Using seasonal rapid stream assessment (RSA) to monitor water quality and stream health parameters at Mulloon Creek, Bungendore NSW

by

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Candidate's Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge, it contains no material previously published or written by another person, except where due reference is made in the text.

YONGJIA ZHU Date:30/10/2023

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Abstract

Water quality is a critical factor in maintaining the health of aquatic ecosystems and supporting human activities like agriculture. In this study, we focus on Mulloon Creek, a stream in southeastern Australia, and analyse water samples to assess a range of water chemistry and physicochemical parameters. Specifically, we measure pH, dissolved oxygen (DO), electrical conductivity (EC), oxidation-reduction potential (ORP), temperature, and total dissolved solids (TDS).

To provide context for our analysis, we review the landscape evolution of Mulloon Creek over the late Quaternary period. This includes the impact of glacial activity, sediment redistribution, swamp expansion, and human settlement on floodplain morphology and sedimentation patterns. By understanding the historical changes in the landscape, we can better interpret current water quality data and identify processes influencing this chemistry.

Our findings indicate that the water quality in Mulloon Creek changes seasonally, at different river flow levels, and with geographic location. An extended period of monitoring is necessary to comprehensively evaluate the intervention's effectiveness.

Overall, our study highlights the importance of regular water quality monitoring and the potential benefits of interventions like strategically located leaky weirs. By continuing to analyse water samples and compare data over time, we can gain valuable insights into the health of Mulloon Creek and make informed decisions about how to protect this important resource.

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Electrical Conductivity	EC
Dissolved Oxygen (%)	DO (%)
Dissolved Oxygen (mg/L)	DO (mg/L)
potential of Hydrogen	pH
Total Dissolved Solid	TDS
Turbidity	Tur
Salinity	Sal
Oxidation Reduction Potential	ORP
South Eastern Highlands	SEH

Chapter 1: INTRODUCTION

1.1 Rationale

This research focuses on sampling and analyzing water samples from Mulloon Creek, specifically to analyse water physicochemical parameters such as pH value, dissolved oxygen (DO), electrical conductivity (EC), and oxidation-reduction potential (ORP), temperature (T) and total dissolved solids (TDS). Additionally, the experiment also evaluates the health of the stream before and after the establishment of a leaky weir and endeavours to assess the effectiveness of weir with respect to water quality.

Monitoring and comparing these parameters serves several purposes:

(1) Assessing weir effectiveness: by comparing the data measured before and after the establishment of the leaky weir, researchers evaluate the effectiveness of the weir in achieving its intended goals. Changes in water chemistry parameters, such as increased DO, or reduced EC, indicate the positive impact of the weir on water quality.

(2) Detecting changes in water quality: Monitoring water chemistry parameters through time allows researchers to detect changes in water quality from the past to the present. Comparing previous and current water quality data reveals any improvement or deterioration in water quality, providing insight into the effectiveness of interventions and any potential impacts from agriculture and other land use.

Water quality testing, comparison, and analysis in the Mulloon Creek area was conducted because:

(1) It is helpful for farms along Mulloon Creek to identify water pollutants or any potential risks associated with contaminants.

(2) Monitoring water quality provides insight into the natural processes that occur in Mulloon Creek, such as floods or droughts, on water quality.

(3) It evaluates the effectiveness of interventions in the Mulloon Creek area (landscape rehydration project).

1.2 Background

This research is very important because at Mulloon Creek as a strategic initiative, a series of leaky weirs have been installed.

The key stakeholders want to know:

1. Seasonal water quality (generally very fresh)
2. Water availability for agriculture
3. Do actions upstream impacting stakeholders downstream?
4. Patterns of groundwater (ingress to stream)
5. Impact of leaky weirs on stream health

To understand these processes, water quality patterns along Mulloon Creek was monitored seasonally in 2023, and this data was compared to prior surveys. Some prior surveys predate the installation of leaky weirs in Lower Mulloon Creek. This will provide information on the impact of leaky weirs as part of the overall regenerative agriculture plan.

1.3 Research Question

(1) How do stream parameters change in high water flow and low water flow periods?
(2) How do stream parameters change in different seasons?
(3) What is the difference between the stream parameters in Mid-Mulloon Creek (Home Farm) and Lower Mulloon Creek?

Chapter 2: Literature

2.1 Landscape evolution (Late Quaternary-Recent)

The late Quaternary floodplain evolution of Mulloon Creek can be described in the following stages:

Stage 1: During the last glacial maximum, extensive sediment reworking occurred (Barrows et al., 2002). Braid-plain gravels were uniformly thick, while remnant terraces at the valley margin thinned down-pocket (Johnston and Brierley, 2006). This suggests that prior to the last glacial maximum, floodplain sediments filled the valleys to a greater extent (Johnston and Brierley, 2006) (Figure 1, Stage 1).

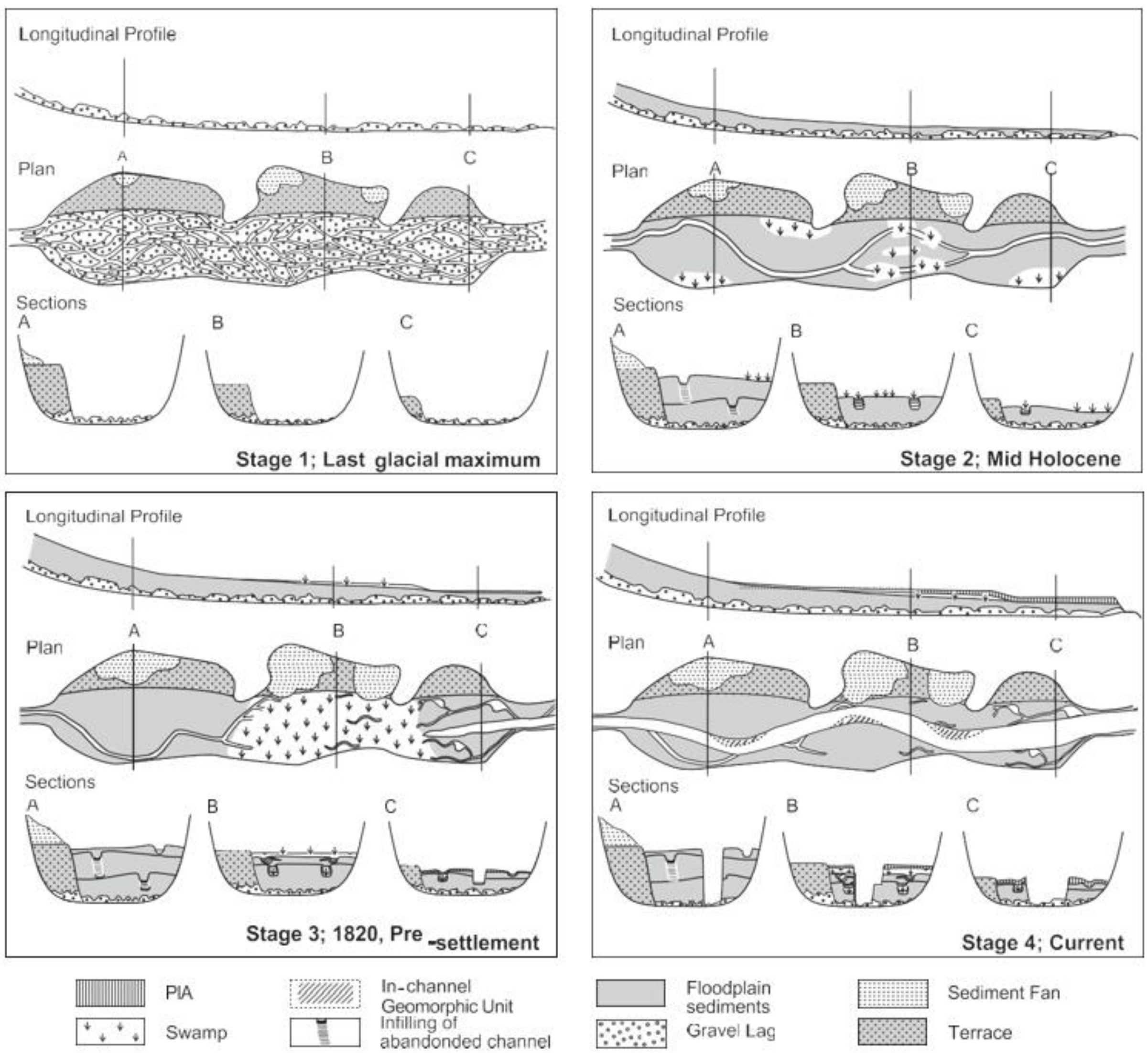


Figure 1. This schematic representation illustrates the changing floodplain morphology and sedimentation patterns over time along Mulloon Creek. highlighting the influence of glacial activity, sediment redistribution, swamp expansion, and the impact of human settlement on the landscape. (Johnston and Brierley, 2006)

In addition, the braid-plain gravels predominantly consist of Ordovician metasediments and Siluro-Devonian granite, forming the primary geological composition of the area (de Lorenzo, 2021).

Stage 2 (Figure 1): During the mid-Holocene era, sediment lobes with perched channels were created as vertically accreted valley fill deposits that extended downstream (Johnston and Brierley, 2006). Swamp formation started within the channel and gradually spread across the valley floor. Distal areas had poor drainage, resulting in boggy ground (Johnston and Brierley, 2006).

Stage 3 (Figure 1): The pre-European settlement period witnessed the development of a wedge-shaped valley fill due to altered depositional conditions (Johnston and Brierley, 2006). The rate of sedimentation decreased downstream and towards the distal areas (Johnston and Brierley, 2006). This caused the proximal floodplain deposits to preserve pebbly gravels, while distal floodplains accumulated finer silt and sand.

Stage 4 (Figure 1): Following European settlement, higher rates of runoff, the loss of vegetation cover, and the presence of a continuous downstream channel in the floodplain pockets collectively triggered the development of head-cuts (Hazell et al. 2003; Johnston and Brierley, 2006). This was further intensified by a series of severe floods that occurred in the region during the mid-nineteenth century. (Johnston and Brierley, 2006). Although similar floods may have occurred throughout the Holocene, human disturbance sensitized the valley floors to change, leading to significant geomorphic adjustments when formative events impacted the ground surface (Johnston and Brierley, 2006; Jenkins et al. 2010; Thackway 2019). Local steepening of slopes along the intermittent watercourse concentrated flow energy within the incised channel, accelerating the rate of retreat and incision upstream (Johnston and Brierley, 2006). As the incision channel and head cut advanced through the pocket, the floodplain fill, and swamp were cut and drained (Johnston and Brierley, 2006). As the channel had limited capacity to accommodate all the downstream flows from the head cut, overbank flows occurred, leading to the deposition of vertical accretion deposits (Johnston and Brierley, 2006). Generally, a wedge-shaped layer of post-incisional alluvium becomes thicker as one moves down-pocket, starting from the middle of the pocket and overlaying the swamp facies (Fryirs and Brierley, 2012).

2.2 Salinity

In Australia, salinity issues pose significant challenges in both dryland and irrigated areas. The dry and variable climate, flat topography, and old, weathered geology contribute to salinity issues (Moore et al., 2018). Australia experiences two distinct types of salinity: “primary salinity” and “secondary salinity” (Khamidov et al., 2022).

Primary salinity arises from natural processes including the gradual breakdown of rocks, and the accumulation of salt over thousands of years deposited by wind and rain, and stored in regolith materials (Hassani et al., 2021).

The factors contributing to heightened secondary salinity levels are primarily human-induced, arising from activities such as land clearing and changes in land use.

(1) Dryland salinization occurs when the removal or substitution of deep-rooted native plants with shallow-rooted varieties having lower water requirements takes place. This imbalance in vegetation water use triggers an increase in water infiltration through the soil, subsequently increasing the groundwater level and bringing salt to the surface (Shrivastava and Kumar, 2015). In conjunction with climate change and increasing temperatures, there is potential for elevated evapotranspiration, including soil water evaporation, which can lead to salt accumulation in the soil, thereby amplifying soil salinity (Nriagu, 2019).
(2) Salinity induced by irrigation arises when an excess of water applied to crops seeps past the root zone, infiltrating the groundwater and resulting in the elevation of both the water table and dissolved salts to the surface.. Once present at or near the land surface, salt can be transported through surface water and shallow groundwater systems (Stanturf and Callaham, 2020).

The main consequence of salinity fluctuations on ecosystems is the disturbance of aquatic ecological balance due to heightened salinity levels (Hart et al., 1990). This disturbance inhibits plant germination, constrains root development, and diminishes plant diversity. Additionally, shifts in salinity levels cause changes in water chemistry, resulting in elevated salt concentrations and diminished dissolved oxygen levels (Hart et al., 1990).

Historical factors such as extensive grazing, irrigation practices, and inadequate management and remediation strategies have exacerbated the salinity problem in Australia. To address this issue, Moore et al. (2018) proposed the Hydrogeological Landscape (HGL) framework as a holistic approach to assess the causes of salinity and design effective management strategies. The HGL technique involves identifying contiguous land parcels affected by specific salinity processes, allowing targeted interventions for each area (de Lorenzo, 2021). Understanding the relationship between groundwater and surface water in a particular region is crucial for ensuring sustainable agricultural production and mitigating salinity increases (Somerville et al., 2006). Moreover, regular monitoring of water quality, including salinity levels, provides insight into the range and variability of salinity in different water bodies. Wetland ecosystems can act as natural filters, trapping and absorbing excess salt and reducing their impact on downstream water bodies (Hart et al., 1990).

2.3 Groundwater - Surface Water Connectivity

The interplay between surface water and groundwater is complex. This arises because both processes are open systems, capable of influencing each other differently in different parts of the landscape, in and on different substrates, and as climate changes. Consequently, when addressing water resource concerns, comprehending the behavior of groundwater and surface water is essential (Banks et al. 2011).

The hyporheic zone refers to the subsurface region where surface water and groundwater interact (Valett et al., 1993). This area exhibits evidence of geochemical, biological, and physical blending (Triska et al., 1989). The extent of the hyporheic zone can extend from centimetres to tens of metres from the stream, (Hickson, 2017).

Hydraulic conductivity is influenced by connectivity, permeability, and transmissivity of the surrounding regolith and geology, as well as the viscosity of the water. To assess the direction and amount of water movement between the aquifer and the stream, hydraulic gradients across a floodplain are analysed, utilizing Darcy's Law. This approach allows for an estimation of the flow rates based on the hydraulic conductivity and the hydraulic gradient between the aquifer and the stream.

The origins of Darcy's Law can be traced back to the laboratory experiments conducted by Henry Darcy in the mid-1800s. Through his research, Darcy demonstrated that the specific discharge, or flow rate per unit area, through a fully saturated cylinder filled with sand, is directly proportional to the difference in water levels between the inflow and outflow, assuming the length of the cylinder remains constant (Welsh, 2007). Conversely, the specific discharge is inversely proportional to the length of the cylinder when the difference in water levels between inflow and outflow remains constant (Welsh, 2007).

Equation 1 and 2 is Darcy’s Experiments (Hubbert, 1956), and Equation 3 and 4 describe Darcy’s Law (Freeze and Cherry, 1979). Darcy’s Law was derived directly from Darcy’s Experiments.

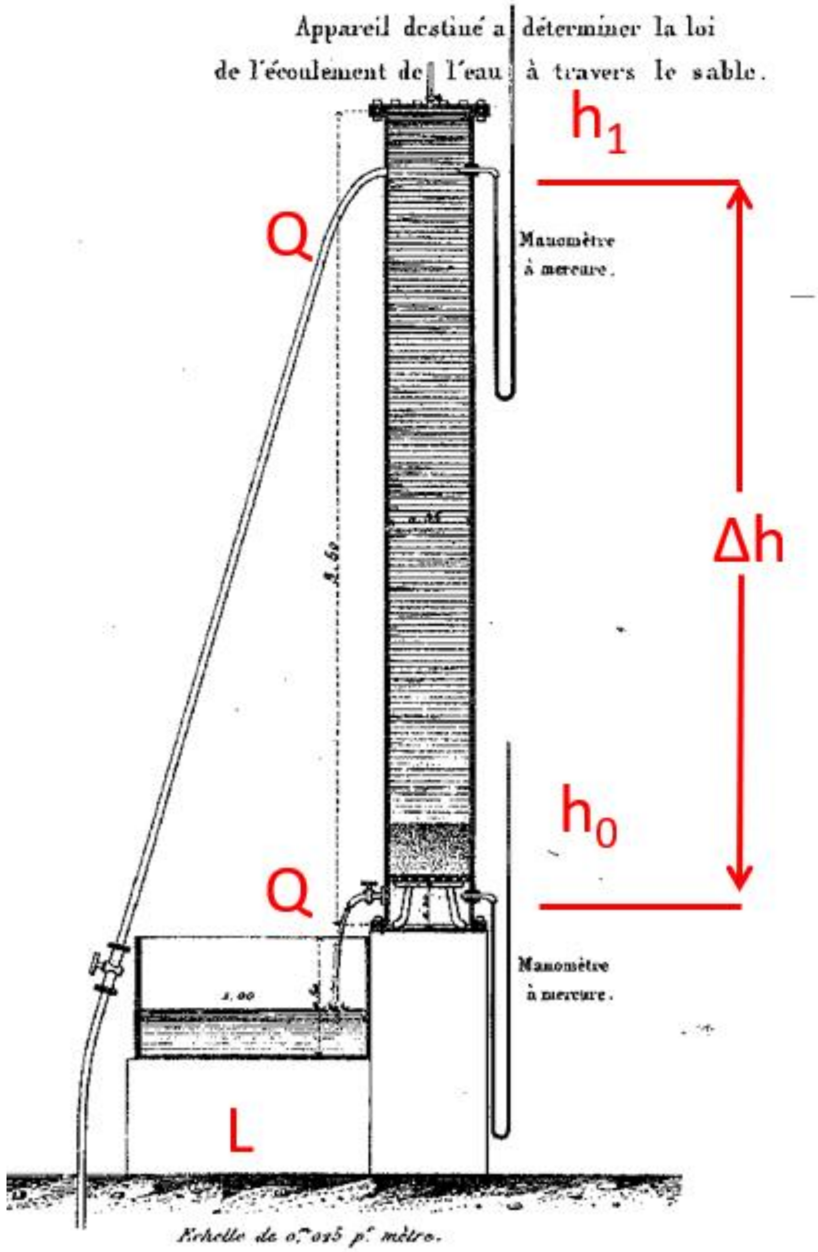


Figure 2. Detail of Darcy's experiments (groundwater flowing in aquifers) (Brown, 2002)

$\Delta = h - h_0 \propto Q$ *Equation 1* (Figure. 2)

Where,

h = hydraulic head (m) and Q = discharge (m^3/s)

$\frac{1}{\Delta l} \propto Q$ *Equation 2*

Where,

Δl = distance (m)

$v = -K\frac{dh}{dl}$ *Equation 3*

Where,

v is specific discharge (m/s) i.e. Q/A; K, the constant of proportionality, is hydraulic conductivity (m/s); h is hydraulic head (m); l is distance (m); dh/dl = hydraulic gradient (m/m)

$Q = -K\frac{dh}{dl}A$ *Equation 4*

Where,

Q is total discharge (m^3/s) through a cross-sectional area of the aquifer; A is cross-sectional area (m^2)

In Darcy's Law, the negative sign in the equation signifies that the variables 'l' and 'v' are measured in a way that reflects the decrease in the hydraulic head ('h') and the increase in length ('l') in the direction of positive flow velocity (Freeze and Cherry, 1979).

Hydraulic conductivity (K) is a function of permeability ($Cd^2 - m^2$) and water properties. The accuracy of all hydrometric methods relies on the true value of 'K,' which can vary significantly, even over small distances (Brodie et al., 2007).

$$K = \frac{Cd^2\rho g}{\mu} \quad \textit{Equation 5}$$

Where,

ρ is water density (kg/m^3)

g is the acceleration due to gravity (m/s^2)

μ is the dynamic viscosity

The connection between a stream and its surrounding groundwater exists when there is either inflow or outflow of water between them, irrespective of the presence of an unsaturated zone (Reid et al., 2009). In the case of a gaining stream (Figure 3a), it receives a portion of its water from the aquifer. Conversely, a losing stream transfers water to the aquifer, and this exchange can occur under both saturated and unsaturated conditions (Figure 3b, c). Bank storage refers to the phenomenon where stream water enters the banks above the previous water table, often during a storm event (Figure 3d). Stored water may be lost from this reservoir in a matter of days or weeks. Given Mulloon Creek's temperate climate with relatively low precipitation and its incised nature, the prevailing flow configuration is predominantly low, in drier times it can sit below the water table in the channel bottom (Stephens, 1995). This does not occur in areas of ponding upstream of leaky weirs. As a result, one likely source of recharge into Mulloon Creek is channel seepage.

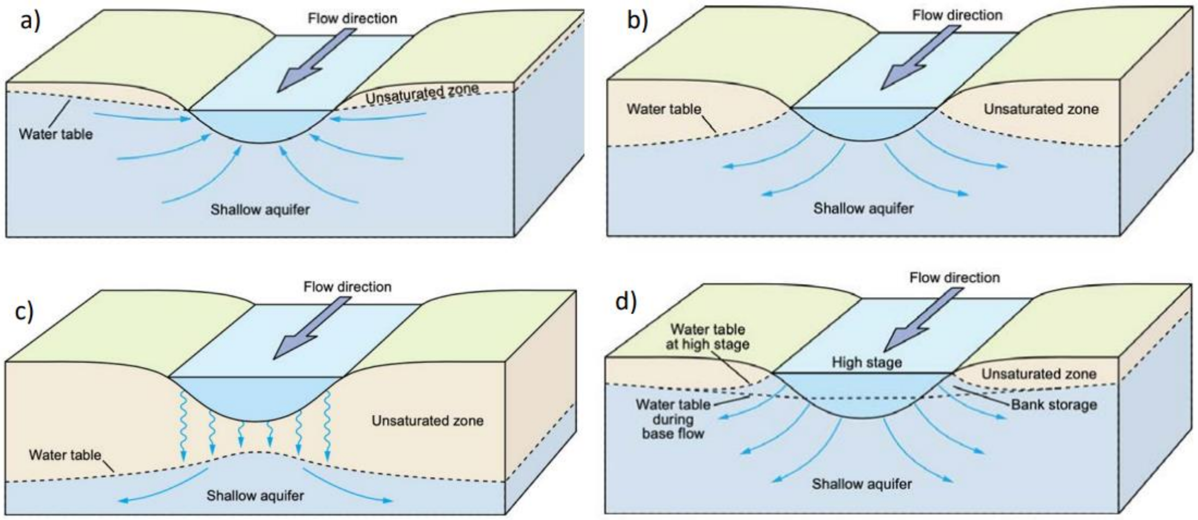


Figure 3. Diagrams illustrate a range of relationships between a stream and the surrounding groundwater. The diagrams depict the following scenarios: (a) Gaining stream: The stream receives water from the adjacent aquifer, resulting in a flow increase. (b) Losing stream without an unsaturated zone: The stream loses water directly to the underlying aquifer without any unsaturated zone separating them. (c) Losing stream with an unsaturated zone: The stream loses water to the aquifer, but there is an unsaturated zone between them, which helps regulate the flow. (d) Losing stream with bank storage: The stream loses water to the aquifer, and there is also storage capacity in the stream banks that can contribute to groundwater or stream recharge (Reid et al., 2009).

Meanwhile, calculating the volume of water flowing through, or stored in, a water body can be achieved through the application of a water budget equation (Healy, 2010). This method utilizes the mass conservation principle, to sum up the inflows and outflows of the water body over a specific timeframe (Healy, 2010). For a floodplain aquifer, the following equation can be used:

$\Delta S = G_{in} - G_{out} + Q_{in} - Q_{out} + P - ET - A$ *Equation 6*

Where:

ΔS represents the change in the amount of water stored in the groundwater system,

G_{in} refers to the groundwater inflow.

G_{out} refers to the groundwater outflow.

Q_{in} represents the surface water inflow,

Q_{out} represents the surface water outflow.

P denotes the inflow of precipitation,

ET represents evapotranspiration from surface water and vegetation, and

A represents the abstraction of water from the system by human activities, such as pumping.

2.4 Regenerative Land Management

2.4.1 Natural Sequence Farming

Natural Sequence Farming (NSF) is an approach to river restoration that aims to address and reverse the degradation of rivers and streams. It shares similarities with eco-engineering solutions in its use of natural materials and design techniques. However, NSF stands out from other approaches due to its scope and scale. It focuses on restoring rivers and streams but also emphasizes the benefits it can bring to agriculture by improving landscape functionality.

According to Williams (2010), NSF is an agricultural system that revolves around understanding ecological and landscape processes. It involves implementing practices in water management land and vegetation that align with these processes to achieve long-term sustainability. In 2006, a pilot project implementing NSF was initiated on the property Home Farm, specifically targeting the restoration of Mulloon Creek (Peel et al., 2022).

The NSF system is guided by four key principles (Norris and Andrews, 2010)

(1) Enhancing Soil Fertility: Restoring the fertility of soils by replenishing nutrients and organic matter improves the overall biological functioning of the soil.
(2) Restoring Hydrological Balance: By reinstating a balanced hydrological system, groundwater storage in the floodplain aquifer can be increased. This leads to enhanced freshwater recharge and a reduction in the discharge of saline groundwater.
(3) Promoting Natural Vegetation Succession: Encouraging the growth of pioneer species and facilitating natural vegetation succession plays a crucial role in supporting the healthy development of native plant communities.
(4) Effective Management Strategies for Ecological Restoration and Maintenance through Comprehensive Understanding of Hydrological and Biogeochemical Processes (Williams, 2010).

2.4.2 The Mulloon Landscape Rehydration Project

The Mulloon Landscape Rehydration initiative serves as a significant case study, representing a comprehensive and ongoing river and floodplain restoration program in the Mulloon Creek catchment, located in the Southern Tablelands of New South Wales, Australia (Kenny and Castilla, 2022). There is evidence that before agricultural clearing, the creek and surrounding floodplain likely consisted of interconnected ponds and swamp-grass complexes, allowing for longer stream presence and improved ecological productivity (Figure 4a) (Johnson and Brierley 2006).

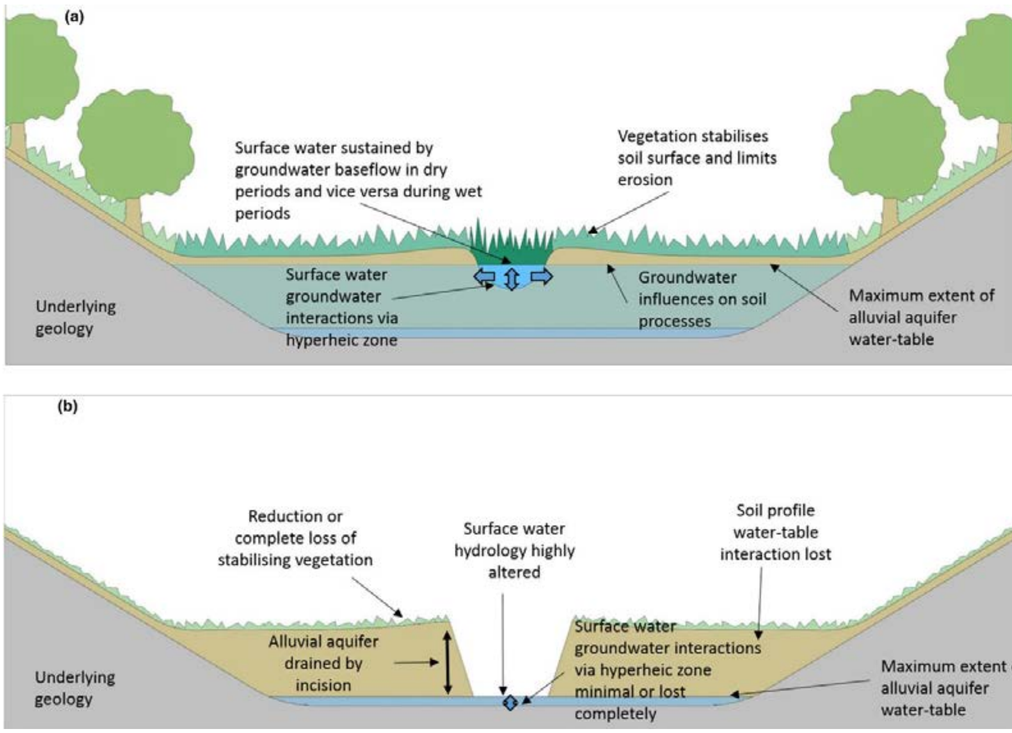


Figure 4. Shown schematically are two representations of a stream, illustrating contrasting conditions. In (a), the stream appears intact, with a natural and undisturbed course. In contrast, (b) depicts an incised stream, characterized by a deeper and narrower channel resulting from erosion. (Peel et al., 2022)

However, by the 21st century, landscape clearing had resulted in increased surface runoff and transformed the creek into a deep, continuous channel that traversed the entire floodplain pocket, rapidly draining the catchment (Figure 4b). The project adopted elements from the Natural Sequence Farming (NSF) approach to address these challenges, employing structural interventions such as logs and rocks to reconnect the stream with the adjacent floodplain. These structures, also referred to as leaky weirs, aimed to restore the natural hydrological dynamics and promote the recovery of native riparian vegetation. Leaky weirs are erosion control structures that manage streambed erosion (Peel et al., 2022). These structures, typically constructed using logs, boulders, soil, and plants, serve the purpose of slowing down the drainage of rainfall from the catchment. By reducing water velocity and increasing water height, leaky weirs facilitate water absorption into the soil (Dobes et al., 2013; Peel et al., 2022).

