Keith Hall Drainage Options Study

WRL TR 2021/06, December 2021

By T A Tucker, D S Rayner and G Lumiatti

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Executive summary

The Keith Hall drainage network is located on the south bank of the Richmond River at the river's entrance to the ocean on the New South Wales north coast. Since the early 19th century, the drainage network has serviced predominantly sugarcane farmland, draining the floodplain and ensuring that the groundwater table is kept sufficiently low to maintain agricultural productivity. Maintenance of the Keith Hall drainage network is shared between Rous County Council, the Keith Hall Drainage Union, and local landowners.

Floodplain runoff flowing through the Keith Hall drainage network primarily discharges to the Richmond River at three locations. Union Drain and Mosquito Creek facilitate runoff to the west of the floodplain directly into the river via floodgates. Keith Hall No. 1 Canal flows to the north and discharges into Mobbs Bay through another set of large floodgates.

Mobbs Bay is a locally important site to the Richmond River community due to the environmental and recreational benefits it provides. Protected by an outer training wall, Mobbs Bay is an important site for migratory shorebirds, aquatic flora (such as mangroves and seagrass) and aquatic fauna (such as dugongs and sea turtles). The bay also provides valuable recreational amenity via fishing and boating.

There have been long term concerns regarding the Keith Hall drainage network discharging poor quality water to Mobbs Bay. This is likely due to the deep drainage canals that intersect large areas of acid sulfate soils. Once drained, these sediments are known to produce acidic runoff laden with heavy metals and low dissolved oxygen. Further, 'blackwater', caused by prolonged floodplain inundation and mono-sulfidic black oozes, has been observed within the drainage network. Other poor water quality observations include high nutrient levels, which can lead to eutrophication, and high levels of microbial bacteria, which can impact recreation and local industries (such as oyster farming).

Based on the above information, this study has been undertaken to investigate options for the Keith Hall drainage network that can achieve the following aims:

1. Reduce any downstream impact on Mobbs Bay and the Richmond River from water quality discharging from Keith Hall No. 1 Canal
2. Improve drainage efficiency and reduce the impact of floodplain inundation, particularly along Keith Hall No. 1 Canal where build-up of sediment and vegetation can occur
3. Reduce maintenance of the Keith Hall drainage network for Rous County Council

The scope of the project, as defined by Rous County Council and Ballina Shire Council, focused on identifying and assessing changes to the drainage channel network that would meet the above project aims. Detailed field investigations were completed to underpin this study. These assisted in developing a conceptual understanding of Mobbs Bay flushing dynamics, identifying key water quality trends of runoff from the floodplain, and development of a numerical model of the drainage network. These outcomes were then used to assess six drainage management options against water quality, drainage, and maintenance objectives.

An analysis of the Mobbs Bay field data helped to provide important insights into the flushing dynamics of the Bay. In brief, flow through Mobbs Bay generally follows the flow direction of the main Richmond River channel. During low tides, the flows are channelled around the training walls, although these walls are overtopped during higher tides. Between low tide and high tide, the volume of water within Mobbs Bay doubles. Except for erosion and accretion around the Mobbs Bay Island and the adjacent channel, the bathymetry has remained largely unchanged over the 15-year period between surveys. This is despite large water volumes flushing in/out of the bay each tide, and episodic flood events. Moreover, flushing dynamics within Mobbs Bay, and the mixing of estuarine water with floodplain runoff, are extremely complex.

Review of the Mobbs Bay flushing dynamics identified that runoff from Keith Hall drainage network has the largest impact on Mobbs Bay during ebb or low tides. At this time inflows from the drainage network are at their peak while the volume of Mobbs Bay is at its lowest. Subsequently, poor water quality originating from the Keith Hall drainage network is less diluted and has larger impacts on the sensitive receivers (e.g. oyster reefs) and recreational values within Mobbs Bay. The impacts of poor water quality are worst during rainfall events when high levels of nutrients and bacteria flow from the floodplain into Mobbs Bay. Nevertheless, following rainfall events and during day-to-day conditions, poor water quality associated with low oxygen ‘blackwater’ and acid sulfate soil runoff also impact Mobbs Bay.

Following consultation between Rous County Council, Ballina Shire Council and local landowners, six drainage options were identified as a potential means of achieving the three study aims. These include:

1. Allowing cyclic flow through the drainage network using the existing infrastructure
2. Allowing cyclic flow through the drainage network using automatic floodgates
3. Increasing tidal flushing within the drainage network by modifying floodgates
4. Amending the floodgate flap design to make it lighter and allow increased drainage
5. Reshaping a section of Keith Hall No. 1 Canal to be shallow and wide (swale) shaped
6. Modifying how Keith Hall No. 2 Canal connects to Mobbs Bay via a new drain

Each of these drainage options outlined above were simulated using a numerical model. Model simulations helped to investigate the value of any proposed option and to develop a quantifiable understanding of the potential risks and benefits. The final outcomes of this analysis are provided in Table ES.1.

Drainage Option 3, which allows increased tidal flushing within the Keith Hall drainage network, was identified as the preferred option. This option achieved water quality and drainage aims with a relatively low cost. It is worth noting that some other Drainage Options (2 and 5) were also identified to improve water quality and increase drainage efficiency, but these options are more expensive.

Overall, this study identified that it is feasible to modify the drainage network to meet water quality, floodplain drainage, and maintenance aims. However, implementation of drainage options may be affected by changes to the floodplain in the future, including sea level rise, and the design life of any on-ground works should be carefully considered.

Table ES.1: Relative analysis of drainage option results

Drainage Option	Water quality improvement			Drainage efficiency		Relative cost	
	Acid drainage	**Blackwater**	**Nutrients/ bacteria**	**Day-to-day**	**Wet event**	**Implementation**	**Maintenance**
Option 1 - Cyclic flow (existing infrastructure)	Moderate to High	None	Moderate*	Improved*	None*	Low	Minimal change
Option 2 - Cyclic flow (automatic floodgates)	High	None	Moderate*	Improved*	None	Medium to High	Increase
Option 3 - Increased tidal connectivity	High	None	Moderate*	Improved*	None	Low	Minimal change
Option 4 - Keith Hall floodgate weight	Reduced quality	Negligible	None	None	Negligible	Medium	No change
Option 5 - Keith Hall No. 1 Canal swale	High	None	None*	Improved*	Negligible reduction	Medium	Minimal change
Option 6 - Keith Hall No. 2 Canal new drain	High	None	Low*	Negligible reduction	Negligible reduction	High	Increase

*See Section 3.8 of the report for detailed information

Contents

List of tables

List of figures

1 Introduction

1.1 Site description

The Keith Hall study site is located on the southern bank of the Richmond River at the river's entrance to the ocean (Figure 1.1). The floodplain area, which also includes South Ballina, is approximately 1,300 hectares and has five major waterways that provide drainage:

- Keith Hall No. 1 Canal (4.2 kilometres)
- Keith Hall No. 2 Canal (2.9 kilometres)
- Mosquito Creek (2.8 kilometres)
- The Escape (0.9 kilometres)
- Union Drain (2.5 kilometres)

Together, these waterways make up the Keith Hall drainage network. Management of these waterways is split between Rous County Council (RCC), the Keith Hall Drainage Union (KHDU), and private landowners. RCC is responsible for managing the floodgate structures that service the Keith Hall floodplain (RCC, 2020).

Prior to construction of the drainage network, farming of the Keith Hall floodplain was limited to the levee bank along the Richmond River. This changed in 1920 with the construction of the Union Drain (RCC, 2020). Early reports of floodplain development indicated that there was a significant increase in agricultural productivity as former wetlands were drained and replaced with crops (TNE, 1934). Drainage of the floodplain continued through the 19^{th} century with The Escape being constructed in 1927 and then Keith Hall No. 1 Canal in the 1960s (TNE, 1934; RCC, 2020). Historical aerial imagery indicates that Keith Hall No. 2 Canal was also constructed at this time.

Soon after the completion of the drainage network, concerns were raised regarding the maintenance of the system. RCC (2020) reports that vegetation accumulation in Keith Hall No. 1 Canal is an ongoing issue with concerns that blockages cause increased flow through Union Drain and The Escape, and increase inundation of low-lying land surrounding Keith Hall No. 1 Canal following rainfall events. Local landowners have also raised concerns regarding the erosion of drain banks along Union Drain.

Along with maintenance issues, RCC (2020) has reported poor water quality associated with the Keith Hall drainage network. Construction of deep drains through acid sulfate soils has resulted in acidic groundwater flowing into the drainage network. In addition to water acidification, the drainage of acid sulfate soils has resulted in high concentrations of iron and the creation of mono-sulfidic black oozes (MBOs). Note, RCC (2020) have also identified that the floodplain has naturally high levels of iron in its soil which is unrelated to iron created from acid sulfate soil oxidation. MBOs in the drainage network are produced in the anoxic sediments of drains and when disturbed are able to strip oxygen from the water column. Other water quality impacts within the drainage network observed by RCC (2020) include low-oxygen blackwater, caused following flood events as vegetation on the floodplain dies and breaks down, as well as high levels of nutrients and microbial bacteria. RCC (2020) noted that discoloured water often discharges from the Keith Hall floodgates. Recent investigations have found that this discoloration is caused by high levels of tannin and lignin. While tannin and lignin are not associated with poor water quality, observations have found that they discharge in higher concentrations from the Keith Hall drainage network at the same time as poor water quality from the sources and processes previously described.

