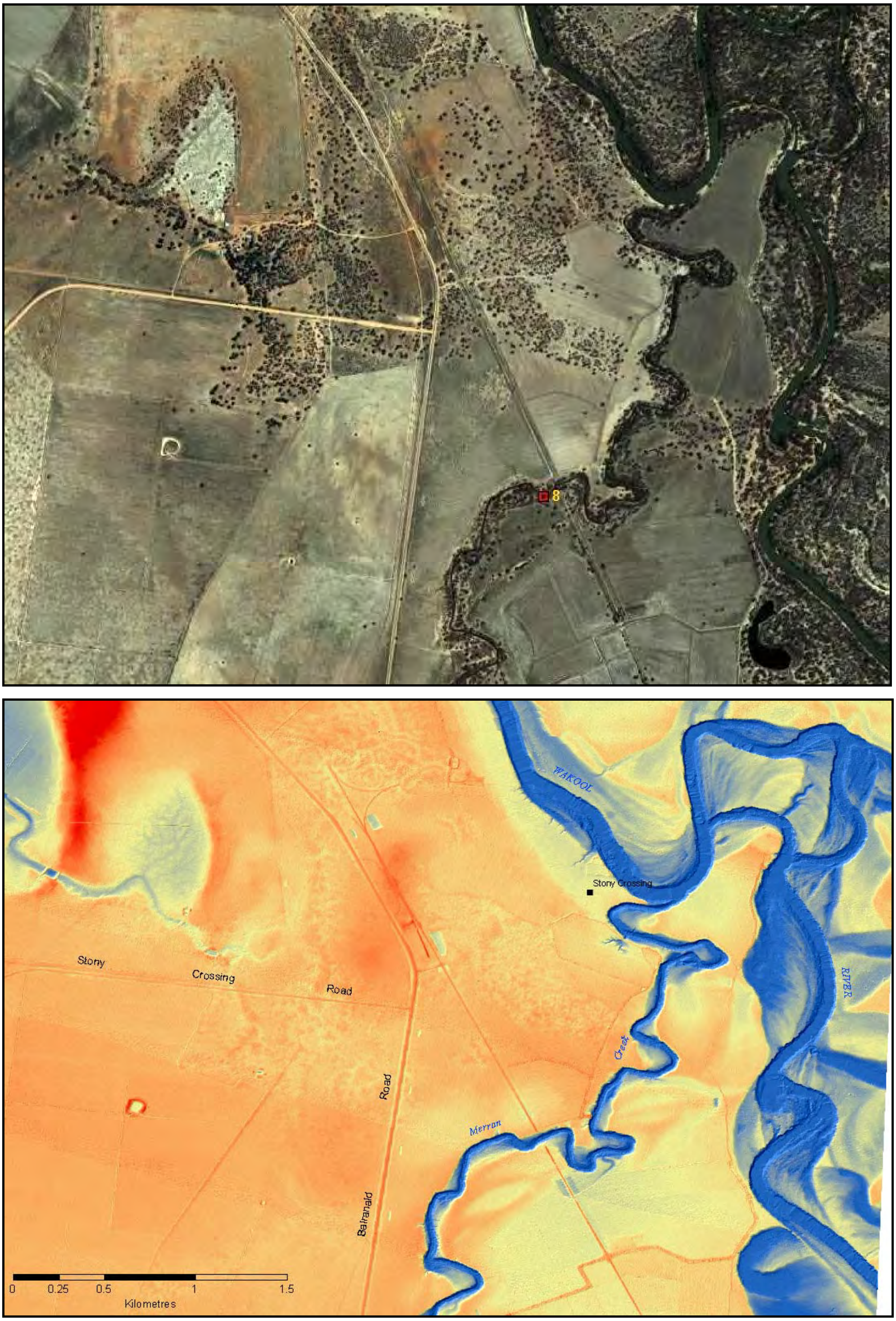


Figure 23. Lower Merran Creek, satellite and LiDAR images

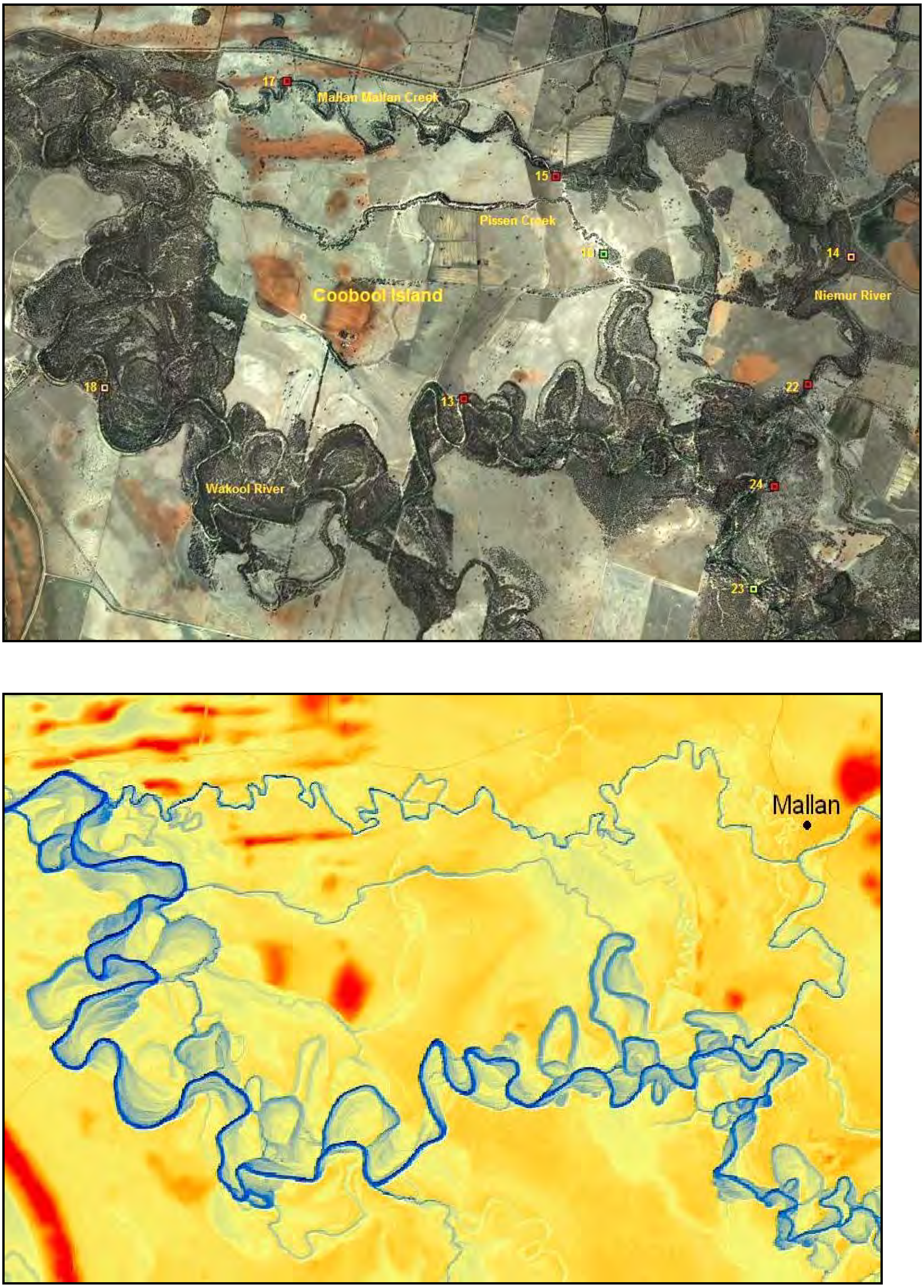


Figure 24. Coobool Island, bounded by Mallan Creek (N) and Wakool (S, W) and Niemur rivers (E), satellite and LiDAR images

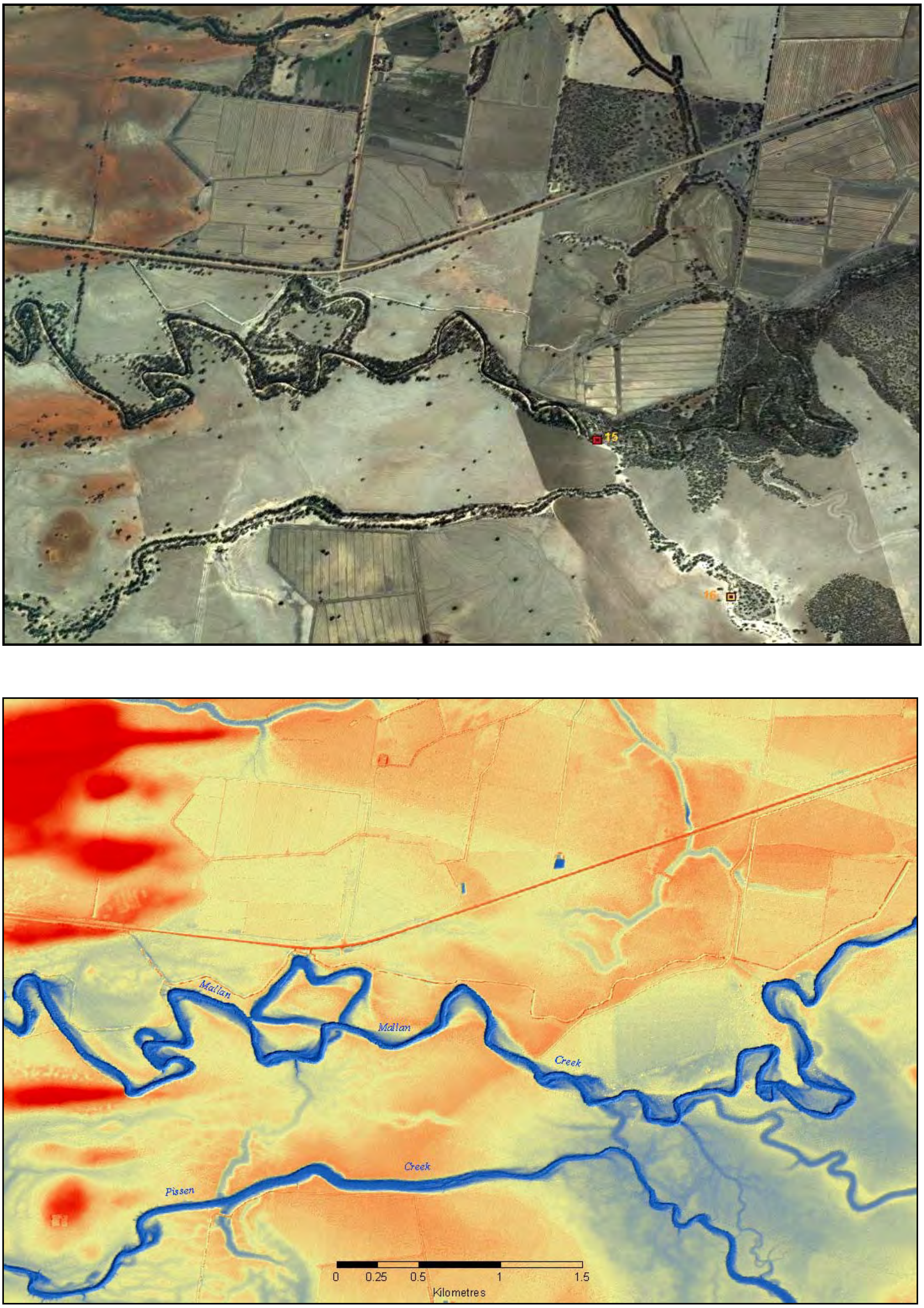


Figure 25. Mallan Mallan Creek, satellite and LiDAR images

Plate 13. Mallan Mallan Creek (Site 15)

Plate 14. Wyam Creek, just above its confluence with the Wakool River (Site 10)

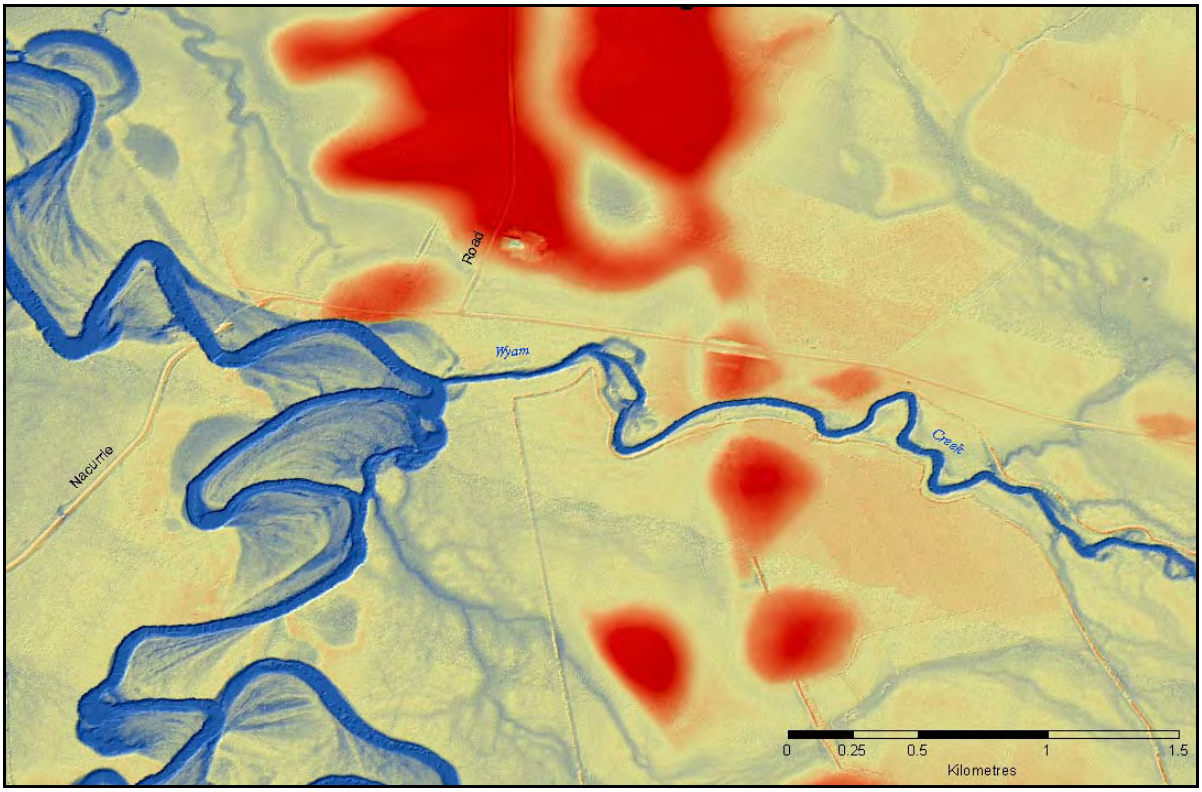


Figure 26. Wakool River and Wyam Creek, satellite and LiDAR images

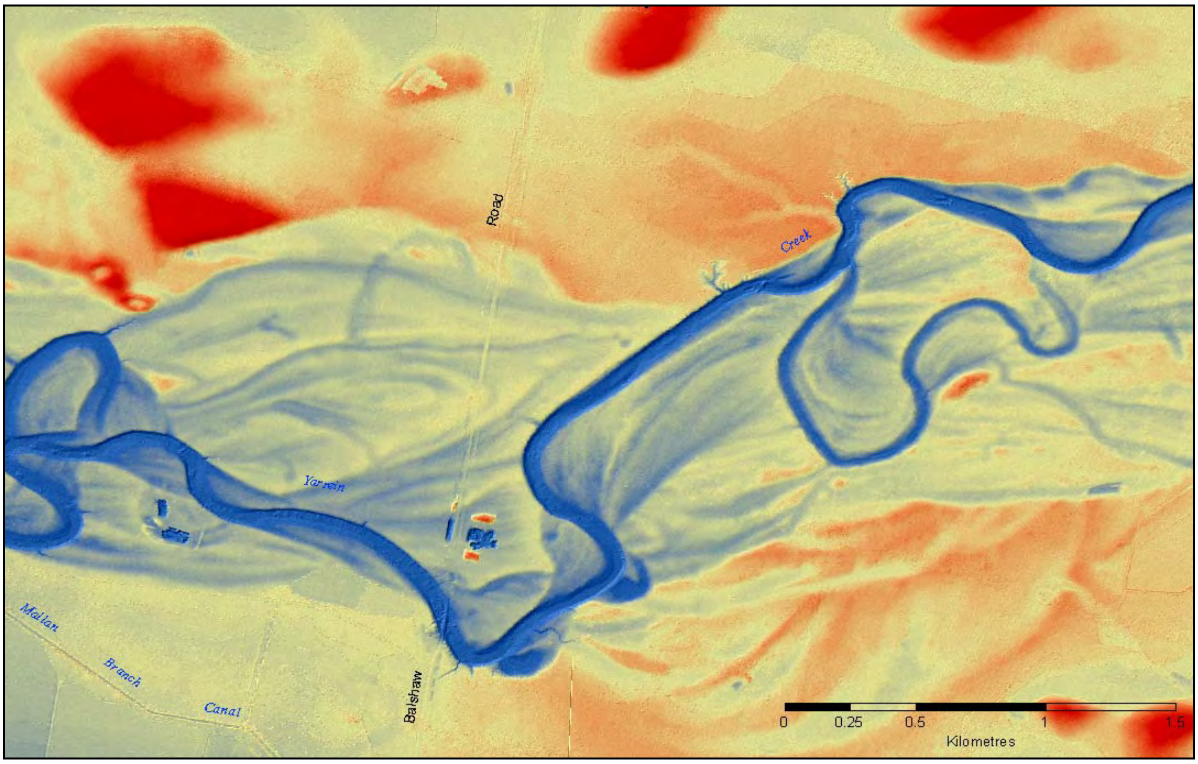


Figure 27. Yarrein Creek, satellite and LiDAR images

Plate 15. Yarrein Creek (Site 32)

Conclusions

- The vast majority of sulfidic channel sites identified in the study area were found in the lower, western part of the study area. Outlier sulfidic sites occurred along Wyam Creek and nearby Wakool River, Jimaringle Creek and Barbers Creek.
- Severely sulfidic sites were overwhelmingly associated with halite salinity and, to a lesser degree, gypsum.
- Severely sulfidic sites were overwhelmingly associated with modern channels incised into residual Shepparton Formation surfaces. Channels formed in younger, reworked Coonambidgal materials were generally not affected.
- The process leading to sulfidisation appeared to be lateral groundwater movement from stream banks from the more saline Shepparton Formation materials, with sodic soils and other indications such as tunnel and other forms of erosion highly correlated with sulfidity and salinity.
- Severely sulfidic sites were generally associated with steep hydraulic gradients into deep, incised channels. Hydraulic gradients have also been steepened by proximity to aeolian deposits, drought, stream regulation and irrigation.
- Subsurface ferruginous hardpans located in the lower, western part of the study area probably operate as aquicludes, leading to perched watertables and groundwater discharge, and may provide an additional source of iron.
- Sulfidisation of Jimaringle Creek, other sulfidic sites located in the Wakool district, and sites in the middle reaches of Barbers Creek identified during this project and previously during the Assessment Project may be associated with the effects of past irrigation practices.