The use of leaky weirs and a range of other structures in river restoration science is not a recent development (Hickson, 2017). DeBano and Schmidt (1987) developed a model for elevating the alluvial groundwater table (Figure. 5). This approach involves the emplacement of moderate-sized structures in the river channel to create new flow dynamics. This approach has facilitated the re-establishment of vegetation along riparian banks. The effectiveness of this method was demonstrated at Red Clover Creek in California, where check dams were utilized to impound the alluvial water table (DeBano and Schmidt, 1987). The results showed that in the treatment area, the gradient between the stream and aquifer head decreased, while the control area experienced a rapid decline in the water table, negatively affecting the floodplain grasslands (Hickson, 2017).

Notably, the floodplain depression in the treatment area exhibited an increase in pasture production (Figure 5: DeBano and Schmidt, 1987).

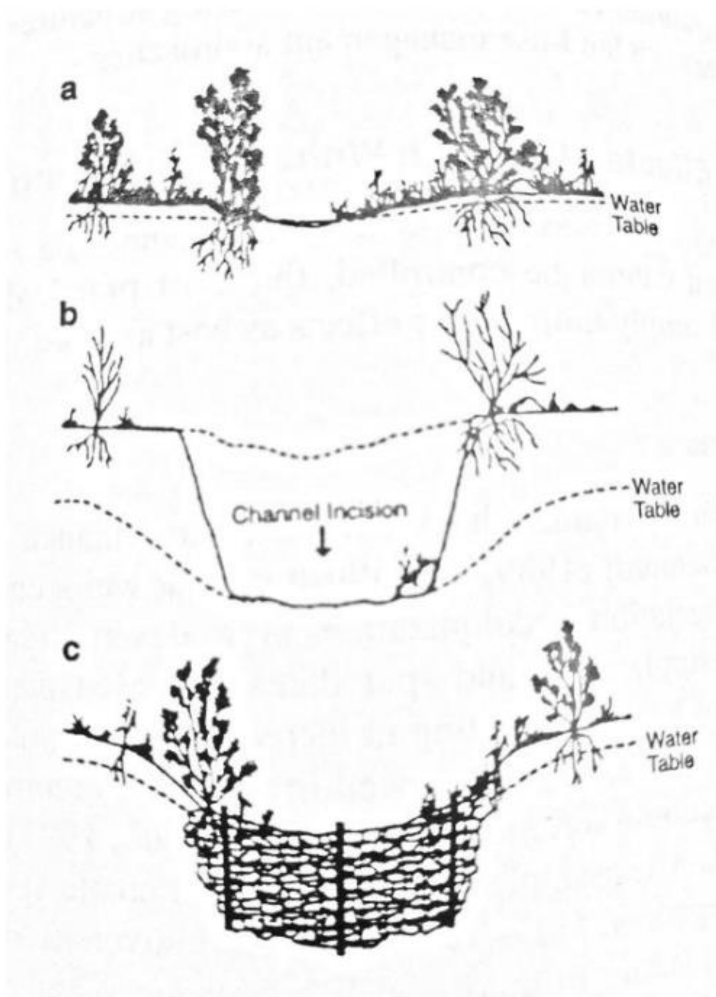


Figure 5. The function of in-stream structures on the water table (DeBano and Schmidt, 1987)

Figure 6. Comparison of pilot projects at Mulloon Creek before and after leaky weir emplacement. In March 2006, a pilot site exhibited signs of degradation, with an eroded stream bank and a noticeable absence of ponding (A). However, by February 2018, significant improvements were evident in the same location (Peter's Pond). Extensive revegetation had taken place along the stream banks, effectively stabilizing them. Additionally, a stone-based 'leaky weir' had been constructed, leading to the formation of large ponds (B) (Peel et al., 2022).

Leaky weirs in the Mulloon Creek area have been instrumental in enhancing river restoration efforts (Figure 6; Peel et al., 2022). By maintaining a consistent flow of water through these structures, the water velocity in the creek decelerates. This slowdown, coupled with elevated water levels, mitigates the erosive impact of swiftly moving water, and it provides a more dependable water source for the local flora and fauna (Dudley and Peel, 2021). Groundwater flows into the creek system, helping maintain water levels and safeguarding vegetation against dehydration. This, in turn, acts as a protective measure for the riverbanks, contributing to a reduction in erosion (Dudley and Peel, 2021). Reinvigoration of streambank revegetation demonstrated the efficacy of the leaky weirs in revitalizing riparian biological processes and reinstating functional linkages between streams and neighboring floodplains.

The influence of leaky weirs extends to stream water quality. Extensive monitoring of established leaky weirs in the Nakdong River, South Korea, notes that observing water quality parameters at individual monitoring point is not as valuable as consideration of the overall pattern these data illustrate (Jo et al., 2022).

Emplacement of leaky weirs may carry potential risks, such as altering the original stream dynamics, including flow patterns and river direction. These changes to the river environment need careful consideration during the establishment of leaky weirs to ensure the overall health of the ecosystem is preserved (Jo et al., 2022).

Over the past few years, the Mulloon Landscape Rehydration initiative has undergone one stage of expansion and has developed a long-term research plan. The focus has shifted towards scaling up activities and securing funding for water recharge projects along the entire Mulloon Creek. These projects are accompanied by a comprehensive research and monitoring program (Peel et al., 2022). A total of 60 landscape rehydration works have been implemented along a 50 km section of Mulloon Creek. These works consist of leaky weirs, each with a height ranging from 0.4 m to 0.6 m. The distance between any two leaky weirs in a series typically ranges from 150 m to 350 m (Meinen, 2022).

The overall objective of the Mulloon Landscape Rehydration project has been to restore and enhance the morphology, hydrology, soil conditions, and vegetation of Mulloon Creek and its floodplain.

2.4.3 Regenerative Agriculture

The Regenerative Agriculture method implemented in the Mulloon Creek area draws inspiration from the natural sequence agriculture approach (Kenny and Castilla-Rho, 2022). Unlike traditional agricultural techniques that prioritize mechanization and reductionist approaches for maximizing yields, Regenerative Agriculture focuses on maintaining landscape function, regenerating biodiversity, integrating the actions of animals and microbes in planning (Newton et al., 2020). At Mulloon Creek, the practice of Regenerative Agriculture encompasses a wide range of strategies aimed at providing an alternative approach to food and fibre production (Kenny and Castilla-Rho, 2022). It places importance on restoring and enhancing resilient systems through functional ecosystem processes and promoting the development of healthy, organic soils (Newton et al., 2020). The goal is to generate a comprehensive range of ecosystem services, including improved soil water retention and soil carbon sequestration (Kenny and Castilla-Rho, 2022).

As the adoption of Regenerative Agriculture increases, so do the barriers to Regenerative Agriculture implementation. The main barriers identified by Kenny and Castilla-Rho (2022) were:

(1) Lack of knowledge and understanding: Many farmers and landowners are unfamiliar with the concept of regenerative agriculture and its benefits. There is a need for education and awareness programs to bridge this gap.

(2) Financial constraints: Transitioning to regenerative agriculture often requires upfront investment and a shift from conventional practices. This associated financial risks and uncertainties deter many farmers from adopting regenerative practices.

(3) Policy and regulatory barriers: Existing policies, regulations, and subsidies favor conventional farming practices. There is a need for supportive policies that incentivize and reward regenerative agriculture.

Regenerative Agriculture piloted at Mulloon Creek proposes several solutions (Kenny and Castilla-Rho, 2022):

(1) Education and awareness programs: Increasing knowledge and understanding about regenerative agriculture through workshops, training sessions, and information campaigns to help overcome the knowledge gap.

(2) Financial support mechanisms: Developing financial programs, such as grants, low-interest loans, or subsidies, specifically designed for regenerative agriculture, that can alleviate the financial burden associated with the transition.

(3) Policy reform: Advocating for policy changes that recognize and support regenerative agriculture, such as revising agricultural subsidies and regulations, that can create an enabling environment for its adoption.

Chapter 3: Setting

3.1 Location

Mulloon Creek is located in New South Wales, approximately 40 km east of Canberra (Figure. 7). Originating from Talaganda National Park and coursing along the eastern periphery of the continental divide in the northerly direction, this headwater tributary contributes to the Upper Shoalhaven River catchment. Mulloon Creek encompasses a catchment area of around 400 km2, shaping a sub-catchment of the Upper Shoalhaven River oriented in a north-south direction. (Hickson, 2017).

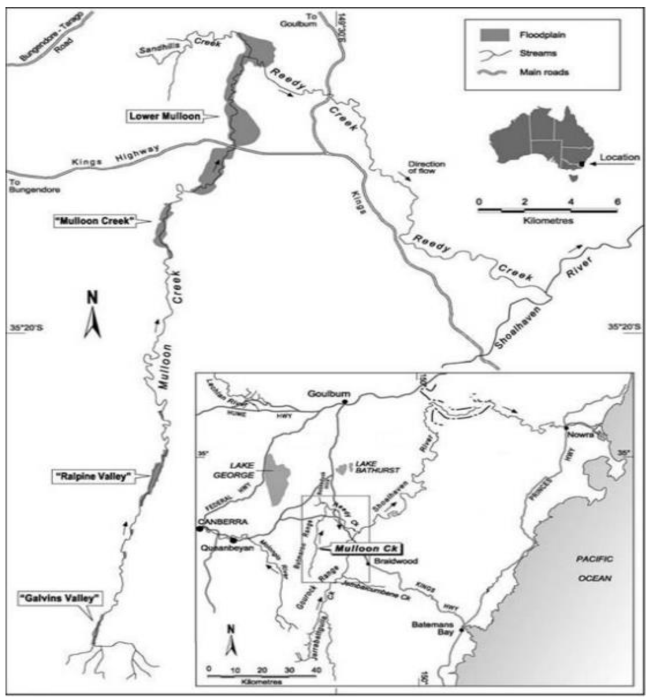


Figure 7. The Location of Mulloon Creek (Johnston and Brierley, 2006)

Mulloon Creek is characterized by a sequence of floodplain pockets, similar to "beads on a string," with bedrock dividing and constraining each pocket (Johnston and Brierley, 2006), so the catchment can be divided into upper, mid- and lower sections. The upper section flows out of the Talaganda Forest and is typically steep and narrow. The mid and lower sections of Mulloon Creek each flow through relatively flat and wide valleys, separated by the incised Mulloon Gorge. Both sections have a meandering channel and well-developed floodplain (Fitzherbert et al., 2011). The research area for this study is located in the mid (Home Farm) and lower (Lower Mulloon) sections of Mulloon Creek.

Home Farm, located on the mid-floodplain pocket, is bisected by a 6 km section of Mulloon Creek. A floodplain extends either side of Mulloon Creek, with low ranges beyond the plain on either side. Home Farm was the site of the original Natural Sequence Farming (NSF) pilot at Mulloon, and most of the leaky weirs in this part of the landscape relate to this early project.

Lower Mulloon Creek flows from the Mulloon Gorge for 10 km through a broad floodplain (<1 km wide). Landscape Rehydration structures in this part of the landscape have typically been emplaced in the past decade.

Mulloon Creek is an important habitat for a range of aquatic and terrestrial species. The creek supports a range of fish and macroinvertebrate communities, while the riparian vegetation along the creek provides a habitat for a diverse array of birds, mammals, and reptiles (SFL, 2023).

3.2 Climate

The Mulloon Creek region has a temperate, semi-humid to humid climate (Johnston and Brierley, 2006). The Braidwood Racecourse AWS monitoring station provides the most extensive and representative temperature data for the study area and the Bungendore Post Office monitoring station provides the most comprehensive coverage of precipitation data (both ~24 km from Mulloon Creek; BOM, 2023a; BOM, 2023b).

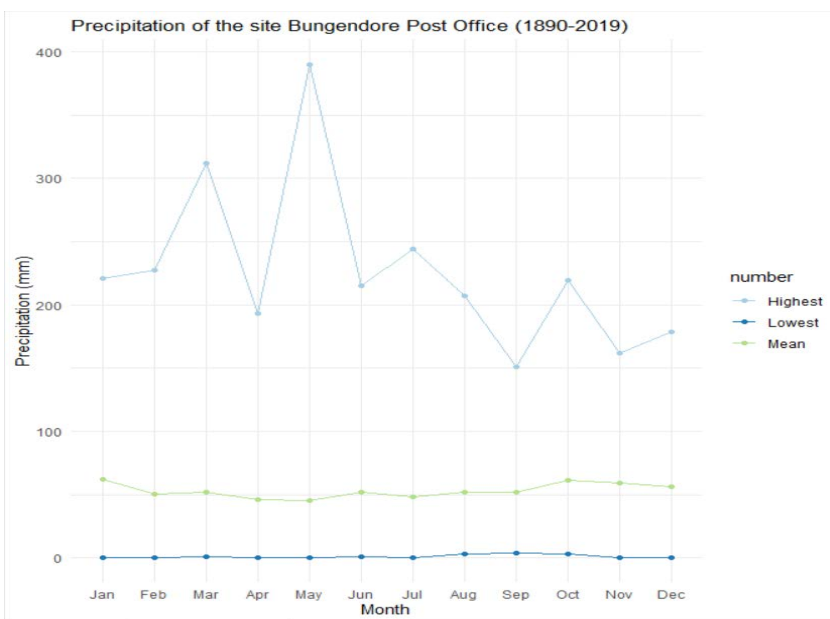


Figure 8. Mean monthly precipitation at Bungendore Post Office (1890-2019; BOM, 2023a)

Annual rainfall in Bungendore is 890.5mm, with a mean maximum monthly rainfall ranging from 48mm to 60mm and a mean minimum monthly rainfall between 0mm and 5mm (BOM, 2023a).

The highest maximum monthly rainfall occurs in Autumn, between April and June (190-390mm), but the average monthly precipitation is higher in summer and lower in winter.

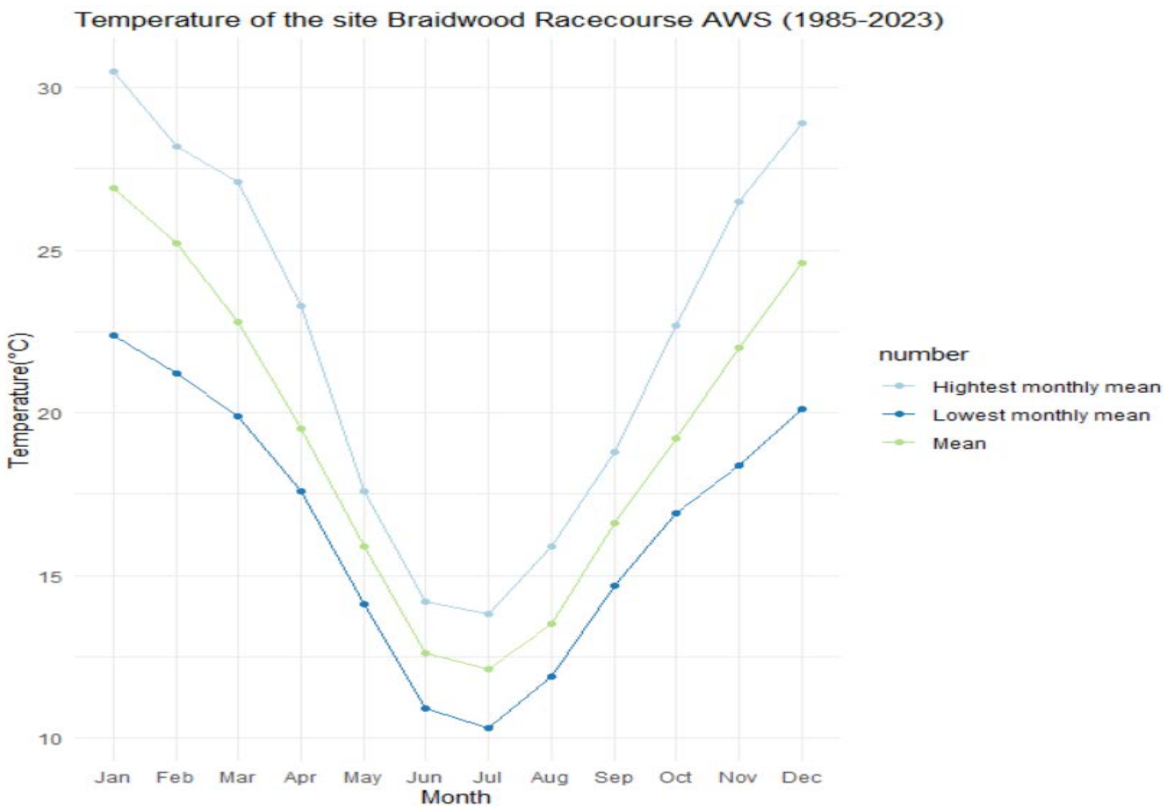


Figure 9. Temperature of the site Braidwood Racecourse AWS (1985-2023) (BOM, 2023b)

The annual average temperature in Braidwood is 19.2°C (Figure 9). The average monthly maximum and average monthly minimum temperatures in January (summer) are the highest annually (30.5 °C and 22.4 °C, respectively; Figure 9). The average monthly maximum and average monthly minimum temperatures in July (winter) are the lowest annually (13.8 °C and 10.3°C respectively) indicating a pattern of warm summers and cold winters (Figure 9; BOM, 2023b).

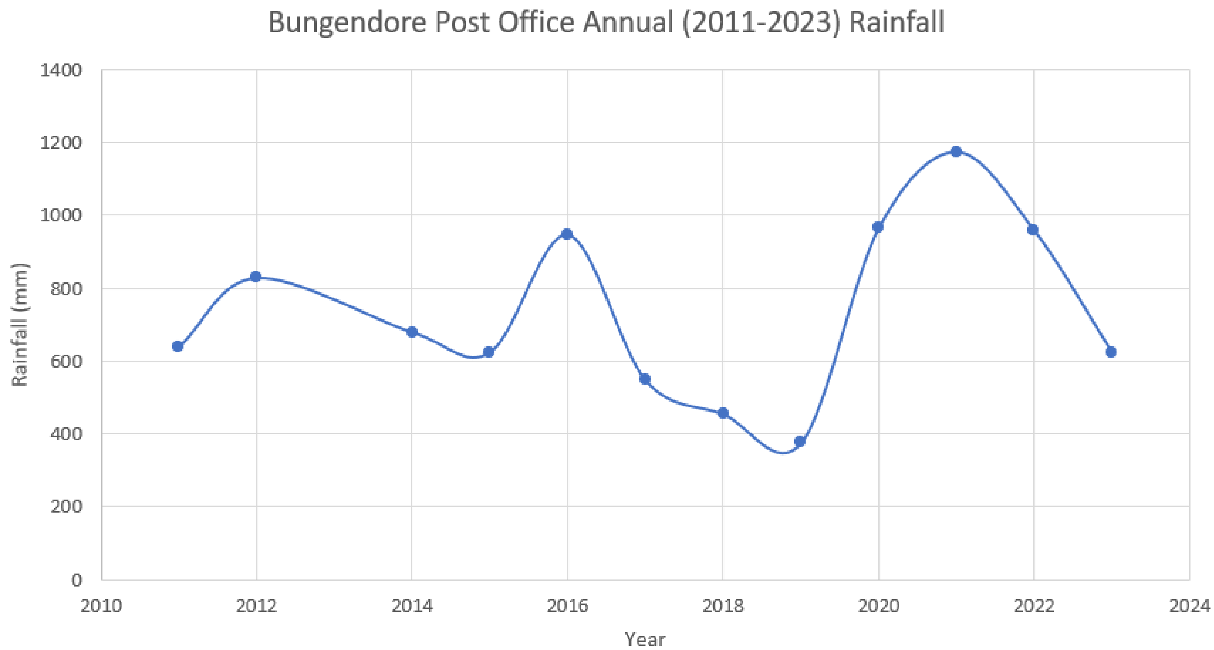
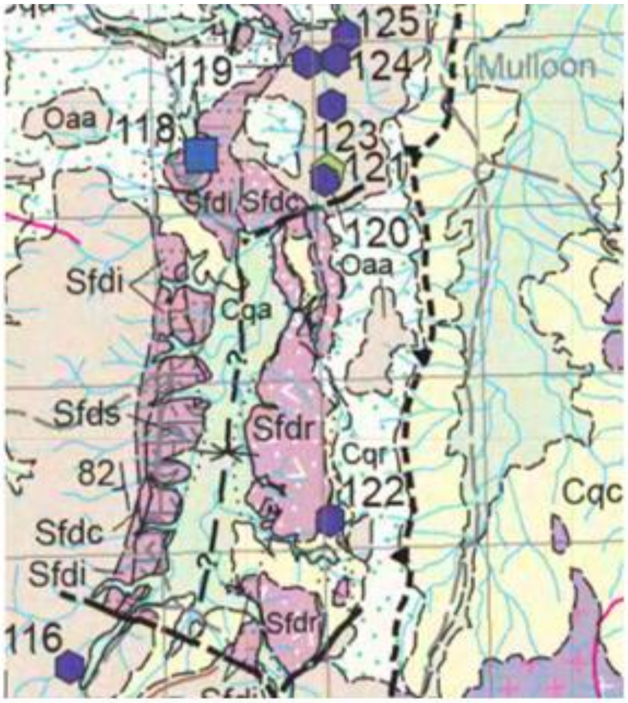
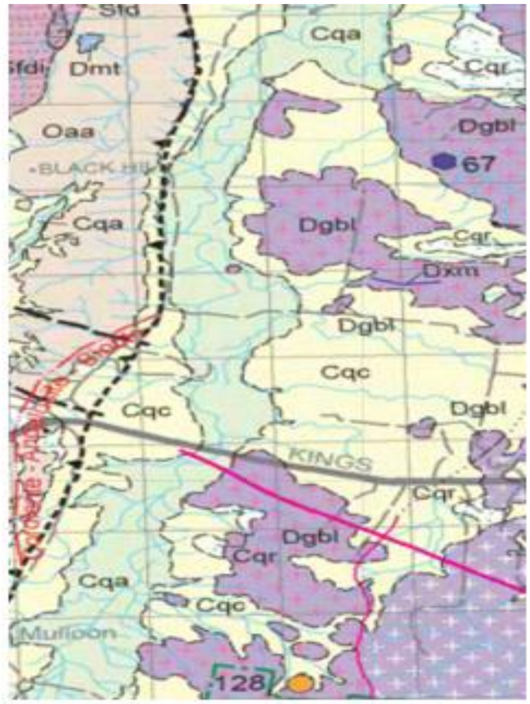


Figure 10. Bungendore Post Office Annual Rainfall (2014-2023). Data source from BOM, 2023a

In recent years Mulloon Creek has experienced the Millennium Drought (2003-2010), the 2012-mid-2015 drought and the 2017-2019 drought (Figure 10). During drought periods there is significantly less rainfall than the long-term annual average and this can cause disruptions to local ecosystems and to agricultural production (Bodner et al., 2015). Although the Mulloon region typically has a climate that is well-suited for agriculture and the support of natural ecosystems (wetlands, forests, grasslands), in periods of drought less water is available to support environmental and farming systems (Hickson, 2017).

3.3 Geology





Quaternary

Cqa: Alluvium: unconsolidated alluvial gravel, sand, silt, and clay with variable humic content; gravels commonly clast supported.

Cqr: In situ regolith: residual deposits of unconsolidated clay-rich coarse- to fine-grained sands to weakly consolidated sandy

clay layers; podzolic soil profiles developed

Cqc: Colluvium: poorly sorted, weakly cemented to unconsolidated colluvial lenses of polymictic conglomerate, interspersed with unconsolidated clay and silty sand layers; modified by pedogenesis

MOUNT Fairy Group

Sfdi: Buff, brown to khaki, diffusely laminated, siltstone, mudstone and very fine-grained sandstone, minor felsic volcaniclastic rocks.

Sfds: Sandhills Creek Limestone Member: Bedded to massive, variably fossiliferous limestone

Sfdc: Polymigtig matrix to clast-supported, pebble to cobble, pebble to cobble conglomerate and pebbly quartz-lithic sandstone conglomerate;casts include chert, mudstone, siltstone, and fine-grained quartz sandstone

Adaminaby Group

Oaa: Buff to brown, grey, fawn to cream, thin- to very thick-bedded, fine- to coarse-grained mica-quartz+feldspar sandstone, interbedded with laminated siltstone and mudstone; sandstone beds typically have normal grading and prominent ripple cross-lamination; discrete chert-rich packages

Figure 11. Home Farm Geology (Mid Mulloon Area) (Fitzherbert,2011)

Figure 12. Lower Mulloon Geology (Fitzherbert,2011)

The Home Farm lies west of the Mulwaree Fault, on the range-forming upfaulted block (horst) and the Lower Mulloon valley lies east of the Mulwaree Fault in the valley formed on the downfaulted block (graben) (Fitzherbert et al., 2011). At Mid Mulloon (Home Farm), Quaternary (Cqa, Cqr) alluvium forms a flood plain that is broader west of Mulloon Creek (Figure 11; Fitzherbert et al., 2011).

The valley is bordered by ranges composed of Ordovician and Silurian sediments (Hickson, 2017). These include layered formations of Silurian siltstone, shale and quartz sandstone from the Mount Fairy Group (Sfdc, Sfdi, Sfdr) and Ordovician Adaminaby Beds (Oaa) (Figure 11). A small body of limestone (Sfds) outcrops on the lower slope west of Mulloon Creek (Fitzherbert et al., 2011).

Lower Mulloon Creek has a broad (<1km) alluvial floodplain with an incised channel (Johnston and Brierley, 2006). The eastern side of the Lower Mulloon valley features rounded low hills of Devonian Boro Granite (Dgbl; Figure 6) (Fitzherbert et al. 2011). On the west side, the Mulwaree Fault escarpment rises sharply above the alluvial floodplain and terraces of Mulloon Creek. The western range is comprised of Ordovician metasediments (turbidites) of the Adaminaby Group (Gray and Foster, 2004; Jenkins et al., 2010; Colquhoun et al., 2020). This geology is dominantly folded, interbedded, and cleaved siltstone, sandstone, and shale with minor greywacke. Quaternary sediments form break-of-slope aprons on the lower colluvial slopes of adjacent hills (Cqc) and form alluvial plains and terraces associated with the formation of Mulloon Creek (Figure 12; Fitzherbert et al., 2011).

The geology of the Mulloon catchment has significantly influenced the landscape and vegetation distribution in the area. For example, the sandstone formations in the Mid Mulloon area provide a fertile substrate for developing soils that support a range of vegetation types (Fitzherbert et al., 2011; Colquhoun et al., 2020). In contrast, the rocky outcrops and steep slopes in the Lower Mulloon area support dry sclerophyll forests and shrublands that are adapted to nutrient-poor soils and drier conditions (Fitzherbert et al., 2011).

3.4 Geomorphology

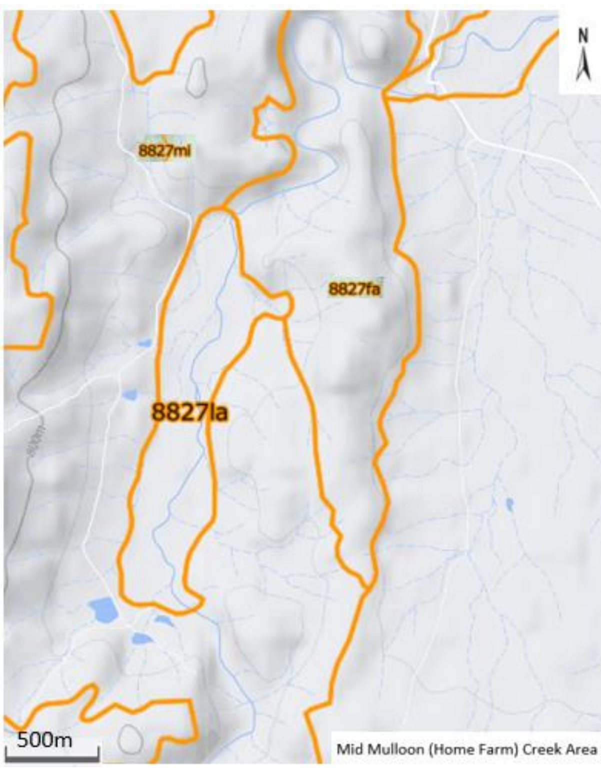
The geomorphology of the Mid Mulloon and Lower Mulloon Creek areas are distinct from each other due to differences in location with respect to the Mulwaree Fault and because of the underlying geology. The Mid Mulloon area is characterized by gently rolling hills and valleys (Fitzherbert et al., 2011). The terrain is relatively flat and broad, with a few steeper slopes and ridges near the creek (Fitzherbert et al., 2011). The area is dominated by alluvial deposits, mainly consisting of sand and clay-sized particles, which have accumulated over time from the surrounding hills and mountains (Johnston and Brierley, 2006).