Keith Hall No. 1 Canal discharges directly into Mobbs Bay. Mobbs Bay is a significant site on the Richmond River due to the environmental value and recreational benefit it provides to the estuary and local community. Mobbs Bay is bordered by an extensive mangrove forest within the Richmond River Nature Reserve, which is mapped as coastal wetlands in the State Environmental Planning Policy (SEPP) (Coastal Management 2018), and is important habitat for migratory shorebirds, aquatic flora and aquatic fauna, such as dugongs which have been known to graze in the bay's seagrass beds (NPWS, 2005). The bay is an important site for boating, fishing and other recreation due to its proximity to the town of Ballina. Oyster leases directly downstream of the Keith Hall floodgates have also been established as a trial site.

Improvement of water quality discharging from the Keith Hall drainage network is important to ensure that the environmental and recreation values of Mobbs Bay and the broader Richmond River estuary can be fully realised. However, any works that are implemented to improve water quality discharging from the drainage network also need to consider floodplain stakeholders. Subsequently, a strategic approach considering water quality, drainage efficiency, and drainage maintenance issues is required.

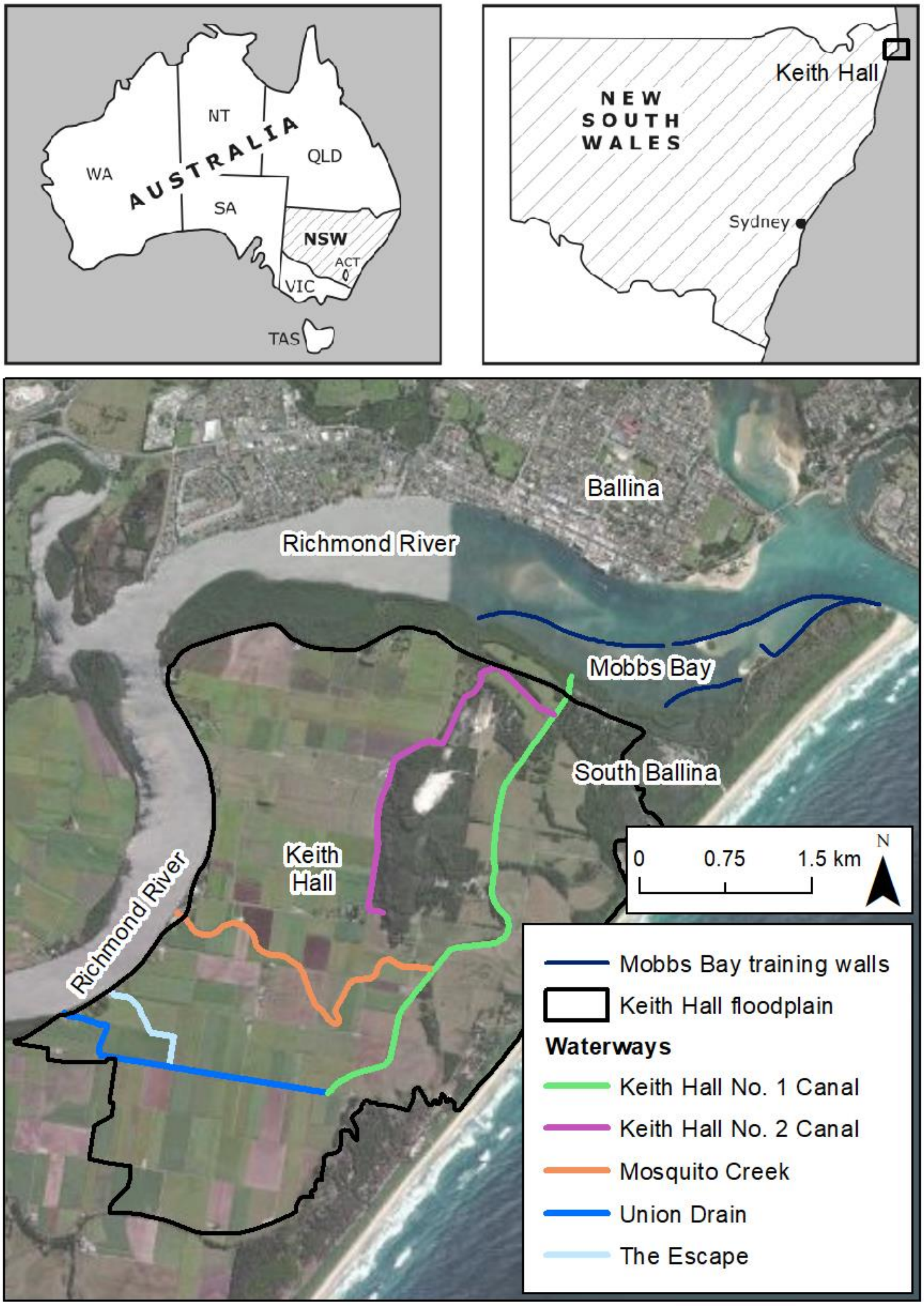


Figure 1.1: Keith Hall study site

1.2 Study aims

The purpose of this study was to develop a hydrological understanding of the Keith Hall drainage network to inform the future management of the floodplain. The scope of this project, as agreed with RCC and Ballina Shire Council (BSC), focussed specifically on six options for modifying the drainage channel network to improve water quality. Options for improving water quality that did not involve modifying the drainage network were not considered.

This investigation had the following three aims:

1. Reduce any downstream impact on Mobbs Bay and the Richmond River from water quality leaving Keith Hall No. 1 Canal
2. Improve drainage efficiency and reduce the impact of floodplain inundation, particularly along Keith Hall No. 1 Canal where build-up of sediment and vegetation can occur
3. Reduce maintenance of the Keith Hall drainage network for Rous County Council

To achieve these aims, a detailed investigation was completed to understand the hydrology of the Keith Hall drainage network, the flow dynamics of Mobbs Bay, and the water quality of the combined system. Field investigations were completed to develop a conceptual understanding of Mobbs Bay and a numerical model of the floodplain drainage network (Appendix A and Appendix B). The numerical model was used to assess potential drainage options against the project aims. These drainage options have also been compared relative to one another in terms of how they meet the project aims.

1.3 About this report

Following this introduction (Section 1), this report has the following sections:

- **Section 2: Water quality and floodplain drainage** – Review of the current floodplain hydrology and sources of poor water quality
- **Section 3: Keith Hall drainage options** – Six potential drainage options have been modelled and assessed against project aims
- **Section 4: Mobbs Bay conceptual understanding** – Compilation and analysis of data to develop an understanding of the physical processes within Mobbs Bay to identify how it is affected by discharges from the Keith Hall drainage network
- **Section 5: Discussion** – Further considerations for implementation of drainage options
- **Section 6: Recommendations** – Based on the study findings
- **Section 7: References**
- **Appendix A: Data synthesis** – Details on data collected during field investigations
- **Appendix B: Numerical modelling** – Technical details for the numerical modelling
- **Appendix C: Cross-section data**
- **Appendix D: Drainage timing and sensitivity analysis** – Investigation on floodplain drainage times for tidal flushing drainage options
- **Appendix E: Impact of water levels on agricultural productivity** – Discussion on how changes to groundwater levels may impact agricultural productivity
- **Appendix F: Rous County Council water quality monitoring**

2 Water quality and floodplain drainage

2.1 Preamble

RCC completed an intensive water quality monitoring program from December 2020 to April 2021 within Keith Hall No. 1 Drain and Mobbs Bay (see Appendix F). Throughout this time, wet weather event based sampling and continuous monitoring of physical water quality parameters was completed. The following section provides a summary of what was found during this monitoring program (Section 2.2). Following this, a discussion is provided for key water quality processes that occur within the Keith Hall drainage network (Section 2.3). Finally, a conceptual understanding of the floodplain drainage processes is outlined (Section 2.4) along with discussion on the impacts of the current active floodgate management of the Keith Hall floodgates (Section 2.5).

2.2 Water quality monitoring program

2.2.1 Event based sampling

Event based water quality sampling was completed within Keith Hall No. 1 Canal to determine how the water quality within the Keith Hall drainage network responds to rainfall runoff events. Grab samples were collected following two rainfall events (BOM, 2021a,b,c):

- 12/12/2020 to 17/12/2020: 343.4 mm in 6 days (slightly less than a 20% annual exceedance probability (AEP) rainfall event)
- 21/3/2021 to 24/3/2021: 219.2 mm in 4 days (between a 1 exceedance per year (EY) and 50% AEP rainfall event)

The surface grab samples collected are outlined in Table 2.1. Exact locations of samples and results are shown in Appendix F.