Appendix 1 Site descriptions

Streams are ordered as per Tables 1 and 2. Sites are ordered upstream to downstream.

Wakool River

Site 57: Wakool River, 307907 **E,** 6069511 **N**, UTM Zone 55
This site was near the point of diffluence of the Wakool from the Edward, ~7 km downstream of Deniliquin. It comprised a slightly curved reach where the Wakool has established in a former back channel of the Edward, at the margin of the inset Coonambidgal and Shepparton Formation sediments. The channel width was ~5 m, and the flow was very low, comprising discontinuous stagnant pools with water depths of up to 0.5 m, with abundant logs and other woody debris. Banks were steep but stable, ~3–4 m high, and covered with grasses and mostly healthy regrowth river red gums. Vegetation was intact along a riparian belt and over much of the Coonambidgal sediments upstream and in the vicinity. Sediment field pH was 6.3–6.4.

Site 46: Wakool River, 303218 **E**, 6071608 **N**, UTM Zone 55
This site was located in a bend of the Wakool, ~12 km downstream of Deniliquin. It comprised a curved reach with the present channel inset into a larger, older channel in Coonambidgal Formation sediments. The present channel was ~4–5 m wide, and the water was very low, comprising discontinuous stagnant, often reedy, pools with water depths of up to 0.1 m. Banks of the present channel were low and stable, ~0.75 m high, the higher outer bank ~4 m high, and covered with grasses and healthy regrowth river red gums. Vegetation was intact along a riparian belt and over much of the Coonambidgal sediments upstream and in the vicinity. Sediment field pH was 6.7–7.3.

Site 53: Wakool River, 296191 **E**, 6069488 **N**, UTM Zone 55
This site was ~19 km downstream of Deniliquin, on a slightly curved reach of a generally low sinuosity section where the Wakool appears to have incised into Shepparton Group sediments along the northern margin of the Cadell Tilt Block. The present inset channel width was ~8 m, and the flow was low, ~0.2 m deep, but connected, with reed beds and woody debris. There was a discontinuous low ~1–2 m stable inset bank, with higher ~5–6 m steep but stable banks of an older, larger channel, covered with grasses and healthy mature and regrowth river red gums, with black box on the upper surface. Vegetation was generally intact along a riparian belt in a generally cleared area. Sediment field pH was 6.7–7.5. Hypersulfidic materials were in layers 1–5.

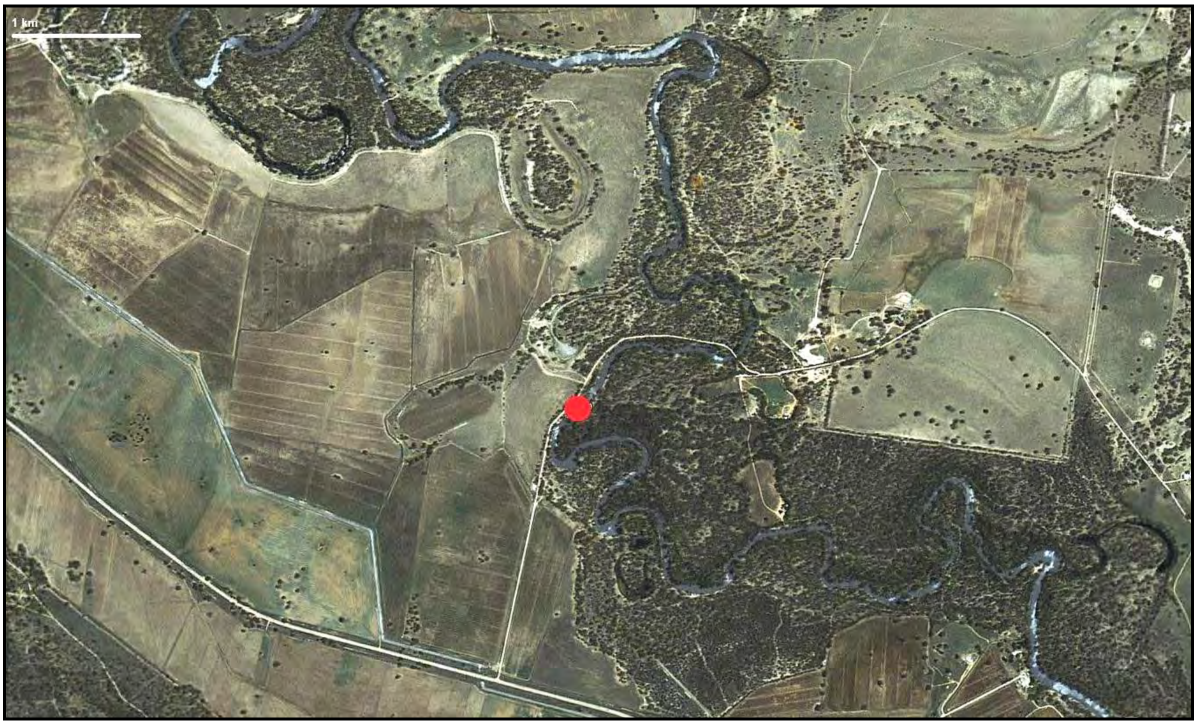
Site 58: Wakool River, 272381 **E**, 6066482 **N**, UTM Zone 55

This site was ~42 km downstream of Deniliquin and 10 km south-east of Wakool. It comprised a bend where the Wakool has established an inset Coonambidgal meander belt within a generally Shepparton Formation surface. The channel width was ~10 m, and the water level was relatively high, up to 1.0 m, with some reed beds and woody debris. The lower northern inside bank was ~1 m high and the southern outside bank ~2–3 m, both stable. Riparian vegetation comprised mature river red gums, which were suffering some stress and dieback. Native vegetation in the vicinity was confined to lower Coonambidgal land surfaces, particularly on inside meanders. Sediment field pH was 7.1–7.3. Hypersulfidic materials were in layer 5.

Site 28: Wakool River, 269263 **E**, 6068830 **N**, UTM Zone 55
This site was ~44 km downstream of Deniliquin and 16 km south-east of Wakool. It comprised a broad, gentle bend just downstream of the confluence of the Wakool and the geomorphically larger Yallakool. The river was broad at this point, ~15 m wide, within a broad Coonambidgal meander belt. Water level was high, 1–2 m, with minor reed beds and woody debris. Both banks were ~1.5–2.0 m high. Riparian vegetation comprised river red gums, which were suffering some stress and dieback. Native vegetation was extensive in the area, on the lower Coonambidgal land surfaces. Sediment field pH was 6.9–7.9.

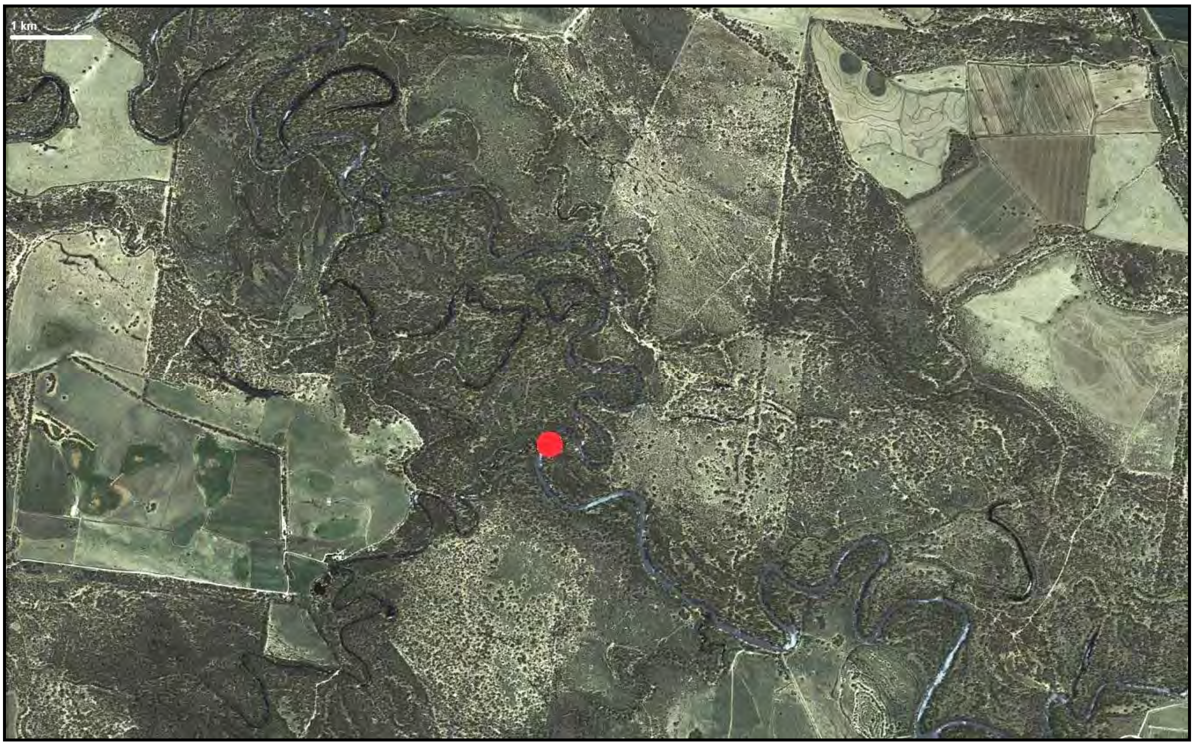
Site 55: Wakool River, 266716 **E**, 6067331 **N**, UTM Zone 55
This site was ~49 km downstream of Deniliquin and 5 km south-east of Wakool. It comprised a long, straight stretch in an otherwise highly sinuous section of the river. The river was broad, ~15 m wide, within an otherwise broad Coonambidgal meander belt that may be confined at this point. The water level was low but continuous, 0.5 m deep, with abundant woody debris. Both banks were ~2–3 m high and moderately steep to steep. Riparian vegetation comprised mature river red gums, with minor dieback. Native vegetation was extensive in the area, on the lower Coonambidgal land surfaces. Sediment field pH was 7.0–7.5.

Site 39: Wakool River, 251807 **E**, 6058998 **N**, UTM Zone 55
This site was ~64 km downstream of Deniliquin and 13 km north-east of Barham. It comprised a gentle bend in an otherwise highly sinuous section of the river shortly after the river turns generally towards the north-west. The river was moderately broad, ~12 m wide, against the boundary between a broad Coonambidgal meander belt, inset into Shepparton Group sediments. Water level was moderately high and continuous, 1.0–1.5 m deep, with some logs and woody debris. The outside bank was ~3 m high and steep, the inside bank ~1 m high. Riparian vegetation comprised mature and regrowth river red gums, with minor dieback and shrubs. Native vegetation was extensive in the area, on the lower Coonambidgal land surfaces. Sediment field pH was 7.5–7.7.



Site 21: Wakool River, 246996 **E**, 6066694 **N**, UTM Zone 55
This site was ~68 km downstream of Deniliquin and 15 km north-east of Barham. It comprised a sharp bend in a highly sinuous section of the river. The river was moderately broad, ~10 m wide, located against the boundary between a broad Coonambidgal meander belt, inset into Shepparton Group sediments. Water level was moderate and continuous, 1.0 m deep, with some logs and woody debris. The outside bank was ~3 m high and steep, the inside bank ~1 m high. Riparian vegetation comprised mature river red gums, with minor dieback and shrubs. Native vegetation was extensive in the area, on the lower Coonambidgal land surfaces.

Site 26: Wakool River, 238603 **E**, 6070395 **N**, UTM Zone 55
This site was ~76 km downstream of Deniliquin and 17 km north of Barham. It comprised a bend in a highly sinuous section of the river. The river was moderately broad, ~12 m wide, located within an extensive Coonambidgal meander belt. Water level was moderately low and continuous, 1.0 m deep, with some woody debris. The higher outside bank was ~3 m high and steep, the lower inside bank was ~1–2 m high. Riparian vegetation comprised mature and regrowth river red gums with shrubs. Native vegetation was extensive in the area on the lower Coonambidgal land surfaces. Sediment field pH was 6.9–7.2.



Site 19: Wakool River, 227872 **E**, 6175875 **N**, UTM Zone 55
This site was ~88 km downstream of Deniliquin and 26 km north-west of Barham. It comprised a sharp bend in a highly sinuous section of the river, where the inset Coonambidgal meander belt abuts the higher Shepparton Formation surface. The river was moderately broad, ~15 m wide. Water level was moderately high and continuous, 1.0–1.5 m deep, with some woody debris and inundation of young river red gum saplings. The higher outside Shepparton bank was ~5 m high and steep, the lower inside bank was ~2–3 m high. Riparian vegetation comprised mature and regrowth river red gums with shrubs. Native vegetation was extensive in the area, but largely confined to the lower Coonambidgal land surfaces. Hyposulfidic materials were in layer 1.

Site 12: Wakool River, 768745 **E**, 6079373 **N**, UTM Zone 54

This site was ~92 km downstream of Deniliquin and 31 km north-west of Barham. It comprised a straight reach in an otherwise highly sinuous section of the river. The river was moderately broad, ~15 m wide, located within a broad Coonambidgal meander belt. The water was 2.5 m deep and continuous, with abundant logs and other woody debris. The higher outside bank was ~5 m high and steep and unstable, the lower inside bank was ~2–3 m high, grassed and stable. Riparian vegetation comprised mature and regrowth river red gums, with grasses and shrubs. Native vegetation was extensive in the area, on the lower Coonambidgal land surfaces. Sediment field pH was 6.9–7.2.

Site 11: Wakool River, 767936 **E**, 6079534 **N**, UTM Zone 54
This site was ~93 km downstream of Deniliquin and 31 km north-west of Barham. It comprised a largely disconnected cut-off meander in a highly sinuous section of the river where the inset Coonambidgal meander belt abuts the higher Shepparton Formation surface. A ferruginous hardpan outcrops on the higher Shepparton bank, and may have contributed to a deepening of the meander at this point. Bank materials have a sodic/saline appearance and show evidence of tunnel erosion. The meander was broad, ~20 m wide, and locally deepened to ~5 m. The only water was in a pool ~100 x 30 m and 0.5 m deep, with fallen logs and other woody debris. Riparian vegetation comprised mature river red gums which were highly stressed with severe dieback, with halophytes and some gum saplings in the meander. Native vegetation was extensive in the area, on the lower Coonambidgal land surfaces. Sediment field pH was 5.5–6.3. Precipitation of iron compounds and halite was evident. Hypermonosulfidic materials were in layers 1, 2, 4 and 5, hypersulfidic in layer 3.

Site 9: Wakool River, 766016 **E**, 6086735 **N**, UTM Zone 54

This site was ~96 km downstream of Deniliquin and 33 km east of Swan Hill. It comprised a large pool in a sharp bend in a highly sinuous section of the river. The river pool was broad, ~20 m wide, located within an extensive Coonambidgal meander belt but close to the Shepparton surface. Water level was moderately low and continuous, 2.5 m deep. The higher outside bank was ~4 m high and steep just downstream where it comprises Shepparton Formation; the lower inside bank was slightly lower, with an even lower more recent inset bank ~1–2 m high. Riparian vegetation comprised mature and regrowth river red gums with shrubs. Native vegetation was extensive in the area, particularly along a broad belt on the lower Coonambidgal land surfaces. Sediment field pH was 6.9–7.0.

Site 23: Wakool River, 754172 **E**, 6103679 **N**, UTM Zone 54

This site was ~113 km downstream of Deniliquin and 27 km north-east of Swan Hill. It comprised a pool in a sharp bend in a highly sinuous section of the river, the pool having been formed by scouring by cut-off flows. The river pool was broad, ~20 m wide, and was located within an extensive Coonambidgal meander belt, but close to the Shepparton surface. Water level was moderately high and continuous, 0.5 m deep. The higher outside bank was ~5 m high and steep and extensively sheet eroded, with a lower bench subject to stream bank erosion. The inside bank was slightly lower. Bank materials have a sodic/saline appearance and show evidence of tunnel erosion. Riparian vegetation comprised mature and regrowth river red gums, with shrubs. The vegetation shows signs of stress and dieback. Native vegetation was extensive in the area, particularly along a broad belt on the lower Coonambidgal land surfaces. Precipitation of iron compounds and halite was evident.