In contrast, the Lower Mulloon area is characterized by steeper slopes especially west of the valley floor. The hilly terrain on either side of the valley is rugged and irregular, with deep gullies and steep hillsides (Fitzherbert et al., 2011). This is because the underlying rocks are resistant to erosion, consisting mainly of granite, sandstone, and conglomerate (Johnston and Brierley, 2006; Fitzherbert et al., 2011).

3.5 Soil Landscapes

3.5.1 Home Farm Soil Landscapes

The Misery Mountain soil landscape extends along the elevated ridges on the west and south-east sides of the Mid-Mulloon catchment (Figure 13). This soil landscape is characterized by rocky soils (lithic tenosols; lithosols) on ridge crests, and on the midslope when rock is in the shallow subsurface.



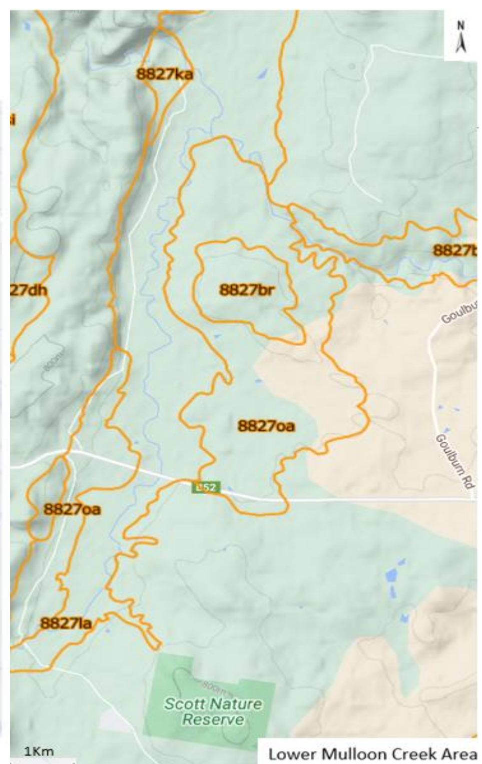


Figure 13. Soil landscapes of the Home Farm (Mid-Mulloon) showing the distribution of the Misery soil landscape (mi), the Fairy soil landscape (fa) and the Larbert soil landscape (la) (Jenkins, 2000)

Figure 14. Soil landscapes of Lower Mulloon Creek showing the distribution of the Fairy soil landscape (fa, Oallen soil landscape (oa), the Lower Boro soil landscape (br), and the Larbert soil landscape (la) (Jenkins, 2000)

There are soils with a defined B horizon on the upper slopes (brown kurosols; yellow podzolic soils) and lower colluvial slopes (yellow kurosols; yellow podzolic soils) (Figure 15) (Jenkins, 2000).

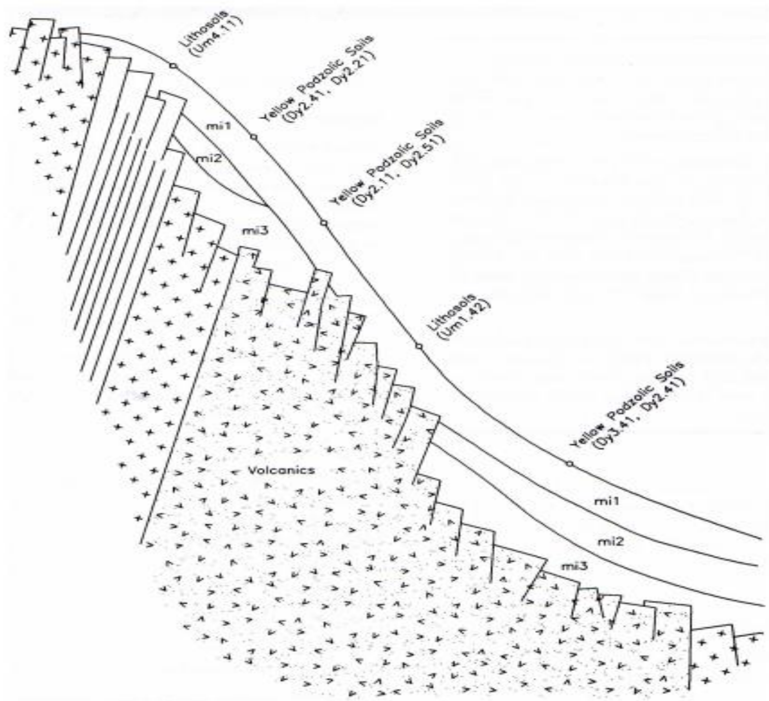


Figure 15. Misery Mountain soil landscape (Jenkins, 2000)

The Fairy soil landscape forms hills on the north-east side of the Mid-Mulloon catchment (Figure 13; Jenkins, 2000). This soil landscape also has rocky soils (lithic tenosols; lithosols) on ridge crests, with poorly stratified soils on the mid slopes (yellow kandosols; yellow earths) and soils with stronger pedogenic development on lower colluvial slopes (yellow kurosols; yellow podzolic soils) (Figure 16; Jenkins, 2000).

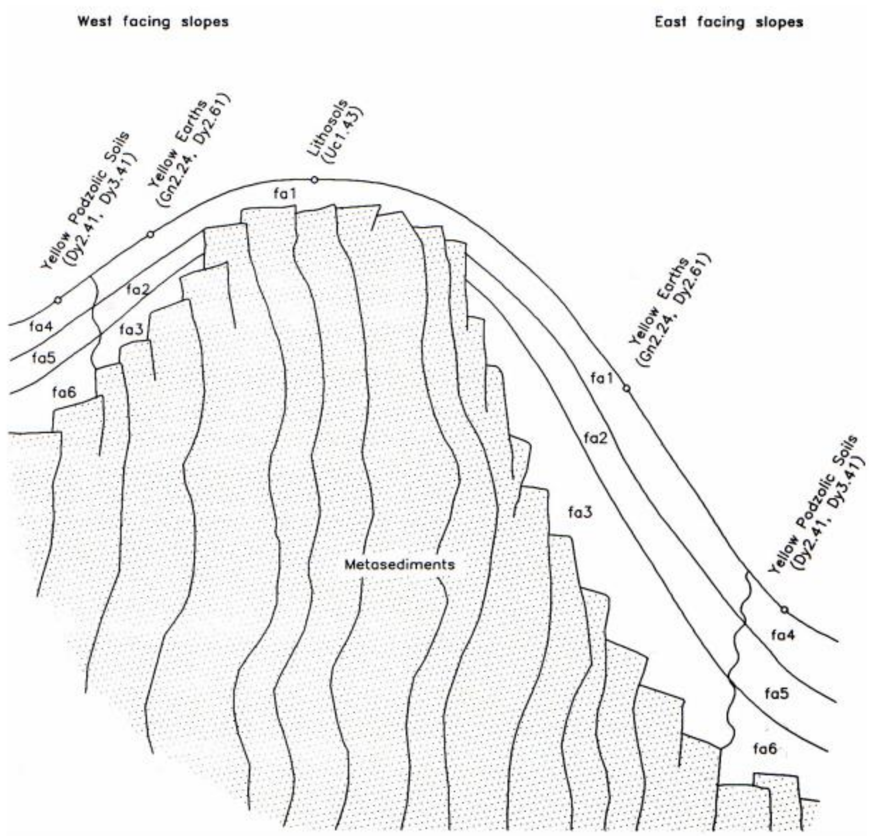


Figure 16. Fairy soil landscape (Jenkins, 2000)

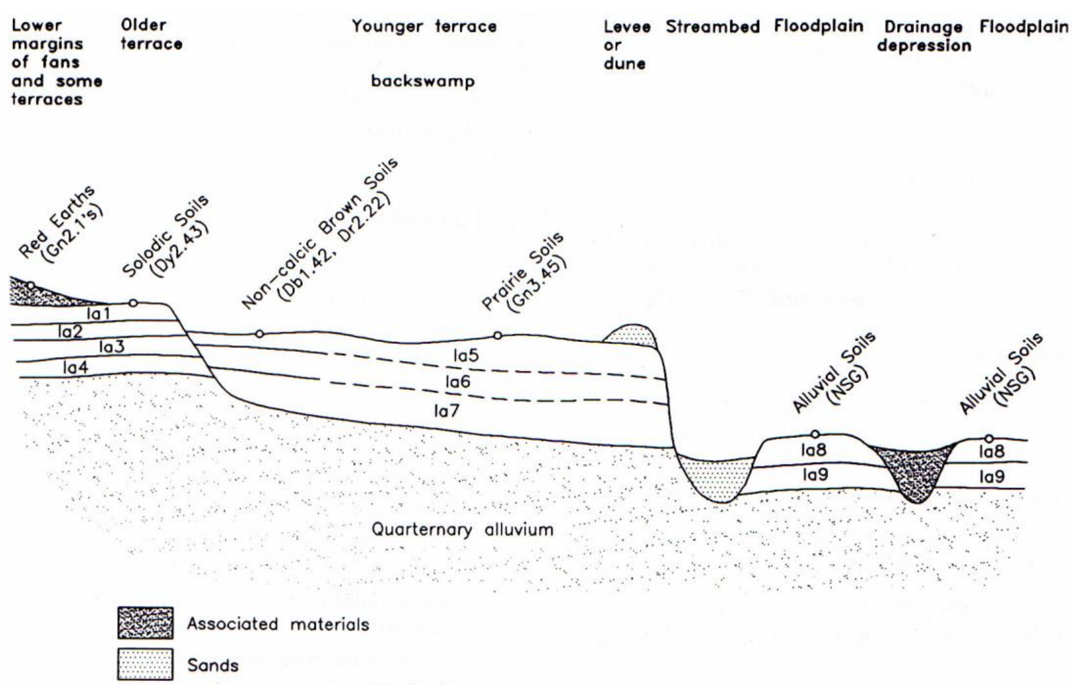


Figure 17. Larbert soil landscape (Jenkins, 2000)

On the valley floor the Larbert soil landscape preserves localized flood plains (rudosols; alluvial soils), and low terraces with dermosols (prairie soils) closer to Mulloon Creek and chromosols (non-calcic brown soils) more distally (Figure 17; Jenkins, 2000). On the west side of the valley floor, near areas of limestone outcrop (Figure 13; Jenkins, 2000), soils are red calcarosols (red calcareous soils) (Jenkins; 2000).

3.5.2 Lower Mulloon Soil Landscapes

The west side of the Lower Mulloon Creek catchment is defined by the Mulwaree Fault (Figure 12) (Fitzherbert et al., 2011.). The Fairy soil landscape is present on the upfaulted western range (Figure 14; Jenkins, 2000). This soil landscape has rocky soils (sedimentary lithics) (lithic tenosols; lithosols) on ridge crests, with poorly stratified soils on the mid slopes (yellow kandosols; yellow earth) and soils with stronger pedogenic development on lower colluvial slopes (yellow kurosols; yellow podzolic soils) (Figure 16; Jenkins, 2000)

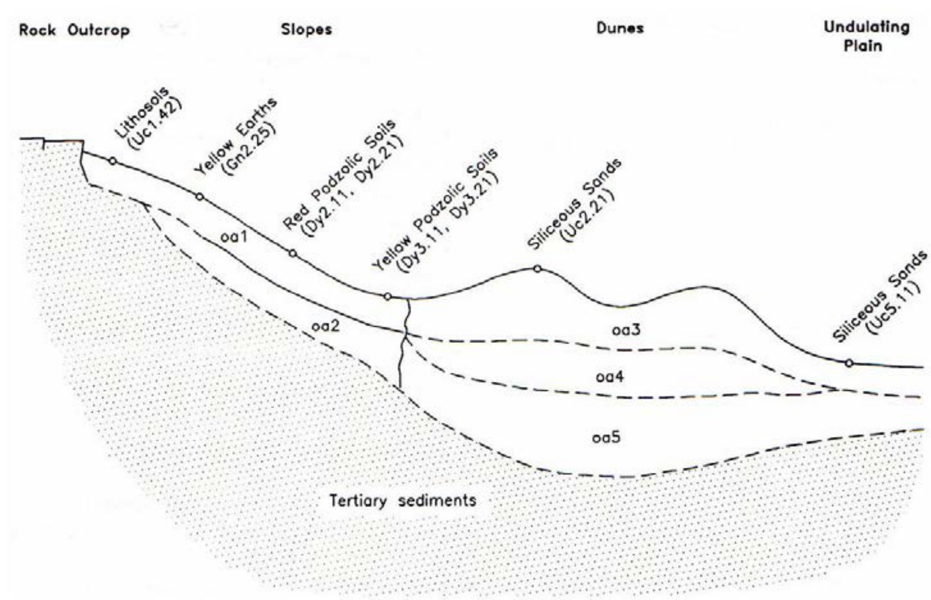


Figure 18. Oallen soil landscape (Jenkins, 2000)

A small area of Sand Hills soil landscape, characterized by siliceous sands, is mapped on the western footslopes, immediately south of the Kings Highway (Figure 14; Jenkins, 2000). Further south, the western footslopes are mantled by colluvial gravels (tenosols; lithosols) of the Oallen soil landscape, with some poorly stratified soils (yellow kandosols; yellow earths) in upper colluvial fan settings and more stratified soils (red and yellow kurosols; red and yellow podzolic soils) in lower colluvial fan settings (Figure 18; Jenkins, 2000).

The Larbert soil landscape is associated with a complex range of landscape facets (piedmont, high terrace, low terrace, and flood plain) on the lower slopes and the valley floor. Small piedmont areas preserve red kandosols (red earths), and adjacent high terraces feature sodosols (solodic soils). On the valley floor, the Larbert soil landscape is characterized by localized flood plains (rudosols; alluvial soils), and low terraces with dermosols (prairie soils) closer to Mulloon Creek and chromosols (non-calcic brown soils) more distally (Figure 17; Jenkins, 2000).

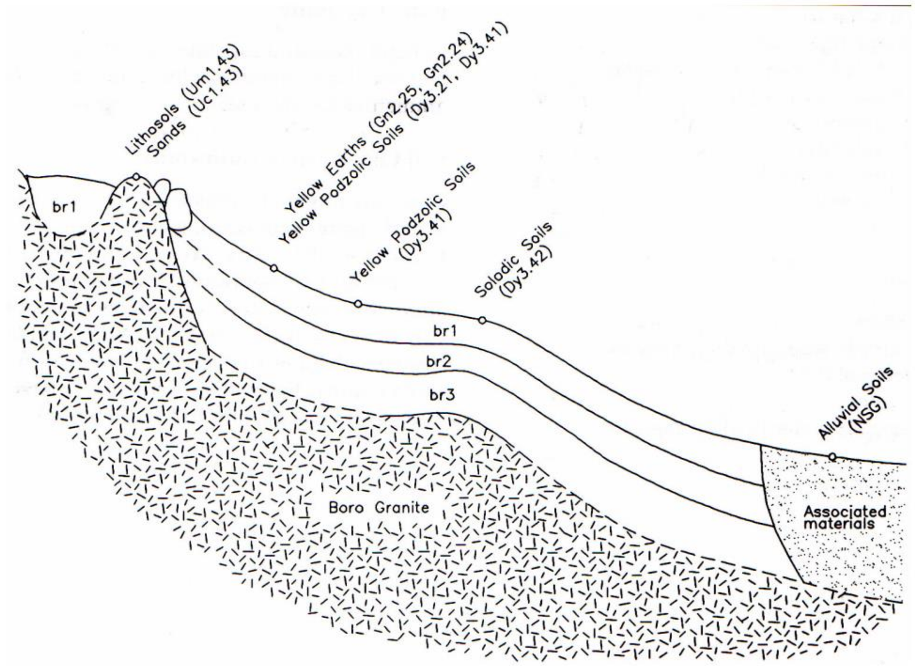


Figure 19. Lower Boro soil landscape (Jenkins, 2000)

Hills on the east side of the valley feature the Lower Boro soil landscape with rocky soils (granitic lithics) (lithic tenosols; lithosols) on ridge crests, with poorly stratified soils on the upper mid-slopes (yellow kandosols; yellow earths), soils with stronger pedogenic development on lower mid-slopes (yellow kurosols; yellow podzolic soils), and sodosols (solodic soils) on flatter areas (Figure 19; Jenkins, 2000). This is surrounded by soils of the Oallen soil landscape, with some poorly stratified soils (yellow kandosols; yellow earths) in upper colluvial fan settings and more stratified soils (red and yellow kurosols; red and yellow podzolic soils) in lower colluvial fan settings (Figure 18; Jenkins, 2000).

3.6 Vegetation

Mulloon Creek lies in the southeastern highland vegetation bioregion (SEH; Figure 20). After the arrival of the first European settlers in the early 1800s, the region surrounding Mulloon Creek underwent extensive vegetation clearance (Johnston and Brierley 2006). The land has been used for both crop cultivation and as pasture for sheep and cattle in the intervening years, leading to pronounced gully erosion and significant landscape degradation (Thackway, 2019).

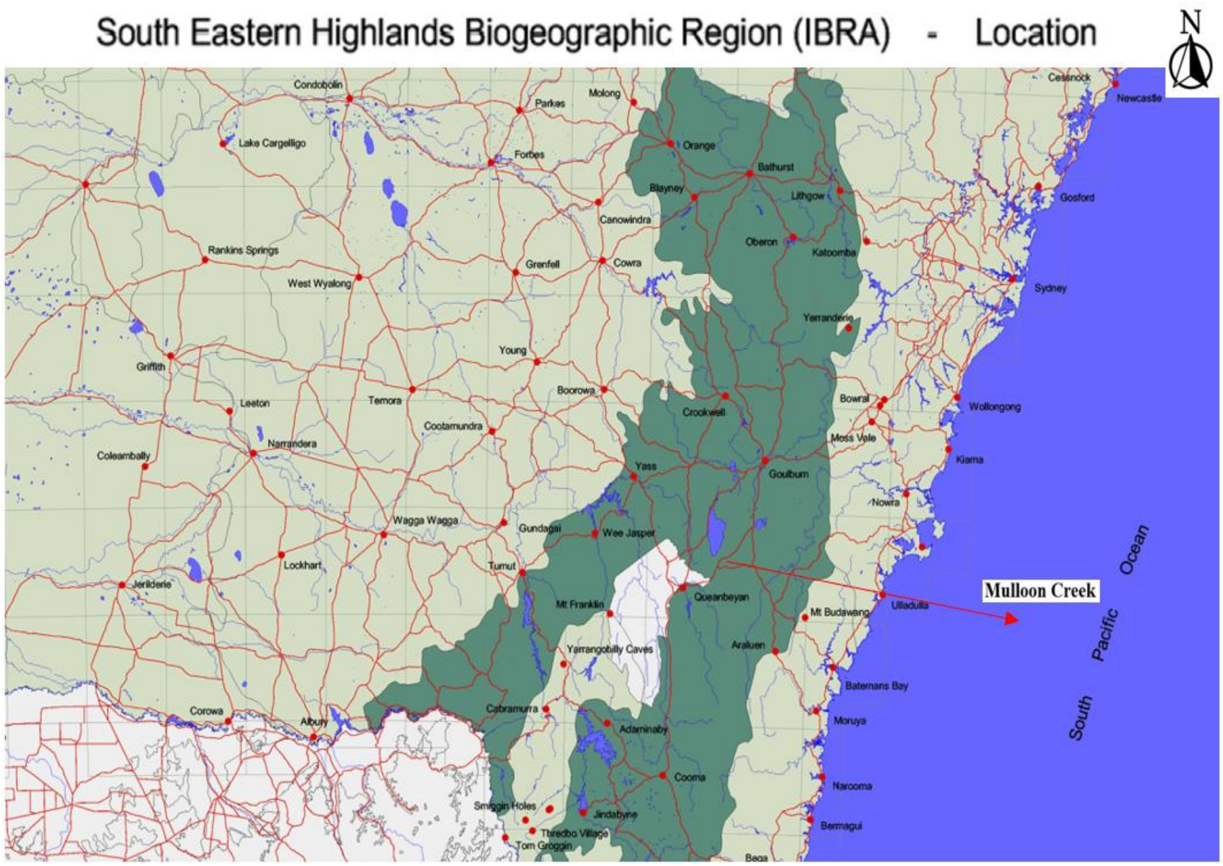


Figure 20. South Eastern Highlands Biogeographic Region. (Sahukar et al., 2003)

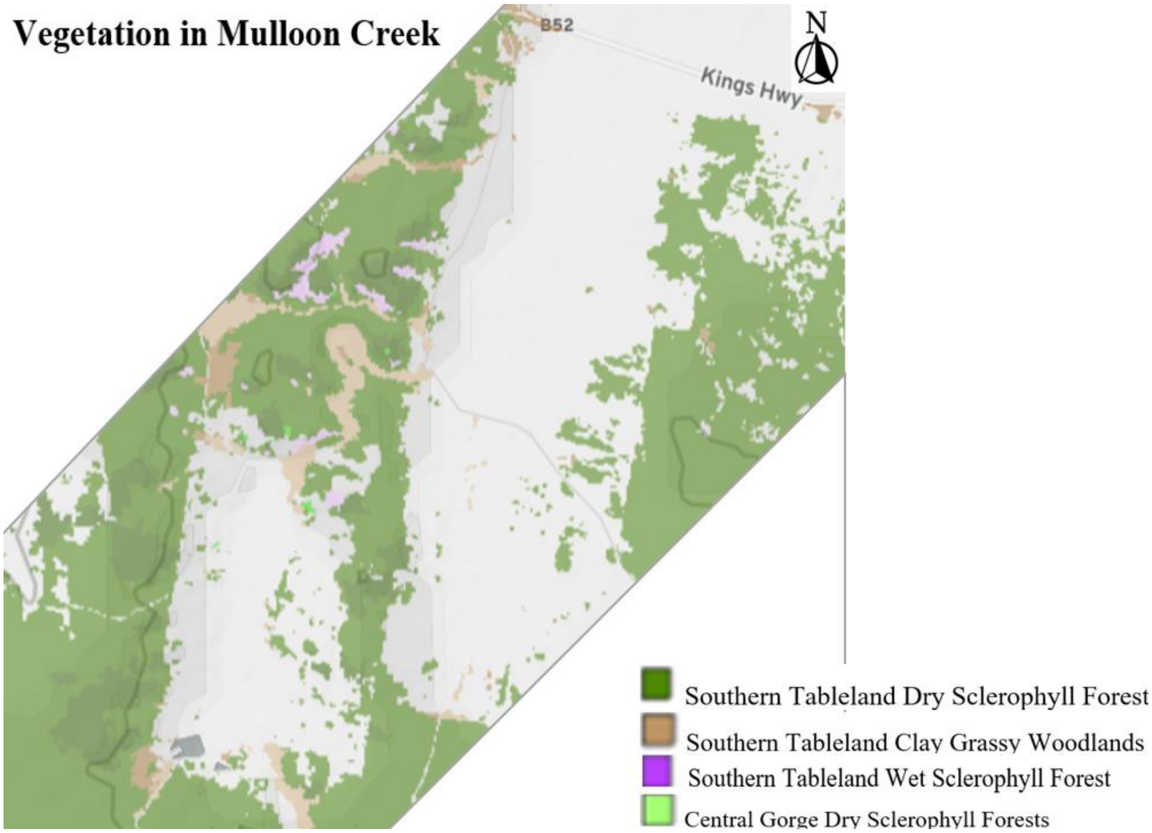


Figure 21. Vegetation of Mid Mulloon and Lower Mulloon Creek area. (NSW DPE, 2023)

The modelled native vegetation class for the study area is dominantly Southern Tableland Dry Sclerophyll Forests (mixed Palerang Hills Peppermint Dry Shrub Forest and Southern Tableland Western Hills Scribbly Gum Forest) on the upper slopes and ridge crests with isolated pockets of Southern Tableland Wet Sclerophyll Forest (Central Tableland Ribbon Gum Sheltered Forest) in sheltered and gorge areas. Tableland Clay Grassy Woodland is present on alluvial fans (Goulburn Tableland Frost Hollow Grassy Woodland), river flats, and along riparian zones (Southern Tableland Grassy Box Woodland). The Central Gorge Dry Sclerophyll Forests (Southern Highlands Red Gum Forest) occurs in steep sheltered parts of the landscape (Figure 21).

The Southern Tableland Dry Sclerophyll Forest is primarily composed of open dry eucalypt forest or woodland (15-20 m) (NSW DPE, 2023). It features an open to sparse sclerophyll shrub layer and a ground cover characterized by its open, grassy nature (NSW DPE, 2023). Typically, these forests thrive as stunted formations on exposed rocky hills (Tozer et al., 2017), but they reach greater heights in deep soils on undulating terrain (NSW DPE, 2023). The dry sclerophyll forests are resilient in periods when there is reduced rainfall (Crockford et al., 1991). These forests play a critical role in regulating local water cycles and in soil conservation (Cavicchiolo, 1991).

The Southern Tableland Wet Sclerophyll Forest is a unique ecosystem characterized by towering sclerophyll trees (20-35m), predominantly found in an open eucalyptus forest structure (Wardell et al., 2017; NSW DPE, 2023). This forest type features a shrub understory and a diverse herbaceous grassy groundcover (NSW DPE, 2023).

The Southern Tableland Clay Grassy Woodlands are present as an open eucalypt forest and woodland (15-30 m). There is a scant shrub layer and a diverse dense ground cover of tussock grasses and herbaceous plants (Benson and Ashby, 2000., Keith and Bedward, 1999., NPWS, 1999). This ecological community is classified as critically endangered (Act, 1999; Hawke, 2010).

The Central Gorge Dry Sclerophyll Forests exhibit characteristics of an open woodland and eucalypt forest, reaching heights of 15-30 meters. The ecosystem features a sparse shrub layer and a ground cover marked by dense and relatively diverse growth of tussock grasses and herbaceous plants. They typically grow in steep, highly dissected canyons on clay soils derived from mudstones and on localized limestone outcrops below 800 m (Keith and Benson, 1988; NPWS, 2003; NSW DPE, 2023).

3.7 Land Use

On the Home Farm grazing on modified pasture occurs on the plains to the northwest, east and south. The ridges and hillslopes have been set aside for native vegetation regeneration (minimal use; Figure 22). In the southeast and northeast parts of the mid-Mulloon valley, small areas of plantation forestry have been established (Figure 22).

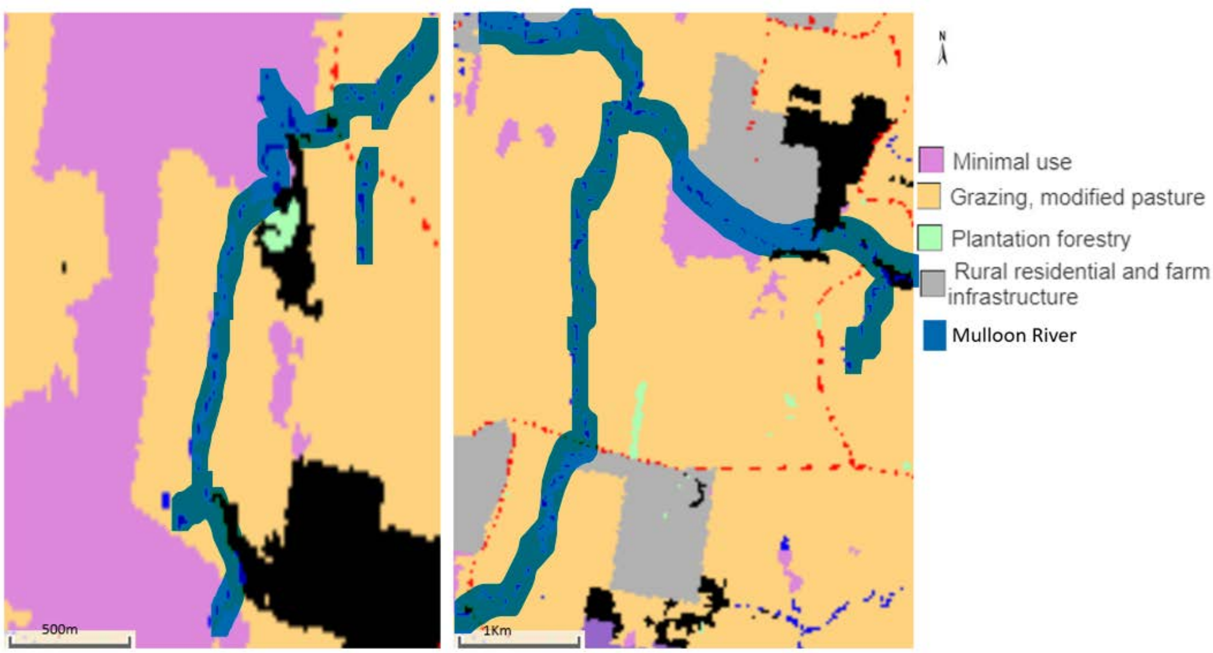


Figure 22. Land use in Mid Mulloon Creek Area (ABARES, 2016)

Figure 23. Land use in Lower Mulloon Creek Area (ABARES, 2016)

In the Lower Mulloon area, the principal land use is grazing on modified pasture with rural residential and farm infrastructure bordering the river (Figure 23) (ABARES, 2016).