Table 2.1: Event based sampling dates

Event	Sample dates	Sample locations (Figure 2.1)
Dry weather	16/10/2020	Keith Hall No. 1 Canal, Mobbs Bay
	25/11/2020	Keith Hall No. 1 Canal, Mobbs Bay
Runoff event 12/12/2020 to 17/12/2020	14/12/2020	Keith Hall No. 1 Canal
	17/12/2020	Keith Hall No. 1 Canal
	21/12/2020	Keith Hall No. 1 Canal
	4/1/2021	Keith Hall No. 1 Canal

Event	Sample dates	Sample locations (Figure 2.1)
	9/3/2021	Keith Hall No. 1 Canal, Mobbs Bay
Runoff event 21/3/2021 to 24/3/2021	23/3/2021	Keith Hall No. 1 Canal
	25/3/2021	Keith Hall No. 1 Canal
	29/3/2021	Keith Hall No. 1 Canal
	31/3/2021	Keith Hall No. 1 Canal
	8/4/2021	Keith Hall No. 1 Canal
	12/4/2021	Keith Hall No. 1 Canal
	21/4/2021	Keith Hall No. 1 Canal
	27/4/2021	Keith Hall No. 1 Canal

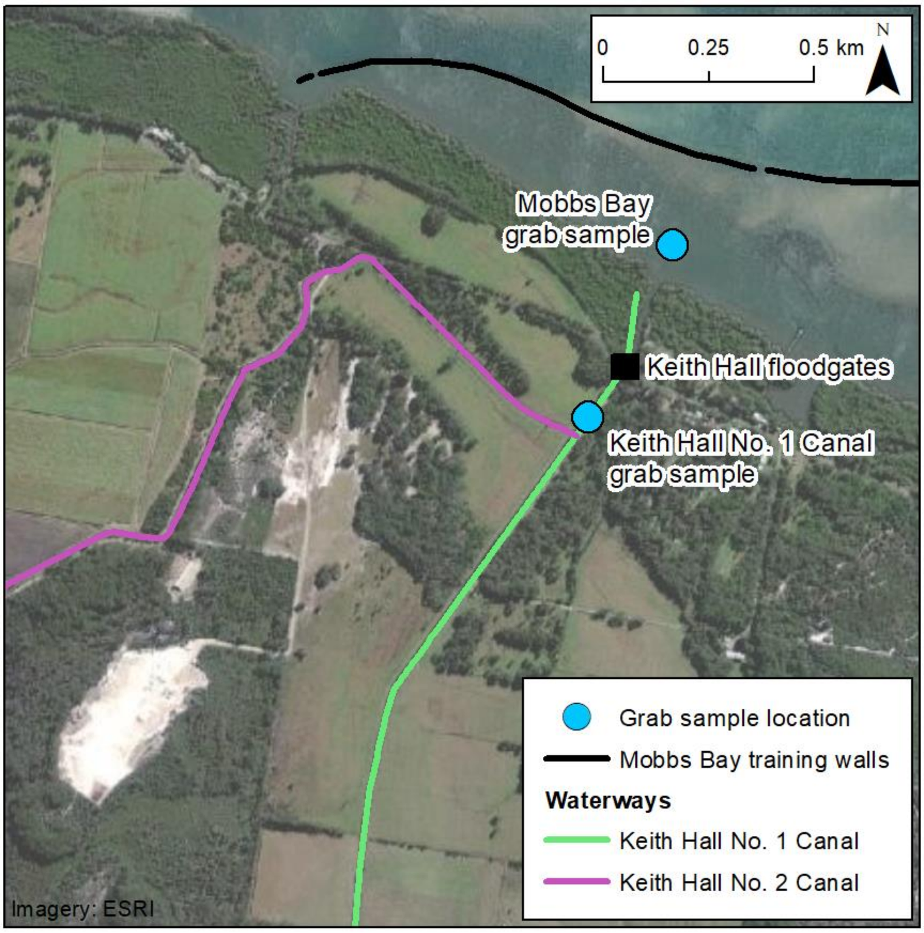


Figure 2.1: Water quality sample locations

Analysis of the event based sampling provided the following observations:

Acid sulfate soils:

- A drop in the chloride: sulfate ratio following runoff events clearly identifies the presence of sulfate and indicates the presence of acid sulfate soils (Figure 2.2) (Sammut et al., 1996)
- The concentration of soluble metals, which are known to occur within acid sulfate soils, clearly increases following runoff events (Figure 2.3)
- A drop in pH occurs (to ~4.2) during the initial first flush of a rainfall event, which may be caused by surface acidity from acid scalds on the floodplain adjacent to Keith Hall No. 1 Canal
- Tidal water is effective at neutralising acid in the Keith Hall No. 1 Canal
- A spike in chemical oxygen demand (COD) immediately following runoff events, which also corresponds with a drop in dissolved oxygen (DO) (measured in the field) to below 0.5 mg/L, indicates the drain is likely to be influenced by mono-sulfidic black ooze (MBO)

Water quality:

- Nutrient levels (nitrogen, phosphorus, silicon, and ammonia) increase following runoff events (landowners noted that fertiliser had been applied immediately before the first event)
- Bacteria concentrations increase following rainfall events to levels that would be expected with runoff from grazing land
- Enterococci concentrations following runoff events were measured at poor to very poor according to the national guidelines for managing risks in recreational water (NHMRC, 2008)
- Runoff events result in increased concentrations of tannin and lignin (up to 6.6 mg/L) in water discharging from Keith Hall drainage network causing visible discolouration (note, concentrations above 1 mg/L generally have a distinctly visible tan colouration)
- Further nitrogen isotope testing could confirm the source of nutrients such as organic (either from sewage or manure) or synthetic (fertiliser) origins

In general, the overall quality of water discharging from the Keith Hall drainage network via Keith Hall No. 1 Canal was found to decrease following runoff events. This was caused by groundwater drainage of acid sulfate soils and runoff increasing in nutrient/bacteria concentrations.

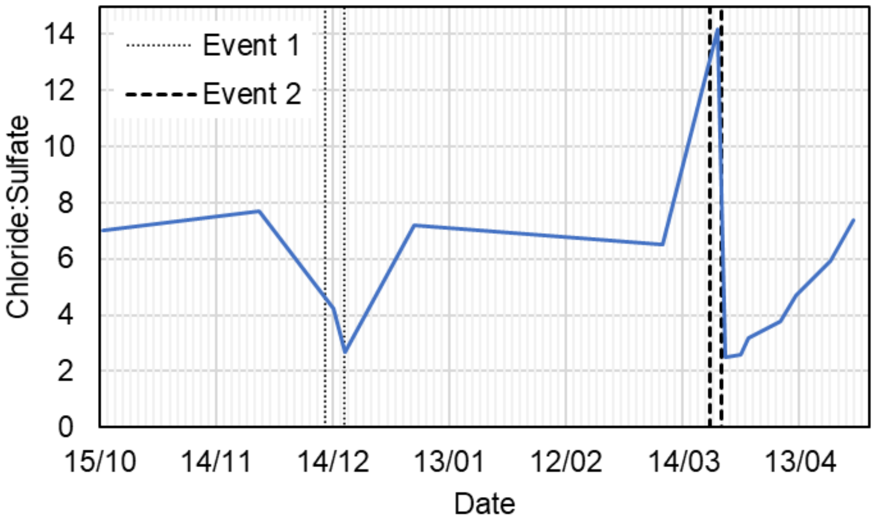


Figure 2.2: Chloride sulfate ratio timeseries

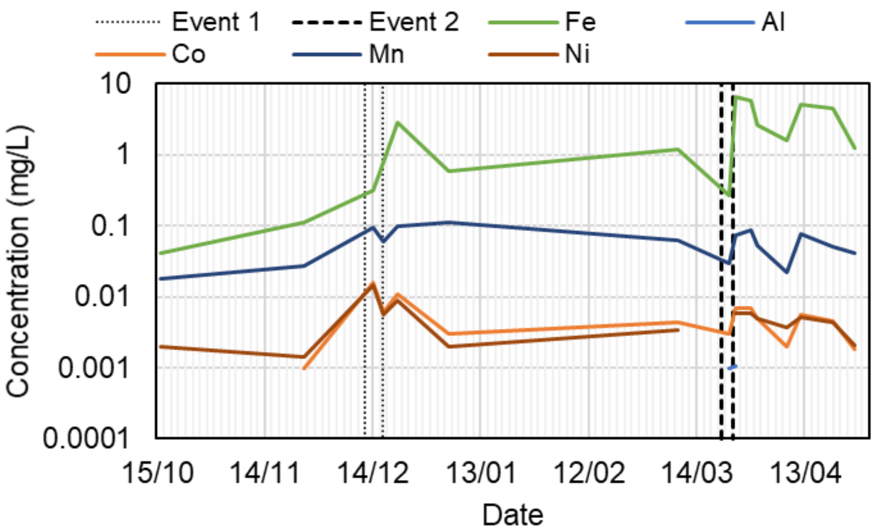


Figure 2.3: Timeseries of soluble metal concentrations

2.2.2 Long-term sampling

Long-term measurements of pH, dissolved oxygen (DO), electrical conductivity (EC), and turbidity were observed every 30 minutes from 10 October 2020 to 26 November 2020, and every hour from 22 December 2020 to 13 April 2021 within Keith Hall No. 1 Canal. Results are shown in Appendix F. Note, some of the measurements for turbidity and pH appeared to be erroneous for the first measurement period. Further investigation is required to verify these measurements. The following observations can be drawn from the measurements:

- Low dissolved oxygen levels were observed for prolonged periods following runoff events
- Further investigations are required to verify basic acidity and high turbidity readings captured in November 2020
- Turbidity remained below 70 NTU from December to April, although turbidity did increase following events, which is typical of catchment runoff following rainfall
- pH levels drop following rainfall but appear to quickly recover to neutral levels likely due to natural buffering from tidal waters
- Multiple rainfall events have the ability to significantly reduce the salinity levels within Keith Hall No. 1 Canal for extended periods, potentially indicating the groundwater has been recharged and is continuously draining to surface waters

2.3 Keith Hall water quality processes

2.3.1 Acid sulfate soils

Soil sample data collected across the Keith Hall floodplain indicates that the floodplain is underlain by acid sulfate soils (see Appendix A). While acid sulfate soils are relatively innocuous when the soils are in anaerobic (zero oxygen) conditions below the water table, drainage of the soil matrix results in the lowering of the water table and exposure of acid sulfate soils to atmospheric oxygen, which creates sulfuric acid (Figure 2.4). Acidic groundwater can drain to surface water channels and be efficiently transported to the estuary, impacting downstream environments. Tulau (2007) has provided a summary of general impacts that acid sulfate soils can have on estuaries (Table 2.2). When acid is generated, metals such as iron and aluminium are also released adding to the environmental impacts (note, iron is also naturally occurring in the groundwater at Keith Hall (RCC, 2020)). Export of acid from acid sulfate soils increases following rainfall events once surface water has receded to normal levels. This is because rainfall events recharge the groundwater table, and allow for an increased flow rate of groundwater containing acid to the surface water drainage network (Figure 2.5).

Acid surface scalding has also been observed at Keith Hall by WRL (2019) who measured surface soils to have a pH of 3.5 on low-lying areas of the floodplain adjacent to Keith Hall No. 1 Canal near its connection with Mosquito Creek (Figure 2.6). Acid scalds occur where acid sulfate soils are located at the ground surface and events such as over grazing or prolonged inundation cause the loss of vegetation and the surface soil layer (Rosicky et al., 2004). Following runoff events, acid on the surface of scalds is easily transported into the drainage network. Currently, the acid scalds at Keith Hall are irregular across the floodplain adjacent to Keith Hall No. 1 Canal, however, unless treated correctly the area of the acid scalds may grow. Note, acid scalds can be rehabilitated by excluding stock and mulching as per the methods outlined by Rosicky et al. (2002) and Rosicky (2006).

In addition to water quality impacts associated with acid sulfate soils, water quality monitoring indicated (by a chloride/sulfate ratio < 3 and high chemical oxygen demand (COD)) that mono-sulfidic black oozes (MBOs) occur within the Keith Hall drainage network. MBOs are often formed in the bottom of drains that intersect acid sulfate soils where high levels of sulphide and dissolved iron occur in anaerobic (zero oxygen) conditions (Sullivan et al., 2018a). When mobilised, MBOs undergo a chemical reaction which removes oxygen from water having a similar impact as low oxygen blackwater (see Section 2.3.2).

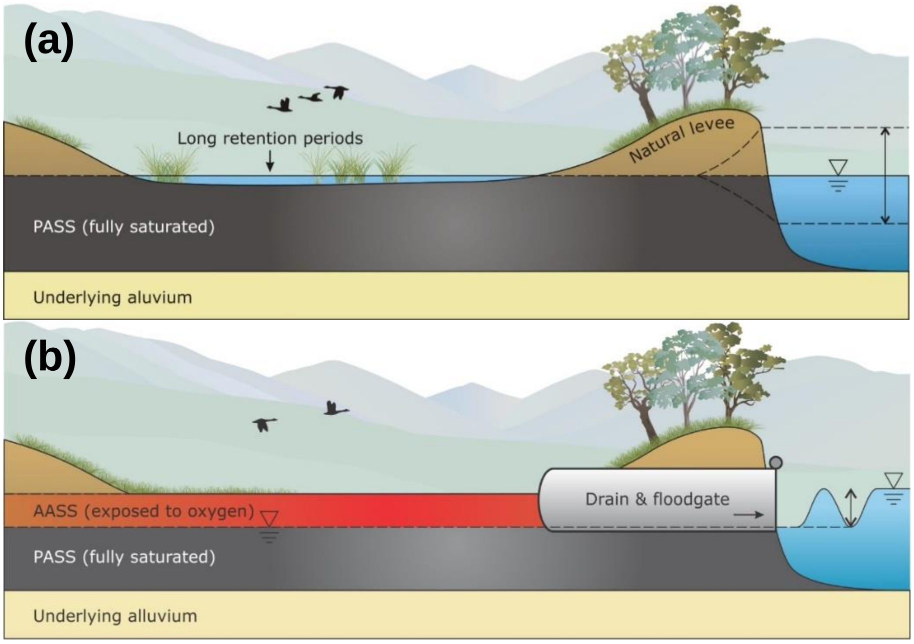


Figure 2.4: Potential acid sulfate soils (PASS) underlying natural wetland (a) and actual acid sulfate soils (AASS) that have become exposed to atmospheric oxygen in air due to floodplain drainage (b)

Table 2.2: Summary of general impacts associated with acid sulfate soils (Tulau, 2007)

Impact type	Description of acid sulfate soils impact
Water quality	Low pH, iron and aluminium toxicity, release of heavy metals from sediments and water deoxygenation.
Aquatic life	Massive kills, disease, reduced hatching, reduced survival and growth rates, habitat degradation, reduced aquatic food resources, reduced migration potential, reduced fish recruitment, altered water plant communities including invasion of acid-tolerant plants.
Infrastructure/ Engineering	Damage to infrastructure (e.g., bridges/bridge footings), changes to soil fabric including shrinkage and lowering of ground surfaces, damage to water pipes and floodgates.
Economic/ Industry	Decreased productivity for: recreational fishing, commercial fishing, aquaculture, sugarcane, tea-tree, grazing and dairy. Reduction in arable land through creation of acid scalds.

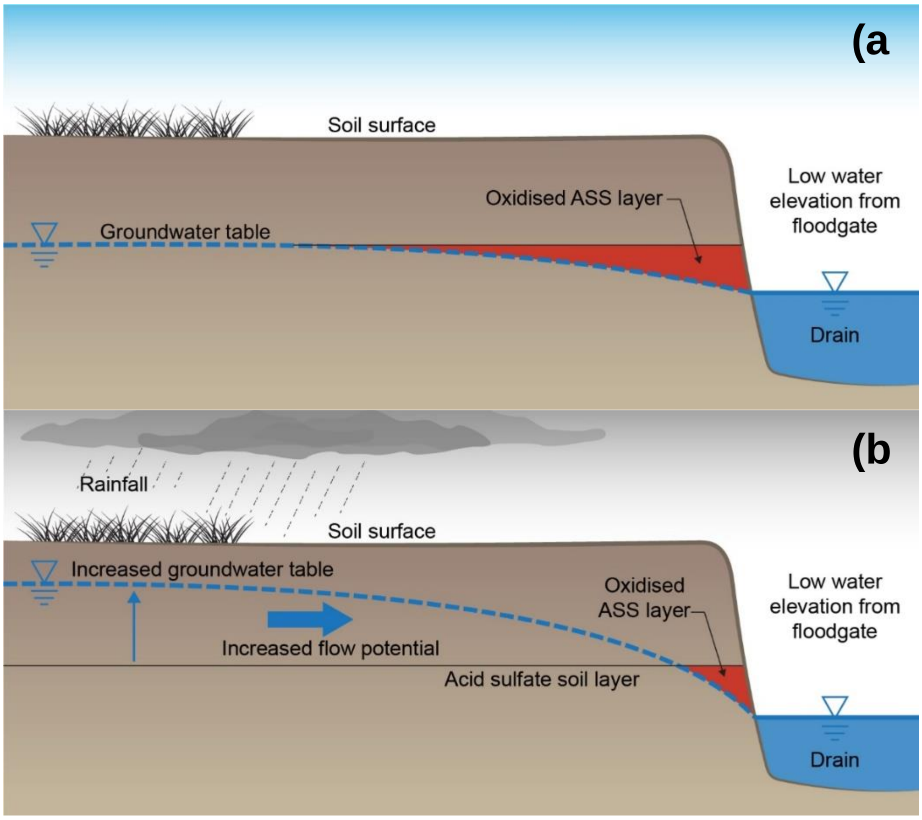


Figure 2.5: Drainage of acidic groundwater during dry times (a) and increased groundwater drainage following the recharge of the groundwater table by a rainfall event (b)

Figure 2.6: Acid scalding adjacent to Keith Hall No. 1 Drain (February 2019)

2.3.2 Blackwater

Low-oxygen blackwater is generated when non-water tolerant vegetation is inundated for prolonged periods of time, leading to die-off and decay of organic material which strips dissolved oxygen from the standing water column. The term blackwater comes from the colour of the water that is typically discharged from the floodplain following these inundation events. Despite the Keith Hall drainage network being efficient, the inundation duration following flood events is determined by ongoing rainfall and water levels in the wider Richmond River estuary, with low-lying areas being subject to prolonged inundation.