Site 24: Wakool River, 754362 **E**, 6104949 **N**, UTM Zone 54

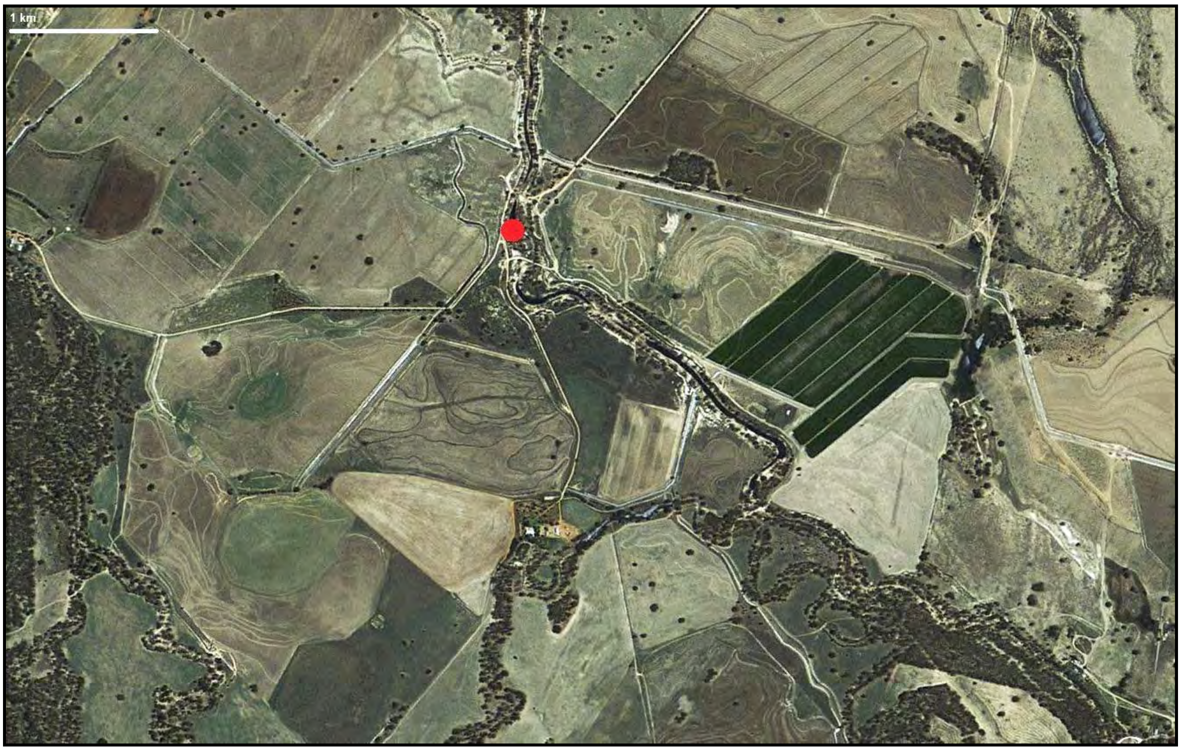
This site was ~114 km downstream of Deniliquin and 28 km north-east of Swan Hill. It comprised a pool formed by a back-channel scour at the point of re-entry back into the main river in a highly sinuous section of the river. The river pool was ~150 x 6 m, depending on water level, but is often cut off from the main river. The river in this section was located within a narrow Coonambidgal meander belt, constrained by the Shepparton surface and perhaps subsurface ferruginous hardpans. Water level in the pool was 0.25 m deep. The higher outside Shepparton bank was ~5 m high, steep and extensively sheet eroded. The inside bank was lower. Bank materials have a sodic/saline appearance and show evidence of tunnel erosion. Riparian vegetation comprised mature and regrowth river red gums, with shrubs and halophytes. The vegetation showed signs of stress and dieback. Native vegetation was extensive in the area, particularly along the narrow lower Coonambidgal land surfaces. Hypermonosulfidic materials were in layers 1 and 3, hypersulfidic in layer 5. Precipitation of iron compounds and halite was evident.

Site 13: Wakool River, 750470 **E**, 6105761 **N**, UTM Zone 54
This site was ~117 km downstream of Deniliquin and 26 km north-east of Swan Hill. It comprised a sharp bend in a highly sinuous section of the river at Coobool Island. The river was broad ~40 m wide at this point. The river in this section was located within a narrow Coonambidgal meander belt, constrained by the Shepparton surface and perhaps subsurface ferruginous hardpans which outcrop on some Shepparton banks. The water was ~1.5 m deep, connected and flowing. The higher outside Shepparton bank was up to 6 m high, steep, with stratigraphic benches and was extensively sheet eroded. The inside bank and land surface was lower, ~3 m. Bank materials have a sodic/saline appearance and show evidence of tunnel erosion. Riparian vegetation comprised mature and regrowth river red gums, with shrubs and halophytes. The vegetation showed signs of severe stress and extensive dieback. Native vegetation in the area occurs along the narrow lower Coonambidgal land surfaces. Sediment field pH was 4.8–5.3. Hypermonosulfidic materials were in layers 2, 3 and 5, hypersulfidic in layer 4. Precipitation of iron compounds and halite was evident.

Site 18: Wakool River, 745958 **E**, 6105637 **N**, UTM Zone 54
This site was ~121 km downstream of Deniliquin and 23 km north-east of Swan Hill. It comprised a gentle bend in a highly sinuous section of the river at Coobool Island. The river was moderately broad, ~20 m wide at this point, and located within a broad Coonambidgal meander belt but near the Shepparton boundary. Water level in the river was low, ~0.5 m deep, but flowing. The higher outside bank was up to 5 m high, steep, with stratigraphic benches and extensively sheet eroded. The inside bank and land surface was lower, ~2 m. Bank materials have a sodic/saline appearance and show evidence of tunnel erosion. Riparian vegetation comprised mature and regrowth river red gums, with shrubs. The vegetation showed signs of severe stress and extensive dieback. Native vegetation in the area occurs along the narrow lower Coonambidgal land surfaces. Hypersulfidic materials were in layer 5. Precipitation of iron compounds was evident.

Wyam Creek

Site 20: Wyam Creek, 769693 **E**, 6082806 **N**, UTM Zone 54
This site was ~92 km downstream of Deniliquin and 33 km north-west of Barham. It comprised a bend in a meandering section of the creek, incised into Shepparton Formation sediments. The creek was narrow, 10 m wide, with a shallow ~0.3 m unconnected pool. Both banks were ~3–4 m high and steep. Bank materials have a sodic/saline appearance and show evidence of tunnel erosion. Riparian vegetation comprised mature river red gum, subject to severe stress with extensive dieback, with halophytes. Native vegetation in the vicinity was confined to a very narrow riparian belt. Hypermonosulfidic materials were in layers 1, 3, 4 and 5, hypomonosulfidic materials in layer 2. Precipitation of iron compounds and halite was evident.



Site 10: Wyam Creek, 767042 **E**, 6086271 **N**, UTM Zone 54
This site was ~95 km downstream of Deniliquin and 38 km north-west of Barham. It comprised a straight reach just above the confluence with the Wakool River, located within Shepparton Formation sediments. The creek was incised and very narrow, ~5 m wide, and both banks were ~4 m high, steep and subject to sheet erosion, the soils having the appearance of being sodic/saline. Water was in small, shallow ~0.1 m unconnected pools. Riparian vegetation comprised mature river red gums subject to severe stress with extensive dieback within the channel, with halophytes and reeds. Native vegetation along the creek was confined to a very narrow riparian belt, but connected to vegetation in a broad meander belt along the Wakool. Sulfuric materials were in layers 1 and 2, hypermonosulfidic materials in layers 3, 4 and 5. Precipitation of iron compounds and halite was evident.

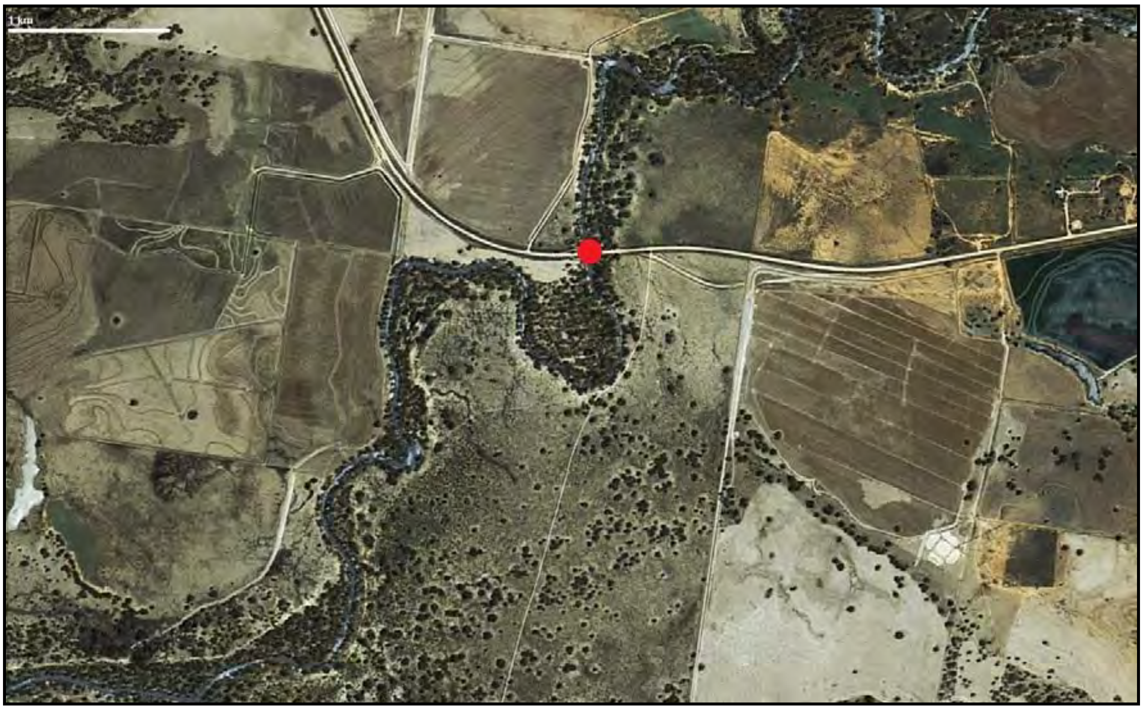
Yallakool Creek

Site 47: Yallakool Creek, 287661 **E**, 6074545 **N**, UTM Zone 55

This site was ~19 km downstream of Deniliquin, downstream of the diffluence from the Edward River and immediately downstream of the Yallakool weir. It comprised a bend in a channel incised into Shepparton Formation sediments to connect to a former upper Yallakool channel, which occupies its own narrow meander belt incised into Shepparton sediments. This section of the creek was ~6 m wide, but had only discontinuous pools ~0.3 m deep, and there were abundant logs and other woody debris. Both banks were ~2 m high, rectilinear and stable. Riparian vegetation was regrowth river red gums. Native vegetation was confined to a very narrow riparian belt. Sediment field pH was 6.8 – 7.3.

Site 54: Yallakool Creek, 286405 **E**, 6069740 **N**, UTM Zone 55

This site was ~29 km downstream of Deniliquin. It comprised a straight reach in a generally meandering stream which occupies a narrow belt of Coonambidgal sediments. This section of the creek was narrow, ~6 m wide, with continuous water ~1.2 m deep, with abundant logs and other woody debris. Both banks were ~2 m high and stable. Riparian vegetation was river red gums and black box. Native vegetation was confined to a very narrow riparian belt. Sediment field pH was 7.1–7.3.



Colligen Creek

Site 48: Colligen Creek, 294935 **E**, 6075412 **N**, UTM Zone 55

This site was ~21 km downstream of Deniliquin, just downstream of its diffluence from the Edward River. It comprised a bend in a meandering section of the creek. The creek was moderately narrow, ~12 m at this point, and was located within a narrow, confined Coonambidgal meander belt. Water level in the creek was low, ~0.5 m deep, connected but not visibly flowing, with abundant logs and other woody debris. Both banks were ~2 m high, steep, rectilinear and bare of vegetation, with stream bank erosion and stratigraphic boundaries obvious. Riparian vegetation comprised mostly regrowth river red gums, with willows. Native vegetation in the area was very limited, and only occurred along the very narrow lower Coonambidgal land surfaces. Sediment field pH was 7.1–7.2. Hypersulfidic materials were in layers 2, 3 and 4.

Site 50: Colligen Creek, 294362 **E**, 6076359 **N**, UTM Zone 55
This site was ~23 km downstream of Deniliquin. It comprised a straight reach of the creek, just downstream of a sharp bend, in a generally highly sinuous section of the creek. The creek was broad, ~25 m at this point, but water level in the creek was very low, ~0.1 m deep, with much of the bed sediments exposed, connected but not visibly flowing, with abundant logs and other woody debris exposed. The creek was located within a broad Coonambidgal meander belt, but at the boundary to the Shepparton Formation. The outside bank was ~3 m high, the inner bank ~1 m high and steep, and both banks are subject to extensive erosion with abundant tree roots exposed. Riparian vegetation included mature and regrowth river red gums with some dieback evident. Native vegetation in the area was very limited, and only occurred along the lower Coonambidgal land surfaces. Sediment field pH was 6.7–6.9. Hypersulfidic materials were in layer 5.

Site 51: Colligen Creek, 284846 **E**, 6078340 **N**, UTM Zone 55
This site was ~32 km downstream of Deniliquin, and 22 km north-east of Wakool. It comprised a straight reach of the creek in an otherwise generally highly sinuous section of the creek. The channel was broad, ~25 m at this point, but water level in the creek was very low, ~0.1 m deep, connected but not visibly flowing, with logs and other woody debris exposed. The creek was located within a narrow Coonambidgal meander belt. The outside bank was ~3 m high and near vertical, with stream bank erosion. The inner bank was low, ~1 m high, grassed and stable. Riparian vegetation included mature and regrowth river red gums and black box, with sedges and rushes. Native vegetation in the area was very limited, and only occurred along the lower Coonambidgal land surfaces. Sediment field pH was 6.5–7.1.

Site 60: Colligen Creek, 281903 **E**, 6078271 **N**, UTM Zone 55

This site was ~35 km downstream of Deniliquin and 19 km north-east of Wakool. It comprised a bend in a generally highly sinuous section of the creek. The overall creek channel was broad, ~20 m at this point, but water level in the creek was very low, ~0.1 m deep, connected but not visibly flowing, with reed beds, logs and other woody debris exposed, with larger pools. The creek was located within a narrow Coonambidgal meander belt. The outside bank was ~3 m high, steep and eroding. The inner bank was low, ~2 m high, but with an inset bank, grassed and stable. Riparian vegetation included mature and regrowth river red gums and black box, with sedges and rushes. Native vegetation in the area was very limited, and only occurs along the lower Coonambidgal land surfaces. Sediment field pH was 6.5–7.1.

Site 52: Colligen Creek, 279207 **E**, 6078240 **N**, UTM Zone 55

This site was ~38 km downstream of Deniliquin and 17 km north-east of Wakool. It comprised a bend in a highly sinuous section of the creek. The creek channel was moderately broad, ~15 m at this point, but water level in the creek was low, 0.75 m deep, connected but not visibly flowing, with logs and abundant other woody debris. The creek was located within a narrow Coonambidgal meander belt. The outside bank was ~4 m high, rectilinear and steep, but generally stable. The inner bank was low, ~2 m high, with stream bank erosion. Riparian vegetation included mature and regrowth river red gums and black box, with sedges and rushes. Native vegetation in the area was very limited, and only occurs along the lower Coonambidgal land surfaces. Sediment field pH was 6.8–7.1.

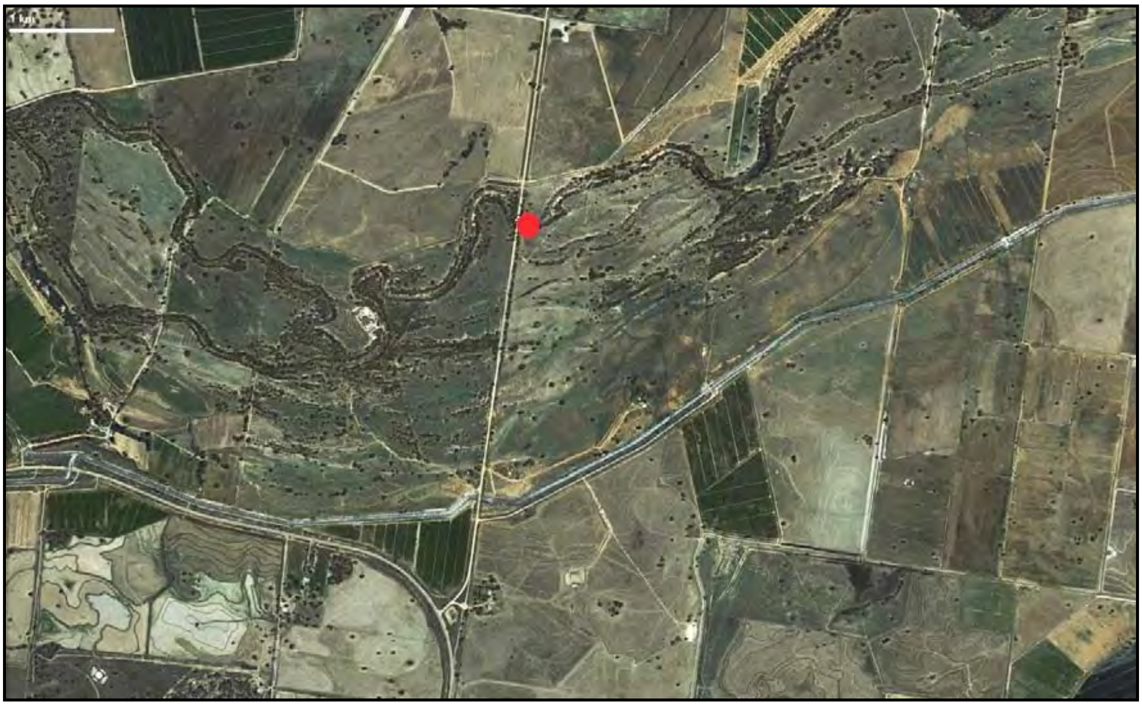
Cockran Creek

Site 59: Cockran Creek, 290150 **E**, 6075056 **N**, UTM Zone 55
This site was ~19 km downstream of Deniliquin, 250 m downstream of the diffluence from Colligen Creek. It comprised a broad shallow channel that has not carried water for many years, as evidenced by extensive regrowth of gum saplings. The shallow channel was ~10 m wide and banks ~2 m high, the outside bank comprising Shepparton Formation materials. Banks were gently sloping, grassed and treed. Vegetation was mature and regrowth river red gums, and grasses. Native vegetation was confined to a very narrow riparian belt. Sediment field pH was 6.2–7.1. Sulfuric materials were in layer 4.