3.8 Hydrogeology

The geomorphic features in the Mid Mulloon Creek control water movement at the land surface and in the shallow subsurface. Semi-confined aquifers are present in the plains sedimentary succession, but the floodplain is dominated by relatively impermeable clay sediments (Muller et al., 2015). On the western ridges groundwater flow primarily takes place along cleavage fractures, faults and bedding planes in the fractured rock. On the lower slopes, there is minor lateral flow through colluvial sediments (Moore et al., 2018). This region's hydraulic transmissivity and conductivity are moderate to low. Groundwater systems are localized, with limited flow distances (SGN DPE, 2023). During intense rainfall events, flows across the land surface. The transmissivity and hydraulic conductivity in this region are moderate. Groundwater systems are localized, and characterized by short flow distances (Muller et al., 2015). The water quality in these systems is generally fresh. The water table depths are intermediate and exhibit seasonal variability. The residence times of groundwater in this area are typically moderate spanning months to years (Muller et al., 2015).

Chapter 4: Method

4.1 Surface Water Monitor Site Number

The fieldwork encompasses two areas: the Home Farm area of Mulloon Creek, consisting of 17 monitoring points (Table 2, Figure 25), and the Lower Mulloon area, comprising 24 monitoring points (Table 2, Figures 25 and 26). The surface water monitoring sites are numbered from upstream to downstream.

4.2 Field Map

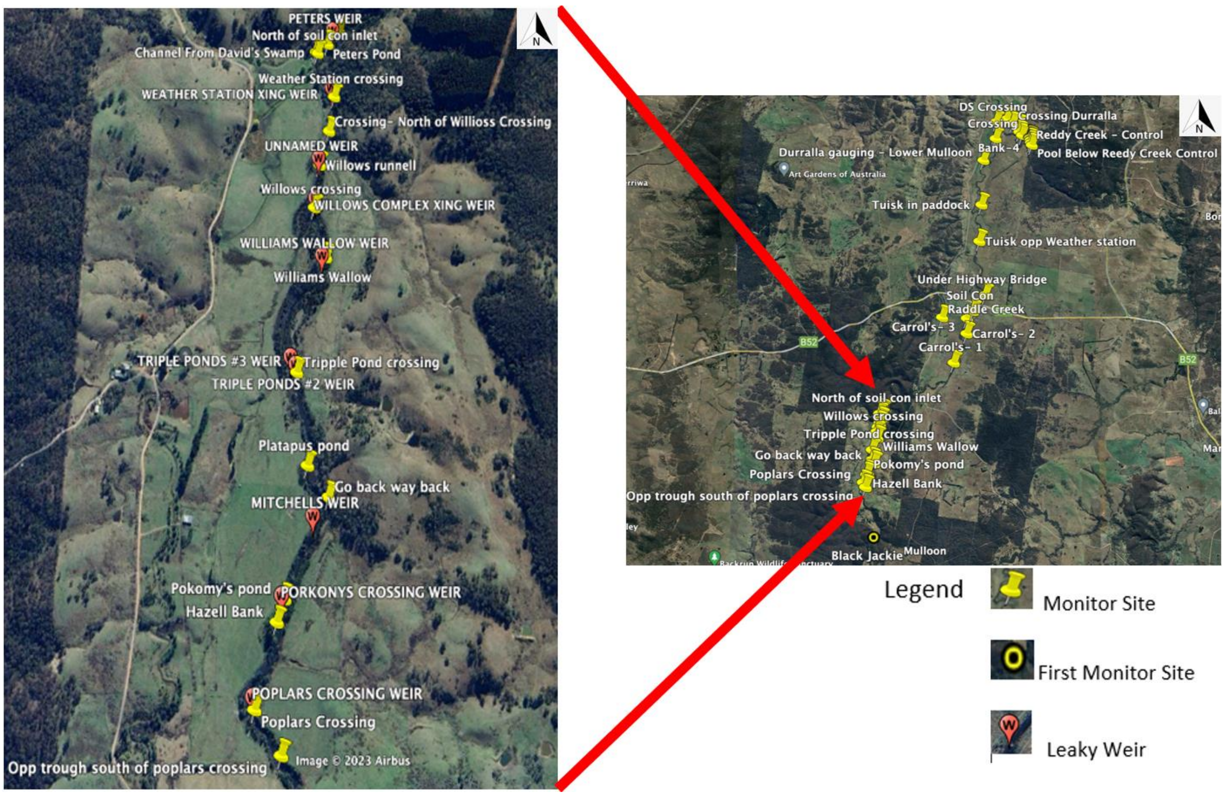


Figure 24. This figure captures a segment of Mulloon Creek, specifically within the Home Farm region. 17 Monitoring Sites. Start monitor site is Black Jackie, end monitor Site is Wombat Pond. (Surface water monitor site is yellow pushpin) (Leaky weirs (red W)). Stream water moves north.

Home Farm area		
Monitor Site Numbers	Monitor Site names	Monitoring point characteristics
1	Black Jackie	The initiation point for creek monitoring, as well as the creek flow monitoring station, is also situated here.
2	Opp Trough South of Poplars Crossing	A relatively wide creek channel

3	Poplars Crossing	A relatively wide creek channel. After the leaky weir exists at this monitoring point
4	Hazell Bank	The creek is wide and the water flow is relatively stable. A leaky weir between Hazell Bank and Pokomy's pond
5	Pokomy's pond	This monitor point exists in the pond
6	Go Back Way back	There is a leaky weir upstream of this monitoring point
7	Platypus Pond	This monitor point exists in the pond
8	Triple Pond Crossing	This monitor point exists in the pond. There are two leaky weirs downstream of this monitoring point
9	Williams Wallow	At a bend in the creek. And there is a leaky weir upstream of this monitoring point
10	Willows Crossing	At this monitoring site, the creek channel is deeper, surrounded by abundant vegetation. The leaky weir is in close proximity, positioned upstream from this monitoring point.
11	Willows Runnel	The creek is wide, and the channel is deep.
12	Crossing- North of Williams Crossing	The creek is extremely wide and there are some aquatic plants in the river.
13	Weather Station Crossing	The terrain of the creek is uneven. There is a lot of gravel near it, causing a slight change in the river's elevation. Its leaky weir is very close to the monitoring point, (the leaky weir is upstream of this monitoring point)
14	Channel from David's Swamp	The monitoring site exists in a swamp and is a tributary of Mulloon Creek (The creek is extremely narrow)
15	South of Soil Con Inlet	The creek is relatively wide and collects a large amount of swamp water flowing out from the monitoring point (Channel From David's Swamp).
16	Peters Pond	This monitor point exists in the pond
17	Wombat Pond	This monitor point exists in the pond (The last monitoring point in the Home Farm area. There is a leaky weir upstream of this monitoring point)

Table 1. Monitoring Site Numbers, Monitor Site names and Monitoring point characteristics (Home Farm Area)

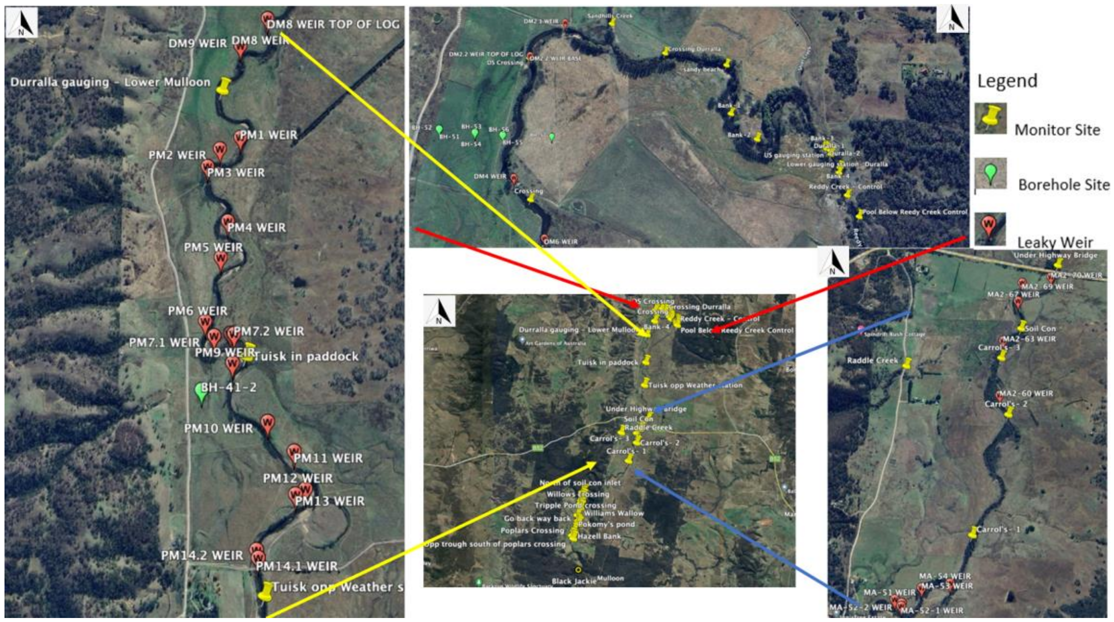


Figure 25. This figure captures a segment of Mulloon Creek, specifically within the Lower Mulloon Creek Area (surface water monitor site shown in yellow pushpin) (Leaky weirs shown in red W) (Borehole show in Green bulb shape) 23 surfaces monitoring sites, start site is Raddle Creek, end site is Pool Below Reedy Creek Control, 1 borehole (BH-41-2) in Transect 3, 6 boreholes (BH-51, BH-52, BH-53, BH-54, BH-55, BH-56, and BH-57) in transect 4. Stream water moves north.

Lower Mulloon area		
Monitor Site Numbers	Monitor Site names	Monitoring point characteristics
18	Raddle Creek	This waterway is a tributary of Mulloon Creek's main channel, with dense vegetation in its vicinity. The creek traverses Ordovician metasediments. The creek eventually joins the main channel of Mulloon Creek
19	Carrol's- 1	The creek where this monitoring point is located is relatively wide and the water depth is shallow. There is more vegetation around the river.
20	Carrol's- 2	The monitoring point sits along a curved section of the creek, and workers elevated the entire upstream site using wood.
21	Carrol's- 3	The creek channel at the monitoring point is relatively wide and the water depth is relatively deep. There is dense vegetation around the river.
22	Soil Con weir at Carrol's	There is a leaky weir upstream of this monitoring point. The creek is relatively wide and the vegetation in the water is extremely lush. There are exposed sandy areas on the banks.
23	Under Highway Bridge	The creek channel where the monitoring point is located is under the highway. The river flow is relatively steady.

		There are some aquatic plants in the creek. There is leaky weir upstream of this monitoring point.
24	Tuisk Opp Weather Station	The creek is wide, and the water flow is relatively stable
25	Tuisk in Paddock	A large amount of sandy soil is exposed around the wide channel of the creek.
26	Lower Mulloon Gauging Station	A large amount of sandy soil is exposed around the wide channel of the creek.
27	Crossing 1	There are large expanses of sand bank surrounding broad creek channels.
28	DS Crossing	Broad creek channels are encircled by extensive stretches of sandy terrain. There is a leaky weir upstream of this monitoring point and it is very close.
29	Sandhills Creek	It's also a tributary of Mulloon Creek, passing through Ordovician metasediments. The creek is bordered by sand, and nearby, there's a substantial chicken farm.
30	Crossing Durralla	The creek channel has broadened, with reduced vegetation in its vicinity. Gravel deposits can be observed scattered around the creekbanks.
31	Sandy Beach	The creek channel appears somewhat enclosed, with a shallow water depth resembling that of a large pond. Abundant gravel in the creek.
32	Bank-1	The creek features at these two monitoring sites share remarkable similarities, and the proximity between them is close. The creek channels exhibit a notable width with shallow water depths, and the prevalent vegetation is predominantly composed of weeds.
33	Bank-2	
34	Bank-3	These six monitoring points are situated in close proximity to each other. The overall features of the creek channels also exhibit considerable similarity. The creek is notably wide, with very shallow water depth, and the creek bed is rich in gravel and sand.
35	Duralla-2	
36	Up of Stream of Gauging Station	
37	Duralla-1	
38	Bank-4	
39	Bank-5	
40	Reedy Creek – Control	The creek at this monitoring point is characterized by many rocks of various shapes scattered along the river channel.
41	Pool Below Reedy Creek Control	This monitoring point is the last monitoring point on Lower Mulloon Creek.

Table 2. Monitoring Site Numbers, Monitor Site names and Monitoring point characteristics (Lower Mulloon Area)

Monitoring points are strategically positioned from upstream to downstream, following the northward flow of the river. A drain originates from David's Swamp in the Home Farm area, merging with Mulloon Creek at the southern end of the soil con inlet. Raddle Creek and

Sandhills Creek in the Lower Mulloon area are tributaries joining the main Mulloon Creek. These tributaries drain landscapes developed on Ordovician metasediments. Some monitoring sites near leaky weirs in Mulloon Creek have changed the configuration of the stream and influenced water quality.

Most leaky weirs have been established upstream of Sandhill Creek, and there are plans for an additional leaky weir on Sandhills Creek near the monitoring site.

4.3 Fieldwork

4.3.1 Surface water

The field investigation took place 20-22 February 2023, 22-24 May 2023 and 21-23 August 2023. A total of 41 monitoring points along Mulloon Creek were sampled each time (Figures 25 and 26). The primary objective of the field trip was to collect data on a range of physicochemical parameters, including DO, T, EC, pH, ORP, Turbidity, Sal, and TDS. Water levels in the Black Jackie, Home Farm, and Lower Mulloon regions were also documented.

4.3.2 Groundwater Transects 3 and 4 (T3 and T4)

During the May 2023 sampling round, physicochemical measurements were taken from 8 groundwater boreholes on 2 transects (T3 and T4) in the Lower Mulloon Creek catchment (Figure 26). The transects are aligned east-west across the valley floor, are sub-parallel and are 2.2 km apart. Samples were taken from borehole T3 41 and boreholes T4 51-57. The T3 borehole was drilled in December 2016, and has a 50mm PVC casing. The T4 boreholes were drilled in December 2019 and have a 90 mm PVC casing. Comparing samples within a transect provides insights into water movement across the floodplain. Comparing samples between the transects provides information along the flood plain.

4.3.3 Stream flow monitoring

Stream flow is monitored using devices positioned at Black Jackie and Wombat ponds (Figure 26 and 27). In this fieldwork, stream flow rates below 15mL/day are categorized as low flow, while rates exceeding 15mL/day are considered high flow.

Figure 26. water level gauge in Black Jackie

Figure 27. water level gauge in Wombat ponds

4.4 Instrumentation

Figure 28. PCS TESTR 35 water quality detector

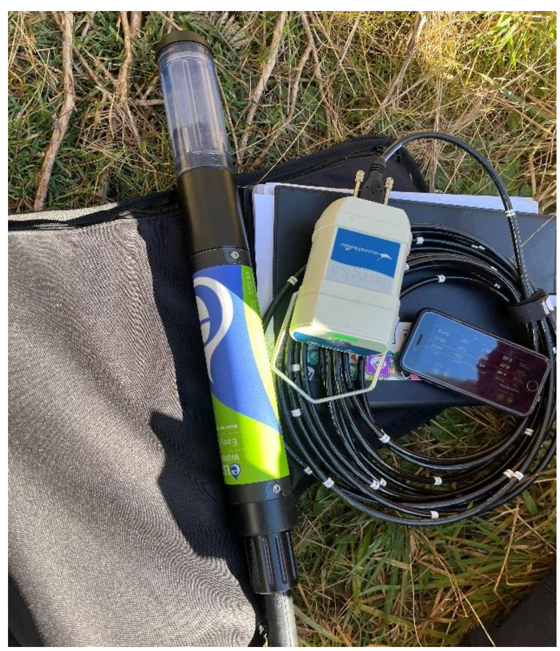


Figure 29. Manta water quality sonde

During the field investigation, two instruments were used to monitor water quality: the PCS TESTR 35 water quality detector (Figure 28) and the Manta water quality sonde (Figure 29). The PCS TESTR 35 water quality detector is capable of measuring five different parameters, namely pH, EC, TDS, Sal, and T. To obtain measurements using this instrument, the surveyor inserts the detector's head into the stream or river being measured and records the data.

The Manta water quality sonde is a multi-sensor probe that measures: T, DO, EC, and pH. The Manta sonde communicates with the MantaMobile™ through a cable attached to a Bluetooth transceiver. It establishes a Bluetooth connection with Android or Apple mobile phones or tablets and the data can be read, recorded, and saved using the electronic device. Both monitoring devices are waterproof, ensuring their functionality in aquatic environments.

Both instruments provide physicochemical information about water quality, but their measurement methods differ. Using devices that measure many of the same parameters allows the practitioner to compare the reliability and accuracy of the data obtained from these instruments.

4.5 Historical Analysis

The rapid stream monitoring project commenced on 25 August 2014, and subsequent monitoring sessions were conducted on 23 September 2014, 3 November 2014, 16 June 2016, 30 November 2016, 10 July 2017, 3 May 2018, 25 March 2020, and in this study on 20 February 2023, 20 May 2023, and 20 August 2023. The monitoring sessions were not evenly distributed through time, and there are gaps in the recorded data for certain years. However, the available data does cover the post-millennium drought (2012 to 2015), the 2017-2019 drought (2017 to 2019), and the intervening and most recent rainy periods (mid-2015 to 2016 and 2020 to 2023 respectively).

4.6 Water Parameters

4.6.1 Water Temperature

Water temperature is expressed in degrees Celsius (°C). Changes in temperature directly affect aquatic organisms, whose growth rate and metabolism are positively correlated with temperature (Wilson, 2021., Kaushal et al, 2010). Changes in temperature also affect the measurements of pH, dissolved oxygen and electrical conductivity (Boulton et al. 2014) (Table 2).

4.6.2 Dissolved Oxygen

The concentrations of dissolved oxygen (DO) play a crucial role in aquatic communities and serve as a significant indicator of water quality conditions in streams (Ice and Sugden, 2003). Most aquatic organisms, plants and animals require oxygen to survive, so dissolved oxygen is important for fish, invertebrates, and all organisms in the aquatic environment (Bozorg, 2021) There are two major situations that limit the amount of dissolved oxygen in a river.

(1) During drought, river flow becomes low or dry, resulting in disconnected ponds whose water quality slowly deteriorates. In addition, aquatic organisms such as fish will compete for oxygen, increasing wildlife stress (NSW Gov, 2023).
(2) During flood events a large amount of organic matter is washed into the river. As this organic matter decomposes oxygen is consumed leading to a drop in dissolved oxygen (NSW Gov, 2023).

Dissolved oxygen levels at or below 4mg/l generally cause physiological stress to aquatic life (Figure. 30; NE CMA, 2023) (Table 2).

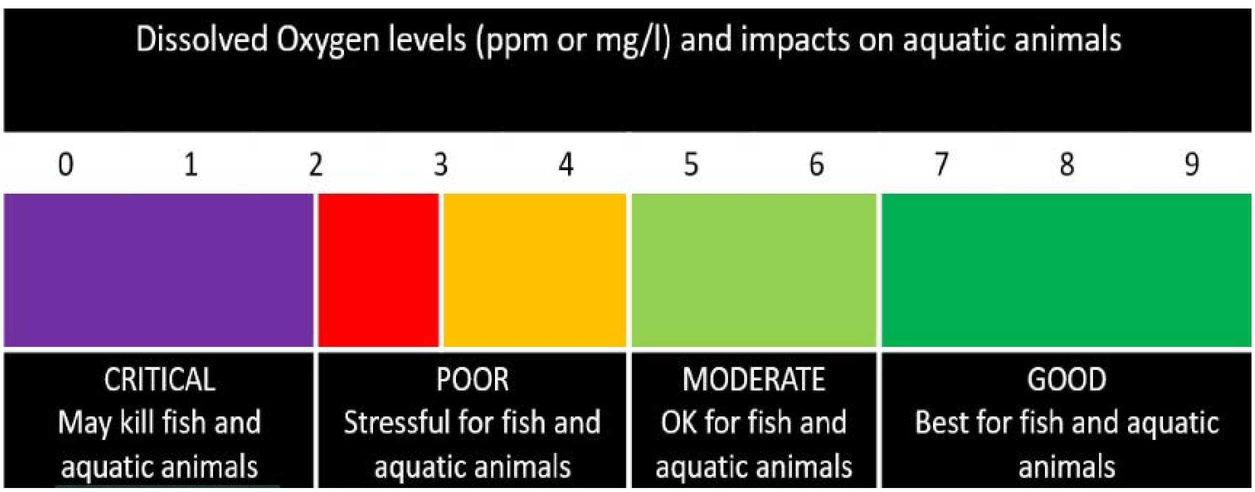


Figure 30. The standard for dissolved oxygen (mg/l) (NE CMA, 2023)

4.6.3 Electric Conductivity, Total Dissolved Solids and Stream Salinity

Salinity is a measure of the soluble salt in a river. Electrical conductivity (EC), the capacity for water to conduct an electric current, is enhanced if salt is dissolved in the water. Total dissolved solids (TDS) is a value typically derived from a measurement of EC using a local conversion factor (typically close to 0.6 at 25°C). Both of these parameters are used to indicate the salinity of the water (Howard, 1933, Rusydi, 2018; Corwin and Yemoto, 2020) (Table 2).

The main source of river salinity is the chemical weathering of the rock, the introduction of salt through anthropogenic activities and via atmospheric deposition (rain and windblown dust) (Corwin and Yemoto, 2020). Changes in salinity can impact the organisms living in the water (James et al. 2003), and human drinking water can also be affected (Lu, 2006). In general, the salinity of potable water should not exceed 800µS/cm (MRCCC, 2013).

4.6.4 Oxidation-reduction potential (ORP)

Oxidation-reduction potential (ORP) represents the capacity of one substance to either oxidize or reduce another substance and is quantified using ORP meters equipped with electrodes (Lowry and Dickman, 2010). A positive ORP reading signifies the oxidizing potential of the water, while a negative reading signifies its reducing potential (Schuyler, 2013). In general, a higher ORP reading is indicative of better overall water quality in a stream (Schuyler, 2013) (Table 2).

Table 3: Water Quality Standards

	Upper Limit	Lowest Limit	Cited
EC (us/cm)	800 (us/cm)		MRCCC, 2013
TDS (mg/L)	480 (mg/L)		Calculated from EC
Salt (ppt)	0.48 (ppt)		Calculated from EC
pH	8	6	NHMRC, 2008
DO (%)		80 (%)	Gov, NT, 2023a
DO (mg/L)		4 (mg/L)	NE CMA, 2023
ORP (mV)		300 (mV)	Gov, NT, 2023b
Turbidity (NTU)	15 (NTU)		Fondriest Environmental, 2014

Chapter 5: Results

5.1 Overall stream flow monitoring data

High water flow (>15ML/day) in Mulloon Creek occurred over the following sampling periods: August, September and November 2014, June 2016, March 2020, and February and May 2023. Low water flow (<15ML/day) in Mulloon Creek occurred over the following sampling periods: November 2016, July 2017, May 2018, and August 2023 (Table 4).

Flow at Gauging Stations when RSA Conducted		
Date	Black Jackie Flow (ML/Day)	Mid-Mulloon Flow (ML/Day)
25/08/2014	60.64	145.6
22/09/2014	26.37	66.73
03/11/2014	16.09	41.24
16/06/2016	37.60	43.09
30/11/2016	7.60	10.7
10/07/2017	1.10	6.80
03/05/2018	0.20	2.90
25/03/2020	35.00	31.00
20/02/2023	20.58	22.12
20/05/2023	18.09	23.74
20/08/2023	12.06	14.09

Table 4: Flow at Gauging Stations when RSA Conducted

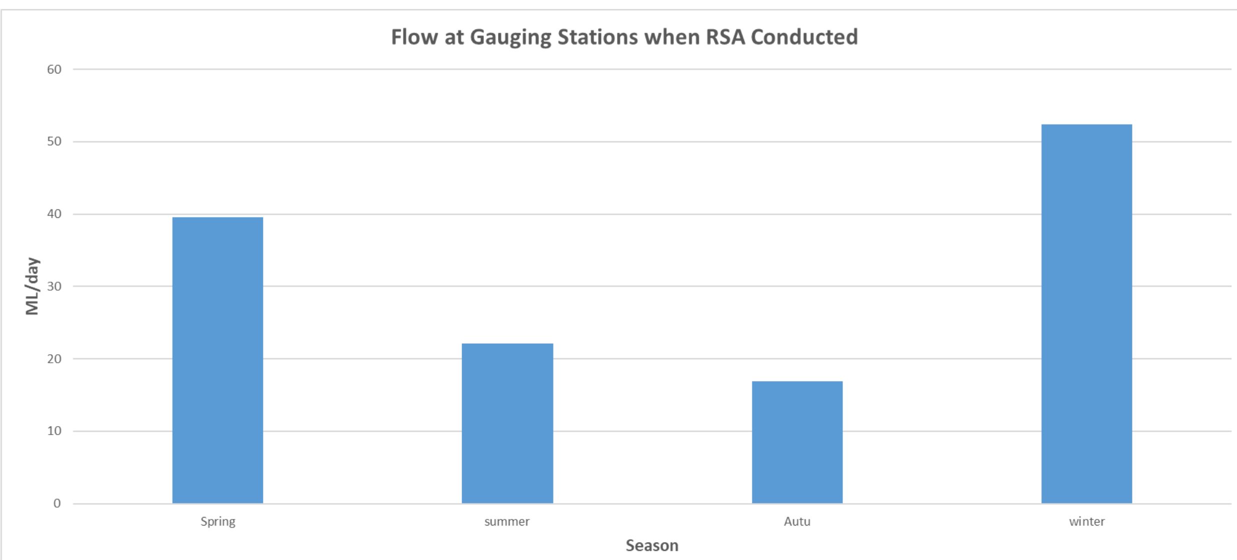


Figure 31. Flow at Gauging Stations when RSA Conducted with season

Winter experiences the highest flow, followed by spring and then summer, with the lowest flow occurring in autumn (Figure 31).

5.2 Stream water (Home Farm) (2014-2023)

5.2.1 Stream water temperature (Home Farm) (2014-2023)

Stream temperature is typically higher in summer, cooler in spring and autumn, and coolest in winter. In most seasons, the water temperature decreases downstream (Figure 32).

During periods of high flow, temperature variations exhibit a consistent pattern. Typically, river temperatures are at their peak during the summer months and reach their lowest points in winter. The temperature data at monitoring points: Opp trough south of Poplars Crossing (Site 2), Hazell Bank (Site 4), Triple Pond crossing (Site 8), Crossing north of Williams Crossing (Site 12), and Channel from David's Swamp (Site 14) is higher that adjacent sites, in the data from September 2014, November 2014, and February 2023 (Figure 33).

The overall temperature trends during periods of low flow are similar, with the November 2016 data showing higher temperatures overall. At monitoring points Opp trough south of Poplars Crossing (Site 2), Triple Pond crossing (Site 8), Williams Wallow (Site 9), Willows Crossing (Site 10), Channel from David's Swamp (Site 14), and South of soil con inlet (Site 15) display higher or lower temperatures during these periods (Figure 34).

As a general trend, when the river water is warmer, monitoring points that show differences exhibit cooler temperatures. When the water temperature is low, water at these monitoring points is commonly warmer (Figure 34).