The drainage network has also altered the rate at which blackwater can be discharged to the estuary. Prior to the drainage works, when blackwater was generated its export from the floodplain would have occurred over a long duration slowly discharging to the estuary via a restricted connection. In some areas significantly disconnected from the estuary, the breakdown of organic material (carbon cycle) would have had time to complete allowing water to regain oxygen before discharging to the estuary. Presently, once the estuary water level lowers following a flood, drainage channels enable blackwater generated on the floodplain to be efficiently transported to the estuary which can impact the downstream receiving water (Figure 2.7).

Discharged blackwater typically contains a high biological oxygen demand (BOD) which further consumes dissolved oxygen from downstream waterways during mixing. Blackwater significantly impacts the environment, and many aquatic species cannot survive in water that does not contain oxygen, with fish impacted when dissolved oxygen levels drop below 1 – 2 mg/L (Abdel - Tawwab et al., 2019).

Note, due to its proximity to the ocean entrance, blackwater in the Keith Hall drainage network generally does not have as large an impact as other floodplain areas on the upper Richmond River estuary. This is because water levels are likely to recede much quicker and when blackwater is discharged it will be diluted quicker with ocean water.

**Figure 2.7: Blackwater flowing from the Keith Hall drainage network to Mobbs Bay on 24 March 2021 (Source: Nearmap)
(corresponding dissolved oxygen measurements in Figure F.2)**

2.3.3 Nutrients

Nutrients such as nitrogen, phosphorus and silica are important for the growth of organic aquatic vegetation. Sources of nutrients include fertilisers, human and animal waste, and the breakdown of organic matter. Plants require nutrients to grow which often means that the amount of vegetation growth in a waterway is limited by the supply of nutrients (Smith et al., 1999). A high abundance of nutrients can often lead to the excessive growth of vegetation. Sudden excessive growth caused by high levels of nutrients is termed 'eutrophication' which is another cause of blackwater. Overall, high levels of nutrients generally result in negative impacts to the environment, such as (Smith et al., 1999; ANZECC and ARMCANZ, 2000):

- Growth of toxic microorganisms
- Reduced water clarity and decreased aesthetic value
- Increased likelihood of animal mortality
- Depletion of oxygen

- Increased pH levels
- Accumulation of toxins in aquatic food consumed by humans

Ammonia is a soil nutrient which can also be washed into waterways. It can also occur from industrial chemicals, human and animal waste, or the decomposition of plant material. At high levels it can be toxic to aquatic organisms with the following effects (Tate et al., 2003):

- Loss of equilibrium
- Reduction in hatching success
- Reduced growth rates
- In extreme cased, coma and death

2.3.4 Faecal pollution

Faecal pollution from human and animal waste can lead to the occurrence of pathogenic microorganisms in waterways (WHO, 2003). When this occurs, waterways become unsafe for human recreation. Impacts of pathogens resulting from faecal pollution to humans include (NHRMRC, 2008):

- Enteric illness
- Respiratory illness
- Ear infection
- Eye and skin problems
- Liver or renal disease

Faecal pollution of waterways is usually measured by either thermotolerant faecal coliforms, Escherichia coli (E. coli), or enterococci (NHRMRC, 2008). Note, these are measured as indicator microorganisms as their presence in waterways generally indicates that the waterway may be polluted with pathogens.

Environmental conditions may impact the prevalence of pathogens in a waterway. Mixing of waters can reduce the probability of the occurrence of pathogens. Alternatively, pathogens are more likely to occur following rainfall events, particularly where rainfall results in sewage overflows or runoff from pasture or forest.

2.3.5 Tannins

Tannins are caused by the decomposition of organic matter and occur naturally in coastal waterways, particularly in wetland environments (Frick et al., 2002). They are often sourced from the breakdown of mangroves, eucalyptus leaves, or from peat layers underneath the floodplain (Maie et al, 2008). Concentrations of tannins in coastal wetlands have been measured up to 14 mg/L (Frick et al., 2002). Tannins contribute acidity to waterways, however, they are weak acids and generally their impact on acidity would be less than that of acid sulfate soils which produce a strong acid (Ahuja et al., 2014). Tannins are known to react with metals such as iron preventing them from precipitating (Dodds, 2002). While the discolouration of water caused by tannins might reduce visual amenity of a waterway, they are caused by natural processes and their presence is not necessarily an indicator of poor water quality.

2.4 Floodplain drainage processes

Historically the Keith Hall floodplain featured extensive wetland areas that would have remained inundated for long periods of time. Construction of the Keith Hall drainage network meant that water that used to remain on the floodplain could now be efficiently drained into the Richmond River and the long-term water table was lowered (Figure 2.8). This allowed for agricultural practices to occur across the Keith Hall floodplain.

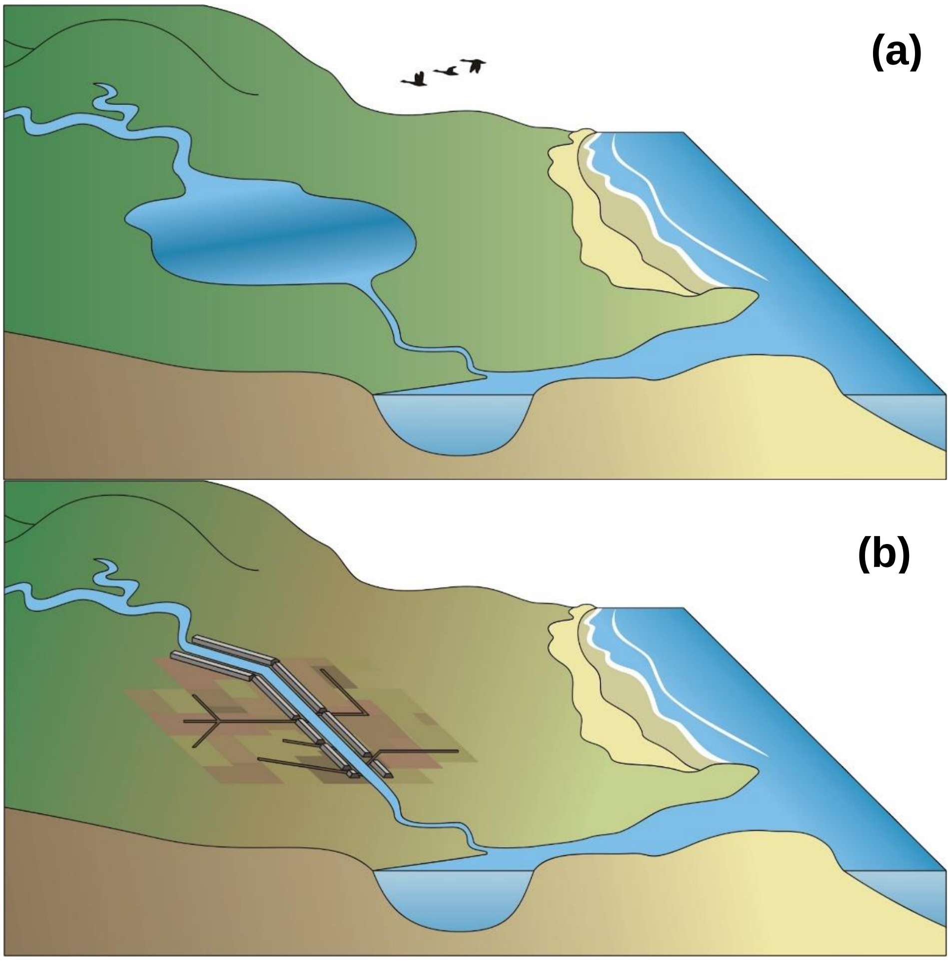


Figure 2.8: Historic wetlands (a) at Keith Hall that was drained following the construction of the Keith Hall drainage network (b)

An important piece of the Keith Hall drainage network is the floodgate infrastructure. Floodgates work by allowing only one-way flow from the floodplain to the Richmond River (Figure 2.9). This effectively keeps the water level on the upstream side of floodgates (within the drainage network) at the low-tide level. Having a low water level within the drainage network means that water on the floodplain and within the groundwater can easily flow into drains. By lowering the water table like this, the floodgates lower the groundwater table and drain acid sulfate soils (Section 2.3.1). The larger the difference in water level on the floodplain (or in the groundwater) to the water level in the drain, the quicker water will flow into the drain. Despite this, water can only flow out of the drain when upstream water levels are higher than the river, which is generally during low-tides, so often it fills up during high tides. Analysis of the capacity of the Keith Hall drainage network showed that if 10 mm of rain occurred across the floodplain and it all flowed into the drainage system (i.e. no infiltration), the drains would become full to the floodplain level unless water flowed through the floodgates and into the estuary.