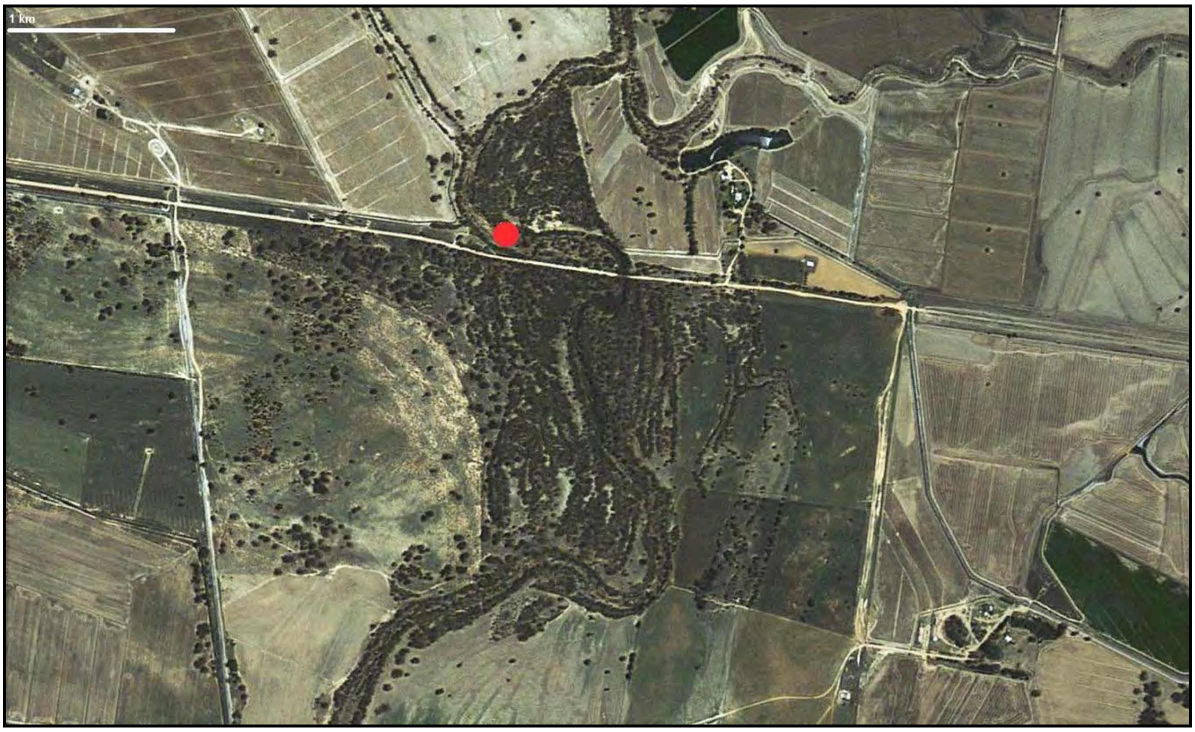
Site 41: Cockran Creek, 277143 **E**, 6074744 **N**, UTM Zone 55

This site was ~38 km downstream of Deniliquin. It comprised a broad shallow channel/swale within a broad (up to 1 km wide) belt of subparallel channels in Coonambidgal sediments. The channel has not carried water for some time. The channel was shallow, ~25 m wide, and banks ~2 m high, gently sloping, grassed and treed. Vegetation was mature and regrowth river red gums, and grasses. Native vegetation was confined to narrow riparian belts among this channel system. Sediment field pH was 5.4–5.7.

Site 40: Cockran Creek, 269760 **E**, 6074232 **N**, UTM Zone 55
This site was ~46 km downstream of Deniliquin. It comprised a broad shallow channel/swale within a broad (up to 1.25 km wide) belt of subparallel channels in Coonambidgal sediments. The channel has not carried water for some time. The channel was shallow, ~15 m wide, and banks ~2 m high, and subject to erosion, with the soils having a sodic/saline appearance. Vegetation was mature and regrowth river red gums, which were under stress and subject to extensive dieback. Native vegetation was confined to very narrow riparian belts among this channel system. Groundcover includes halophytes. Sediment field pH was 5.2–5.9. Sulfuric material was in layer 4.



Site 38: Cockran Creek, 266785**E**, 6079092 **N**, UTM Zone 55
This site was ~49 km downstream of Deniliquin. It comprised a shallow channel ~30 m wide, meandering within a broad (up to 1.25 km wide) prior channel. The channel has not carried water for some time. Banks were ~2 m high and relatively stable. Vegetation was mature and regrowth river red gums, with some under stress and subject to dieback, and grasses, although there were also bare areas on the channel bed. Native vegetation was confined to narrow riparian belts among this prior channel system. Sediment field pH was 6.0–6.9.



Jimaringle Creek

Site 37: Jimaringle Creek, 257674 **E**, 6084280 **N**, UTM Zone 55
This site was ~60 km downstream of Deniliquin. It comprised a broad shallow channel incised into a Shepparton land surface. The channel was ~25 m wide, with banks ~2 m high, and relatively stable. The channel has not carried water for some time, leading to extensive death of reeds. Vegetation was mature and regrowth river red gums and black box, and grasses. Dead trees were in the channel. In this area, native vegetation was confined to a very narrow riparian belt. Sediment field pH was 6.7–7.0. Hypersulfidic materials were in layers 1 and 2.

Site 44: Jimaringle Creek, 254118 **E**, 6084386 **N**, UTM Zone 55

This site was ~63 km downstream of Deniliquin and 16 km north-west of Wakool. It comprised a bend in a meandering section of the creek, located within Shepparton Formation sediments. The creek was moderately broad, ~15 m wide. Water level was moderately low, ~0.5 m deep, and continuous, but with no evidence of flow, with abundant logs and woody debris. The outside bank was ~3 m high, grassed and stable in places, subject to sheet erosion in others, where the soils had the appearance of being sodic/saline. Riparian vegetation comprised mature river red gums, but all dead, and halophytes. There was black box on higher surfaces. Native vegetation in the vicinity was confined to a very narrow meander belt. Sediment field pH was 5.9–6.5. Hyposulfidic material was in layer 1, hypersulfidic materials in layers 2, 3, 4 and 5. Precipitation of iron compounds and possibly halite was evident.

Site 36: Jimaringle Creek, 252688 **E**, 6084092 **N**, UTM Zone 55
This site was ~65 km downstream of Deniliquin and 17 km north-west of Wakool. It comprised a bend in a meandering section of the creek, just downstream of the bridge, located within Shepparton Formation sediments. The creek was moderately broad, ~20 m wide. Water level was low, ~0.1 m deep, in a long but unconnected pool, with no evidence of flow and with some woody debris. The outside bank was ~3 m high, subject to sheet and tunnel erosion, with a sodic/saline appearance. Riparian vegetation comprised mature river red gums, but all dead, and halophytes. There was black box on higher surfaces. Native vegetation in the vicinity was confined to a very narrow meander belt. Sediment field pH was 5.6–6.4. Hypermonosulfidic material was in layer 1, hyposulfidic material in layer 5. Precipitation of iron compounds and halite was evident.

Site 45: Jimaringle Creek, 248099 **E**, 6087742 **N**, UTM Zone 55

This site was ~70 km downstream of Deniliquin and 22 km north-west of Wakool. It comprised a bend in a meandering section of the creek, located within Shepparton Formation sediments. The creek was moderately broad, ~20 m wide. The creek had no surface water. The outside bank was ~3 m high and stable, the inside bank slightly lower, the soils having a sodic/saline appearance. Riparian vegetation comprised mature black box, subject to severe stress with extensive dieback, and halophytes. Native vegetation in the vicinity was confined to a very narrow riparian belt. Sediment field pH was 6.1. Precipitation of iron compounds and halite was evident.

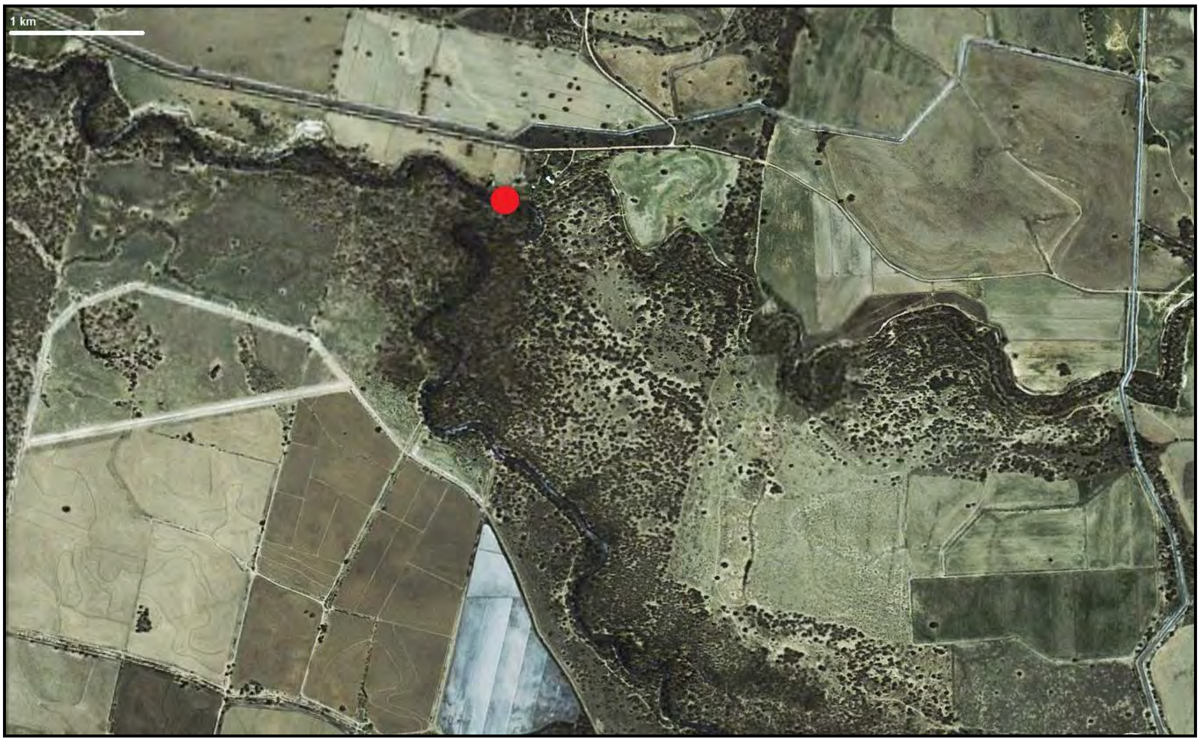
Niemur River

Site 49: Niemur River, 264604 **E**, 6089918 **N**, UTM Zone 55

This site was ~55 km downstream of Deniliquin, and 18 km north of Wakool. It comprised a bend in a meandering section towards the head of the river, where it emerges from the Werai forest. The river channel was ~10 m wide at this point, water level in the river was moderately low, ~0.75 m deep, continuous but not visibly flowing, with logs and abundant other woody debris. The creek was located within a very large area of depositional Coonambidgal sediments, comprising the Werai. The outside bank was ~4 m high, rectilinear and steep, but generally stable. The inner bank was low, ~2 m high, grassed and stable. Riparian vegetation included mature and regrowth river red gums. The site was located towards the southern edge of the Werai, an extensive area of native vegetation. Sediment field pH was 7.1–7.2.

Site 56: Niemur River, 253733 **E**, 6094854 **N**, UTM Zone 55

This site was ~67 km downstream of Deniliquin and 25 km north-west of Wakool. It comprised a bend in a sinuous section of the river, although the river was not highly sinuous and there are no cut-off meanders, which suggests that this section of the river was of relatively recent age and incised into older Shepparton sediments. The river channel was ~10 m wide at the widest point, although the water level in the river was very low, ~0.3 m deep, barely continuous and flowing slightly, with logs and abundant other woody debris. Both banks were ~4 m high, rectilinear and steep, but generally stable. Riparian vegetation included mature and regrowth river red gums and black box. Native vegetation occurs in a narrow belt along the river. Sediment field pH was 6.8–7.0.



Site 35: Niemur River, 241974 **E**, 6092946 **N**, UTM Zone 55

This site was ~78 km downstream of Deniliquin and 23 km south-east of Moulamein. It comprised a straight reach in a sinuous section of the river where it was incised into older Shepparton sediments. The river channel was broad, ~20 m wide at this point, water level was ~1.5 m deep, continuous and flowing slightly, with logs and other woody debris. Both banks were ~2–3 m high, often rectilinear and steep, but generally stable. Riparian vegetation included mature and regrowth river red gums, with black box further from the river. Native vegetation occurs in a narrow belt along the river. Sediment field pH was 7.5–7.9.

Site 43: Niemur River, 235442 **E**, 6092128 **N**, UTM Zone 55

This site was ~83 km downstream of Deniliquin and 21 km south of Moulamein. It comprised a straight reach in a meandering section of the river. The river channel was broad, ~20 m wide at this point, but the water was shallow, ~0.5 m deep, and continuous, with logs and other woody debris. Both banks were ~2–3 m high, steep and rectilinear, but generally stable. Riparian vegetation included mature and regrowth river red gums, with reeds. Native vegetation was extensive in the area. Sediment field pH was 6.7– 7.3. Hypersulfidic material was in layer 3.

Site 29: Niemur River, 770065 **E**, 6097897 **N**, UTM Zone 54

This site was ~96 km downstream of Deniliquin and 16 km south-west of Moulamein. It comprised a sharp bend in a highly sinuous section of the river, incised into Shepparton Formation materials. The river channel was narrow, ~5 m wide at this point, water was shallow, ~0.5 m deep, and continuous, with abundant logs and other woody debris. The outside bank was 3 m high, steep and rectilinear, but generally stable, and the inside bank 1 m high and grassed. Riparian vegetation included mature and regrowth river red gums. Native vegetation was extensive in the area. Sediment field pH was 6.7–8.4.

Site 30: Niemur River, 769488 **E**, 6102002 **N**, UTM Zone 54

This site was ~98 km downstream of Deniliquin and 13 km south-west of Moulamein. It comprised a very sharp bend in a highly sinuous section of the river, and incised into Shepparton Formation materials. The river channel was narrow, ~7 m wide at this point, the water was shallow, ~0.5 m deep, and continuous, with abundant logs and other woody debris. The outside bank was 3 m high, steep and rectilinear, with stream bank erosion. Bank materials have a sodic appearance. The inside bank was ~1 m high. Riparian vegetation included mature and regrowth river red gums. Native vegetation was extensive in the area. Sediment field pH was 6.6–6.9.

Site 31: Niemur River, 766160 **E**, 6104046 **N**, UTM Zone 54

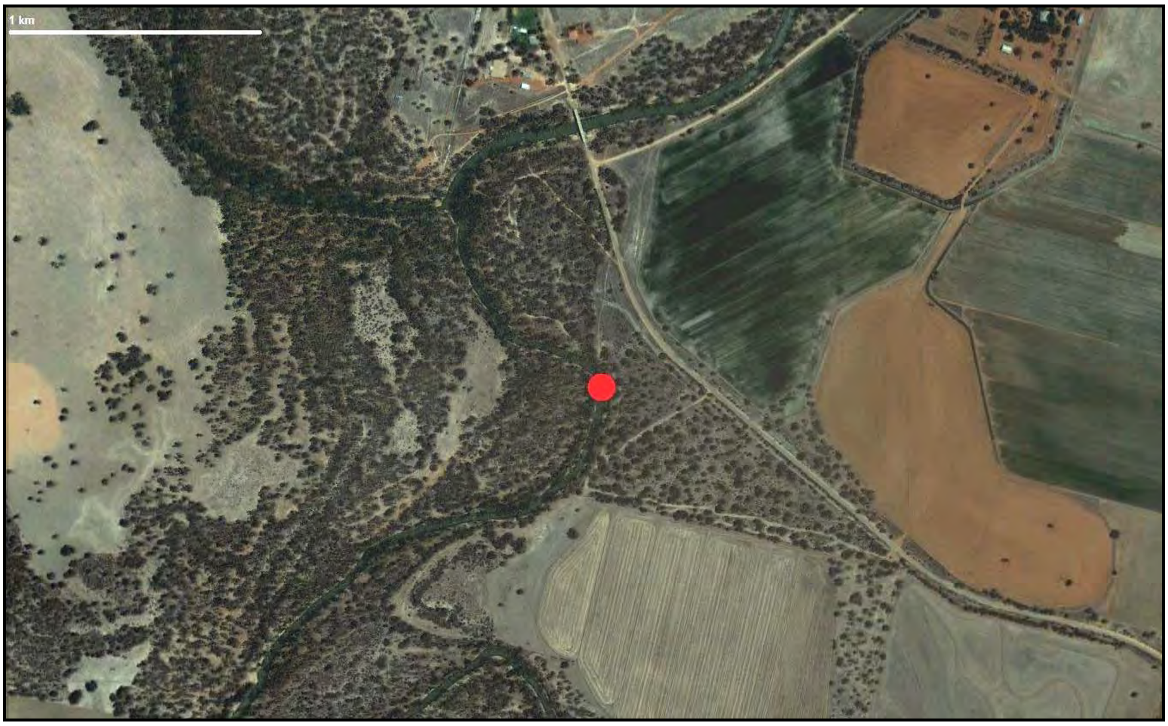
This site was ~102 km downstream of Deniliquin and 14 km south-west of Moulamein. It comprised a straight stretch in a generally sinuous section of the river, incised into a general Shepparton land surface. The river was relatively narrow, ~10 m wide at this point, the water was shallow, ~0.5 m deep, and continuous, with abundant logs and other woody debris. Both banks were ~3 m high, steep and eroding, with the materials having a sodic/saline appearance and showing evidence of tunnel erosion. A sand hill comes close to the northern bank. Riparian vegetation was mature and regrowth river red gums, which are highly stressed, with severe dieback. Native vegetation was confined to a relatively narrow meandering belt. Sediment field pH was 6.0–6.8.