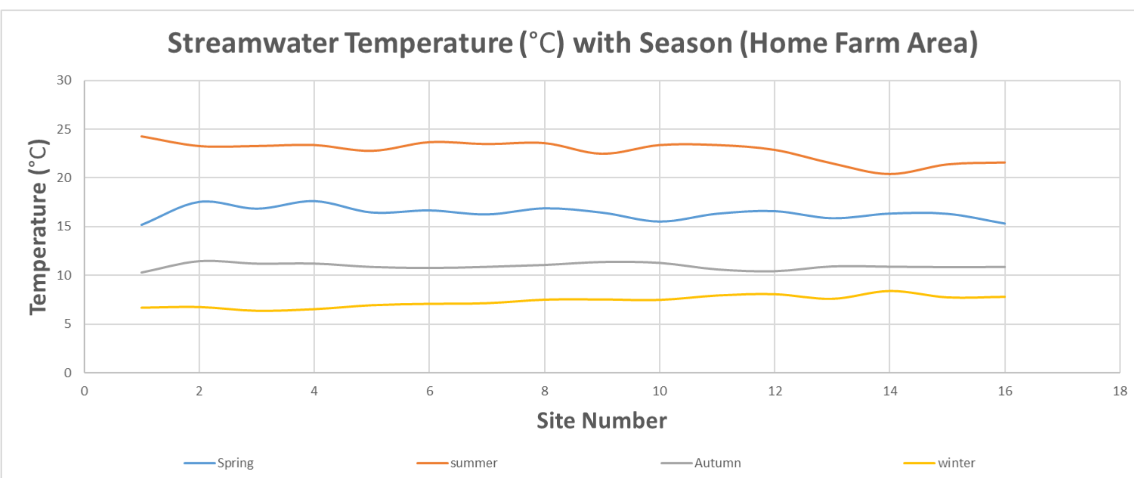
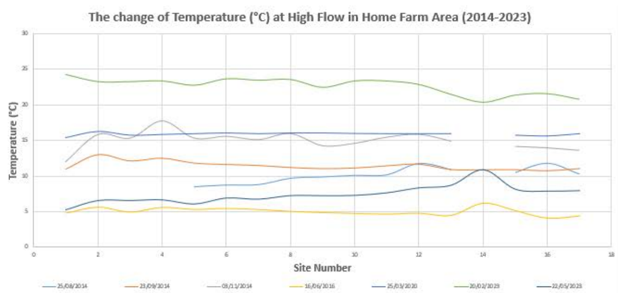


Figure 32. Stream water Temperature (°C) with Season (Home Farm)



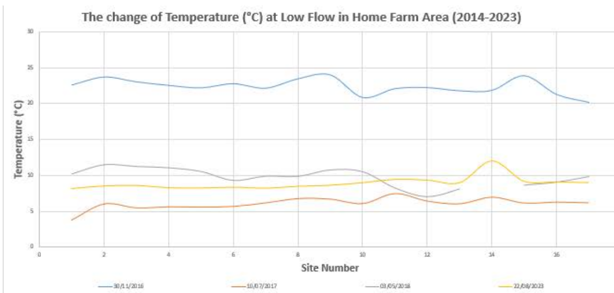


Figure 33. The change of Temperature (°C) at High Flow in Home Farm

Figure 34. The change of Temperature (°C) at Low Flow in Home Farm

5.2.2 Stream water Electrical Conductivity (Total Dissolved Solid and Salinity) (Home Farm) (2014-2023)

The water in mid-Mulloon Creek (Home Farm) is fresh, in the range EC 100-200 µS/cm (TDS 60-120 mg/L; Sal 0.06 0.12 ppt) at most monitoring sites. There were some instances where recorded EC levels were up to 400 µS/cm (TDS 240 mg/L; Sal 0.24 ppt) (excluding Site 14), but these values consistently stayed below the maximum potable water threshold of 800 µS/cm (TDS 480 mg/L; Sal 0.48 ppt). Measured EC (TDS and Sal) values were highest in: autumn, and lower in summer, spring, and winter respectively (Figures 35, 38, 41).

The overall pattern at high flow is very consistent, apart from March 2020. At this time readings were higher at all sites (except Site 14) but Hazell Bank (Site 4), and Williams Wallow (Site 9) were marginally fresher than adjacent sites (Figures 36, 39, 42). The EC (TDS and Sal) values for the Channel from David's Swamp (Site 14) are consistently much higher (EC 550-800 µS/cm; TDS 330-480 mg/L; Sal 0.33-0.48 ppt) than all other measured values at Home Farm, with the highest values recorded in June 2016 (Figures 32-40). During the low-flow period, patterns for November 2016, July 2017, and August 2023 are similar, and parallel those observed at higher flow. In May 2018, the EC (TDS and Sal) values were higher overall, with more saline readings at Opp trough south of Poplars Crossing (Site 2), Williams Wallow (Site 9) and Willows Runnel (Site 11) (Figures 37, 40, 43).

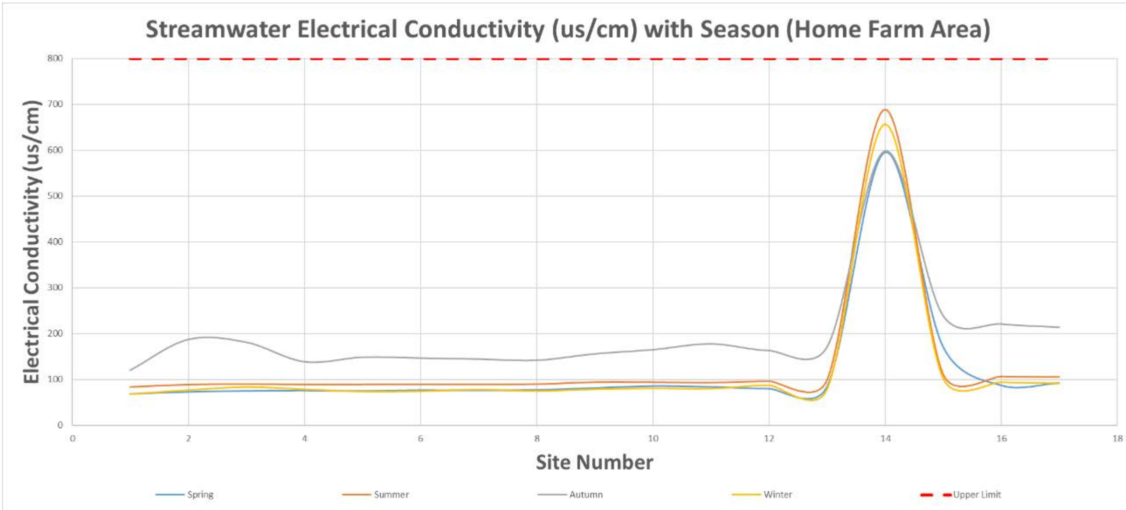
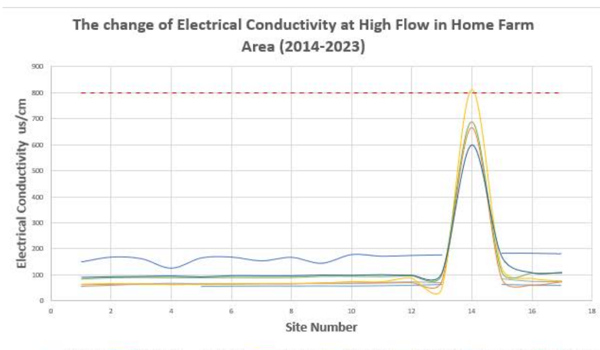


Figure 35 Stream water Electrical Conductivity (us/cm) with Season (Home Farm Area)



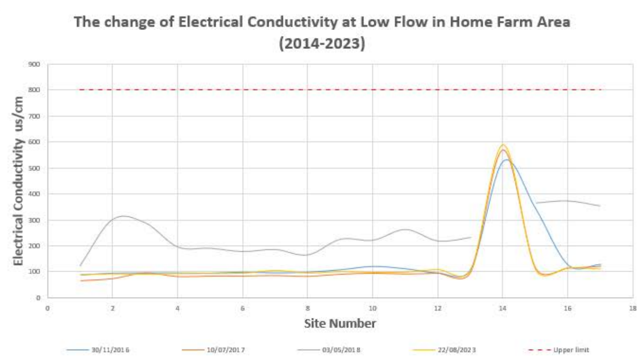


Figure 36. The change of Electrical conductivity at High flow in Home Farm (2014-2023)

Figure 37. The change of Electrical conductivity at Low flow in Home Farm (2014-2023)

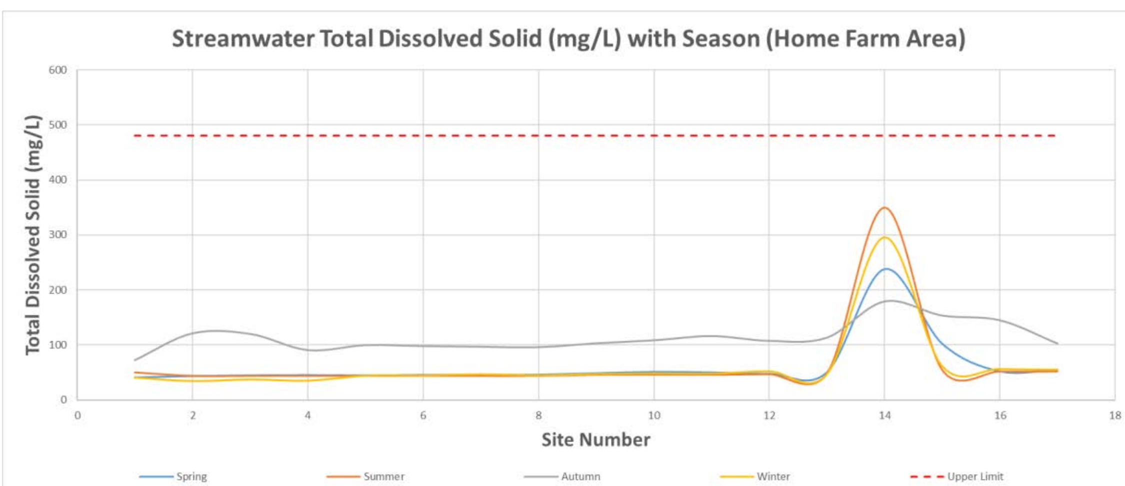
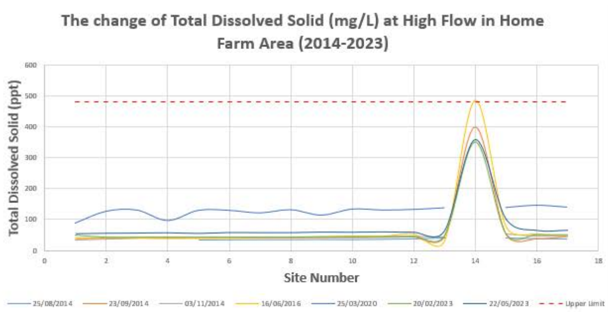


Figure 38. Stream water Total Dissolved Solid (mg/L) with Season (Home Farm)



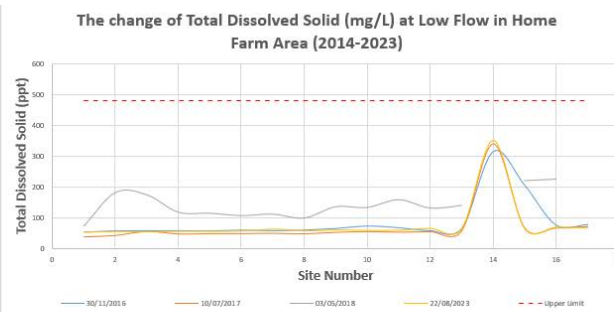


Figure 39. The change of Total Dissolved Solid (mg/L) at High flow in Home Farm (2014-2023)

Figure 40. The change of Total Dissolved Solid (mg/L) at Low flow in Home Farm (2014-2023)

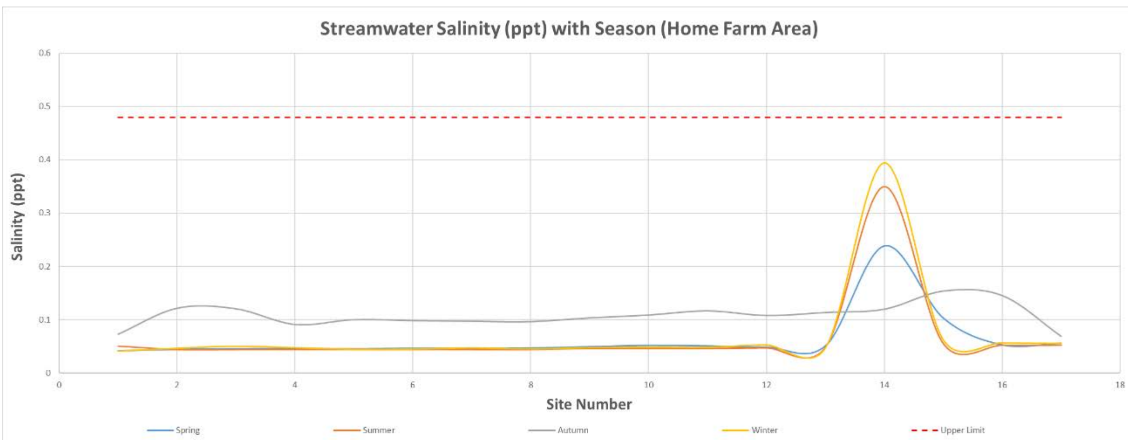
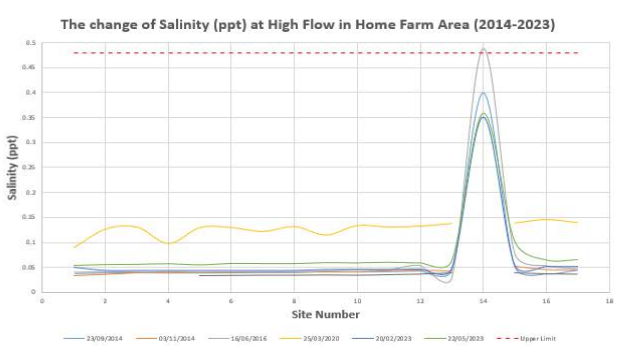


Figure 41. Stream water Salinity (ppt) with Season (Home Farm)



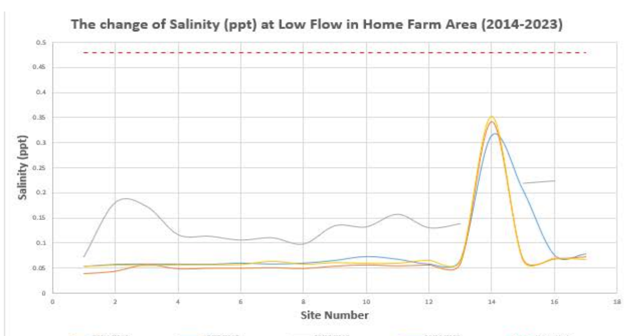


Figure 42. The change of Salinity (ppt) at High flow in Home Farm (2014-2023)

Figure 43. The change of Salinity (ppt) at Low flow in Home Farm (2014-2023)

In general, the EC (TDS and Sal) variations during high-flow periods (rainy season) are less pronounced than those observed during low-flow periods (dry season) (Figures 36, 37, 30, 40, 42, 43). Although EC (TDS and Sal) are typically low, if measured values in Mulloon Creek remain consistent at higher flows, then salt export (load) is higher in periods of high flow.

5.2.3 Stream water Dissolved Oxygen (Home Farm) (2014-2023)

Measured dissolved oxygen (DO mg/L and $\%_{sat}$) values for mid-Mulloon Creek (Home Farm) were typically in the healthy range (>4 mg/L; >80$\%_{sat}$) for natural waters, with notably higher levels at Opp trough south of Poplars Crossing (Site 2), Willows Runnel (Site 11) and Weather Station Crossing (Site 13) in summer (Figures 44, 47). Overall, measured DO values were highest in winter, and lower in spring, summer, and autumn, respectively (Figures 44, 47).

Under high-flow conditions DO values consistently exceed 4 mg/L (>80$\%_{sat}$), but in June 2016 and February 2023 large variations in dissolved oxygen were observed along Mid-Mulloon Creek. In June 2016 values typically exceeded 10 mg/L (>100$\%_{sat}$), with higher values at Hazell Bank (Site 4), Pokomy's Pond (Site 5), Platypus Pond (Site 7), Williams Wallow (Site 9) and Crossing north of Williams Crossing (Site 12). In February 2023, there were very high values at Opp trough south of Poplars Crossing (Site 2), Willows Runnel (Site 11) and Weather Station crossing (Site 13), and an anomalous low at Channel from David's Swamp (Site 14) (0.13 mg/L; 2.6$\%_{sat}$) (Figures 45, 48).

Under low-flow conditions DO values showed greater variation from site to site and were very low (<10mg/L; 80$\%_{sat}$). Values for May 2018 dropped below 4 mg/L, indicating poor conditions for natural waters to support functioning aquatic ecosystems. At this time Williams Wallow (Site 10) and Willows Crossing (Site 11) were dry (Figures 46, 49).

Overall, the DO is typically higher in wet (high flow) periods and lower in dry (low flow) periods (Figures 45, 46, 48 and 49). In general, dissolved oxygen has more consistent values along the length of Mid-Mulloon Creek during wet periods (Figures 45, 48), with greater fluctuation in DO values from site to site in dry periods (Figures 46, 49).

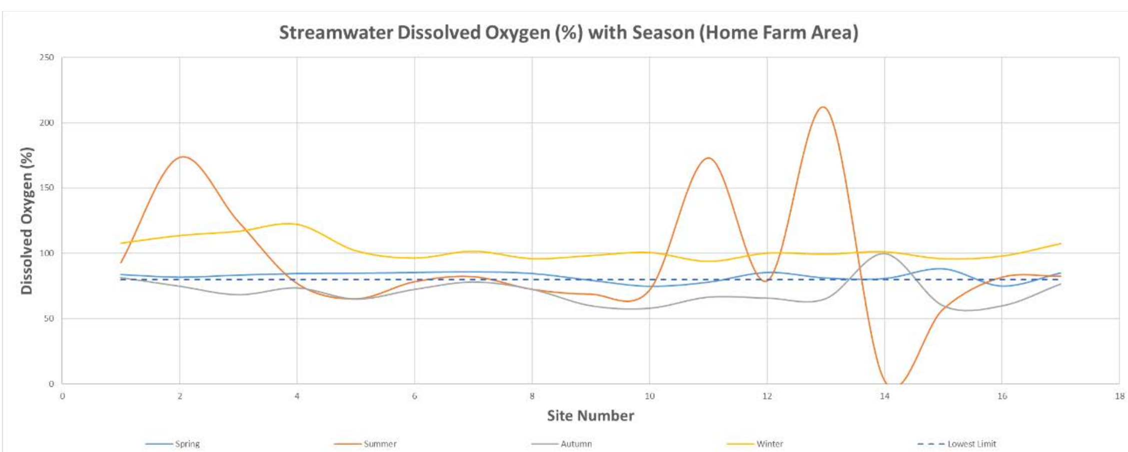
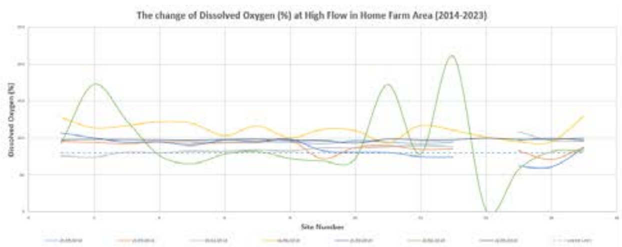


Figure 44. Stream water Dissolved Oxygen (%) with Season (Home Farm)



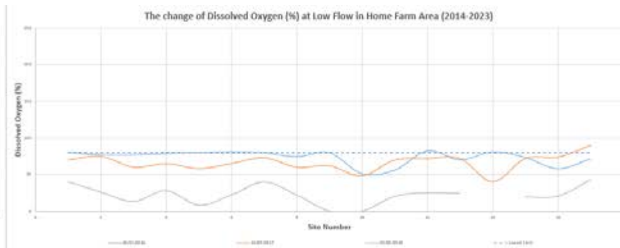


Figure 45. The change of Dissolved Oxygen (%) at High Flow in Home Farm

Figure 46. The change of Dissolved Oxygen (%) at Low Flow in Home Farm

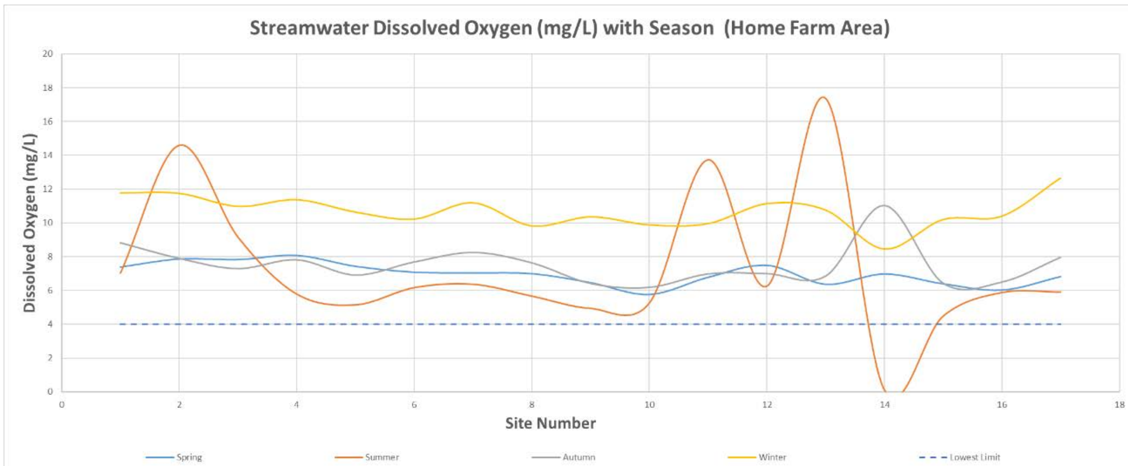
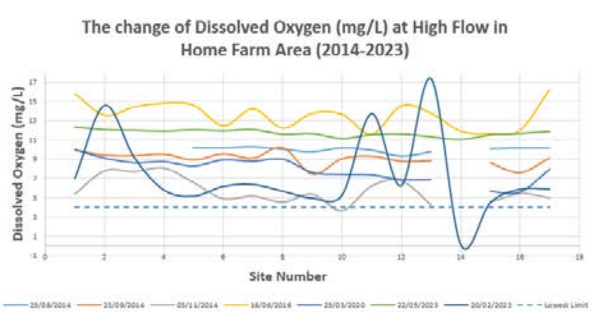


Figure 47. Stream water Dissolved Oxygen (mg/L) with Season (Home Farm)



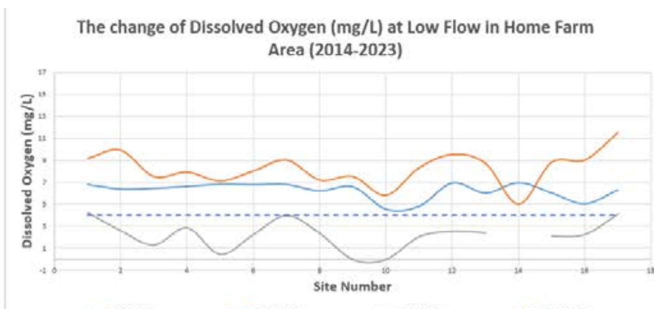


Figure 48. The change of Dissolved Oxygen (mg/L) at High flow in Home Farm (2014-2023)

Figure 49. The change of Dissolved Oxygen (mg/L) at Low flow in Home Farm (2014-2023)

5.2.4 Stream water pH (Home Farm) (2014-2023)

Measured pH values were very stable for Mid-Mulloon Creek (typically 6.5-7.5) and remained within the range for natural waters (Figure 50). In autumn and summer values were marginally more variable, with values up to pH 8 at the Channel from David's Swamp (Site 14). In general, there were slightly higher values in winter, and lower values in spring, autumn and summer respectively (Figure 50). The pH showed no distinguishable pattern when high and low flow rates, were considered (Figures 51, 52).

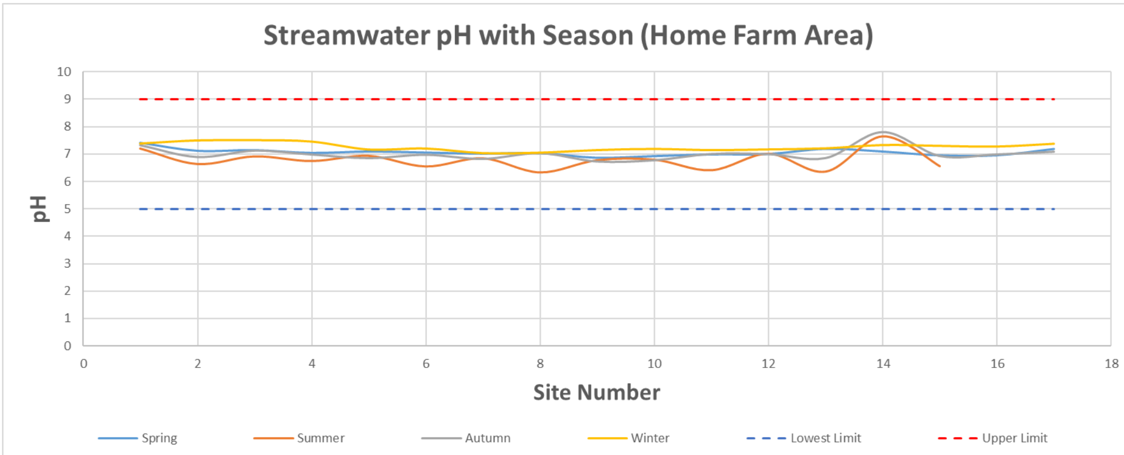
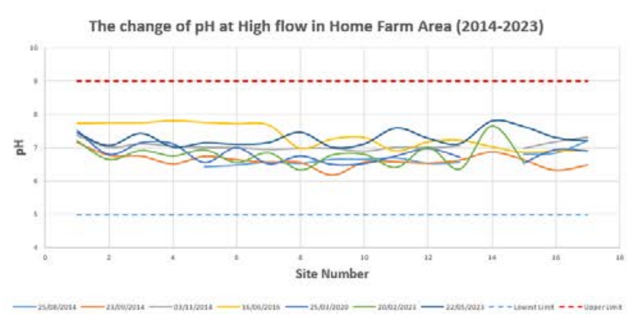


Figure 50. Stream water pH with Season (Home Farm)



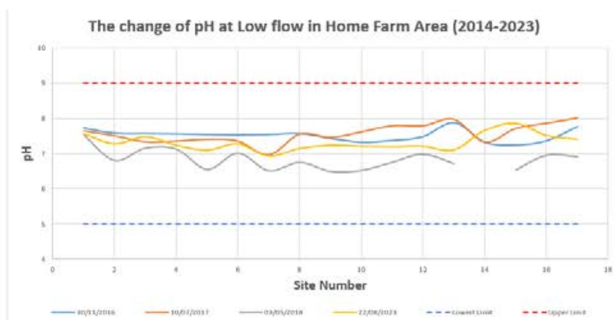


Figure 51. The change of pH at High flow in Home Farm (2014-2023)

Figure 52. The change of pH at Low flow in Home Farm (2014-2023)

5.2.5 Stream water Turbidity (Home Farm) (2014-2023)

Measured Turbidity (NTU) values were most variable and highest in autumn, and less variable and lower in winter, spring and summer, respectively (Figure 53).

Under high flow conditions, water is typically clear with most measured turbidity values below the 15 NTU optimum limit for natural waters. In August 2014, water was slightly more turbid at the Crossing north of Williams Crossing (Site 12; 35 NTU) and in March 2020, water was muddy at Poplars Crossing (Site 3; 180 NTU), Pokomy's Pond (Site 5; 40 NTU), Williams Wallow (Site 9; 55 NTU), and the Crossing north of Williams Crossing (12; 50 NTU) (Figure 54).

Under low flow conditions, turbidity in Mid-Mullon Creek is highly variable and locally visibly muddy. In November 2016 measured turbidity levels were elevated at three adjacent sites: Williams Wallow (Site 9; 100 NTU), Willows Crossing (Site 10; 90 NTU), and Willows Runnel

(Site 11; 90 NTU), and also at Peter's Pond (Site 16; 100 NTU). In July 2017, waters were turbid at Opp trough south of Poplars Crossing (Site 2; 80 NTU), Hazell Bank (Site 4; 190 NTU), Williams Wallow (Site 9; 150), Willows Crossing (Site 10; 190), Channel from David's Swamp (Site14; 175 NTU) and Peter's Pond (16; 70 NTU). In May 2018 the highest values were recorded with muddy water at Platypus Pond (Site 7; 100 NTU), Willows Crossing (Site 10; 850 NTU) and the Crossing north of William's Crossing (Site 12; 450 NTU). In August 2023 waters were mostly clear with tubid water measured only at the Channel from David's Swamp (Site 14; 110 NTU) (Figure 55).