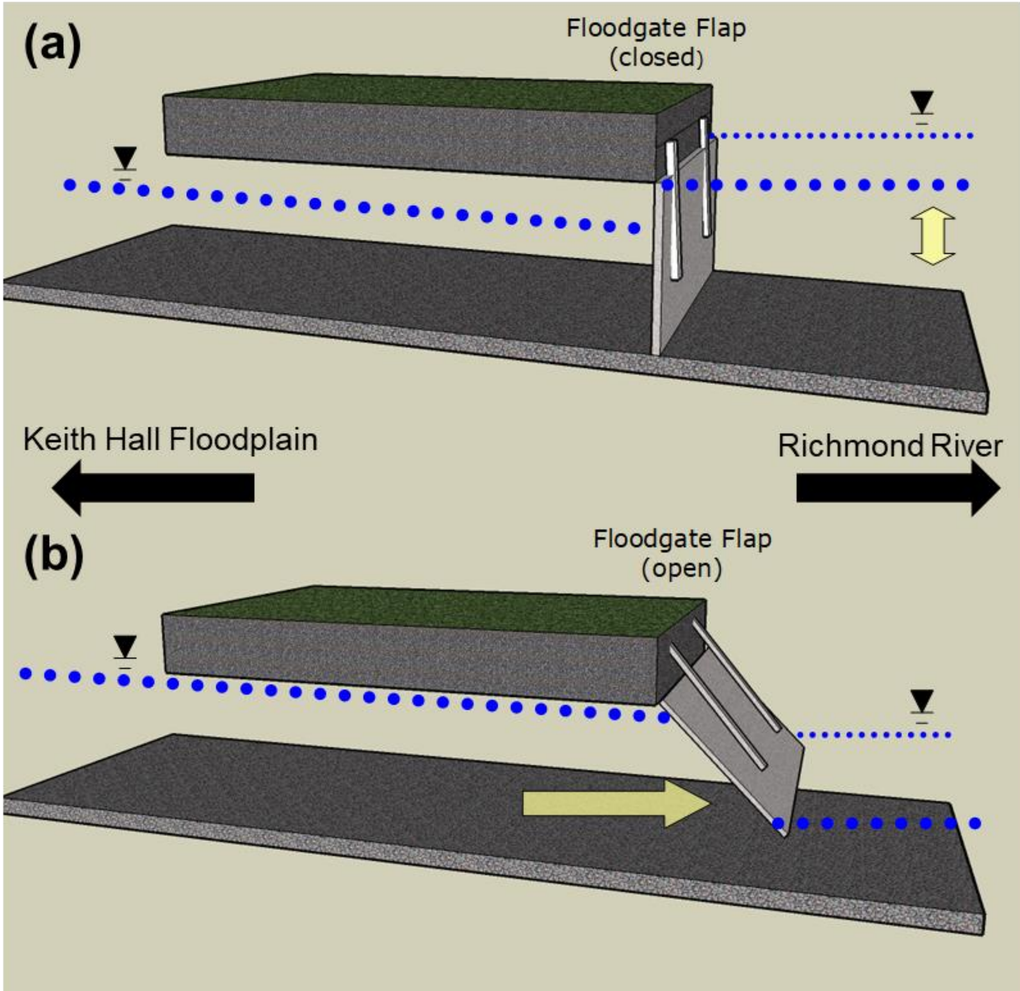


Figure 2.9: Diagram showing how floodgates function dependant on the tidal water level by (a) preventing tidal water flowing upstream and (b) allowing water in the drain to flow downstream

When the Richmond River floods the water level downstream of the Keith Hall floodgates remains high. This means that water on the Keith Hall floodplain is unable to drain. Prolonged inundation like this is what results in the generation of low oxygen blackwater (Section 2.3.2). During day-to-day conditions the Keith Hall drainage network is able to efficiently transport water from the floodplain to the estuary. Modelling shows that following nuisance flooding (e.g. a 50% annual exceedance probability (AEP) event which may occur one in every 1.4 years, on average), water in the Keith Hall drainage network will drain to low tide levels in less than 3 days if there are normal tides (Appendix D). Once water has receded following an event, flow from the floodplain to Mobbs Bay will be governed by the volume and flowrate of groundwater drainage (which depends on the groundwater level).

2.5 Active floodgate management

2.5.1 Summary of the active management plan (RCC, 2020)

Active management of the Keith Hall floodgates has occurred since 2006 when the first buoyancy controlled auto-tidal gate was installed on the existing one-way floodgates. In 2014, a second buoyancy gate was installed and then in 2019, one of the buoyancy gates was removed and replaced with a manually operated sluice gate (RCC, 2020). These modifications are designed to allow controlled tidal flushing to low elevations within the drainage network to improve water quality, control freshwater weed growth, and provide aquatic connectivity. This is the current configuration of the floodgates today (Figure 2.10). RCC have developed an active floodgate management plan for the Keith Hall floodgates for the purpose of documenting and communicating the following (RCC, 2020):

- "*how active management can assist in reducing the environmental impact of the floodgate,*
- *a strategy for how that will be monitored and achieved,*
- *appropriate and consistent strategy for opening the floodgate and returning it to the operational position or state and by whom,*
- *safe operating procedures for volunteers and Council staff,*
- *how adverse effects on current land use will be identified and prevented, and*
- *additional management strategies for the drainage system that would further reduce the environmental impact of flood mitigation".*

Figure 2.10: Keith Hall floodgates (October 2020)

RCC actively manage the floodgates according to the following operational rules (RCC, 2020):

- Close the sluice gate if any of the following occur:
  - If a flood watch is issued and it is likely a minor flood warning will follow
  - If a minor flood warning is issued
- Partially close the sluice gate so it is only open 50 mm if any of the following occur:
  - Tides are predicted above 1.85 m lowest astronomical tide (LAT)
  - The Bureau of Meteorology issue a warning of abnormally high tides
- Open the sluice gate 200 mm if all of the following occur:
  - The flood or high tide warning is cancelled
  - When the lifting mechanism is visible
  - Water levels in the drain and river are not visibly elevated

2.5.2 Influence on floodplain hydrology

Active management of the floodgates allows tidal water to flow upstream of the Keith Hall floodgates to levels that will not impact the existing function of the Keith Hall drainage network. The volume of water allowed into the drainage network depends on the number and size of openings in the floodgates as well as the climate conditions (e.g. during dry periods tidal flushing will flow further into the drainage network). If a larger volume of water is allowed upstream of the floodgates, then the water level upstream of the floodgates will also be higher.

At Keith Hall, a trial was completed in 2019 whereby a sluice gate was installed to allow a larger volume upstream than the existing buoyancy gates. This change in volume can be seen by an increase in the drain water level (Figure 2.11). Analysis of water levels and salinity data found that tidal flushing using the Keith Hall floodgates can flow throughout the Keith Hall No. 1 Canal and Union Drain dependant on the climate conditions (Appendix A). The tidal range upstream can also be altered by changing the level of the sluice gate opening. Modifications like this have potential to impact the floodplain hydrology in three ways:

- Tidal inundation
- Increased groundwater levels
- Reduced storage capacity within the drainage network

Modifications such as sluice gates or buoyancy gates mean that the water upstream of the floodgates becomes tidal. Since the inflow of water to the drainage network is limited the tidal range of water upstream of the floodgates will be significantly smaller than the tidal range downstream (Figure 2.12). By changing the size of the sluice or floodgate openings, this tidal range can be altered. Sluice gate trials completed in 2019 found that this tidal range was increased by approximately 0.2 m to 0.3 m and allowed water to reach an elevation of +0.05 m AHD (Australian height datum, where 0.0 m AHD is equal to mean sea level (MSL)). Analysis of the floodplain elevation has indicated that water will only begin to inundate the connected low-lying floodplain areas once it reaches an elevation of +0.3 m AHD with significant inundation only occurring at elevations above +0.6 m AHD (Appendix B). Subsequently, the current active management of the floodgates (with one sluice and one buoyancy gate) will not result in out of drain tidal inundation.

Raising the in-drain water level will also mean that the groundwater levels become raised. Appendix E provides a detailed discussion on how a raised groundwater table may impact agricultural productivity. An increase in the groundwater table attributed to tidal flushing as a result of the active management of the Keith Hall floodgates as outlined by RCC (2020) would be unlikely to result in any significant impact to agricultural productivity. However, further research is required to empirically quantify how tidal flushing may have influenced the groundwater table.