Site 34: Niemur River, 761437 **E**, 6108273 **N**, UTM Zone 54

This site was ~108 km downstream of Deniliquin and 16 km south-west of Moulamein. It comprised a gentle bend in a generally sinuous section of the river. The general Shepparton surface of the district was overlain by isolated sand hills through which winds a narrow Coonambidgal meander belt, which was 250 m wide here, between two sand hills. The river was relatively narrow, ~5 m wide at this point, but sits in a larger incised channel, outcropping at the base of which was a ferruginous hardpan. Water level was shallow, ~0.5 m deep, and flowing on this hardpan. There were abundant logs and other woody debris. Both banks were ~3 m high, the outside bank steeper and eroding, with the materials having a sodic/saline appearance. Riparian vegetation was mature and regrowth river red gums, which are stressed, with signs of dieback. Native vegetation was confined to a relatively narrow meandering belt. Sediment field pH was 7.4–7.6

Site 14: Niemur River, 755037 **E**, 6107247 **N**, UTM Zone 54

This site was ~114 km downstream of Deniliquin, and 22 km west of Moulamein. It comprised a bend in the section of the lower Niemur that avulsed to the Wakool, leaving the former lower Niemur at Mallan Mallan Creek. This section of the Niemur is therefore geomorphically recent with few cut-off meanders, and is deeply incised into Shepparton Formation materials. The river was narrow, ~5 m wide at this point. Water level was shallow, ~0.5 m deep, and there were abundant logs and other woody debris. Both banks were ~3 m high, the outside bank steeper and eroding, with the materials having a sodic/saline appearance. Riparian vegetation was mature and regrowth river red gums and black box, which are stressed, with signs of dieback. Native vegetation was confined to a relatively narrow meandering belt. Sediment field pH was 6.0–6.3. Hypermonosulfidic material was in layer 3, hypersulfidic material in layer 4. Precipitation of possible iron compounds was evident.

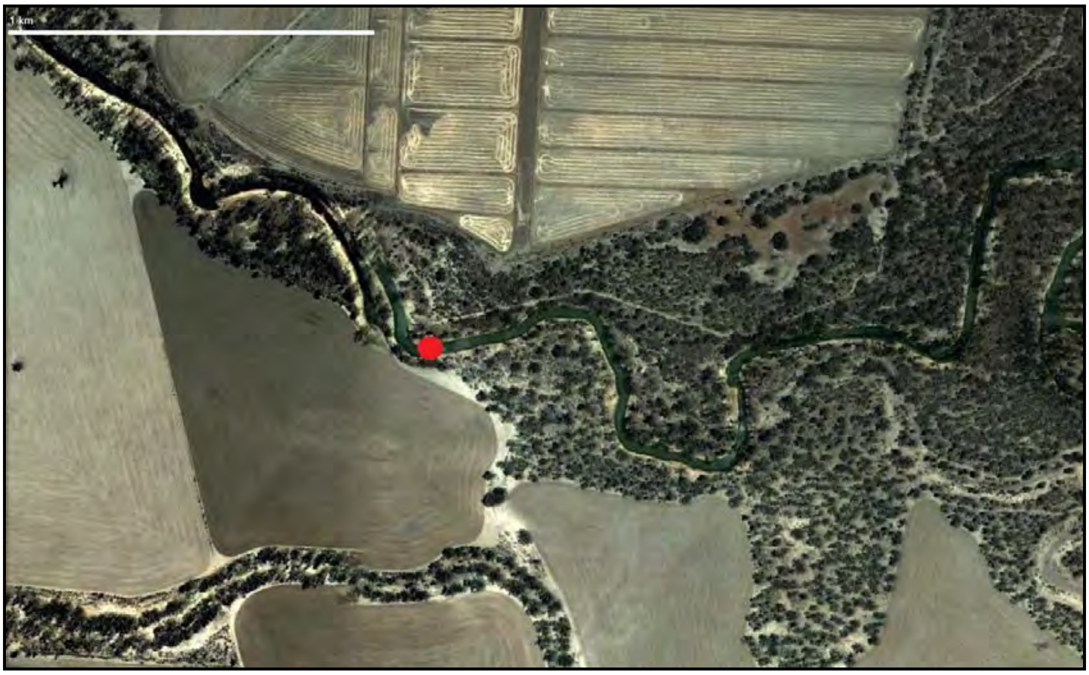


Site 22: Niemur River, 754724 **E**, 6106256 **N**, UTM Zone 54

This site was ~113 km downstream of Deniliquin and 23 km west of Moulamein. It comprised a straight stretch in the section of the lower Niemur that avulsed to the Wakool. This section of the Niemur is therefore geomorphically recent with few cut-off meanders, and is deeply incised into Shepparton Formation materials. The river was narrow, ~5 m wide at this point. Water level was shallow, ~0.5 m deep, and there were abundant logs and other woody debris. A ferruginous hardpan was exposed on the lower opposite bank. Both banks were ~3 m high, the outside bank steeper and eroding, with the materials having a sodic/saline appearance with evidence of tunnel erosion. Riparian vegetation was mature and regrowth river red gums and black box, which are severely stressed, with severe dieback or dead. Native vegetation was confined to a relatively narrow meandering belt. Hypermonosulfidic materials were in layers 1, 2 and 3, hyposulfidic materials in layer 4. Precipitation of iron compounds and halite was evident.

Mallan Mallan Creek

Site 15: Mallan Mallan Creek, 751415 **E**, 6108620 **N**, UTM Zone 54
This site was ~29 km north-east of Swan Hill at Coobool Island. It comprised a bend in the creek where it passes out of a former lake basin, where it has a highly sinuous pattern, to a straighter pattern as the creek incises into a higher Shepparton land surface. The creek was narrow, ~7 m wide, with both banks 4–5 m, steep and subject to sheet and tunnel erosion, with the soils having a sodic/saline appearance. Water level was low, 0.3 m deep, with woody debris. Riparian vegetation comprised mature and regrowth river red gums and black box under extreme stress, with severe dieback progressing to death in many cases. Sediment field pH was 5.7–6.5. Hypomonosulfidic materials were in layers 1, 2, 3 and 5, hypermonosulfidic materials in layer 4. Precipitation of iron compounds and halite was evident.



Site 17: Mallan Mallan Creek, 748030 **E**, 6109556 **N**, UTM Zone 54
This site was ~27 km north-east of Swan Hill at Coobool Island. It comprised a straight reach, with the creek deeply incised into Shepparton Formation materials. The creek was narrow, ~5 m wide, with both banks 4–5 m, steep and subject to sheet and tunnel erosion, with the soils having a sodic/saline appearance. Water level was low, 0.3 m deep, with woody debris. Riparian vegetation comprised mature and regrowth river red gums and black box under extreme stress, with severe dieback progressing to death in many cases. Groundcover includes halophytes. Hypomonosulfidic materials were in layers 1, 2, and 3, hyposulfidic materials in layer 4. Precipitation of iron compounds and halite was evident.

Pissen Creek

Site 16: Pissen Creek, 752154 **E**, 6107665 **N**, UTM Zone 54
This site was ~116 km downstream of Deniliquin, 25 km west of Moulamein. It comprised a reach of the lower creek, which was located in Shepparton Formation sediments on Coobool Island. The creek was very broad, ~20 m wide, and shallow, as the creek is perched on a ferruginous hard pan. Both banks are ~2 m high, gently inclined, but subject to sheet and tunnel erosion, with the soils having a sodic/saline appearance. Riparian vegetation comprised river red gums and black box. Native vegetation was confined to a very narrow riparian belt. Sediment field pH was 4.2–6.3. Precipitation of halite was strongly evident.

Yarrein Creek

Site 32: Yarrein Creek, 754718 **E**, 6114930 **N**, UTM Zone 54

This site was ~117 km downstream of Deniliquin and 22 km west of Moulamein. It comprised a sharp bend where the creek, otherwise highly sinuous within Coonambidgal sediments, abuts the Shepparton Formation surface. The creek was very broad, ~25 m wide. The outside bank, in Shepparton materials, was ~3–4 m high, steep and subject to sheet and tunnel erosion, the soils appearing sodic/saline. Riparian vegetation comprised mature river red gums subject to severe stress with extensive dieback, with halophytes. Native vegetation was confined to a very narrow riparian belt. Sediment field pH was 5.5–6.1. Hypomonosulfidic materials were in layer 5. Precipitation of iron compounds and halite was evident.

Site 33: Yarrein Creek, 749985 **E**, 6117278 **N**, UTM Zone 54
This site was ~122 km downstream of Deniliquin, 26 km east of Kyalite and 27 km west of Moulamein. It comprised a straight reach of the creek, otherwise generally highly sinuous within Coonambidgal sediments. The creek was broad, ~15 m wide, and has not carried water for some time. Both banks are ~3 m high and stable. Riparian vegetation comprised mature river red gum, shrubs and grasses. Native vegetation was confined to a very narrow riparian belt. Sediment field pH was 6.3–6.8.

Barbers Creek

Site 42: Barbers Creek, 244413 **E**, 6057817 **N**, UTM Zone 55

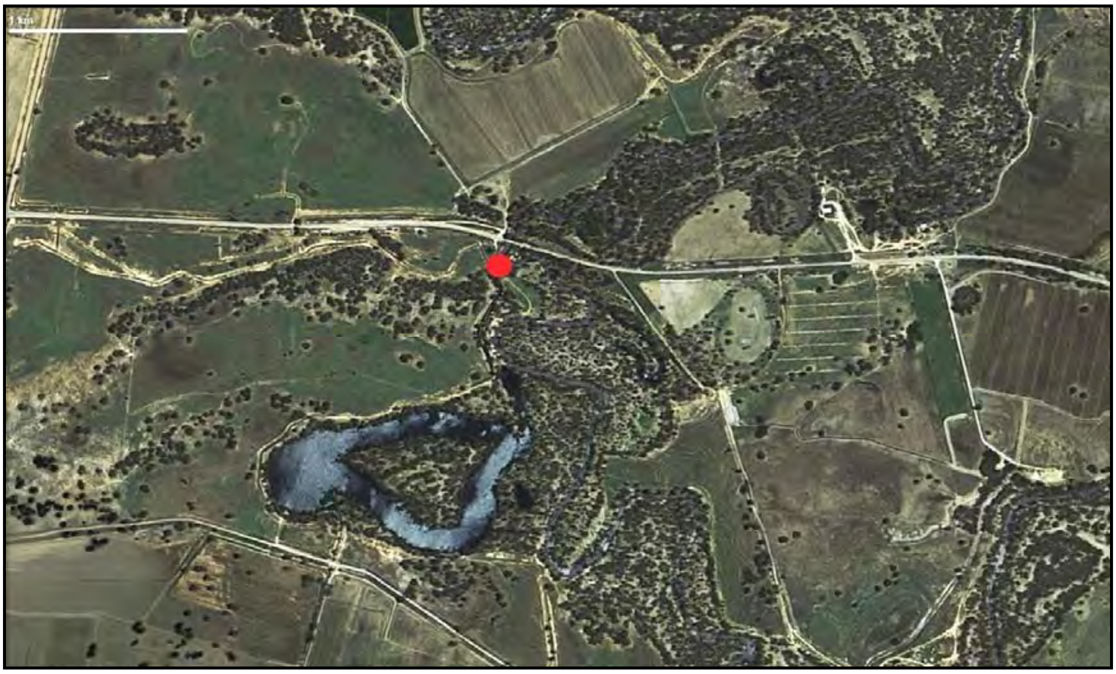
This site was ~6 km north-east of Barham. It comprised a sharp bend in a highly sinuous system entrenched into the broad depositional Coonambidgal surface of Koondrook forest. The creek was ~30 m wide and was entrenched 4–6 m into the surrounding land surface. However, the creek was dry and had been so for some years. Vegetation comprised mature and regrowth river red gums, with grasses and shrubs. Native vegetation was extensive in the area of Koondrook forest. Sediment field pH was 4.2–5.5. Hypomonosulfidic materials were in layer 1, sulfuric materials in layers 2, 3 and 4, and hypersulfidic materials in layer 5. Precipitation of iron compounds was evident.

Site 25: Barbers Creek, 237273 **E**, 6065545 **N**, UTM Zone 55
This site was ~13 km north of Barham. It comprised a bend in a highly sinuous section of the creek. The creek was moderately broad, ~10 m wide, located within a narrow Coonambidgal meander belt. Water level was moderate, 1.5 m deep, with some woody debris. Both banks were ~2 m high and steep, with some stream bank erosion. Riparian vegetation comprised mature and regrowth river red gums, which were severely stressed, with extensive dieback. Native vegetation was locally confined to a narrow belt, but was more extensive upstream. Sediment field pH was 6.8–7.3. Hypermonosulfidic materials were in layers 2, 3 and 4.

Site 27: Barbers Creek, 232306 **E**, 6070711 **N**, UTM Zone 55
This site was ~19 km north-west of Barham. It comprised a bend in a highly sinuous section of the creek. The creek was narrow, ~6 m wide, located within a narrow Coonambidgal meander belt. Water level was low, 0.25 m deep, with the channel choked by reeds, with logs and some woody debris. Both banks were ~2 m high and steep, but stable. Riparian vegetation comprised mature and regrowth river red gums, with extensive recruitment of gum saplings within the channel. Native vegetation was locally confined to a narrow belt, but was more extensive upstream. Sediment field pH was 6.8–7.2.

Merran Creek

Site 5: Merran Creek, 770400 **E**, 6070339 **N**, UTM Zone 54
This site was ~22 km north-west of Barham. It comprised a sharp bend in a highly sinuous section of the creek with many cut-off meanders. The creek was narrow, ~7 m wide, located within a narrow Coonambidgal meander belt. Water level was moderately high and flowing, 2.0 m deep, with some reed beds on inside bends, with some logs and other woody debris. The outside bank was ~2–3 m high, and steep, with some stream bank erosion. The inside bank was ~1 m and stable. Riparian vegetation comprised mature and regrowth river red gums, reeds and grasses. Native vegetation was locally confined to a narrow meander belt. Sediment field pH was 7.0–7.4.



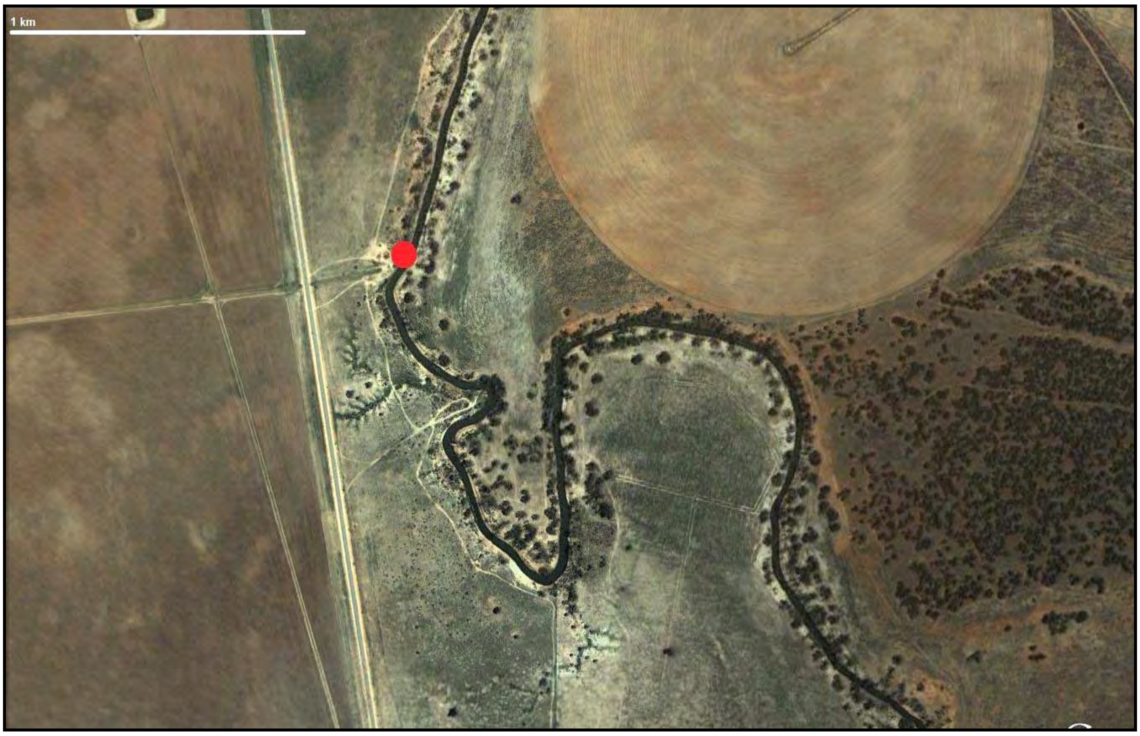
Site 6: Merran Creek, 751479 **E**, 6086667 **N**, UTM Zone 54
This site was ~19 km east of Swan Hill. It comprised a bend in a section of the creek where the creek changes morphology from highly sinuous on an alluvial surface to much straighter as it incises into a surface with sand hills. The river was moderately broad, ~15 m wide. Upstream there is a Coonambidgal meander belt, but downstream riparian vegetation was very limited. Water level was moderate, 2.0 m deep, with some reed beds and woody debris. The outside bank was ~2 m high and steep, with some stream bank erosion. The inside bank was ~1 m and stable. Bank materials have a sodic/saline appearance and show evidence of tunnel erosion. Riparian vegetation comprised mature and regrowth river red gums, highly stressed with extensive dieback, halophytes, shrubs, and reeds. Hypersulfidic materials were in layers 2 and 3. Precipitation of iron compounds and halite was evident.

Site 1: Merran Creek, 745200 **E**, 6097000 **N**, UTM Zone 54
This site was ~16 km north-east of Swan Hill. It comprised a bend in a section of the creek where the creek flows on former lake basin sediments, and where the course of the creek is confined by lunette remnants. The creek was narrow, ~7 m wide. Water level was moderate, 1.5 m deep, with reed beds and woody debris. The outside bank was ~3 m high and steep, with some stream bank erosion. The inside bank was ~1 m and stable. Riparian vegetation comprised mature and regrowth river red gums, reeds and shrubs. Sediment field pH was 6.9–7.4.