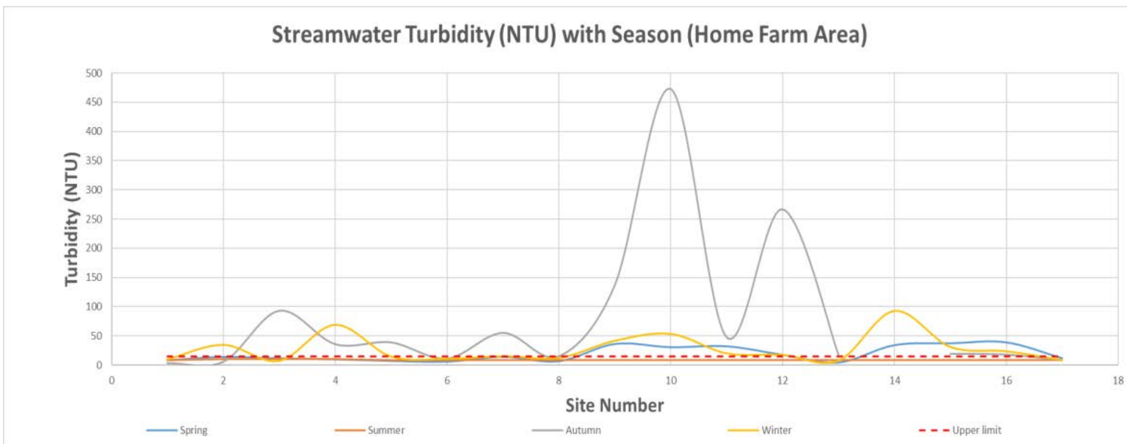
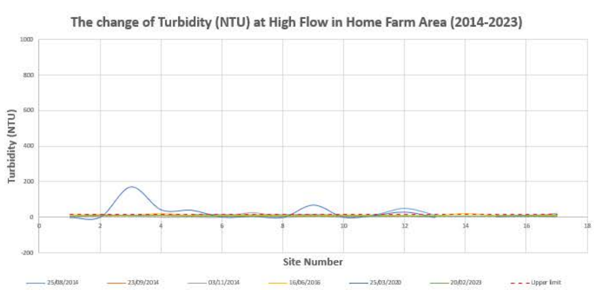


Figure 53. Stream water Turbidity (NTU) with Season (Home Farm)



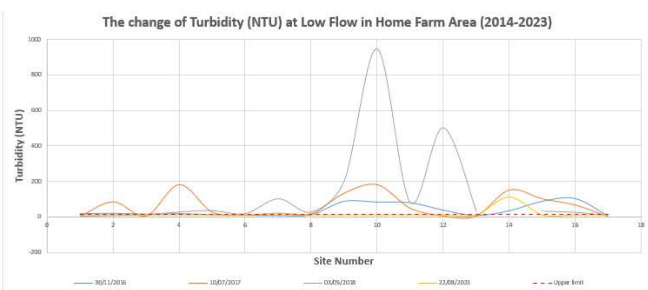


Figure 54. The change of of Turbidity (NTU) at High flow in Home Farm (2014-2023)

Figure 55. The change of of Turbidity (NTU) at Low flow in Home Farm (2014-2023)

5.2.6 Stream water Oxidation Reduction Potential (mV) (Home Farm) (2014-2023)

Measured Oxidation-Reduction Potential (ORP) values were highest in summer, and lower in autumn, winter, and spring, respectively (Figure 56), and values fall in the range typical for natural waters.

Under high flow conditions, measured values for November 2014, June 2018 and March 2020 are significantly lower (mostly <150mV) than those measured in 2023 (mostly >150mV), with lowest values measured at the Channel from David’s Swamp (Site 14), increasing again once waters reach Peter’s Pond (Site 16) (Figure 57).

Under low flow conditions, most measurements in November 2016, July 2017 and May 2018 (typically <100mV) are lower than those measured in August 2023 (>100mV). The exception is in May 2018 when water downstream of Willows Runnel (Site 9) had ORP values in the order of 150mV (Figure 58).

Overall, measured ORP values are less than 300mV, and are generally higher at high flow than at low flow. Water entering Mid-Mulloon Creek from the Channel from David's Swamp (Site 14) lowers the ORP values measured at this site.

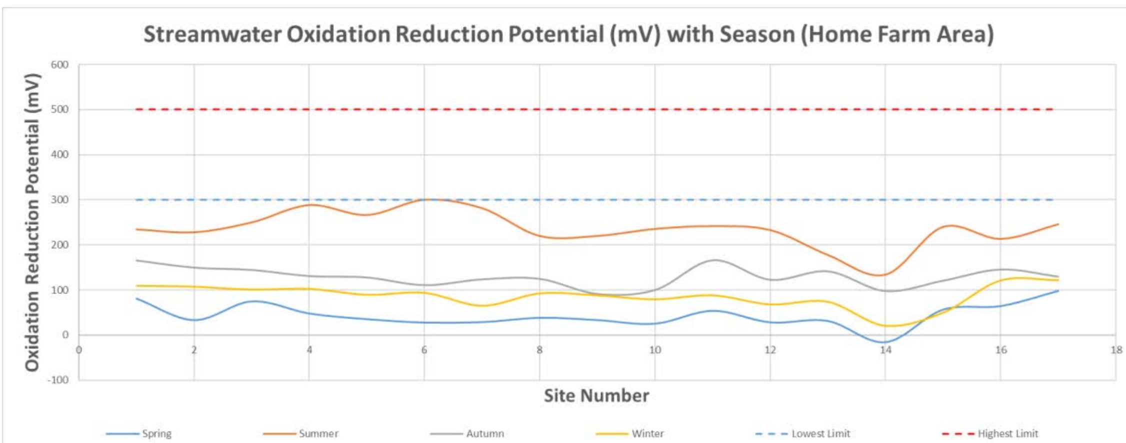


Figure 56. Stream water Oxidation Reduction Potential (mV) with Season (Home Farm)

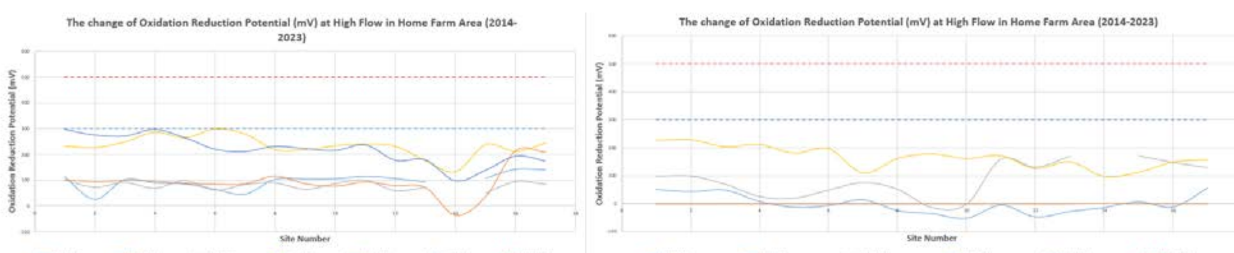


Figure 57. The change of Oxidation Reduction Potential (mV) at High Flow in Home Farm (2014-2023)

Figure 58. The change of Oxidation Reduction Potential (mV) at Low Flow in Home Farm (2014-2023)

5.3 *Stream water (Lower Mulloon) (2014-2023)*

5.3.1 Stream water Temperature (Lower Mulloon) (2014-2023)

In the Lower Mulloon Creek, measured daytime water temperature values are typically in the range 5-25°C, and were highest in summer, and lower in spring, autumn, and winter, respectively (Figure 59).

Under high flow conditions, water temperature was relatively constant along Lower Mulloon Creek for each measurement period, with highest temperatures in February 2023. At specific sites, small changes in water temperature show different patterns at different sampling times. Compared with upstream values, warmer water was measured at Tuisk opp Weather Station (Site 24) in August (+6°C) and September 2014 (+4°C) and cooler water was measured at the same site in November 2014 (-3°C) and May 2023(-5°C). Warmer water was measured at Carrol’s 2 (Site 20) in May 2023 (+3°C). In February 2023 there was a notable decrease in water temperature (26°C to 18°C) when water from Sandhills Creek (Site 29) entered Lower Mulloon Creek (Figure 60).

Under low flow conditions, measured water temperatures are very consistent for Lower Mulloon Creek. The highest temperatures were measured in July 2017 and there was a slight increase in temperature downstream (17.5°C to 23°C). In all other periods (November 2016, May 2018 and August 2023) the water was cooler, typically between 5°C and 10°C (Figure 61).

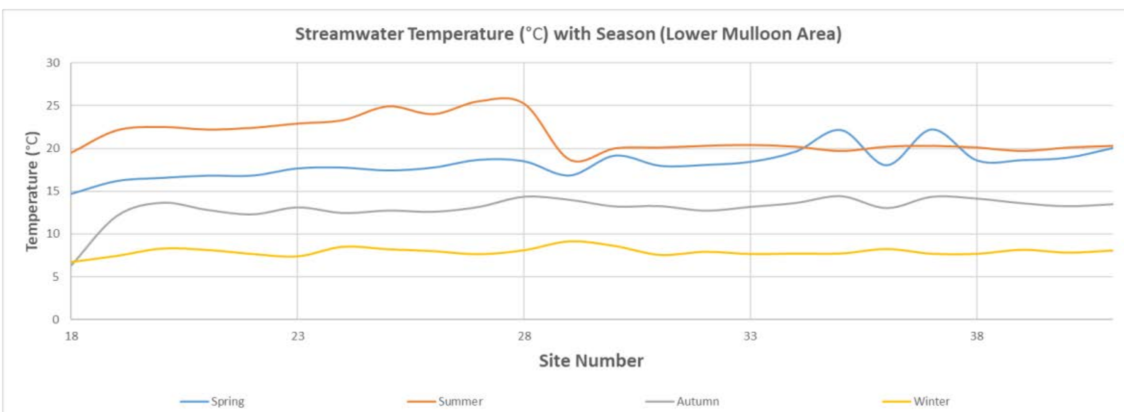
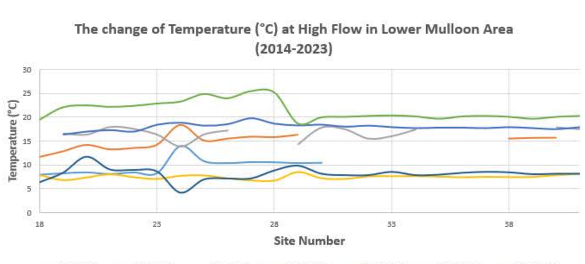


Figure 59. Stream water Temperature (°C) with Season (Lower Mulloon)



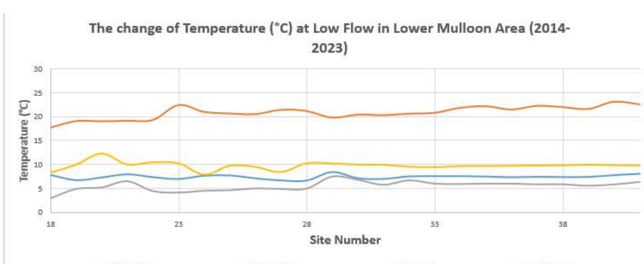


Figure 60. The change of Temperature (°C) at High Flow in Lower Mulloon (2014-2023)

Figure 61. The change of Temperature (°C) at Low Flow in Lower Mulloon (2014-2023)

5.3.2 Stream water Electric Conductivity (Total Dissolved Solid and Salinity) (Lower Mulloon) (2014-2023)

In the Lower Mulloon Creek, the measured EC (TDS and Sal) values are highest in autumn, and lower in spring, winter and summer, respectively (Figures 62, 65, 68).

Under high flow conditions, EC (TDS and Sal) values lie in the fresh range for natural waters (EC 30-200µS/cm) along Lower Mulloon Creek and through time, with higher values consistently recorded at Raddle Creek (Site 18; 550-800µS/cm) and Sandhills Creek (Site 29; 500-725µS/cm). The measured EC values are marginally higher in Lower Mulloon Creek downstream of the Sandhills Creek confluence. Small variations relative to upstream values were observed in March 2020 at Tuisk opp Weather Station (Site 24; +90µS/cm) and Bank 1 (Site 32; +150µS/cm). In May 2023 values were marginally higher than previously recorded with variations at Tuisk opp Weather Station (Site 24; -30µS/cm) and at Bank 4 (Site 38; +20µS/cm) (Figure 63). Similar trends were observed in TDS and Sal data (Figures 66, 69).

Under low flow conditions, the overall EC (TDS and Sal) values are typically in the range 100-200µS/cm upstream of Sandhills Creek and in the range 200-300 µS/cm downstream of Sandhills Creek. Higher values are consistently recorded at Raddle Creek (Site 18; 550-700µS/cm) and at Sandhills Creek (Site 29; 600-820µS/cm). In July 2017 there was a variation relative to upstream values at Carrols 2 (Site 20; +90µS/cm). The EC measurements in May 2018 were higher and more variable than otherwise recorded, with values around 200µS/cm above the Sandhills Creek confluence, and elevated values below the confluence with peak values for specific sites at Sandy Beach (Site 31; 375µS/cm), Bank 1 (Site 32; 340µS/cm), Bank 3 (Site 34; 525µS/cm), and downstream of Duralla 1 (Site 37; 520µS/cm) (Figure 64). Similar trends were observed in TDS and Sal data (Figures 67, 70).

Overall EC (TDS and Sal) values low and stable during periods of high flow, with higher values recorded at Raddles Creek (Site 18) and Sandhills Creek (Site 29). In periods of low flow periods, EC (TDS and Sal) values are higher and exhibit more variation along Lower Mulloon Creek.

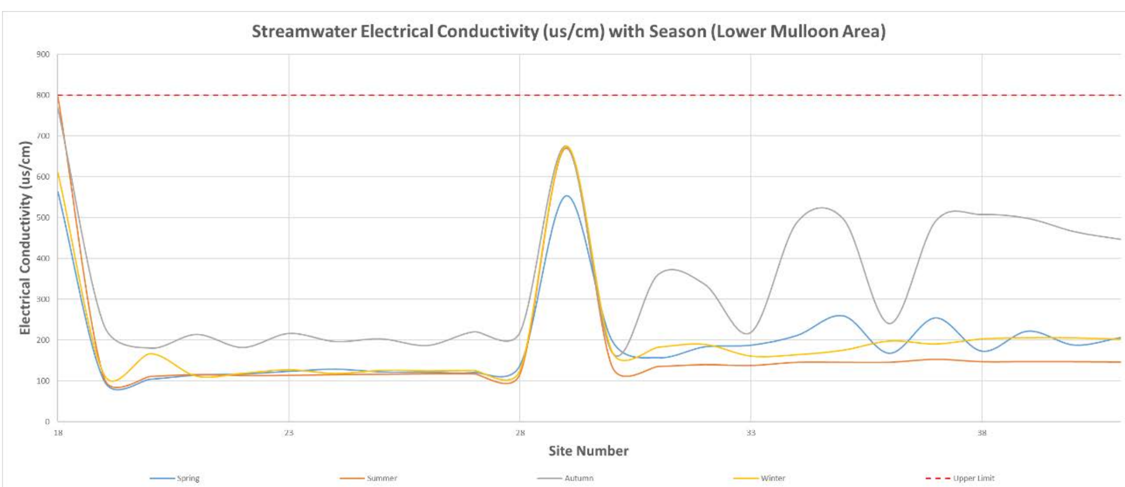
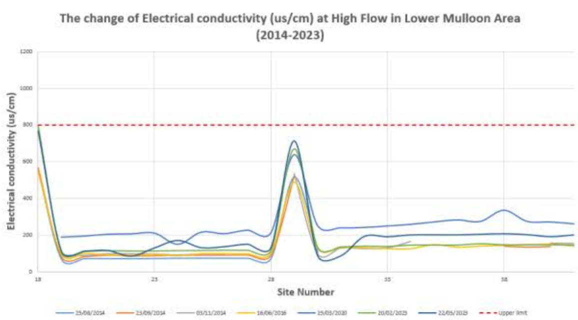


Figure 62. Stream water Electrical Conductivity (us/cm) with Season (Lower Mulloon)



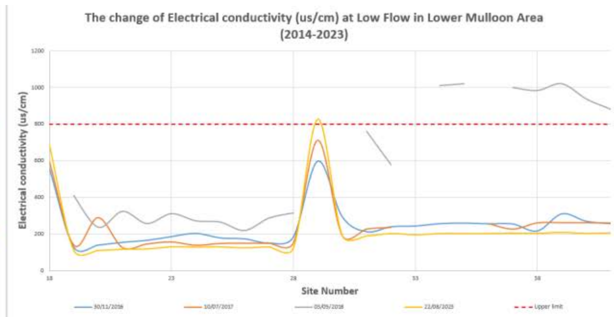


Figure 63. The change of Electrical conductivity (us/cm) at High Flow in Lower Mulloon (2014-2023)

Figure 64. The change of Electrical conductivity (us/cm) at Low Flow in Lower Mulloon (2014-2023)

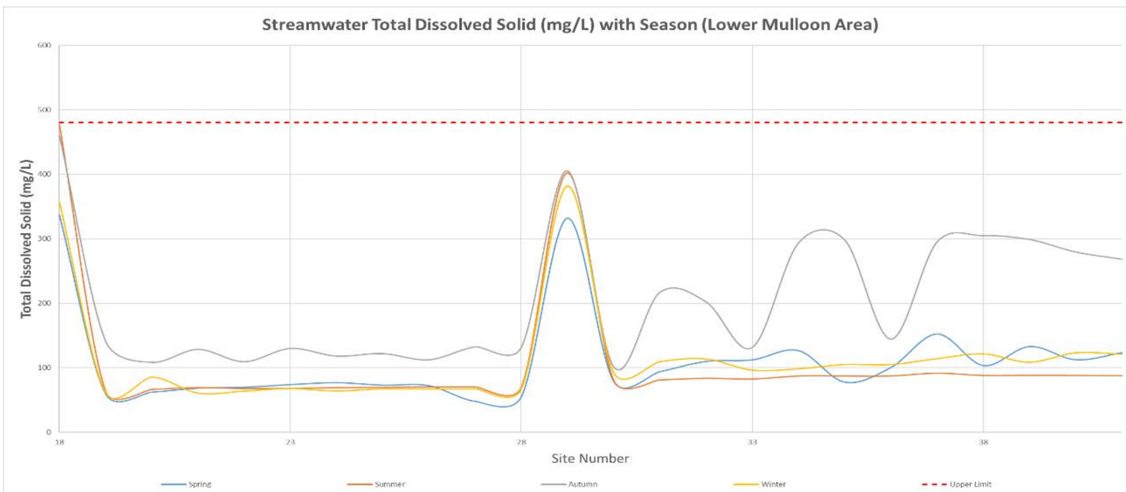
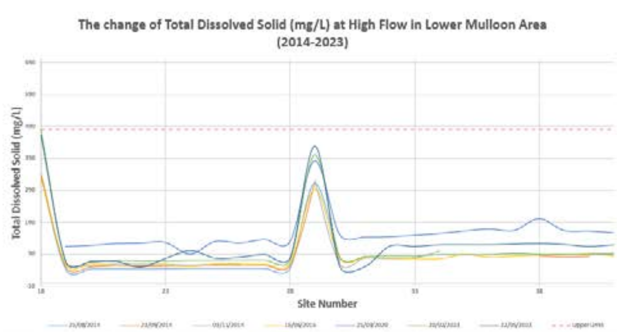


Figure 65. Stream water Total Dissolved Solid (mg/L) with Season (Lower Mulloon)



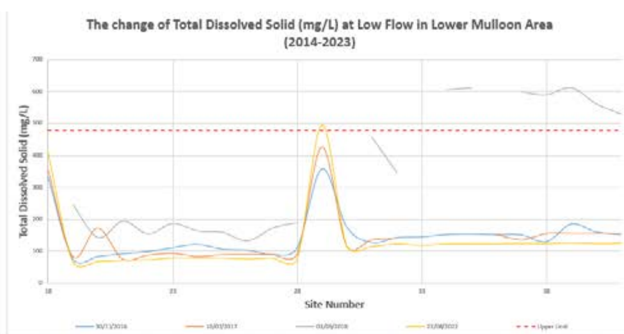


Figure 66. The change of Total Dissolved Solid (mg/L) at High Flow in Lower Mulloon (2014-2023)

Figure 67. The change of Total Dissolved Solid (mg/L) at Low Flow in Lower Mulloon (2014-2023)

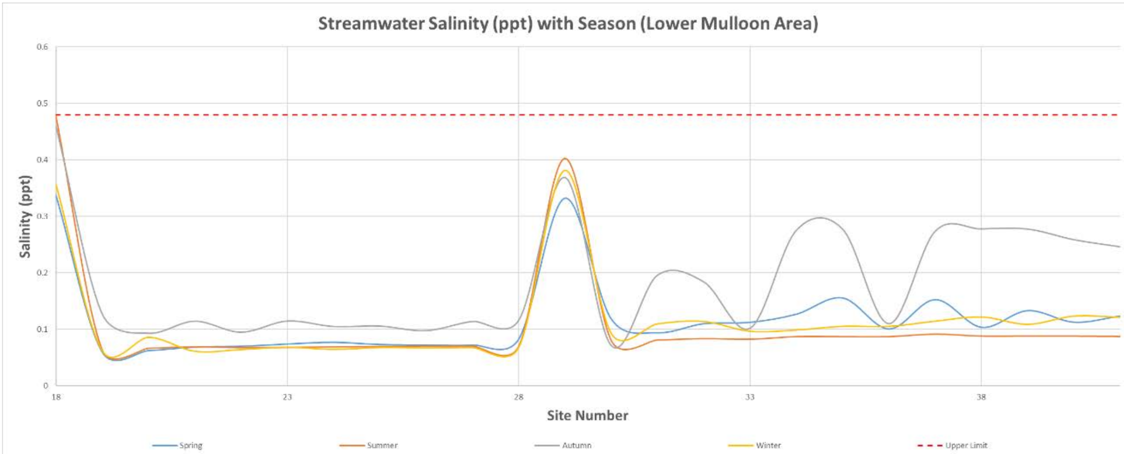
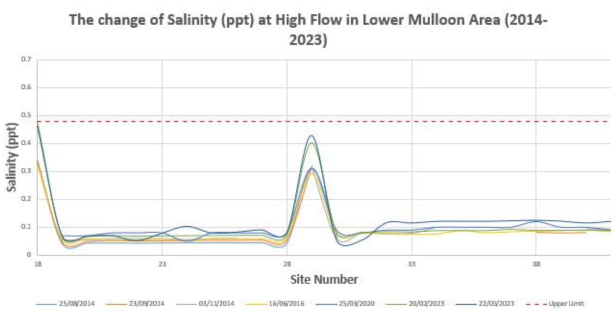


Figure 68. Stream water Salinity (ppt) with Season (Lower Mulloon)



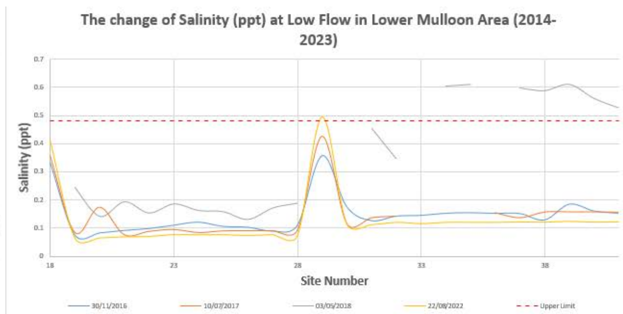


Figure 69. The change of Salinity (ppt) at High Flow in Lower Mulloon (2014-2023)

Figure 70. The change of Salinity (ppt) at Low Flow in Lower Mulloon (2014-2023)

5.3.3 Stream water Dissolved Oxygen (Lower Mulloon) (2014-2023)

Measured dissolved oxygen (DO mg/L and $\%_{sat}$) values for Lower Mulloon Creek were typically low, (commonly <10mg/L and <100$\%_{sat}$) with significant seasonal variation, including notably higher measured values Under the Highway Bridge (Site 23; 280$\%_{sat}$), at the Lower Mulloon Gauging Station (Site 26; 170$\%_{sat}$), at Sandhills Creek (Site 29; 280$\%_{sat}$), at Bank 1 (Site 32; 230$\%_{sat}$), at Bank 3 (Site 34; 140$\%_{sat}$), Upstream of Gauging Station (Site 36; 200$\%_{sat}$), Duralla 1 (Site 37; 150$\%_{sat}$), Bank 5 (Site 39; 270$\%_{sat}$) (Figure 68). Simlar patterns were observed in the DO mg/L data (Figure 71). Overall, measured DO values were highest in summer, and lower in spring, winter, and autumn, respectively (Figures 71, 74).

Under high flow conditions, with the exception of limited dissolved oxygen (DO mg/L and $\%_{sat}$) data from November 2014 and highly variable readings in February 2023, recorded values are relatively consistent for Lower Mulloon Creek. In November 2014 values were high at, and downstream of, Sandhills Creek (Site 29). In February 2023 low values were recorded at the Soil Con Weir at Carrols (Site 22), at Crossing 1 (Site 27) and at the Pool below Reedy Creek control (Site 41), and high values were recorded Under the Highway Bridge (Site 23), at the Lower

Mulloon Gauging Station (Site 26), at Bank 1 (Site 32), at Bank 3 (Site 34), Upstream of Gauging Station (Site 36), Duralla 1 (Site 37), and Bank 5 (Site 39) (Figure 72). Simlar patterns were observed in the DO mg/L data (Figure 75).

Under low flow conditions almost all readings were below 80%$_{sat}$ (and <10 mg/L) indicating relatively poor conditions to sustain diverse aquatic ecosystems in natural waters (Figure 73, 76).

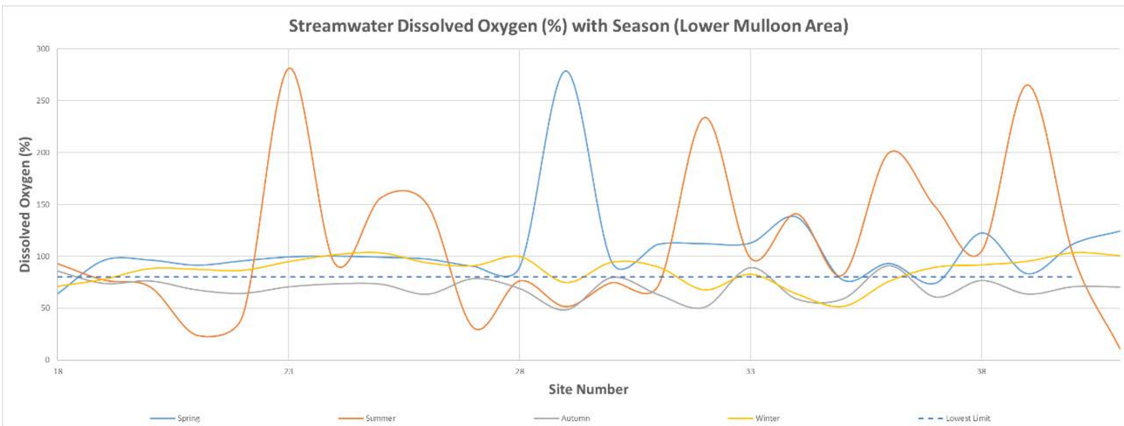
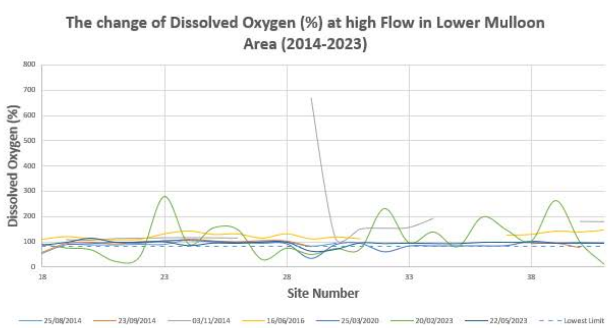


Figure 71. Stream water Oxygen (%) Lower Mulloon (2014-2023)



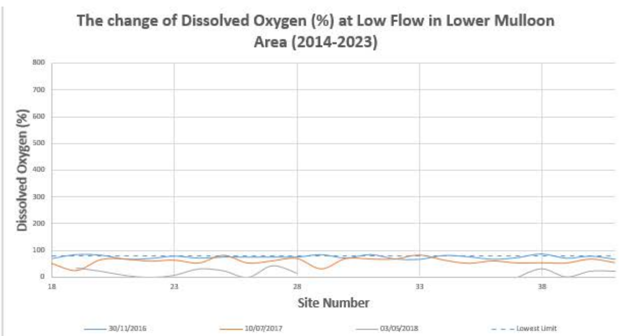


Figure 72. The change of Dissolved Oxygen (%) at High Flow in Lower Mulloon (2014-2023)

Figure 73. The change of Dissolved Oxygen (%) at Low Flow in Lower Mulloon (2014-2023)

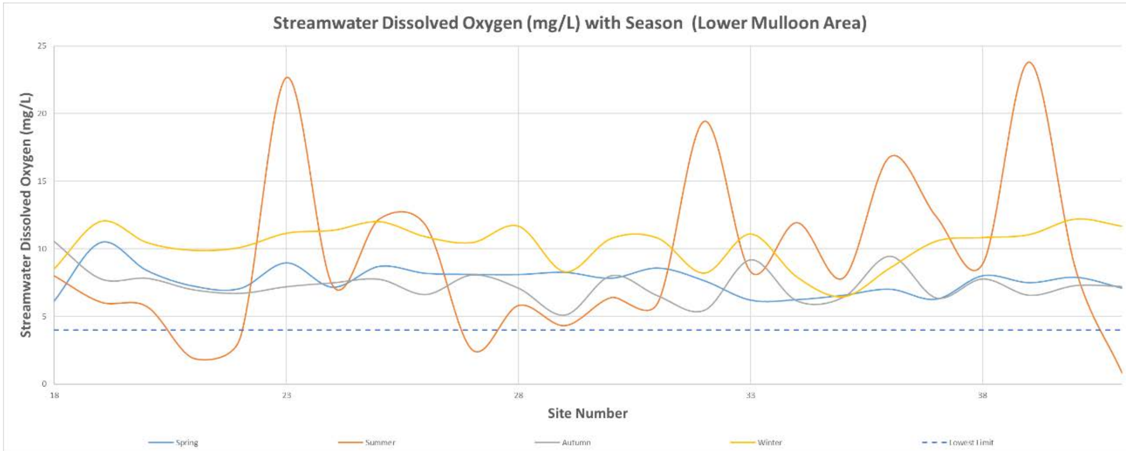
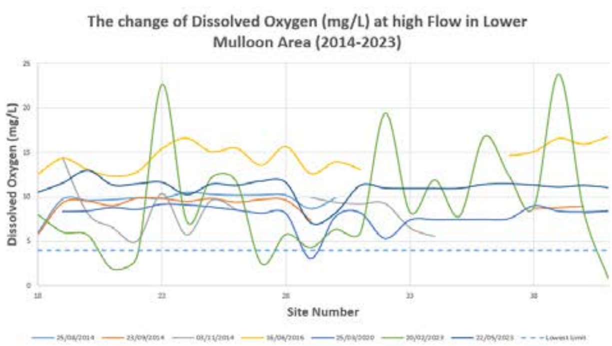


Figure 74. Stream water Dissolved Oxygen (mg/L) with Season (Lower Mulloon)



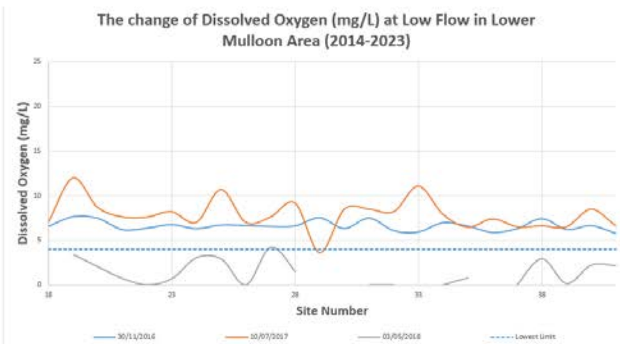


Figure 75. The change of Dissolved Oxygen (mg/L) at High Flow in Lower Mulloon (2014-2023)

Figure 76. The change of Dissolved Oxygen (mg/L) at Low Flow in Lower Mulloon (2014-2023)

5.3.4 Stream water pH (Lower Mulloon) (2014-2023)

Measured pH values were very stable for Lower Mulloon Creek (typically 6.5-7.5) and remained within the range for natural waters (Figure 47). In autumn and summer values were marginally more variable, with values approaching pH 8 at Raddle Creek (Site 18). In general, there were slightly higher values in winter, and lower values in spring, autumn and summer respectively (Figure 77). The pH showed no distinguishable pattern when high and low flow rates, were considered (Figures 78, 79).