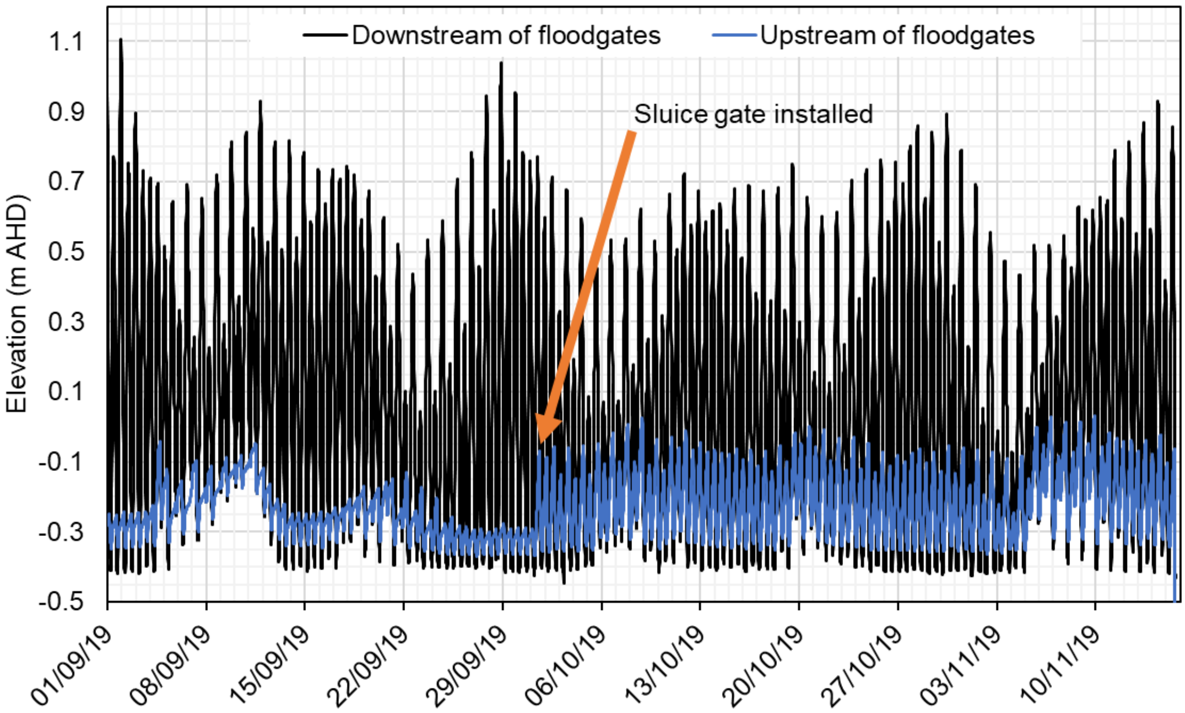


Figure 2.11: Water levels upstream and downstream of the floodgates before and during the 2019 sluice gate trial

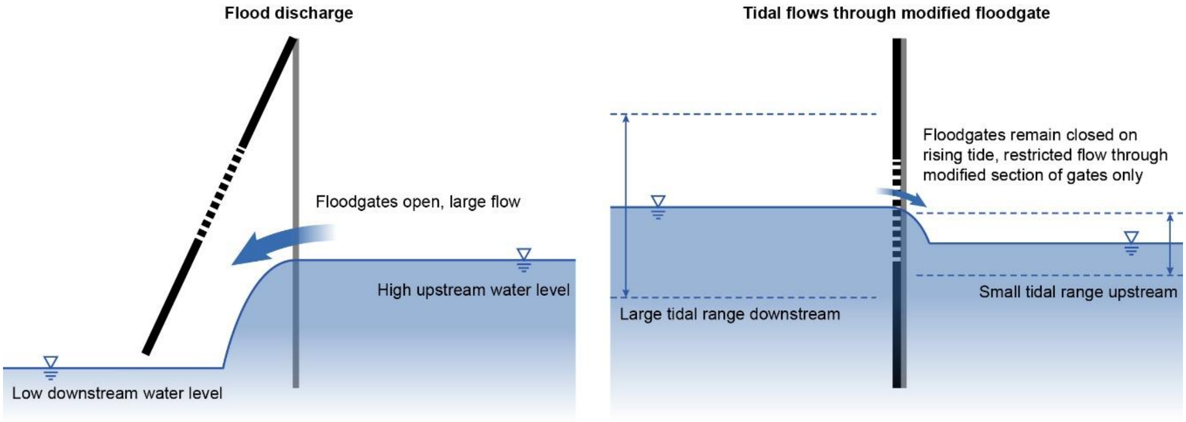


Figure 2.12: Function of a modified floodgate during low and high tides

When rainfall falls on the Keith Hall flood catchment, there are a number of processes that determine if floodplain inundation will occur and influence the extent, depth, and duration of inundation. These include:

- Rainfall volume and intensity
- Volume/level of water within the drainage network
- Catchment runoff routing (how far water needs to travel to reach the drainage system)
- The downstream water level (within the Richmond River)
- Antecedent conditions (is the floodplain dry or wet prior to rainfall)
- Tidal dynamics (low/high tides, spring/neap tides)
- Floodplain drainage structures (such as weirs or culverts)
- Connectivity of the floodplain and overland flow paths to secondary and major drains
- Management of floodplain structures (e.g. the active floodgate management plan (RCC, 2020))

A conceptual understanding of these processes can be used alongside floodplain drainage analysis (Appendix D) to assess how increased tidal flushing may affect floodplain inundation and subsequently impact existing land uses. The following conclusions can be drawn from the data available for the Keith Hall drainage network:

- Modelling showed that following inundation up to 1 m AHD, the water level will fall to within the drain banks in less than 24 hours which is unlikely to cause impacts to vegetation due to inundation (this is comparative to a 50% annual exceedance probability (AEP) rainfall event with a 6 hour duration)
- For large rainfall events (e.g. above a 20% AEP) the volume of storage within the drainage network lost due to tidal flushing is negligible compared to the rainfall volume (lost storage due to tidal flushing will equate to less than 3% of the total rainfall volume for a 6 hour duration rainfall event)
- Modelling showed that by closing the sluice gate 72 hours prior to a predicted flood, water levels in the drainage network will reduce to low-tide elevations and there will be no reduction storage due to tidal flushing (i.e. active management of the floodgates will mitigate the risks associated with tidal flushing reducing in-drain storage capacity)

Subsequently, it is unlikely there will be any significant impact of floodplain inundation on existing land use due to increased water levels within the drainage network from the existing tidal flushing. Note, this first pass assessment for the effects of floodplain inundation is based on a conceptual understanding of the floodplain. For a detailed impact assessment, additional investigation should be completed. Additionally, consideration should be given to the impacts of saline tidal water spilling onto the floodplain if the drainage network banks overflow.

2.5.3 Influence on water quality

One-way floodgates prohibit tidal inundation, maximise drainage, and maintain drain and groundwater levels at low tide elevations. When acid sulfate soils are present, tidal floodgates increase soil oxidation and acid discharge, release of heavy metals such as iron and aluminium, and restrict in-drain buffering by tidal waters. Eyre et al. (2006) suggests the lowering of groundwater tables by one-way floodgates also results in a change in ground vegetation cover away from water tolerant species towards dryland species used for grazing and agriculture, exacerbating issues associated with blackwater.

Floodgate management and/or modification to improve water quality outcomes and enable aquatic connectivity is widely practiced in NSW. In the Shoalhaven River estuary, Glamore (2003) showed that modified floodgates that permit two-way tidal flows significantly improved water quality within the drainage system, and generally reduced the downstream impacts of acid sulfate soil discharges. Glamore (2003) also states that dissolved oxygen levels increase through regular flushing and may limit the formation of mono-sulfidic black ooze (MBOs). However, unless the additional tidal flushing is associated with inundation of upstream floodplain areas and a subsequent change in vegetation, modification of floodgates to allow tidal flushing is unlikely to have a significant impact on blackwater generation in the short term.

Benefits of floodgate modification also include:

- Improved drain water quality through flushing and acid buffering
- Reduced exotic vegetation within the channel (reducing maintenance costs)
- Increased groundwater table reducing the production of acid
- Increased fish passage (NSW DPI, 2007)

Modification of floodgates to allow tidal flushing is typically undertaken to allow controlled upstream flows by limiting the tidal amplitude. This means that the upstream land uses are not impacted. The extent of tidal restoration at a site is often dependent on the site topography, tidal elevations, available bicarbonate/carbonate from tidal water, and current land use practices. Typically, landholders use controlled in-drain tidal flushing to control weed vegetation, while not impacting adjacent floodplain areas of agricultural production. The installation of auto-tidal gates permits tidal flushing up to a predetermined elevation based on design. Maximum tidal flushing elevations are usually dependent on the topography of upstream land. Figure 2.13 depicts how a modified floodgate can restore tidal flushing to a drainage channel.