Site 2: Merran Creek, 744600 **E**, 6100400 **N**, UTM Zone 54
This site was ~18 km north-east of Swan Hill. It comprised a bend in a section of the creek where the creek flows on former lake basin sediments, and where the course of the creek is confined by lunette remnants. The creek was narrow, ~7 m wide. Water level was moderate, 1.5 m deep, with reed beds and woody debris. The outside bank was ~3 m high and steep, with some stream bank erosion. The inside bank was ~2 m and stable. Riparian vegetation comprised mature and regrowth river red gums and black box, which showed signs of stress with moderate dieback, and reeds and shrubs. Sediment field pH was 7.1 – 7.6. Hypersulfidic materials were in layer 3.

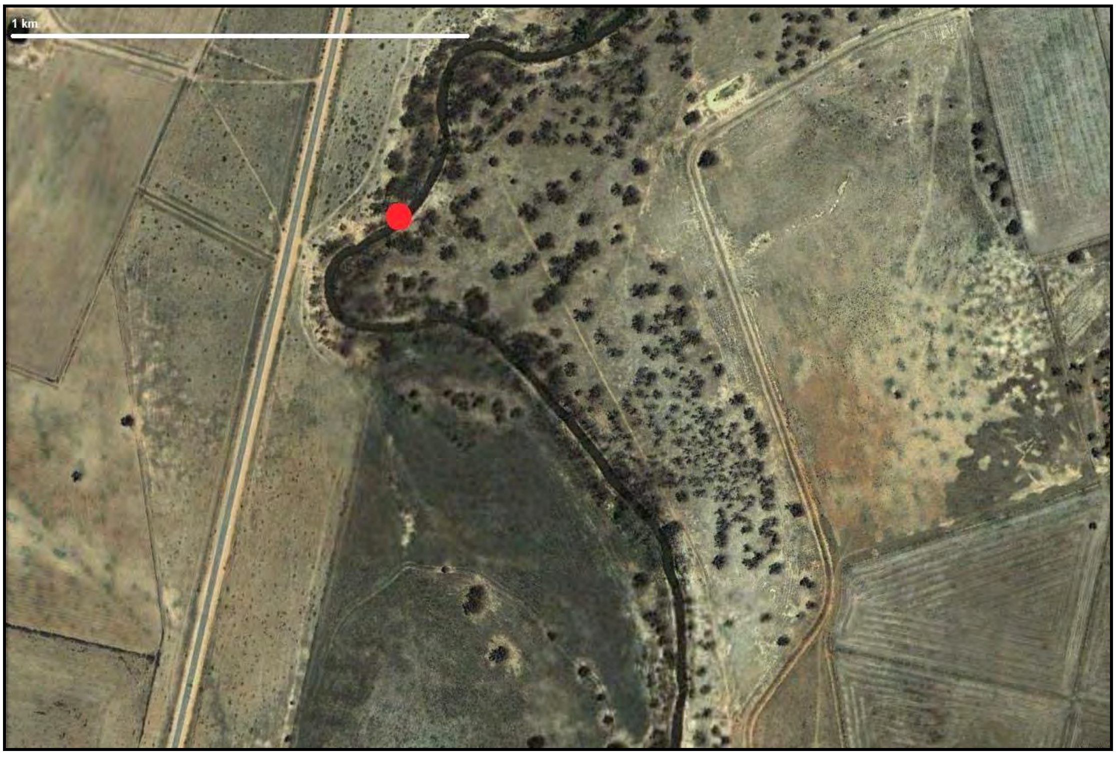
Site 3: Merran Creek, 738000 **E**, 6105200 **N**, UTM Zone 54
This site was ~19 km north of Swan Hill. It comprised a straight reach of the creek where the creek emerges from a former lake basin, and where the creek begins to incise into a higher Shepparton Formation land surface. The creek was moderately broad, ~10 m wide. Water level was moderate, 1.5 m deep, with some reed beds and woody debris. Both banks were ~3 m high and steep, with some stream bank erosion and the soils having a sodic/saline appearance. Riparian vegetation comprised mature and regrowth river red gums and black box, which showed signs of stress with moderate to severe dieback. Sediment field pH was 6.9–7.2. Hypersulfidic materials were in layers 1, 3 and 5, hypermonosulfidic material in layer 2.

Site 4: Merran Creek, 734500 **E**, 6109500 **N**, UTM Zone 54
This site was ~23 km north of Swan Hill. It comprised a gradual curve in a generally straight reach of the creek where the creek was deeply incised into a higher Shepparton Formation land surface. The creek was moderately narrow, ~7 m wide, with the outside bank ~5 m high, steep and subject to sheet and tunnel erosion, with the soils having a sodic/saline appearance. Water level was low, 0.3 m deep, with abundant logs and woody debris. Riparian vegetation once comprised mature and regrowth river red gums and black box, but severe dieback has progressed to death in most cases. Groundcover includes halophytes. Sediment field pH was 7.0–7.4. Hypersulfidic materials were in layers 1, 3, 4 and 5, hypermonosulfidic materials in layer 2. Precipitation of iron compounds and halite was evident.



Site 7: Merran Creek, 734767 **E**, 6113357 **N**, UTM Zone 54
This site was ~27 km north of Swan Hill. It comprised a gradual curve in a generally straight reach of the

creek where the creek was deeply incised into a higher Shepparton Formation land surface. The creek was moderately narrow, ~7 m wide, with both banks 4–5 m high, the outside bank steep and subject to sheet and tunnel erosion, with the soils having a sodic/saline appearance. Water level was low, 0.3 m deep, with logs and woody debris. Riparian vegetation comprised mature and regrowth river red gums and black box, but was under extreme stress, with severe dieback progressing to death in many cases. Groundcover includes halophytes. Sediment field pH was 7.3–8.0. Hypersulfidic materials were in layers 2 and 4, hypermonosulfidic materials in layer 3. Precipitation of iron compounds and halite was evident.



Site 8: Merran Creek, 735457 **E**, 6114554 **N**, UTM Zone 54
This site was ~28 km north of Swan Hill. It comprised a gradual curve in a generally straight reach of the creek where the creek was deeply incised into a higher Shepparton Formation land surface. The creek was narrow, ~5 m wide, with the outside bank 4–5 m, steep and subject to sheet and tunnel erosion, with the soils having a sodic/saline appearance. Water level was low, 0.3 m deep, with logs, woody debris and reed beds. Riparian vegetation comprised mature and regrowth river red gums and black box, but was under extreme stress, with severe dieback progressing to death in many cases. Groundcover includes halophytes. Sediment field pH was 6.9–7.4. Hypersulfidic materials were in layers 2 and 3, hypermonosulfidic materials in layer 4 and hyposulfidic materials in layer 5. Precipitation of iron compounds and halite was evident.

Appendix 2 Soil laboratory data

Site No.	Sample No.	Depth	pH_w	pH_{KCl}	pH_{fox}	pH incubation	TAA	RIS (S_{CR})	RA	ANC	Net acidity	AVS	ASS material type
		Metres below sediment surface	pH unit	pH unit	pH unit	pH unit	mol H^+ t^{-1}	%S	mol H^+ t^{-1}	%$CaCO_3$	mol H^+ t^{-1}	%S	Class
1	1	0 – 0.05	6.07	4.89	1.81	6.43	3.93	0.00	0.00	0.00	3.93	0.00	Other Soil Materials
	2	0.05 – 0.1	6.12	4.56	1.90	5.16	6.18	0.00	0.00	0.00	6.18	0.00	Other Acid Soils
	3	0.1 – 0.2	6.17	4.51	2.33	4.95	8.91	0.00	0.00	0.00	8.91	0.00	Other Acid Soils
	4	0.2 – 0.4	6.10	5.03	2.86	5.06	2.91	0.00	0.00	0.00	2.91	0.00	Other Acid Soils
	5	0.4 – 0.9	5.84	5.09	2.99	4.96	2.68	0.00	0.00	0.00	2.68	0.00	Other Acid Soils
2	1	0 – 0.05	6.19	4.19	1.93	4.42	18.13	0.00	0.00	0.00	18.13	0.00	Other Acid Soils
	2	0.05 – 0.1	6.09	4.41	1.72	4.38	9.23	0.00	0.00	0.00	9.23	0.00	Other Acid Soils
	3	0.1 – 0.2	6.04	4.34	1.87	4.36	10.63	0.02	0.00	0.00	24.00	0.00	Hypersulfidic
	4	0.2 – 0.4	6.04	4.27	1.97	4.40	19.35	0.00	0.00	0.00	19.35	0.00	Other Acid Soils
	5	0.4 – 0.9	5.70	4.33	2.29	4.78	25.24	0.00	0.00	0.00	25.24	0.00	Other Acid Soils
3	1	0 – 0.05	5.49	4.26	2.82	4.18	16.09	0.02	0.00	0.00	28.35	0.00	Hypersulfidic
	2	0.05 – 0.1	5.82	4.30	2.27	4.09	21.45	0.09	2.00	0.00	79.91	0.04	Hypermonosulfidic
	3	0.1 – 0.2	6.01	4.39	2.48	4.33	15.23	0.02	0.00	0.00	26.92	0.00	Hypersulfidic
	4	0.2 – 0.4	6.20	4.82	2.07	4.38	7.34	0.00	0.00	0.00	7.34	0.00	Other Acid Soils
	5	0.4 – 0.9	6.32	6.39	3.17	4.13	2.43	0.03	0.00	0.00	19.01	0.00	Hypersulfidic
4	1	0 – 0.05	6.50	7.00	1.92	2.84	0.00	0.15	0.00	0.27	60.75	0.00	Hypersulfidic
	2	0.05 – 0.1	7.11	7.48	1.73	1.92	0.00	0.45	0.00	0.37	232.67	0.03	Hypermonosulfidic
	3	0.1 – 0.2	7.25	7.44	4.26	2.87	0.00	0.58	0.00	0.66	273.33	0.00	Hypersulfidic
	4	0.2 – 0.4	7.32	6.94	3.60	5.80	0.00	0.41	0.00	0.60	174.55	0.00	Hypersulfidic
	5	0.4 – 0.9	7.36	7.04	3.86	3.17	0.00	0.49	0.00	0.60	227.46	0.00	Hypersulfidic
5	1	0 – 0.05	6.65	4.49	1.84	4.32	18.02	0.00	2.00	0.00	20.02	0.00	Other Acid Soils
	2	0.05 – 0.1	6.79	4.13	2.17	4.05	31.67	0.00	0.00	0.00	31.67	0.00	Other Acid Soils
	3	0.1 – 0.2	6.47	3.97	1.89	4.01	45.75	0.00	0.00	0.00	45.75	0.00	Other Acid Soils
	4	0.2 – 0.4	5.69	4.17	2.47	4.14	38.29	0.00	0.00	0.00	38.29	0.00	Other Acid Soils
	5	0.4 – 0.9	5.68	4.32	2.53	4.12	32.27	0.00	0.00	0.00	32.27	0.00	Other Acid Soils
6	1	0 – 0.05	5.93	4.85	2.33	4.23	2.94	0.00	0.00	0.00	2.94	0.00	Other Acid Soils
	2	0.05 – 0.1	5.53	4.98	2.60	4.01	3.21	0.01	0.00	0.00	11.18	0.00	Hypersulfidic
	3	0.1 – 0.2	5.64	5.38	3.51	3.62	2.55	0.04	0.00	0.00	26.30	0.00	Hypersulfidic
	4	0.2 – 0.4	6.19	5.92	4.76	4.39	2.82	0.00	0.00	0.00	2.82	0.00	Other Acid Soils
	5	0.4 – 0.9	5.58	6.38	5.86	5.47	1.13	0.00	0.00	0.00	1.13	0.00	Other Soil Materials
7	1	0 – 0.05	5.88	6.24	5.93	5.07	2.98	0.00	0.00	0.00	2.98	0.00	Other Acid Soils
	2	0.05 – 0.1	6.58	6.12	6.48	5.34	2.96	0.02	0.00	0.00	12.81	0.00	Hypersulfidic
	3	0.1 – 0.2	6.66	7.96	6.97	4.01	0.00	0.61	0.00	1.05	239.70	0.31	Hypermonosulfidic
	4	0.2 – 0.4	7.16	7.57	3.69	1.76	0.00	1.16	0.00	0.90	601.66	0.00	Hypersulfidic
8	1	0 – 0.05	7.63	5.66	4.22	4.91	3.15	0.00	0.00	0.00	3.15	0.00	Other Acid Soils
	2	0.05 – 0.1	6.53	5.94	5.93	4.65	2.81	0.02	0.00	0.00	14.21	0.00	Hypersulfidic
	3	0.1 – 0.2	6.30	5.83	5.34	4.80	2.63	0.04	0.00	0.00	26.37	0.00	Hypersulfidic
	4	0.2 – 0.4	6.46	6.28	5.41	3.70	2.81	0.06	0.00	0.00	38.45	0.02	Hypermonosulfidic
	5	0.4 – 0.9	6.60	6.76	6.66	4.15	0.00	0.05	0.00	0.26	-4.71	0.00	Hyposulfidic
9	1	0 – 0.05	6.87	5.35	3.33	4.40	3.94	0.00	0.00	0.00	3.94	0.00	Other Acid Soils
	2	0.05 – 0.1	6.65	4.96	3.28	3.74	3.38	0.00	0.00	0.00	3.38	0.00	Other Acid Soils
10	1	0 – 0.05	3.49	3.83	2.93	3.35	24.12	0.00	70.00	0.00	94.12	0.00	Sulfuric Soil
	2	0.05 – 0.1	3.19	3.64	2.87	3.17	41.38	0.01	15.00	0.00	63.90	0.00	Sulfuric Soil
	3	0.1 – 0.2	6.08	5.68	5.62	4.99	16.39	0.85	0.00	0.00	546.98	0.54	Hypermonosulfidic
	4	0.2 – 0.4	6.22	5.91	4.24	5.31	7.61	0.51	0.00	0.00	327.04	0.46	Hypermonosulfidic
	5	0.4 – 0.9	6.35	5.39	1.51	2.60	3.40	0.26	0.00	0.00	165.74	0.02	Hypermonosulfidic

Site No.	Sample No.	Depth	pH_w	pH_{KCl}	pH_{fox}	pH incubation	TAA	RIS (S_{CR})	RA	ANC	Net acidity	AVS	ASS material type
		Metres below sediment surface	pH unit	pH unit	pH unit	pH unit	mol H^+ t^{-1}	%S	mol H^+ t^{-1}	$\%CaCO_3$	mol H^+ t^{-1}	%S	class
11	1	0 – 0.05	5.86	5.70	2.52	2.81	4.20	0.23	0.00	0.00	145.03	0.12	Hypermonosulfidic
	2	0.05 – 0.1	5.54	5.28	2.61	3.72	7.15	0.05	0.00	0.00	41.19	0.02	Hypermonosulfidic
	3	0.1 – 0.2	5.43	5.65	4.12	3.66	6.90	0.02	0.00	0.00	18.56	0.00	Hypersulfidic
	4	0.2 – 0.4	5.71	5.12	3.27	3.05	11.53	0.24	0.00	0.00	162.36	0.21	Hypermonosulfidic
	5	0.4 – 0.9	6.11	4.42	5.25	3.01	27.70	0.34	2.00	0.00	244.57	0.25	Hypermonosulfidic
12	1	0 – 0.05	6.58	5.29	4.67	4.37	5.65	0.00	0.00	0.00	5.65	0.00	Other Acid Soils
	2	0.05 – 0.1	6.34	4.63	6.77	5.11	8.15	0.00	0.00	0.00	8.15	0.00	Other Acid Soils
	3	0.1 – 0.2	6.37	5.25	6.62	5.42	13.58	0.00	0.00	0.00	13.58	0.00	Other Acid Soils
13	1	0 – 0.05	6.26	4.72	2.56	4.12	9.17	0.00	0.00	0.00	9.17	0.00	Other Acid Soils
	2	0.05 – 0.1	6.34	5.16	2.02	4.16	3.21	0.04	0.00	0.00	26.05	0.01	Hypermonosulfidic
	3	0.1 – 0.2	6.30	5.09	2.09	4.42	4.09	0.05	0.00	0.00	37.82	0.03	Hypermonosulfidic
	4	0.2 – 0.4	6.04	5.27	3.52	4.49	5.05	0.02	0.00	0.00	17.21	0.00	Hypersulfidic
	5	0.4 – 0.9	5.95	5.49	3.65	4.29	5.24	0.13	0.00	0.00	84.29	0.04	Hypermonosulfidic
14	1	0 – 0.05	6.95	5.31	3.18	5.24	4.07	0.00	0.00	0.00	4.07	0.00	Other Acid Soils
	2	0.05 – 0.1	6.37	4.69	1.79	4.40	4.45	0.00	0.00	0.00	4.45	0.00	Other Acid Soils
	3	0.1 – 0.2	6.68	5.56	4.72	4.98	3.96	0.04	0.00	0.00	31.20	0.01	Hypermonosulfidic
	4	0.2 – 0.4	6.59	5.80	5.56	4.73	3.71	0.02	0.00	0.00	16.01	0.00	Hypersulfidic
15	1	0 – 0.05	7.12	8.25	6.96	6.44	0.00	0.04	0.00	0.76	-77.79	0.02	Hypomonosulfidic
	2	0.05 – 0.1	7.27	8.90	7.25	6.70	0.00	0.26	0.00	1.44	-27.29	0.17	Hypomonosulfidic
	3	0.1 – 0.2	7.40	8.93	7.27	6.53	0.00	0.27	0.00	1.78	-68.38	0.18	Hypomonosulfidic
	4	0.2 – 0.4	7.11	8.78	3.34	6.28	0.00	0.23	0.00	0.31	101.29	0.03	Hypermonosulfidic
	5	0.4 – 0.9	6.68	8.56	5.45	5.83	0.00	0.01	0.00	0.25	-26.07	0.01	Hypomonosulfidic
16	1	0 – 0.05	5.98	5.14	5.28	4.73	4.93	0.00	0.00	0.00	4.93	0.00	Other Acid Soils
	2	0.05 – 0.1	5.47	4.88	5.39	4.51	7.40	0.00	0.00	0.00	7.40	0.00	Other Acid Soils
	3	0.1 – 0.2	5.09	4.72	4.29	4.37	9.31	0.00	0.00	0.00	9.31	0.00	Other Acid Soils
17	1	0 – 0.05	7.08	8.67	6.92	4.97	0.00	0.27	0.00	1.52	-34.71	0.20	Hypomonosulfidic
	2	0.05 – 0.1	7.00	8.69	6.61	6.63	0.00	0.18	0.00	1.41	-76.83	0.11	Hypomonosulfidic
	3	0.1 – 0.2	6.23	8.31	6.64	6.14	0.00	0.19	0.00	0.87	-0.37	0.10	Hypomonosulfidic
	4	0.2 – 0.4	6.78	6.71	5.19	4.16	0.00	0.08	0.00	0.71	-45.91	0.00	Hyposulfidic
18	1	0 – 0.05	6.63	6.25	5.91	6.04	3.14	0.00	0.00	0.00	3.14	0.00	Other Soil Materials
	2	0.05 – 0.1	7.51	7.40	6.02	6.62	0.00	0.00	0.00	0.05	-6.70	0.00	Other Soil Materials
	3	0.1 – 0.2	7.04	7.61	4.25	6.39	0.00	0.00	0.00	0.05	-7.11	0.00	Other Soil Materials
	4	0.2 – 0.4	6.97	7.71	5.21	6.73	0.00	0.00	0.00	0.02	-2.91	0.00	Other Soil Materials
	5	0.4 – 0.9	7.15	8.18	3.73	4.18	0.00	0.02	0.00	0.07	2.26	0.00	Hypersulfidic
19	1	0 – 0.05	6.97	8.27	6.38	7.45	0.00	0.01	0.00	0.88	-109.70	0.00	Hyposulfidic
	2	0.05 – 0.1	6.92	8.72	6.62	7.67	0.00	0.00	0.00	2.95	-392.95	0.00	Other Soil Materials
	3	0.1 – 0.2	6.91	8.63	6.44	7.79	0.00	0.00	0.00	1.51	-200.86	0.00	Other Soil Materials
	4	0.2 – 0.4	6.76	8.01	6.46	7.31	0.00	0.00	0.00	1.54	-204.93	0.00	Other Soil Materials
	5	0.4 – 0.9	6.83	8.35	6.72	7.04	0.00	0.00	0.00	4.19	-558.71	0.00	Other Soil Materials
20	1	0 – 0.05	6.98	8.76	7.14	6.85	0.00	0.57	0.00	2.60	10.41	0.20	Hypermonosulfidic
	2	0.05 – 0.1	7.01	8.54	6.95	6.81	0.00	0.18	0.00	2.06	-164.62	0.15	Hypomonosulfidic
	3	0.1 – 0.2	6.95	8.23	6.40	6.55	0.00	0.55	0.00	0.97	212.29	0.19	Hypermonosulfidic
	4	0.2 – 0.4	6.90	8.33	6.58	6.37	0.00	0.26	0.00	0.96	34.90	0.16	Hypermonosulfidic
	5	0.4 – 0.9	6.75	6.85	3.18	3.58	0.00	0.12	0.00	0.40	19.48	0.04	Hypermonosulfidic