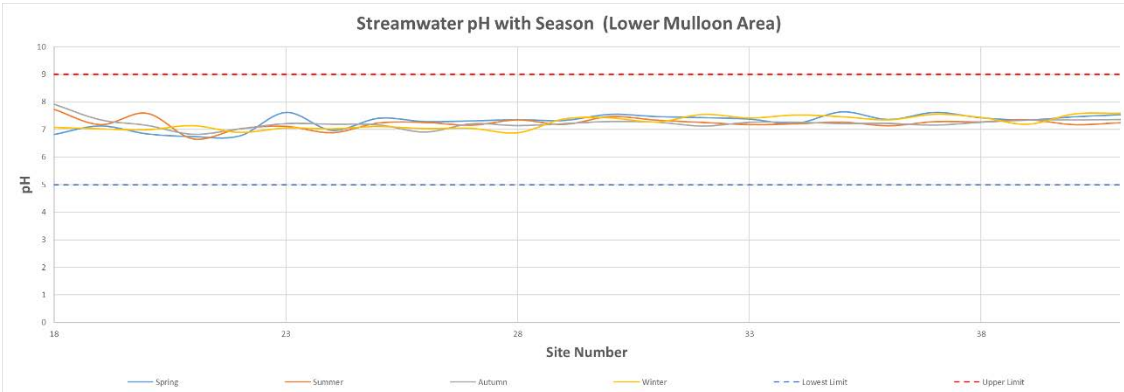
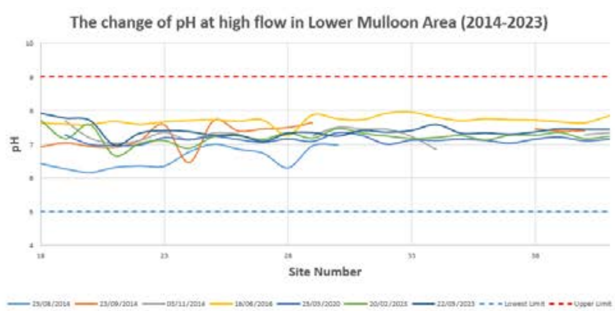


Figure 77. Stream water pH with Season (Lower Mulloon)



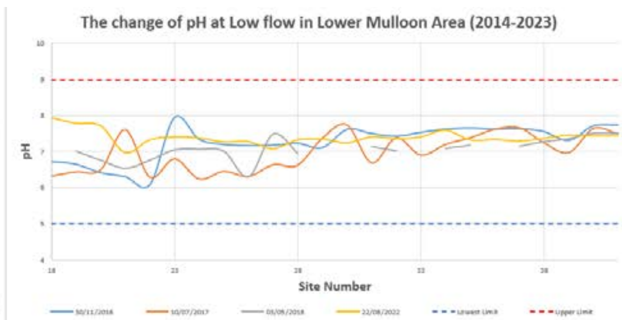


Figure 78. The change of pH at High flow in Lower Mulloon (2014-2023)

Figure 79. The change of pH at Low flow in Lower Mulloon (2014-2023)

5.3.5 Stream water Turbidity (Lower Mulloon) (2014-2023)

Measured Turbidity (NTU) values were most variable and highest in autumn, and less variable and lower in winter, spring and summer, respectively (Figure 80).

Under high flow conditions, water is typically clear with most measured turbidity values below the 15 NTU optimum limit for natural waters. Higher values are recorded in September and November 2014 and June 2016 at Carrol's 3 (Site 21) and Soil Con weir @ Carrol’s (Site 22); and in March 2020 Under Highway Bridge (Site 23) and at Duralla 1 (Site 37) (Figure 81).

Under low flow conditions, turbidity in Mid-Mullon Creek is highly variable and locally visibly muddy. High values were recorded in November 2016 at Carrol’s 2 (Site 20), Tuisk opp Weather Station (Site 24) and Bank 4 (Site 38); in July 2017 at Carrol’s 3 (Site 21), Tuisk opp Weather Station (Site 24), and Bank 5 (Site 39); and in May 2018 at DS Crossing (Site 28), Duralla 2 (Site 35), and Duralla 1 (Site 37) (Figure 82).

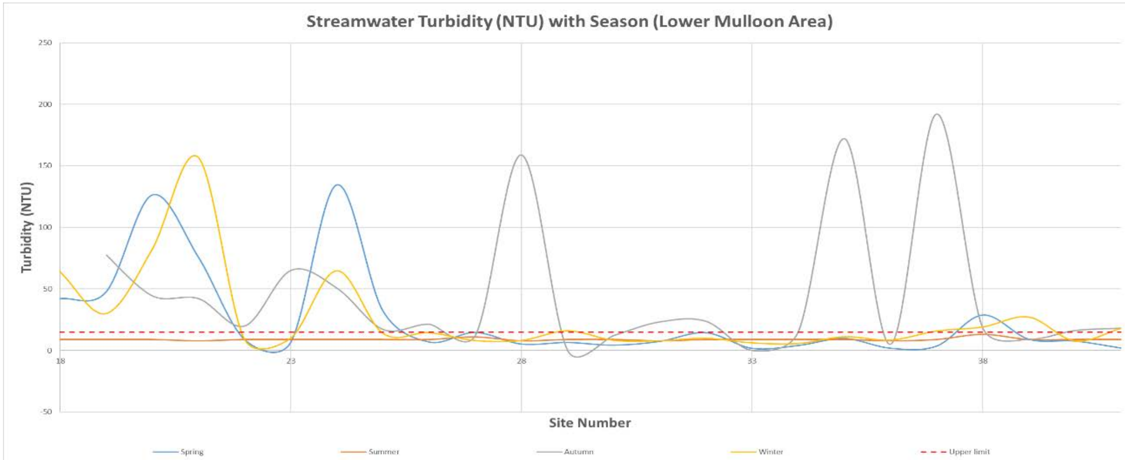
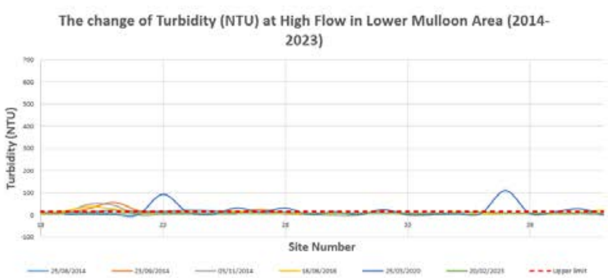


Figure 80. Stream water Turbidity (NTU) with Season (Lower Mulloon)



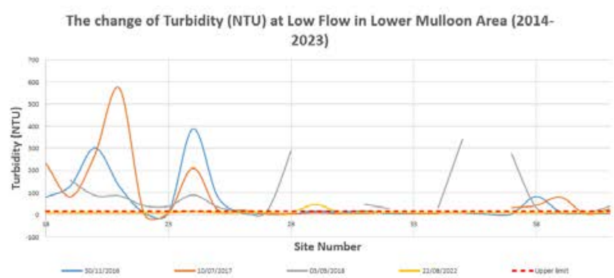


Figure 81. The change of Turbidity (NTU) at High Flow in Lower Mulloon (2014-2023)

Figure 82. The change of Turbidity (NTU) at Low Flow in Lower Mulloon (2014-2023)

5.3.6 Stream water Oxidation Reduction Potential (Lower Mulloon) (2014-2023)

Measured Oxidation-Reduction Potential (ORP) values were highest in summer, and similar in autumn, winter, and spring (Figure 83), and values fall in the range typical for natural waters.

Under high flow conditions, measured values for November 2014, June 2018 and March 2020 are significantly lower (mostly <150mV) than those measured in February 2023 (mostly >200mV), with lowest values measured at Carrol's 3 (Site 21) (Figure 84).

Under low flow conditions, most measurements in November 2016, July 2017 and May 2018 (typically <150mV) are lower than those measured in August 2023 (100-300mV) (Figure 85).

The ORP values are marginally higher in periods of high flow relative to low flow periods (Figure 85).

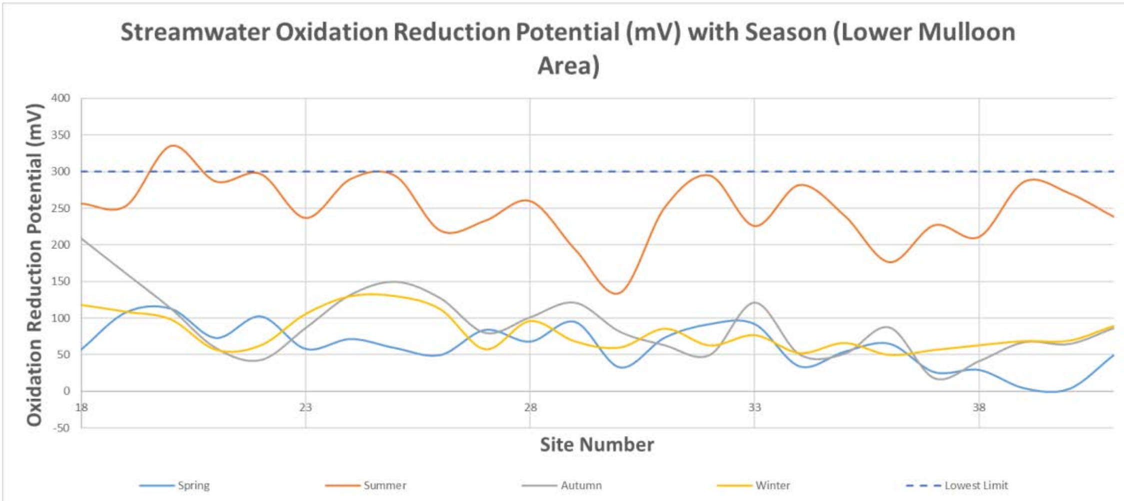
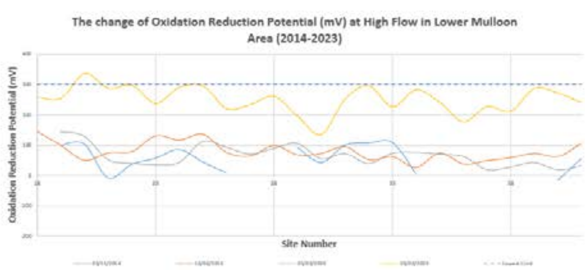


Figure 83. Stream water Oxidation Reduction Potential (mV) with Season (Lower Mulloon)



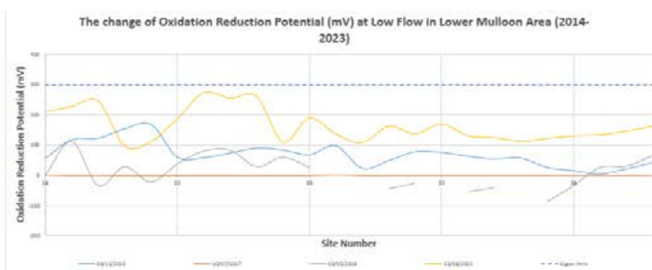


Figure 84. The change of Oxidation Reduction Potential (mV) at High Flow in Lower Mulloon (2014-2023)

Figure 85. The change of Oxidation Reduction Potential (mV) at Low Flow in Lower Mulloon (2014-2023)

5.4 The difference between stream parameters in mid-Mulloon Creek (Home Farm) and Lower Mulloon Creek (2014-2023)

5.4.1 The difference in EC between mid-Mulloon Creek (Home Farm) and Lower Mulloon Creek

The overall EC values in Lower Mulloon Creek are higher than in the Mid-Mulloon Creek (Home Farm). In general, there is a progressive increase in EC downstream (Figure 86).

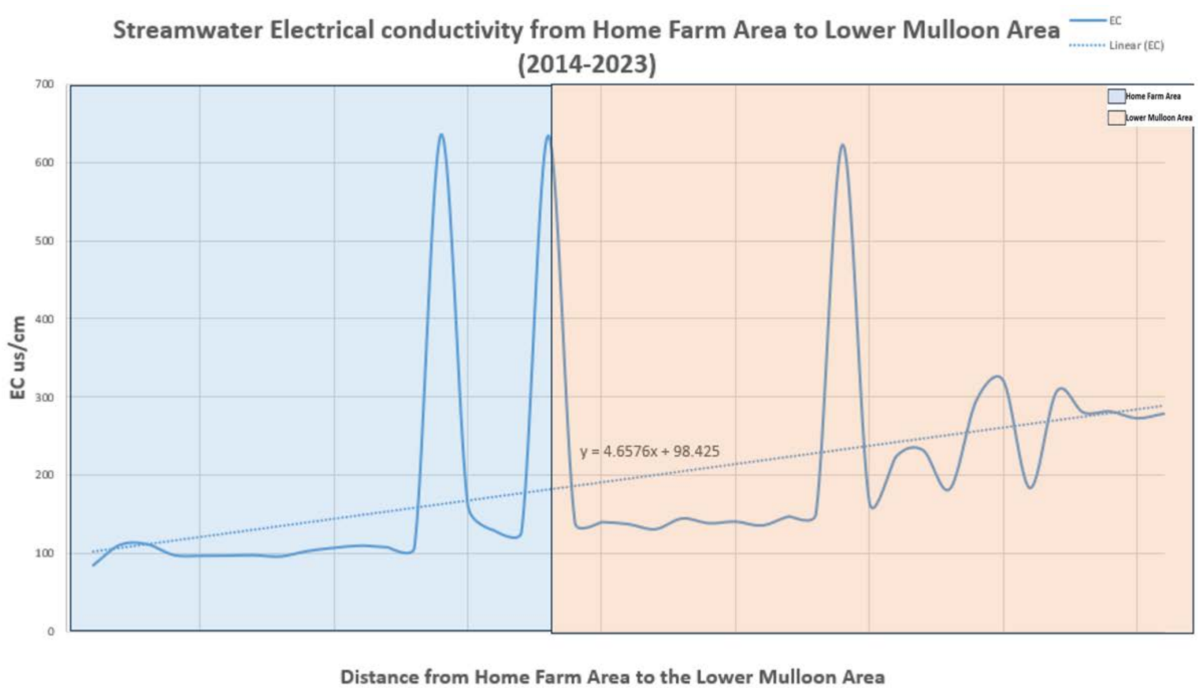


Figure 86. Stream water Electrical conductivity from Home Farm to Lower Mulloon

5.4.2 The difference DO ($\%_{sat}$) and (mg/L) between mid-Mulloon Creek (Home Farm) and Lower Mulloon Creek

The overall DO ($\%_{sat}$ and mg/L) values in Lower Mulloon Creek are higher than in the Mid-Mulloon Creek (Home Farm). In general, there is a progressive increase in DO downstream (Figures 87, 88).

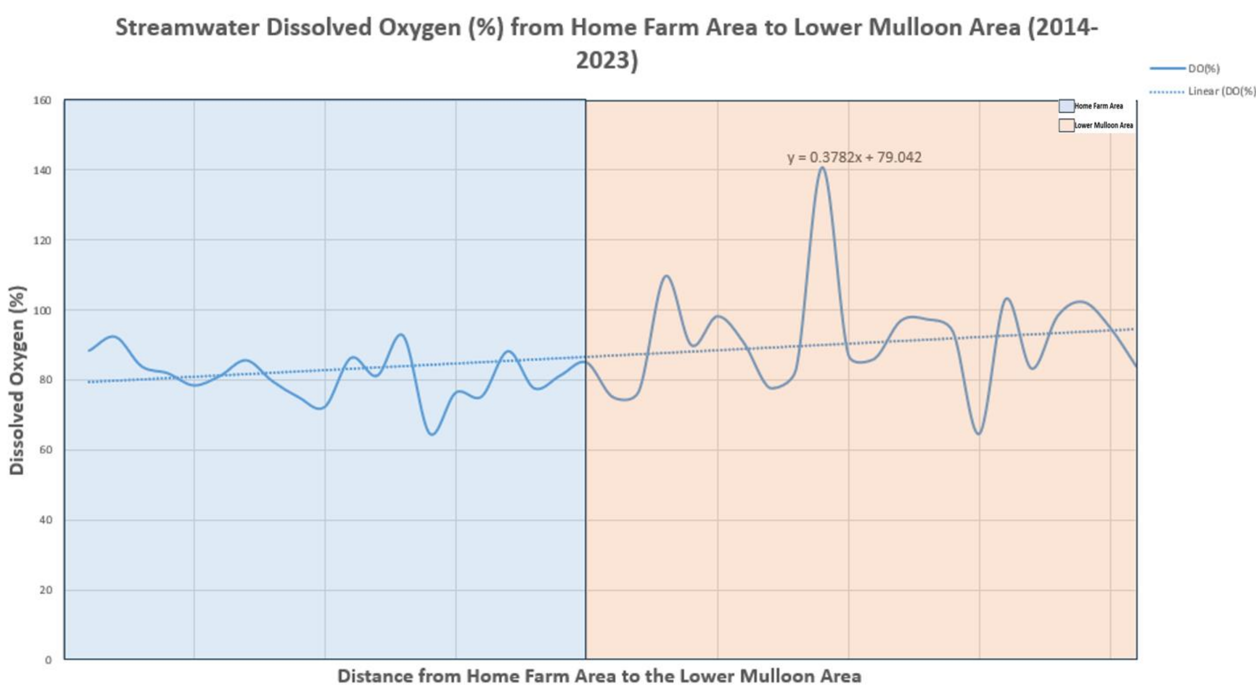


Figure 87. Stream water Dissolved Oxygen (%) from Home Farm to Lower Mulloon (2014-2023)

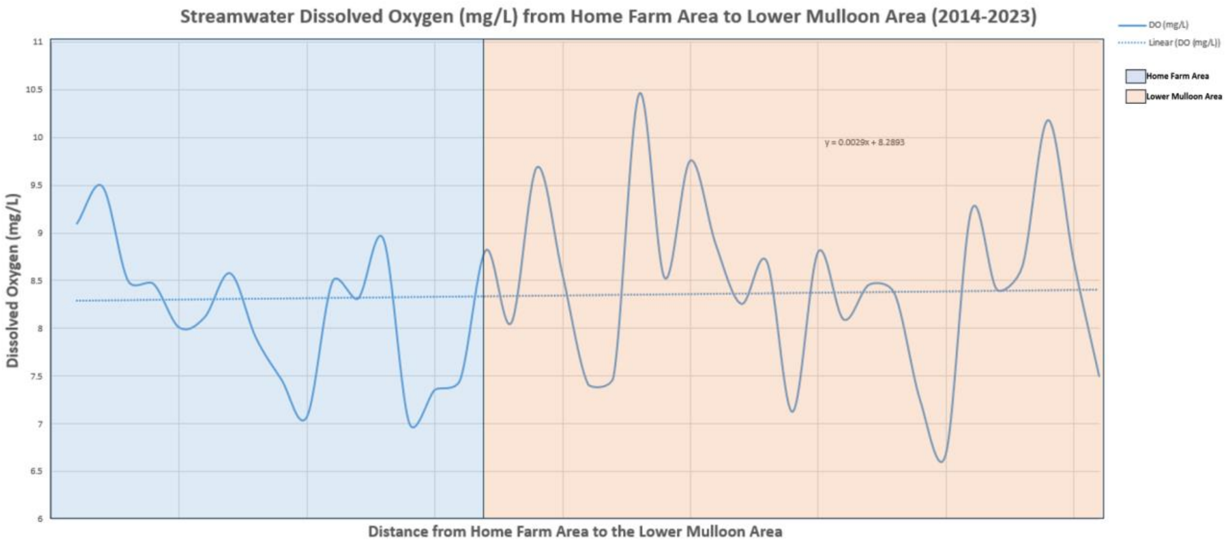


Figure 88. Stream water Dissolved Oxygen (mg/L) from Home Farm to Lower Mulloon (2014-2023)

5.4.3 The difference in Turbidity (NTU) between mid-Mulloon Creek (Home Farm) and Lower Mulloon Creek

Although there is a lot of variation, the overall Turbidity (NTU) values in Lower Mulloon Creek are lower than in the Mid-Mulloon Creek (Home Farm). In general, there is a progressive decrease in Turbidity (i.e. waters are clearer) downstream (Figure 89).

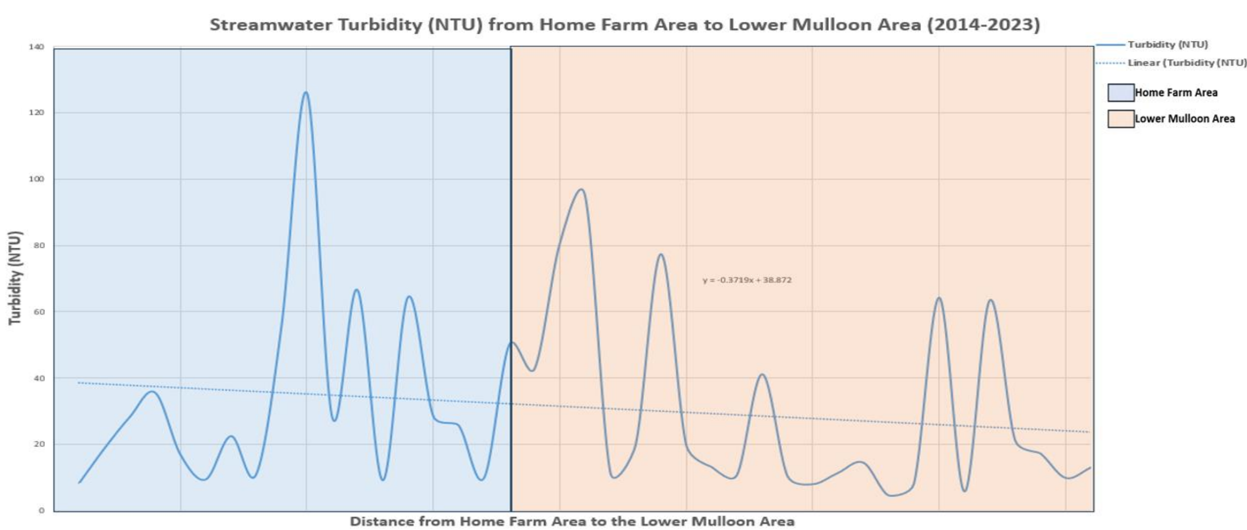


Figure 89. Stream water Turbidity (NTU) from Home Farm to Lower Mulloon (2014-2023)

5.4.4 The difference in Oxidation Reduction Potential (mV) between mid-Mulloon Creek (Home Farm) and Lower Mulloon Creek

The overall ORP (mV) values in Lower Mulloon Creek are lower than in the Mid-Mulloon Creek (Home Farm). In general, there is a progressive decrease in ORP downstream (Figure 90).

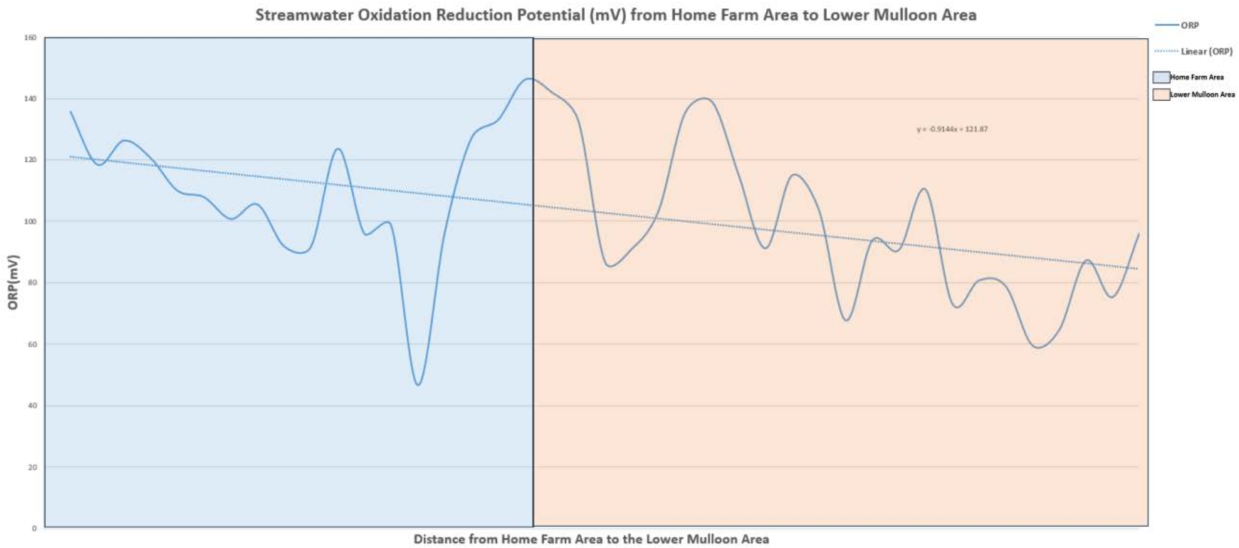


Figure 90. Stream water Oxidation Reduction Potential (mV) from Home Farm to Lower Mulloon (2014-2023)

5.5 *The change in physicochemical parameters in weir ponds on Mid-Mulloon Creek (Home Farm) (2016 and 2023)*

Physicochemical measurements were taken at weir ponds on Mid-Mulloon Creek (Home Farm), in 2016 (30 November 2016; 7.60ML/day) and 2023 (22 August 2023; 12.06ML/day) at a similar, relatively low flow rate.

5.5.1 The change in Electrical Conductivity in weir ponds on Mid-Mulloon Creek (Home Farm) (2016 and 2023)

For both periods electrical conductivity typically increases downstream, indicating salt accession from the landscape as Mulloon Creek passes through the Home Farm (Figure 91). Values are marginally higher in November 2016 than August 2023, likely reflecting drier antecedent conditions in November 2016.

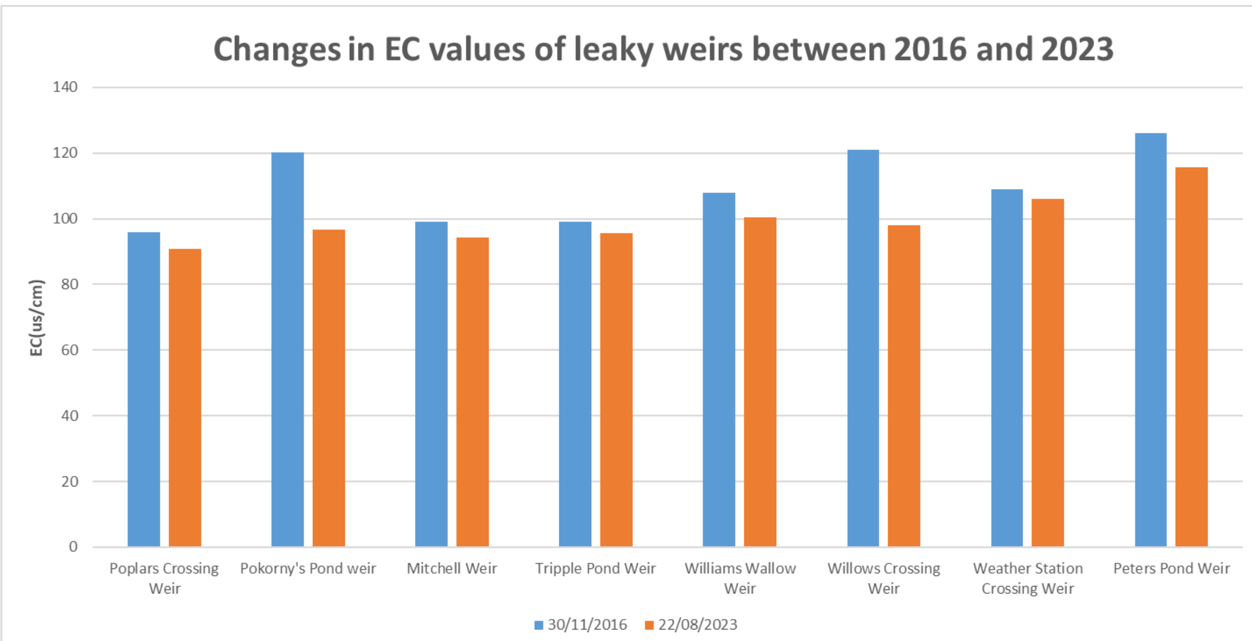


Figure 91 The change in Electrical Conductivity in weir ponds on the Mid-Mulloon Creek (Home Farm) in late 2016 and late 2023 (8 leaky weirs)

5.5.2 The change in Oxidation Reduction Potential (mV) of weir ponds on Mid-Mulloon Creek (Home Farm) (2016 and 2023)

The measured ORP values in 2016 and 2023 in weir ponds on Mid-Mulloon Creek (Home Farm), show considerably lower ORP values in November 2016 than in August 2023 when flow was marginally higher and antecedent conditions wetter (Figure 92). At most ponds conditions were reducing in November 2016.

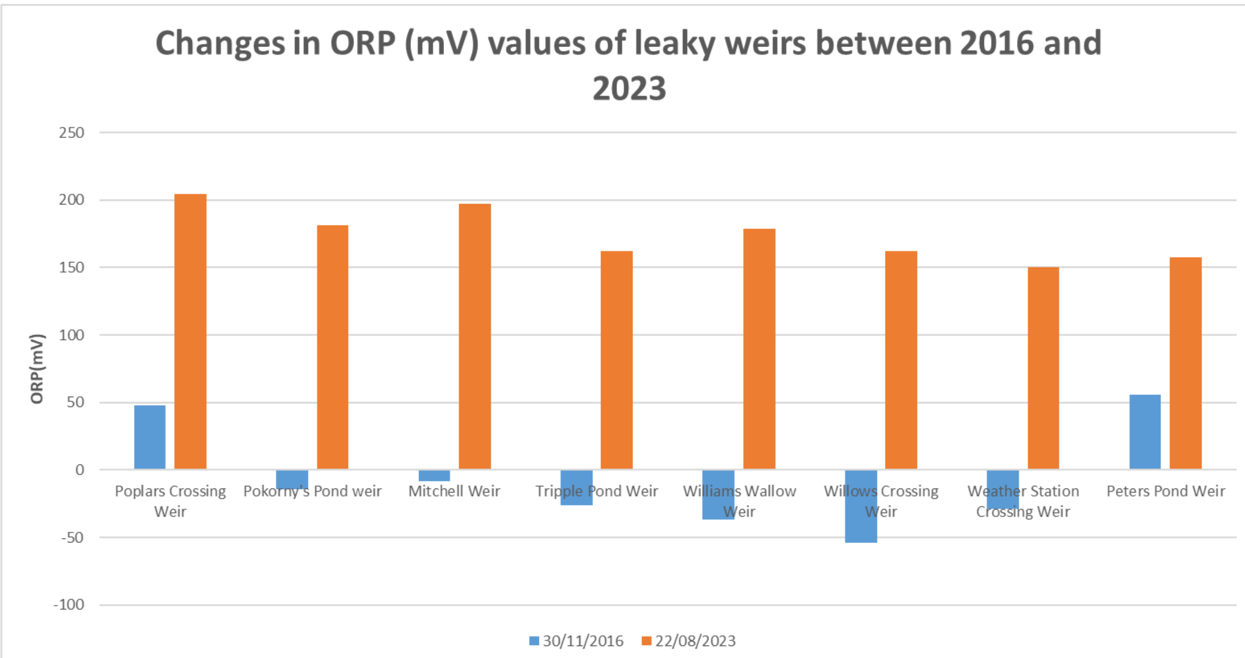


Figure 92. The change in oxidation-reduction potential (ORP mV) in weir ponds on the Mid-Mulloon Creek (Home Farm) in late 2016 and late 2023 (8 leaky weirs)

5.5.3 The change in Turbidity (NTU) of weir ponds on Mid-Mulloon Creek (Home Farm) (2016 and 2023)

The measured turbidity values in 2016 and 2023 in weir ponds on Mid-Mulloon Creek (Home Farm), generally show higher turbidity in November 2016 than in August 2023 when flow was marginally higher and antecedent conditions wetter (Figure 92). At three ponds, William's Wallow, Willow's Crossing and Peter's Pond weir, water was very turbid in November 2016, in part because these areas are used as stream crossings.

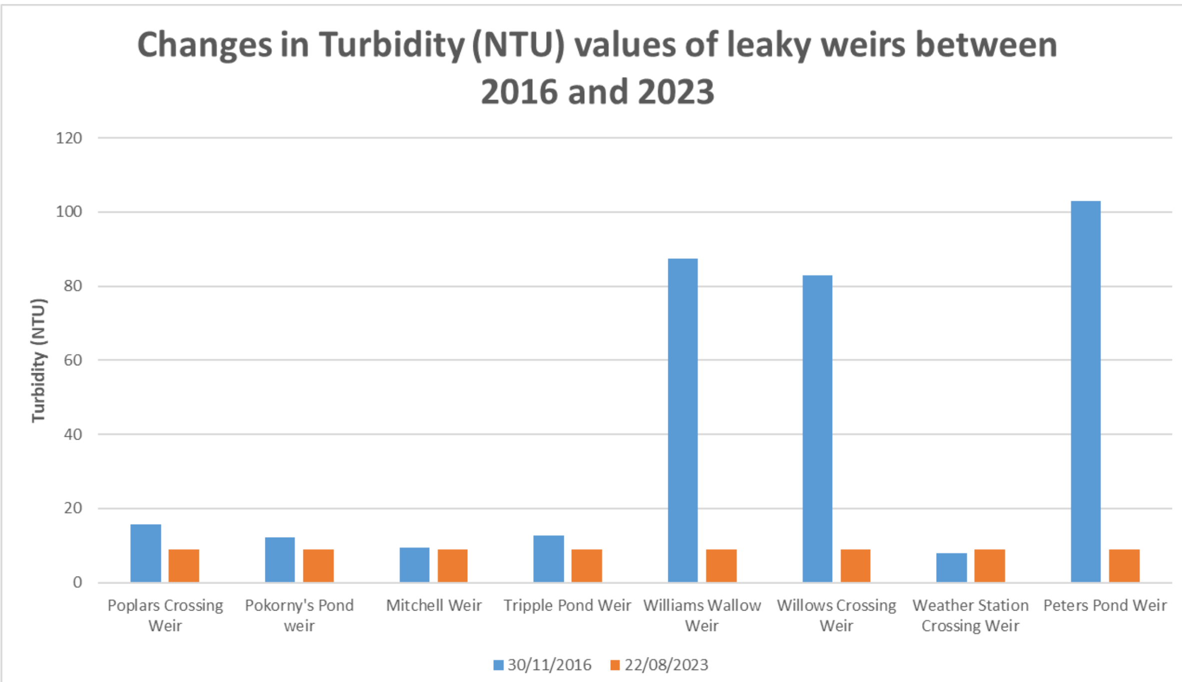


Figure 93. The change in Turbidity (NTU) in weir ponds on the Mid-Mulloon Creek (Home Farm) in late 2016 and late 2023 (8 leaky weirs)

Chapter 6: Discussion

6.1 Home Farm

6.1.1 Stream Temperature (°C) Mid-Mulloon Creek (Home Farm)

The stream water temperature in Mid-Mulloon Creek is higher in summer and cooler in winter, a pattern that mirrors the general pattern for year-round air temperature. When we compare stream temperatures in spring and autumn, the spring temperatures are slightly higher than those in autumn because spring data were gathered closer to the summer months.

Compared to upstream and downstream sites, warmer temperatures were recorded at the Channel from David's Swamp (Site 14) (Figure 94). The David's Swamp area ponds shallow water that can be heated by the sun prior to entering Mid-Mulloon Creek via the drainage channel, resulting in consistently higher temperature measurements at this site.

In general, when the stream water temperature is warm, monitoring points that show differences exhibit cooler temperatures. When the stream water temperature is low, water at these monitoring points is commonly warmer. Some variations in temperature could be attributed to the presence of larger bodies of ponded water behind leaky weirs maintaining more constant temperatures than flowing sections of Mulloon Creek. This might explain warming at some sites including Triple Pond Crossing (Site 8) and Peter's Pond (Site 16).

If we assume that groundwater in this part of the catchment remains at a relatively steady temperature year-round, then one explanation for cool variations in temperature at some sites during the warmer months or warm variations in temperature at some sites in cooler months, could be attributed to net gain of groundwater into Mid-Mulloon Creek. Variations were observed at Opp trough south of Poplars Crossing (Site 2); Hazell Bank (Site 4), William's Wallow (Site 9); Willows Crossing (Site 10); Willows Runnel (Site 11); Crossing north of Williams Crossing (Site 12).

6.1.2 Stream Electrical Conductivity (EC) Mid-Mulloon Creek (Home Farm)

The measured EC (TDS and Sal) values in Mid-Mulloon Creek are relatively low, in the range EC 100-200 µS/cm (TDS 60-120 mg/L; Sal 0.06 0.12 ppt) at most monitoring sites, indicating that the water is fresh.

Compared to upstream and downstream sites, higher EC (TDS and Sal) values were recorded at the Channel from David's Swamp (Site 14) (Figure 94; EC 550-800 µS/cm; TDS 330-480 mg/L; Sal 0.33-0.48 ppt). The David's Swamp area ponds shallow water and evaporative concentration can increase the salinity of this water prior to entering Mid-Mulloon Creek via the drainage channel, resulting in consistently higher EC (TDS and Sal) measurements at this site.

It has been established that groundwater in the Lower Mulloon Creek catchment is more saline (has higher EC) than stream water (Hickson, 2017; de Lorenzo, 2021), so if this is also true for Mid-Mulloon Creek, one explanation for variations in EC (TDS and Sal) at some sites could be attributed to net gain of groundwater into Mid-Mulloon Creek. Variations were observed at Opp trough south of Poplars Crossing (Site 2); Hazell Bank (Site 4), William's Wallow (Site 9); and Willows Runnel (Site 11). During periods of high flow, these patterns are less apparent as stream water dilutes the groundwater signal.

Figure 94. Water in the channel from David's Swamp (Site 14) is typically warmer and more saline that water in Mid-Mulloon Creek

6.1.3 Stream water DO (mg/L) and DO (%$_{sat}$) Mid-Mulloon Creek (Home Farm)

Measured dissolved oxygen (DO %$_{sat}$ and mg/L) is higher at high stream flow and lower at low stream flow. During periods of high flow increased river flow velocities lead to greater turbulence as water rushes over rocky substrates, facilitating the absorption of oxygen from the atmosphere. Cool water temperatures may also influence observed patterns as oxygen is more soluble in colder water. Higher average dissolved oxygen values were measured in winter in Mid-Mulloon Creek.

High DO values were recorded in summer at Opp trough south of Poplars Crossing (Site 2) Willows Runnel (Site 11) and Weather Station Crossing (Site 13). In warmer and sunnier months, phytoplankton activity (photosynthesis) can locally elevate dissolved oxygen levels.

Extremely low DO values were recorded at the Channel from David's Swamp (Site 14; Figure 94) in every sampling period. Introduction of warm saline water into Mid-Mulloon Creek at this site can adversely impact photosynthesising organisms due to ion toxicity, osmotic stress, nutrient deficiency and oxidative stress (Shrivastava and Kumar, 2015). These detrimental factors can result in very low dissolved oxygen (DO) values in natural waterways.

In periods of low flow, low DO values can be attributed to limited aquatic ecosystem function. In addition, if organic matter decays in ponded stagnant or slow flowing stream water, oxygen is consumed, thereby reducing DO levels in stream water.

6.1.4 Stream water pH Mid-Mulloon Creek (Home Farm)

Measured pH values in Mid-Mulloon Creek were relatively constant (pH 6.5-7.5) across the measurement period. The primary factors influencing pH levels are temperature and the concentration of dissolved species, including carbon dioxide (CO_2), in stream water (Wurts and Durborow, 1992; Garcia and Ramirez, 2017). Measurement of dissolved ions is beyond the scope of this study, but the limited variation in measured pH in Mid-Mulloon Creek suggests that these values remain relatively constant across the sampling period, apart from locations with recognised salt input (e.g. Site 14). Observed variations can generally be attributed to changes in temperature with pH values decreasing marginally with increased temperature.

6.1.5 Turbidity Mid-Mulloon Creek (Home Farm)

During high flow periods water in Mid-Mulloon Creek is typically clearer than in low flow periods, and there is a lot of local variation in turbidity in periods of low flow. Some of the field sites are near stream crossings and, although sampling was timed to avoid this impact, some elevated measurements may relate to anthropogenic or stock disturbance at the sites (Figure 95). In areas where sediment accumulates and is not readily flushed downstream, for example in ponded areas, there may be elevated turbidity.

Figure 95. Crossing north of Williams Crossing (Site 12) is episodically disturbed by vehicles crossing, and stock watering

In areas where saline water enters a waterway, suspended clays can flocculate and settle resulting in clearer water downstream of ingress zones. This pattern is not observed clearly at Mid-Mulloon Creek, likely because the saline flux is localised and relatively dilute.

6.1.6 Stream water ORP Mid-Mulloon Creek (Home Farm)

Seasonal fluctuations in Oxidation-Reduction Potential (ORP) are linked to temperature variations (Hamilton, 2023). In general, elevated temperatures facilitate redox reactions, resulting in elevated ORP. Measured ORP values in Mid-Mulloon Creek are higher in summer and lower in winter, indicating that there is some temperature control on ORP.

Higher ORP levels observed in February and May 2023 coincided with periods of high water flow. This can be attributed to increased water velocity, and possibly intensified photosynthesis by aquatic organisms (more likely in February) during these periods, resulting in elevated Dissolved Oxygen (DO) levels, and consequently increased ORP.

At sites where there is a localized influx of saline surface water or groundwater the salinity profile in Mid-Mulloon Creek changes, impacting DO levels, in turn affecting ORP levels. At the Channel from David's Swamp (Site 14), saline surface water enters Mid-Mulloon Creek and reduced ORP values were measured at this site.

During low-flow periods, the overall decline in ORP values may be caused by higher EC levels and lower DO values, associated with reduced stream water flow.

6.2 Lower Mulloon

6.2.1 Stream water Temperature (°C) Lower Mulloon Creek

Seasonal variations in stream temperature exhibit a positive correlation with seasonal air temperature in Lower Mulloon Creek.

Local observations of higher temperatures in the wet season may be attributed to the ingress of groundwater, for example the pattern observed at Carrol's 2 (Site 20) and Tuisk opp Weather Station (24) in August 2014 and September 2014. During this period, the groundwater temperature is likely to be higher than the relatively cool stream water. Marked decreases in temperature observed at the same sites in November 2014 may indicate that the groundwater has a lower temperature than the relatively warm stream water.

6.2.2 Stream EC (TDS and Sal) Lower Mulloon Creek

The seasonal EC pattern observed in Lower Mulloon Creek mirrors that of the Mid-Mulloon Creek with relatively fresh water at most sites.

At Raddle Creek (Site 18; Figure 96), Tuisk opp Weather Station (Site 24), and Sandhills Creek (Site 29; Figure 97) higher EC measurements can be attributed to flow of water through and over regolith materials developed on Ordovician meta-sediments (Figure 12), that host stored salts. Some evidence of flocculation of fine sediments due to the presence of dissolved salt, is apparent in Sandhills Creek (Site 29; Figure 97).

In a study of groundwater in the Lower Mulloon Creek area, all measured groundwater values were more saline (200µS/cm to >3000µS/cm; Figures 98, 99) than measured stream water values (<200µS/cm; Figures 98, 99). In periods of low flow EC may increase in areas downstream of surface or groundwater saline water ingress locations, where water is ponded and evaporatively concentrated (e.g. at Bank 3 (Site 34) in May 2018).

Figure 96. Clear water at Raddle Creek (Site 18) with elevated EC relative to Lower Mulloon Creek

Figure 97. Relatively clear water Sandhills Creek (Site 29) with elevated EC relative to Lower Mulloon Creek

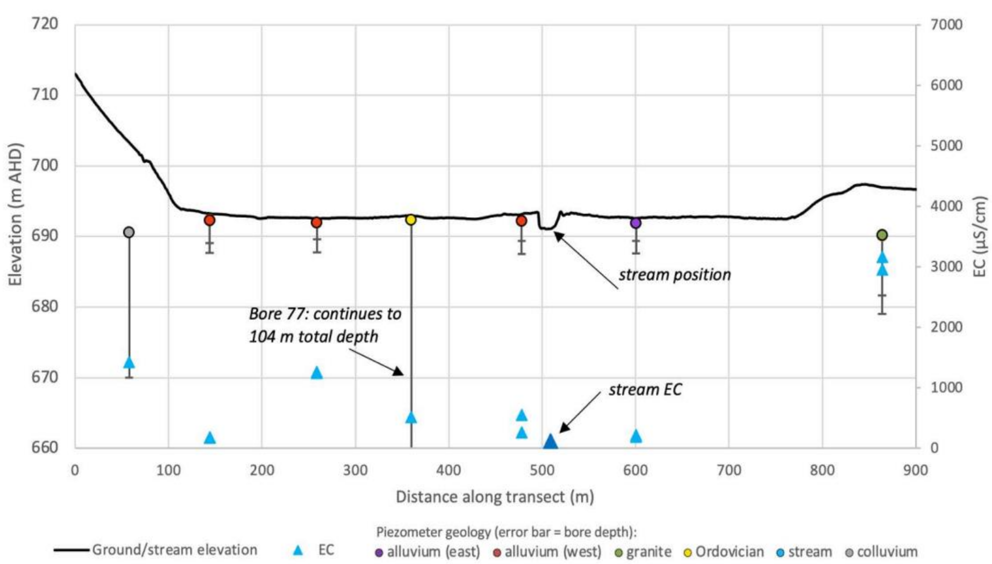


Figure 98. Groundwater Transect 3. across Lower Mulloon Creek shows piezometer depth, hydraulic potential, EC, stream water level and EC for Lower Mulloon Creek in September 2020 (de Lorenzo, 2021).

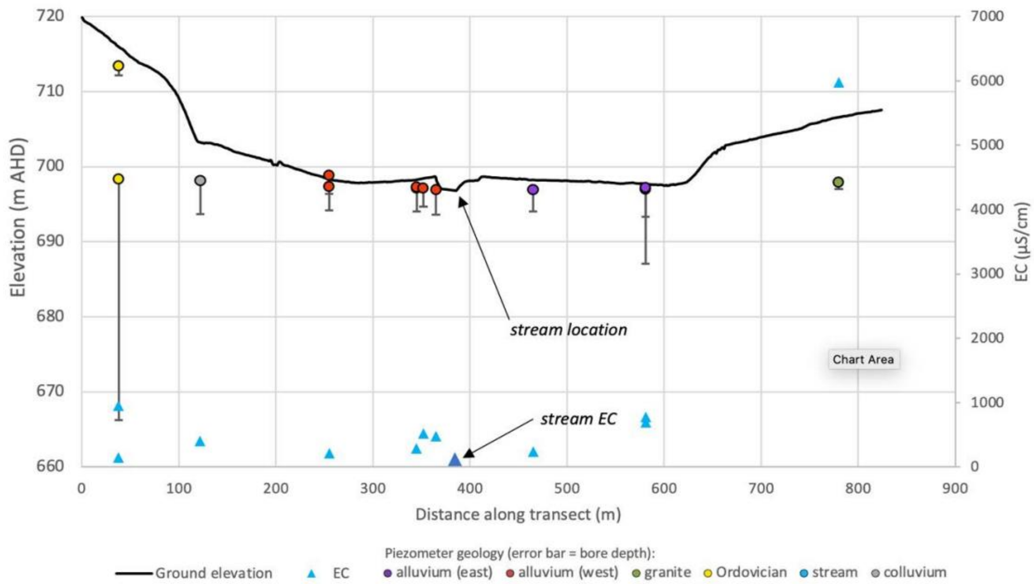


Figure 99. Groundwater Transect 4. across Lower Mulloon Creek shows piezometer depth, hydraulic potential, and EC, stream water level and EC for Lower Mulloon Creek in September 2020 (de Lorenzo, 2021).

6.2.3 Stream water DO (mg/L) and DO (%) (Lower Mulloon)

As observed in Mid-Mulloon Creek, higher DO values are typically recorded at times of high stream flow.

Low DO values were consistently measured at Raddle Creek (Site 18) and Sandhills Creek (Site 29) due to salt ingress at these sites. The abnormally low DO values registered at Carrol's 3 (Site 21) and Soil Con weir at Carrol's (22) in February 2023, were primarily caused by an influx of salt from Reedy Creek (stored salts in regolith over Ordovician metasediments; Figure, 12). This influx of salt inhibited the photosynthesis of aquatic organisms at these 2 sites, reducing the DO levels.

Low DO levels were associated with all periods of low stream flow due to limited turbulent flow, warmer water conditions (lower solubility of oxygen), and potentially due to decay of organic matter in areas of stagnant or low flow stream water.

6.2.4 Stream water pH Lower Mulloon Creek

Measured pH values in Lower Mulloon Creek were relatively constant (pH 6.5-7.5) across the measurement period. Observed variations can generally be attributed to changes in temperature with pH values decreasing marginally with increased temperature. At Raddles Creek (Site 18) values approach pH 8 reflecting the influx of saline water at this site.

6.2.5 Turbidity Lower Mulloon Creek

Seasonal variations in turbidity in the lower Mulloon area, reflect those observed at Mid-Mulloon Creek (Home Farm) with clear water in periods of high flow and muddy water at some sites associated with periods of low flow. For example, in September and November 2014, and June 2016, elevated turbidity measurements at Carrol's 3 (Site 21; Figure 100) and Soil Con Weir at Carrol's 3 (Site 22; Figure 101) were the result of localized waterlogging. Water flow during these periods brings sand and silt into the stream. The stream at this time resembles a large pond, with an abundance of aquatic plants. The presence of these aquatic plants leads to the entanglement and retention of sediment.

The reason why turbidity was elevated in November 2016 and November 2017, can be attributed to a substantial drop in water level to the point where sites were no longer connected by flowing water. Sediments were deposited at this time due to low water velocity.

In May 2018 there was a peak in turbidity conditions, because flows were extremely low. During this month, minimal flow occurred between sites and as a consequence, a significant volume of sediment accumulated.

Figure 100. Carrol's 3 (Site 21) experienced elevated turbidity associated with localized waterlogging in 2014 and 2016.

Figure 101. Soil Con weir at Carrol's (Site 22) experienced elevated turbidity associated with localized waterlogging in 2014 and 2016.

6.2.6 Stream water ORP Lower Mulloon Creek

The reasons for the seasonal variations in overall oxidation-reduction potential (ORP) in the Lower Mulloon area align with those observed in the Home Farm area. Low measured ORP values typically occurred when DO was also low. At periods of low flow ORP can be affected due to the impact of water scarcity on DO levels.

6.3 The difference between the stream parameters in Mid-Mulloon Creek and Lower Mulloon Creek

The elevated salinity in the Lower Mulloon area compared to the Home Farm area can be attributed to several factors. Firstly, a number of tributaries (Raddle Creek, Sandhills Creek and Reedy Creek) in the Lower Mulloon area traverse regolith developed over Ordovician metasediments that store salt. In association with heavy or sustained rainfall, these soluble salts can mobilise into streams, along with sediment particles. Locally, there may be an influx of groundwater into the Lower Mulloon Creek as well. These factors collectively contribute to an increase in salinity, consequently leading to higher EC (TDS and Sal).

In general, the DO levels are higher in the Lower Mulloon area than the Home Farm area. This could be attributed to the presence of a larger number of leaky weirs in the Lower Mulloon Creek area, that create disrupted flow as water passes through and over the weirs (aerating the water) and ponds where photosynthesizing aquatic organisms can thrive. It is important to note that there is elevated salts in the Lower Mulloon Creek that can locally inhibit oxygenating processes.

6.4 Changes in stream parameters in weir ponds with different antecedent conditions (2016 and 2023).

The effects of antecedent conditions (drier versus wetter) on water quality are evident when comparing conditions in November 2016 (drier antecedent conditions) and August 2023 (wetter antecedent conditions) at similar flow rates (7.60 ML/day and 12.06 ML/day respectively). If landscape systems are wetter, there has been notable improvement in overall water quality. This includes: a decrease in EC (lower water salinity), in increase in oxidation-reduction potential (ORP) associated with elevated dissolved oxygen (DO) levels, and less turbidity. This indicates that ether more salt is mobilized and/or there is less dilution of salts in the stream when conditions are drier. When conditions have been wetter and streamflow more energetic the DO and ORP values are typically higher. When flow has been lower, the turbidity is typically higher, as there is more exposed muddy material to be mobilised.

6.5 Suggestions for improving the water quality in Mulloon Creek

1. The stream significantly benefits from the presence of sizable fallen tree trunks in their vicinity (Meleason et al., 2002). When trees fall near streams, they release leaves and branches, providing essential nourishment for aquatic life (Brody, 1992). In addition, they act as natural barriers that mitigate stream-bank erosion in the by impeding the force of rushing water (Mass.gov, 2022). The resulting deeper pools have the capacity to retain more water in the dry season, maintaining a close connection with cooler groundwater (Mass.gov, 2022). Over time, these fallen logs functioned as leaky weirs (Figure 98) (Meleason et al., 2002), similar to the manmade ones observed at Mulloon Creek. In turn the presence of ponded water enhances the growth of riparian vegetation.

Figure 102. Fallen trees create natural leaky weirs (Meleason et al., 2002)

2. Mitigate overgrazing in the vicinity of streams, as excessive grazing can lead to significant vegetation loss and trigger soil erosion (Evans, 1977). This results in a substantial influx of soil from the banks into the stream, impacting the water quality.
3. Undertake the planting and protection of native trees and shrubs along streams in the Mulloon area. The rise in river water temperatures, attributed to the diminished solubility and heightened rates of biochemical reactions, stems from the depletion of shaded riparian vegetation or an increase in surface exposure caused by impoundment in the river channel (Moring, 1975). Apart from shading streams and aiding aquatic life by maintaining cool water temperatures, these native plants anchor their roots firmly in the soil, minimizing riverbank erosion.

Chapter 7: Conclusion

This research highlights the importance of monitoring water quality in agricultural areas like Mulloon Creek. By analyzing water chemistry and physicochemical parameters, we can gain valuable insights into the health of the stream and the effectiveness of interventions like leaky weirs. The results of this study suggest that the water quality in Mulloon Creek fluctuates based on the different seasons, river flow, and geographic location. In addition, the weirs have had a positive impact on water quality, which is an encouraging sign for the future of regenerative agriculture in the area. However, continued monitoring and analysis of water quality data is necessary to ensure that the health of the stream is maintained over time. Overall, this research demonstrates the value of scientific inquiry in addressing environmental challenges and promoting sustainable agriculture.

While there has been progress in my research this time, there are still some shortcomings to address:

1. The research data over the ten-year period wasn't evenly distributed annually, despite conducting water quality monitoring multiple times throughout the 10-year period. As a result, there are gaps in the data for certain years.
2. Parameters including temperature, pH, EC (TDS and Sal), DO and ORP acquired during the field program, serve as fundamental indicators for water quality monitoring. While these parameters are effective in addressing general stream health issues, they lack the capacity for more in-depth exploration of biological and hydrological factors, such as studying river bacteria (E. coli), and soluble ions and trace elements.
3. The data collected before 2023 lacks readily accessible ground-level photos, hindering the analysis of the original state of the field sites.

To address these limitations, future research should be aware of the following points:

1. Increase sampling frequency to monthly to monitor fluctuations in water quality.
2. Parameters such as T, pH, EC (TDS and Sal), DO and ORP should continue to be recorded but analyses should be expanded to include soluble ions, trace elements and biological factors, and monitoring of the major tributaries should take place. Sandhills Creek and Reedy Creek.
3. Maintain a photographic journal for each sampling site to document spatial and temporal changes for future reference.

Despite these limitations these results are still able to provide an important framework for the sustainable management of Mulloon Creek. In addition, the results of this study may provide a foundation for ongoing monitoring of Mulloon Creek in future.

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