Site No.	Sample No.	Depth	pH_w	pH_{KCl}	pH_{fox}	pH incubation	TAA	RIS (S_{CR})	RA	ANC	Net acidity	AVS	ASS material type
		Metres below sediment surface	pH unit	pH unit	pH unit	pH unit	mol H^+ t^{-1}	%S	mol H^+ t^{-1}	$\%CaCO_3$	mol H^+ t^{-1}	%S	class
21	1	0 – 0.05	6.53	4.80	2.19	4.72	2.70	0.00	0.00	0.00	2.70	0.00	Other Acid Soils
	2	0.05 – 0.1	5.72	4.73	3.01	4.79	3.58	0.00	0.00	0.00	3.58	0.00	Other Acid Soils
	3	0.1 – 0.2	6.25	4.32	2.46	4.68	11.27	0.00	10.0	0.00	21.27	0.00	Other Acid Soils
	4	0.2 – 0.4	5.93	4.37	2.00	4.47	6.90	0.00	8.0	0.00	14.90	0.00	Other Acid Soils
	5	0.4 – 0.9	5.68	4.43	2.66	4.48	6.66	0.00	8.0	0.00	14.66	0.00	Other Acid Soils
22	1	0 – 0.05	6.51	5.85	5.66	5.01	4.14	0.07	0.00	0.00	46.00	0.05	Hypermonosulfidic
	2	0.05 – 0.1	6.77	6.35	5.71	4.56	4.24	0.11	0.00	0.00	74.77	0.09	Hypermonosulfidic
	3	0.1 – 0.2	6.70	6.82	3.85	6.09	0.00	0.04	0.00	0.16	3.81	0.01	Hypermonosulfidic
	4	0.2 – 0.4	7.29	7.35	6.99	7.02	0.00	0.02	0.00	0.23	-15.90	0.00	Hyposulfidic
23	1	0 – 0.05	5.88	5.26	3.03	4.96	4.03	0.00	0.00	0.00	4.03	0.00	Other Acid Soils
	2	0.05 – 0.1	6.46	5.12	2.49	4.61	2.25	0.00	0.00	0.00	2.25	0.00	Other Acid Soils
	3	0.1 – 0.2	6.42	4.94	2.20	4.35	3.47	0.00	0.00	0.00	3.47	0.00	Other Acid Soils
	4	0.2 – 0.4	6.45	4.90	2.09	4.17	3.41	0.00	0.00	0.00	3.41	0.00	Other Acid Soils
	5	0.4 – 0.9	6.13	5.20	2.87	4.61	3.88	0.00	0.00	0.00	3.88	0.00	Other Acid Soils
24	1	0 – 0.05	6.38	6.32	4.39	3.28	4.71	0.20	0.00	0.00	128.34	0.12	Hypermonosulfidic
	2	0.05 – 0.1	6.28	5.87	5.46	5.16	3.86	0.00	0.00	0.00	3.86	0.00	Other Acid Soils
	3	0.1 – 0.2	6.07	5.62	4.14	4.76	4.67	0.08	0.00	0.00	52.09	0.03	Hypermonosulfidic
	4	0.2 – 0.4	6.01	6.03	4.46	4.78	4.36	0.00	0.00	0.00	4.36	0.00	Other Acid Soils
	5	0.4 – 0.9	6.27	6.47	6.16	4.28	3.65	0.02	0.00	0.00	17.43	0.00	Hypersulfidic
25	1	0 – 0.05	6.82	4.31	4.50	4.45	13.62	0.00	0.00	0.00	13.62	0.00	Other Acid Soils
	2	0.05 – 0.1	6.09	4.14	2.64	4.21	16.34	0.02	0.00	0.00	28.78	0.02	Hypermonosulfidic
	3	0.1 – 0.2	6.47	4.32	3.51	3.61	15.85	0.08	0.00	0.00	66.13	0.04	Hypermonosulfidic
	4	0.2 – 0.4	6.43	4.52	2.61	4.36	12.22	0.05	0.00	0.00	45.29	0.03	Hypermonosulfidic
	5	0.4 – 0.9	6.08	4.73	4.96	4.96	7.66	0.00	0.00	0.00	7.66	0.00	Other Acid Soils
26	1	0 – 0.05	6.15	4.67	2.74	5.09	4.21	0.00	0.00	0.00	4.21	0.00	Other Acid Soils
	2	0.05 – 0.1	6.12	4.42	2.29	5.38	6.65	0.00	0.00	0.00	6.65	0.00	Other Acid Soils
	3	0.1 – 0.2	5.61	4.40	2.56	5.07	7.68	0.00	0.00	0.00	7.68	0.00	Other Acid Soils
	4	0.2 – 0.4	5.57	4.70	3.16	4.75	6.94	0.00	0.00	0.00	6.94	0.00	Other Acid Soils
	5	0.4 – 0.9	6.01	4.95	3.10	4.99	6.12	0.00	0.00	0.00	6.12	0.00	Other Acid Soils
27	1	0 – 0.05	5.82	4.52	1.96	4.99	7.06	0.00	0.00	0.00	7.06	0.00	Other Acid Soils
	2	0.05 – 0.1	5.74	4.56	2.95	4.82	7.81	0.00	0.00	0.00	7.81	0.00	Other Acid Soils
	3	0.1 – 0.2	5.56	4.71	2.34	4.99	4.20	0.00	0.00	0.00	4.20	0.00	Other Acid Soils
28	1	0 – 0.05	5.91	4.06	3.84	4.59	20.59	0.00	0.00	0.00	20.59	0.00	Other Acid Soils
	2	0.05 – 0.1	5.48	3.94	4.46	4.26	25.88	0.00	0.00	0.00	25.88	0.00	Other Acid Soils
	3	0.1 – 0.2	5.63	4.03	2.68	4.36	23.41	0.00	0.00	0.00	23.41	0.00	Other Acid Soils
	4	0.2 – 0.4	6.02	4.31	4.38	4.75	16.96	0.00	0.00	0.00	16.96	0.00	Other Acid Soils
	5	0.4 – 0.9	5.19	4.34	3.24	4.88	13.80	0.00	0.00	0.00	13.80	0.00	Other Acid Soils
29	1	0 – 0.05	5.70	4.25	2.65	4.40	11.80	0.00	4.00	0.00	15.80	0.00	Other Acid Soils
	2	0.05 – 0.1	6.16	4.23	1.87	4.31	8.30	0.00	2.00	0.00	10.30	0.00	Other Acid Soils
	3	0.1 – 0.2	5.33	4.16	2.08	4.62	8.52	0.00	3.00	0.00	11.52	0.00	Other Acid Soils
	4	0.2 – 0.4	5.01	4.18	1.48	4.47	9.85	0.00	0.00	0.00	9.85	0.00	Other Acid Soils
	5	0.4 – 0.9	5.64	4.31	1.84	4.97	8.57	0.00	0.00	0.00	8.57	0.00	Other Acid Soils
30	1	0 – 0.05	5.73	4.45	3.40	4.95	11.37	0.00	0.00	0.00	11.37	0.00	Other Acid Soils
	2	0.05 – 0.1	6.19	4.39	3.41	5.14	10.64	0.00	0.00	0.00	10.64	0.00	Other Acid Soils
	3	0.1 – 0.2	6.36	4.48	3.55	5.27	8.25	0.00	0.00	0.00	8.25	0.00	Other Acid Soils
	4	0.2 – 0.4	6.01	4.32	4.37	5.07	10.16	0.00	0.00	0.00	10.16	0.00	Other Acid Soils
	5	0.4 – 0.9	5.91	3.98	4.30	4.50	16.84	0.00	0.00	0.00	16.84	0.00	Other Acid Soils

Site No.	Sample No.	Depth	pH_w	pH_{KCl}	pH_{fox}	pH incubation	TAA	RIS (S_{CR})	RA	ANC	Net acidity	AVS	ASS material type
		Metres below sediment surface	pH unit	pH unit	pH unit	pH unit	mol $H^+ t^{-1}$	%S	mol $H^+ t^{-1}$	$\%CaCO_3$	mol $H^+ t^{-1}$	%S	class
31	1	0 – 0.05	5.51	4.75	2.93	4.30	5.10	0.00	0.00	0.00	5.10	0.00	Other Acid Soils
	2	0.05 – 0.1	5.42	4.72	2.67	4.09	5.89	0.00	0.00	0.00	5.89	0.00	Other Acid Soils
	3	0.1 – 0.2	5.56	4.78	2.08	4.14	4.15	0.00	0.00	0.00	4.15	0.00	Other Acid Soils
	4	0.2 – 0.4	5.49	4.77	2.05	3.85	6.65	0.00	0.00	0.00	6.65	0.00	Other Acid Soils
	5	0.4 – 0.9	5.76	5.02	2.23	3.87	5.92	0.00	0.00	0.00	5.92	0.00	Other Acid Soils
32	1	0 – 0.05	6.42	8.34	6.71	6.53	0.00	0.00	0.00	1.45	-193.62	0.00	Other Soil Materials
	2	0.05 – 0.1	5.25	8.35	4.13	5.16	0.00	0.00	0.00	1.38	-183.72	0.00	Other Acid Soils
	3	0.1 – 0.2	4.42	5.12	3.41	3.06	9.43	0.00	0.00	0.00	9.43	0.00	Other Acid Soils
	4	0.2 – 0.4	5.15	6.72	3.79	4.64	0.00	0.00	0.00	0.53	-70.48	0.00	Other Acid Soils
	5	0.4 – 0.9	6.05	7.88	5.89	6.05	0.00	0.09	0.00	0.95	-70.14	0.05	Hypomonosulfidic
33	1	0 – 0.05	6.35	5.86	5.15	5.94	2.85	0.00	0.00	0.00	2.85	0.00	Other Soil Materials
	2	0.05 – 0.1	5.93	5.57	4.26	5.96	2.95	0.00	0.00	0.00	2.95	0.00	Other Soil Materials
	3	0.1 – 0.2	5.58	5.33	4.16	5.32	6.60	0.00	0.00	0.00	6.60	0.00	Other Soil Materials
	4	0.2 – 0.4	5.34	5.02	3.88	5.11	7.64	0.00	0.00	0.00	7.64	0.00	Other Acid Soils
	5	0.4 – 0.9	5.78	5.28	4.83	5.37	4.91	0.00	0.00	0.00	4.91	0.00	Other Soil Materials
34	1	0 – 0.05	6.39	4.76	3.20	5.01	3.46	0.00	0.00	0.00	3.46	0.00	Other Acid Soils
	2	0.05 – 0.1	5.97	4.30	3.74	4.51	9.57	0.00	0.00	0.00	9.57	0.00	Other Acid Soils
35	1	0.1 – 0.2	6.37	4.63	4.55	4.91	3.95	0.00	0.00	0.00	3.95	0.00	Other Acid Soils
	2	0.2 – 0.4	6.07	4.67	3.89	4.79	4.09	0.00	0.00	0.00	4.09	0.00	Other Acid Soils
	3	0.4 – 0.9	6.44	4.62	3.39	4.78	6.54	0.00	0.00	0.00	6.54	0.00	Other Acid Soils
36	1	0 – 0.05	5.51	5.58	2.95	5.65	4.21	0.47	0.00	0.00	296.56	0.12	Hypermonosulfidic
	2	0.05 – 0.1	4.81	5.14	2.34	4.89	7.91	0.00	0.00	0.00	7.91	0.00	Other Acid Soils
	3	0.1 – 0.2	4.73	5.13	3.78	4.88	8.13	0.00	0.00	0.00	8.13	0.00	Other Acid Soils
	4	0.2 – 0.4	5.11	5.56	4.31	4.51	8.95	0.00	0.00	0.00	8.95	0.00	Other Acid Soils
	5	0.4 – 0.9	5.80	6.65	5.84	5.12	0.00	0.04	0.00	0.46	-37.70	0.00	Hyposulfidic
37	1	0 – 0.05	6.02	5.06	2.94	5.47	9.37	0.01	0.00	0.00	16.04	0.00	Hypersulfidic
	2	0.05 – 0.1	5.82	5.02	3.01	5.48	9.08	0.02	0.00	0.00	20.27	0.00	Hypersulfidic
	3	0.1 – 0.2	5.62	4.79	3.05	5.25	7.91	0.00	0.00	0.00	7.91	0.00	Other Soil Materials
	4	0.2 – 0.4	5.37	4.81	4.25	5.46	6.87	0.00	0.00	0.00	6.87	0.00	Other Acid Soils
	5	0.4 – 0.9	5.35	4.88	4.77	5.52	7.90	0.00	0.00	0.00	7.90	0.00	Other Acid Soils
38	1	0 – 0.05	5.37	4.95	4.17	4.75	7.17	0.00	0.00	0.00	7.17	0.00	Other Acid Soils
	2	0.05 – 0.1	4.88	4.52	3.57	4.58	11.37	0.00	0.00	0.00	11.37	0.00	Other Acid Soils
	3	0.1 – 0.2	4.75	4.60	3.33	4.94	12.60	0.00	0.00	0.00	12.60	0.00	Other Acid Soils
	4	0.2 – 0.4	5.09	4.92	4.21	5.35	4.91	0.00	0.00	0.00	4.91	0.00	Other Acid Soils
39	1	0 – 0.05	5.07	3.76	3.50	4.79	42.64	0.00	7.00	0.00	49.64	0.00	Other Acid Soils
	2	0.05 – 0.1	4.21	3.85	3.40	4.84	36.26	0.00	0.00	0.00	36.26	0.00	Other Acid Soils
	3	0.1 – 0.2	4.15	3.67	3.14	4.68	45.14	0.00	6.00	0.00	51.14	0.00	Other Acid Soils
	4	0.2 – 0.4	4.33	3.57	3.46	4.15	63.00	0.00	5.00	0.00	68.00	0.00	Other Acid Soils
40	1	0 – 0.05	5.15	5.16	3.29	5.36	12.15	0.00	0.00	0.00	12.15	0.00	Other Acid Soils
	2	0.05 – 0.1	4.74	4.28	2.21	4.17	15.35	0.00	25.0	0.00	40.35	0.00	Other Acid Soils
	3	0.1 – 0.2	4.03	4.10	2.95	4.06	18.34	0.00	63.0	0.00	81.34	0.00	Other Acid Soils
	4	0.2 – 0.4	3.85	4.48	2.36	4.59	10.66	0.00	0.00	0.00	10.66	0.00	Sulfuric Soil
	5	0.4 – 0.9	4.39	4.80	2.99	4.97	10.18	0.00	0.00	0.00	10.18	0.00	Other Acid Soils

Site No.	Sample No.	Depth	pH_w	pH_{KCl}	pH_{fox}	pH incubation	TAA	RIS (S_{CR})	RA	ANC	Net acidity	AVS	ASS material type
		Metres below sediment surface	pH unit	pH unit	pH unit	pH unit	mol $H^+ t^{-1}$	%S	mol $H^+ t^{-1}$	%$CaCO_3$	mol $H^+ t^{-1}$	%S	class
41	1	0 – 0.05	4.93	5.40	3.15	4.67	4.45	0.00	0.00	0.00	4.45	0.00	Other Acid Soils
	2	0.05 – 0.1	4.19	4.67	2.66	4.42	8.10	0.00	0.00	0.00	8.10	0.00	Other Acid Soils
	3	0.1 – 0.2	4.34	5.03	2.76	4.69	5.58	0.00	0.00	0.00	5.58	0.00	Other Acid Soils
	4	0.2 – 0.4	4.62	5.28	3.12	4.78	4.43	0.00	0.00	0.00	4.43	0.00	Other Acid Soils
	5	0.4 – 0.9	4.68	5.53	3.22	4.98	4.61	0.00	0.00	0.00	4.61	0.00	Other Acid Soils
42	1	0 – 0.05	4.28	4.27	2.78	3.83	38.22	0.08	201.0	0.00	291.03	0.02	Hypermonosulfidic
	2	0.05 – 0.1	3.66	3.97	2.10	3.62	42.63	0.02	0.00	0.00	54.06	0.00	Sulfuric Soil
	3	0.1 – 0.2	3.35	3.63	2.19	3.40	51.79	0.00	2.00	0.00	53.79	0.00	Sulfuric Soil
	4	0.2 – 0.4	3.36	3.69	1.97	3.34	46.31	0.00	12.0	0.00	58.31	0.00	Sulfuric Soil
	5	0.4 – 0.9	4.97	4.84	3.77	4.23	11.12	0.02	0.00	0.00	24.65	0.00	Hypersulfidic
43	1	0 – 0.05	6.51	3.97	2.77	4.75	18.91	0.00	0.00	0.00	18.91	0.00	Other Acid Soils
	2	0.05 – 0.1	6.01	4.02	3.84	4.76	16.27	0.00	0.00	0.00	16.27	0.00	Other Acid Soils
	3	0.1 – 0.2	5.11	4.04	3.11	4.66	14.87	0.00	0.00	0.00	14.87	0.00	Other Acid Soils
	4	0.2 – 0.4	4.70	4.17	2.90	4.81	16.08	0.03	0.00	0.00	32.80	0.00	Hypersulfidic
	5	0.4 – 0.9	4.91	4.08	3.54	4.32	13.62	0.13	0.00	0.00	95.65	n/a	Hypersulfidic
44	1	0 – 0.05	5.99	7.53	4.89	5.56	0.00	0.49	0.00	5.22	-390.75	0.00	Hyposulfidic
	2	0.05 – 0.1	5.33	5.88	3.58	4.72	5.41	0.04	0.00	0.00	30.33	0.00	Hypersulfidic
	3	0.1 – 0.2	5.74	5.31	4.03	2.33	7.56	0.06	0.00	0.00	43.35	0.00	Hypersulfidic
	4	0.2 – 0.4	4.92	5.13	2.10	2.51	7.10	0.24	0.00	0.00	156.76	0.00	Hypersulfidic
	5	0.4 – 0.9	0.00	7.16	0.00	1.82	0.00	0.40	0.00	1.06	107.71	0.00	Hypersulfidic
45	1	0 – 0.05	5.93	6.14	5.68	4.98	5.78	0.00	0.00	0.00	5.78	0.00	Other Acid Soils
	2	0.05 – 0.1	4.58	4.83	3.66	4.37	8.79	0.00	0.00	0.00	8.79	0.00	Other Acid Soils
46	1	0 – 0.05	5.64	4.51	2.89	4.11	7.37	0.00	0.00	0.00	7.37	0.00	Other Acid Soils
	2	0.05 – 0.1	5.42	4.56	3.13	4.15	4.93	0.00	0.00	0.00	4.93	0.00	Other Acid Soils
	3	0.1 – 0.2	5.13	4.55	2.78	4.17	4.37	0.00	0.00	0.00	4.37	0.00	Other Acid Soils
	4	0.2 – 0.4	5.29	4.57	3.68	4.18	5.43	0.00	0.00	0.00	5.43	0.00	Other Acid Soils
47	1	0 – 0.05	6.01	5.14	2.62	5.43	3.17	0.00	0.00	0.00	3.17	0.00	Other Acid Soils
	2	0.05 – 0.1	5.82	4.86	1.88	5.16	4.39	0.00	0.00	0.00	4.39	0.00	Other Acid Soils
	3	0.1 – 0.2	5.92	4.44	2.54	4.85	8.06	0.00	0.00	0.00	8.06	0.00	Other Acid Soils
	4	0.2 – 0.4	5.81	4.57	2.80	4.40	5.61	0.00	0.00	0.00	5.61	0.00	Other Acid Soils
48	1	0 – 0.05	5.93	4.22	2.78	4.14	7.88	0.00	5.00	0.00	12.88	0.00	Other Acid Soils
	2	0.05 – 0.1	5.83	4.37	2.80	4.04	6.67	0.01	2.00	0.00	17.73	0.00	Hypersulfidic
	3	0.1 – 0.2	5.37	4.59	2.01	2.61	2.96	0.03	0.00	0.00	18.97	0.00	Hypersulfidic
	4	0.2 – 0.4	5.43	4.67	2.35	4.80	5.04	0.01	0.00	0.00	11.68	0.00	Hypersulfidic
49	1	0 – 0.05	6.76	6.19	6.96	6.40	4.61	0.00	0.00	0.00	4.61	0.00	Other Soil Materials
	2	0.05 – 0.1	6.42	6.21	6.43	7.02	3.49	0.00	0.00	0.00	3.49	0.00	Other Soil Materials
	3	0.1 – 0.2	6.72	6.30	6.85	7.29	4.94	0.00	0.00	0.00	4.94	0.00	Other Soil Materials
50	1	0 – 0.05	5.55	3.95	2.24	4.21	29.10	0.00	0.00	0.00	29.10	0.00	Other Acid Soils
	2	0.05 – 0.1	5.83	3.95	1.95	4.18	29.83	0.00	0.00	0.00	29.83	0.00	Other Acid Soils
	3	0.1 – 0.2	5.80	4.00	2.34	4.10	30.78	0.00	0.00	0.00	30.78	0.00	Other Acid Soils
	4	0.2 – 0.4	5.97	4.00	2.69	4.05	29.33	0.00	0.00	0.00	29.33	0.00	Other Acid Soils
	5	0.4 – 0.9	5.79	4.05	2.45	4.26	24.36	0.01	0.00	0.00	30.98	0.00	Hypersulfidic

Site No.	Sample No.	Depth	pH_w	pH_{KCl}	pH_{fox}	pH incubation	TAA	RIS (S_{CR})	RA	ANC	Net acidity	AVS	ASS material type
		Metres below sediment surface	pH unit	pH unit	pH unit	pH unit	mol $H^+ t^{-1}$	%S	mol $H^+ t^{-1}$	$\%CaCO_3$	mol $H^+ t^{-1}$	%S	class
51	1	0 – 0.05	4.61	4.65	2.78	4.75	4.34	0.00	0.00	0.00	4.34	0.00	Other Acid Soils
	2	0.05 – 0.1	4.41	4.47	2.45	4.43	4.42	0.00	0.00	0.00	4.42	0.00	Other Acid Soils
	3	0.1 – 0.2	4.28	4.49	2.53	4.60	5.13	0.00	0.00	0.00	5.13	0.00	Other Acid Soils
	4	0.2 – 0.4	5.13	4.77	2.61	5.08	3.43	0.00	0.00	0.00	3.43	0.00	Other Acid Soils
	5	0.4 – 0.9	4.66	4.11	3.54	4.52	16.82	0.00	0.00	0.00	16.82	0.00	Other Acid Soils
52	1	0 – 0.05	5.05	4.12	3.25	4.70	27.80	0.00	4.00	0.00	31.80	0.00	Other Acid Soils
	2	0.05 – 0.1	5.43	3.95	3.31	4.60	31.57	0.00	1.00	0.00	32.57	0.00	Other Acid Soils
	3	0.1 – 0.2	5.38	3.99	2.70	4.58	28.61	0.00	8.00	0.00	36.61	0.00	Other Acid Soils
	4	0.2 – 0.4	5.37	3.98	2.46	4.52	34.37	0.00	6.00	0.00	40.37	0.00	Other Acid Soils
	5	0.4 – 0.9	5.15	4.42	3.30	4.24	19.32	0.00	4.00	0.00	23.32	0.00	Other Acid Soils
53	1	0 – 0.05	6.47	5.13	2.77	4.88	2.87	0.01	0.00	0.00	11.99	0.00	Hypersulfidic
	2	0.05 – 0.1	6.24	4.91	2.27	4.40	3.43	0.01	0.00	0.00	11.77	0.00	Hypersulfidic
	3	0.1 – 0.2	6.18	4.85	2.61	4.18	2.96	0.09	0.00	0.00	59.53	0.00	Hypersulfidic
	4	0.2 – 0.4	6.25	4.76	2.83	4.37	4.01	0.03	0.00	0.00	24.67	0.00	Hypersulfidic
	5	0.4 – 0.9	6.18	4.31	3.44	4.57	8.86	0.04	7.00	0.00	40.03	0.00	Hypersulfidic
54	1	0 – 0.05	6.67	7.38	4.19	4.58	0.00	0.00	0.00	1.35	-179.42	0.00	Other Acid Soils
	2	0.05 – 0.1	6.35	6.35	2.68	4.65	5.68	0.00	0.00	0.00	5.68	0.00	Other Acid Soils
	3	0.1 – 0.2	5.66	4.87	3.77	4.18	11.90	0.00	0.00	0.00	11.90	0.00	Other Acid Soils
	4	0.2 – 0.4	4.98	4.54	3.22	4.52	12.12	0.00	0.00	0.00	12.12	0.00	Other Acid Soils
55	1	0 – 0.05	5.45	4.45	4.48	4.68	6.19	0.00	6.00	0.00	12.19	0.00	Other Acid Soils
	2	0.05 – 0.1	4.58	4.36	2.43	4.51	10.86	0.00	5.00	0.00	15.86	0.00	Other Acid Soils
	3	0.1 – 0.2	6.07	4.29	4.17	5.07	11.63	0.00	1.00	0.00	12.63	0.00	Other Acid Soils
	4	0.2 – 0.4	5.00	4.24	2.84	4.56	11.60	0.00	3.00	0.00	14.60	0.00	Other Acid Soils
	5	0.4 – 0.9	5.86	4.12	3.32	4.26	10.35	0.00	3.00	0.00	13.35	0.00	Other Acid Soils
56	1	0 – 0.05	5.49	4.74	3.52	4.76	3.45	0.00	0.00	0.00	3.45	0.00	Other Acid Soils
	2	0.05 – 0.1	6.03	4.53	3.09	4.59	5.39	0.00	0.00	0.00	5.39	0.00	Other Acid Soils
	3	0.1 – 0.2	5.76	4.40	2.35	4.10	6.40	0.00	0.00	0.00	6.40	0.00	Other Acid Soils
	4	0.2 – 0.4	5.56	4.24	4.07	4.04	8.00	0.00	0.00	0.00	8.00	0.00	Other Acid Soils
	5	0.4 – 0.9	5.35	3.94	2.72	3.96	17.72	0.00	0.00	0.00	17.72	0.00	Other Acid Soils
57	1	0 – 0.05	5.75	4.57	2.44	5.03	7.63	0.00	0.00	0.00	7.63	0.00	Other Acid Soils
	2	0.05 – 0.1	5.95	4.58	1.66	5.00	5.30	0.00	0.00	0.00	5.30	0.00	Other Acid Soils
	3	0.1 – 0.2	5.72	4.41	1.75	4.77	6.27	0.00	1.00	0.00	7.27	0.00	Other Acid Soils
	4	0.2 – 0.4	5.59	4.49	3.70	4.83	5.17	0.00	6.00	0.00	11.17	0.00	Other Acid Soils
	5	0.4 – 0.9	5.52	3.83	3.27	4.41	27.37	0.00	4.00	0.00	31.37	0.00	Other Acid Soils
58	1	0 – 0.05	5.73	4.10	2.81	4.70	13.32	0.00	2.00	0.00	15.32	0.00	Other Acid Soils
	2	0.05 – 0.1	6.03	4.04	2.21	4.50	16.44	0.00	5.00	0.00	21.44	0.00	Other Acid Soils
	3	0.1 – 0.2	6.16	3.84	2.85	4.24	23.38	0.00	6.00	0.00	29.38	0.00	Other Acid Soils
	4	0.2 – 0.4	4.54	3.77	4.10	4.72	30.70	0.00	4.00	0.00	34.70	0.00	Other Acid Soils
	5	0.4 – 0.9	5.58	3.92	0.00	4.38	23.18	0.01	0.00	0.00	31.45	0.00	Hypersulfidic
59	1	0 – 0.05	5.50	5.15	4.96	4.84	9.82	0.00	0.00	0.00	9.82	0.00	Other Acid Soils
	2	0.05 – 0.1	4.52	4.22	4.59	4.57	27.01	0.00	0.00	0.00	27.01	0.00	Other Acid Soils
	3	0.1 – 0.2	4.11	4.06	4.04	4.51	32.20	0.00	0.00	0.00	32.20	0.00	Other Acid Soils
	4	0.2 – 0.4	3.64	3.58	2.51	4.33	48.18	0.00	0.00	0.00	48.18	0.00	Sulfuric Soil
60	1	0 – 0.05	5.35	4.41	1.70	4.84	8.28	0.00	0.00	0.00	8.28	0.00	Other Acid Soils
	2	0.05 – 0.1	5.00	4.29	4.10	4.32	6.62	0.00	0.00	0.00	6.62	0.00	Other Acid Soils
	3	0.1 – 0.2	5.39	4.47	2.29	4.75	8.12	0.00	0.00	0.00	8.12	0.00	Other Acid Soils
	4	0.2 – 0.4	5.75	4.31	4.82	4.70	13.99	0.00	0.00	0.00	13.99	0.00	Other Acid Soils
	5	0.4 – 0.9	4.87	4.13	2.80	4.41	13.74	0.00	0.00	0.00	13.74	0.00	Other Acid Soils

Appendix 3 Site water data

Site no.	Temperature	Specific electrical conductivity	Dissolved oxygen	Dissolved oxygen	pH	ORP	Turbidity
	(deg C)	(uS/cm)	(%)	(mg/l)		(mV)	(NTU)
1	12.4	118.2		7.54	6.93	351	
2	12.7	92.5		6.23	7.03	344.9	80
3	13.5	84		7.3	6.9	358	80
4	14.1	297		9.7	7.07	369.4	150
5	12.5	52.8	71.4	7.64	7.09	299	60
6	13.2	153.5	1.8	0.19	6.71	331.9	60
7	15.8	386	109.8	11.01	7.86	41.8	
8	14.7	633	2.2	0.22	7.27	-30.1	200
9	12.2	74.6	78.3	8.43	7.18	342	38
10	9.9	3710	64.7	7.38	3.8	381.2	23
11	17.7	59600	21.9	2.07	3.3	401.1	95
12	14	107.7	45.7	4.87	7.49	343.4	20
13	11.2	185.2	99.9	11.06	4.51	321.4	43
14	12.2	63.9	91.8	9.81	5.99	341.1	56
15	19.5	85.2	113.8	10.65		290.2	80
16	14.1	93.1	105.2	10.68	5.18	284.8	300
17	9.5	14860	127.7	14.57		236.9	11
18	12	184	100.9	10.98		315.4	34
19	10.8	50.2	91.2	9.86		298	35
20	18.6	89.9	3.3	0.3		209.2	10
21	11.8	49.2	92.6	10.02		268.8	55
22	10.5	74.2	98.5	10.97		309.6	78
23	11.5	101.4	92.6	10.08		302.5	31
24	13.9	7810	20.5	2.09		310.7	31
25	11.3	55	86.5	9.63	7.76	334.3	80
26	13.2	53.2	91.1	9.61	7.1	347.2	31
27	9.3	36.2	57.3	6.48	6.8	350.8	14
28	10.5	125.5	75.4	8.45	6.9	279	150
29	7.5	33.1	95.4	11.62	8.5	329.1	35
30	9.1	35.2	93.2	10.88	6.9	341	52
31	10.2	364	92.5	10.52	6.6	277.2	63
32	10.7	20090	105.3	11.83	5.8	232	10
33	Dry						
34	10.5	37.3	92.9	10.37	7.3	305.1	40
35	11.3	33.6	86	9.37	7.6	295.2	40
36	13.2	15060	111.3	11.61	5.9	262.7	12
37	Dry						
38	Dry						

Site no.	Temperature	Specific electrical conductivity	Dissolved oxygen	Dissolved oxygen	pH	ORP	Turbidity
	(deg C)	(uS/cm)	(%)	(mg/l)		(mV)	(NTU)
39	8.9	553	82.1	9.87	7.4	309.6	63
40	Dry						
41	Dry						
42	7.3	10010	52.8	6.49	3.64	338.9	246
43	11	35000	81.9	9.17	6.58	322	67
44	12.1	15610	153.6	16.54	3.3	467	9
45	11.1	21700	26.4	2.92	5.01	388.8	575
46	11.5	56.3	82.2	9	7.85	283.4	29
47	11.4	30.3	3.1	0.34	6.7	315.6	557
48	7.3	34.1	104.2	11	7.3	346.1	120
49	10.6	33.9	73.5	8.2	7.5	322.2	48
50	12.5	13.9	1.1	0.11	5.9	-104.1	
51	8.1	34.4	83.4	9.02	6.2	334.7	115
52	10.4	35.4	75.5	8.45	6.6	2014.2	53
53	10.7	2910	84.8	9.46	5.9	254.7	17
54	11	37.8	68.7	7.62	6.8	287.4	97
55	9.5	70	76.1	8.82	6.5	292.6	102
56	10.7	33.3	83.2	9.31	6.5	279.7	72
57	10.4	293	95.4	10.72	6.1	266.7	89
58	7.5	124.8	72.7	8.76	6.5	268.8	55
59	Dry						
60	9.6	83.2	87.4	9.97	6.1	345.3	52

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