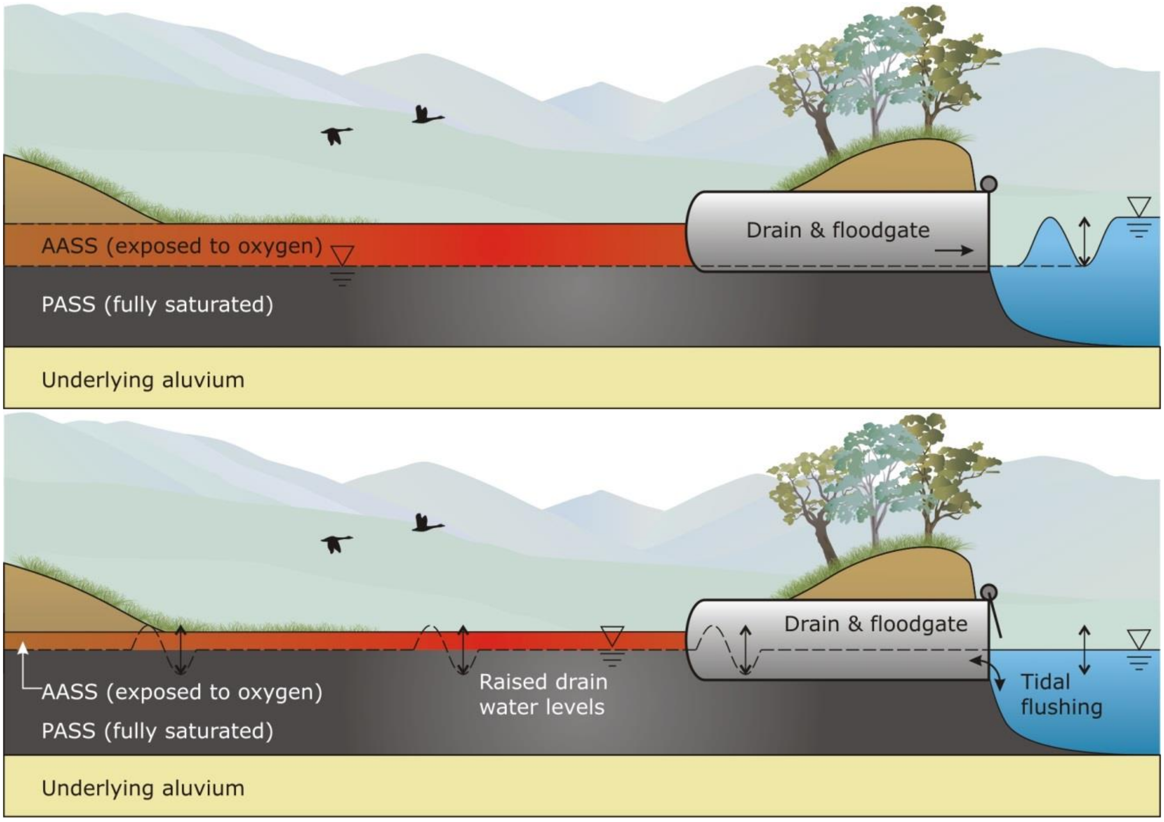


Figure 2.13: Before and after floodgate modification
(AASS = actual acid sulfate soils, PASS = potential acid sulfate soils)

3 Keith Hall drainage options

3.1 Preamble

Following consultation with local landowners, RCC and BSC, six drainage options were selected for evaluation against the project aims. These options were:

1. Cyclic flow (existing infrastructure)
2. Cyclic flow (automatic floodgates)
3. Increased tidal connectivity
4. Keith Hall floodgate weight
5. Keith Hall No. 1 Canal swale
6. Keith Hall No. 2 Canal new drain

The following section describes each drainage option and provides an assessment for how each option meets the project aims. Where drainage options are similar in theory, for example drainage options 1 and 2, there may be some repetition regarding how they meet project aims. Technical details for each drainage option and how they were assessed can be found in Appendix B. A sensitivity test relevant for the tidal flushing scenarios (Options 1, 2 and 3) can be found in Appendix D. A discussion on the effects of in-drain water levels on the groundwater across the floodplain and subsequent impacts on agricultural productivity is provided in Appendix E.

3.2 Option 1: Cyclic flow (existing infrastructure)

3.2.1 Description

Consultation with local landowners identified that historically the Keith Hall drainage network was able to operate as a cyclic system. That is, water was able to enter the network through the floodgates on Union Drain, and progress, over several tide cycles, through the network more or less in the same direction before exiting through the floodgates on Keith Hall No. 1 Canal. This would have kept the water turning over in the drainage network, with associated improvements in water quality and weed reduction.

Drainage Option 1 assesses whether the drainage network can in fact operate in this cyclic manner. Configurations have been investigated for clockwise flow (from Keith Hall No. 1 Canal to Union Drain) and counter-clockwise flow (from Union Drain to Keith Hall No. 1 Canal).

To facilitate cyclic flow through the drainage network the following changes to the floodgate infrastructure were considered:

- Removal of buoyancy driven tidal floodgates
- Adjustment of sluice gate management
- Winching floodgates open

This drainage option was only considered for dry periods. The hydrology of the floodplain during wet conditions should not be impacted provided operational rules for the management of the floodgates are implemented (see Appendix D).

3.2.2 Numerical model results

Five configurations were assessed allowing cyclic flow through the Keith Hall drainage network. Table 3.1 summarises how each of these configurations performed. A detailed description and specifications of each configuration are available in Appendix B.

Table 3.1: Assessment of different configurations for drainage Option 1

Configuration	Flow direction[1]	Percentage of flow that travelled through the system[2]	Floodplain inundation[3]
1A – Keith Hall sluices	Clockwise	<10%	None
1B – Keith Hall winched floodgate	Clockwise	30-60%	Moderate
1C – Union Drain and The Escape sluices	Counter-clockwise	30%	None
1D – Union Drain only sluice	Counter-clockwise	10%	None
1E – Union Drain winched floodgate	Counter-clockwise	50%	Major

[1] Clockwise flow is from Keith Hall to Union Drain. Counter-clockwise flow is from Union Drain to Keith Hall.
[2] Note: the existing floodgate configuration (one sluice and one buoyancy gate on the Keith Hall floodgates) does not allow tidal water to flow through the system in a cycle (i.e. currently the percentage of flow travelling through the system is 0%)
[3] See Appendix B for further information. Inundation is via overtopping of the main channel levees.

Numerical modelling found that through the different configurations it was possible to facilitate cyclic flow through the Keith Hall drainage network. Note, water was not able to completely travel from one side of the drainage network to the other during a single tidal cycle. Cyclic flow of water through the drainage network was found to occur as water was 'pumped' through the system over multiple tidal cycles. This was able to occur because each tidal cycle, estuarine water mixed with the catchment runoff in the drainage network. When drainage occurred, a proportion of the estuarine water remained within the drainage network. This proportion of estuarine water could then be pushed further through the system on the next incoming tide.

Of the configurations, 1B and 1E were found to result in floodplain inundation. Locations where inundation occurs are shown in Appendix B. The risk of inundation caused for configuration 1B could be reduced through the construction of additional small floodgates or levees.

3.2.3 Water quality assessment

Enabling the Keith Hall drainage network to operate in a cyclic manner would result in the following changes to water quality:

- Increased flow throughout the system preventing nutrient accumulation and enabling flushing to improve overall water quality
- Increased saline water throughout the system which can buffer acid generated from acid sulfate soils
- A higher water table elevation would reduce further oxidisation of acid sulfate soils
- A higher water table elevation would reduce the export of acidic groundwater to the drain
- Increased risk of mono-sulfidic black ooze (MBO) being mobilised and removing oxygen from the water column (note, this risk will be highest when tidal flushing is first implemented and the overall accumulation of new MBOs after the initial flushing period will be reduced)
- For some configurations (1A and 1B) floodplain runoff can be routed through Union Drain avoiding Mobbs Bay

Flushing through the Keith Hall drainage network would affect Keith Hall No. 1 Canal, Union Drain, The Escape, and downstream sections of Keith Hall No. 2 Canal. No changes to the flow regime in Mosquito Creek are expected to occur and subsequently no changes to the water quality in this part of the system.

Configurations 1A and 1B would result in significantly improved water quality within Mobbs Bay as water is forced to exit the system on the western side of the floodplain to the Richmond River. This contrasts with configurations 1C, 1D and 1E which would all result in an increased volume of floodplain runoff discharging through the Keith Hall floodgates. For configurations 1C, 1D and 1E, the benefits of improvement of water quality within the Keith Hall drainage network (outlined above) should be weighed up against the risks associated with the overall increase in discharges into Mobbs Bay.

Note, drainage Option 1 targets improvements in water quality during dry periods. Poor water quality associated with wet events, such as high nutrient loads or blackwater, is not expected to change.

3.2.4 Drainage assessment

Allowing cyclic flow through the Keith Hall drainage network would result in increased water levels during dry times. The risk of increased water levels resulting in floodplain inundation or increased groundwater levels was assessed using the numerical model.

Numerical modelling indicated that of the five configurations assessed to allow cyclic flow through the Keith Hall drainage network, three (1A, 1C and 1D) would not result in floodplain tidal inundation. While no floodplain inundation occurs for these options, it is likely that the groundwater table will be increased. The median (50^{th} percentile) drain water level has been used as an indicator for increased groundwater levels. Depending on the elevation of the floodplain and land use surrounding the drainage network this can have impacts on agricultural productivity (see Appendix E). The effect of these three options on the median in-drain water levels within the Keith Hall drainage network is shown in Table 3.2. Note, increases in the median water levels throughout Keith Hall No. 2 Canal only occur in the downstream sections of the drain. Increases in the median water levels occur throughout the entire length of the other major floodplain drains.

Table 3.2: Impact of drainage Option 1 on the median in-drain water levels[1]

Drain	Base case median water level (m AHD)	Maximum increase in median water level (m)			Maximum median water level (m AHD)		
Configuration	**Base case**	**1A**	**1C**	**1D**	**1A**	**1C**	**1D**
Keith Hall No. 1 Canal	-0.10	0.04	0.04	0.01	-0.07	-0.06	-0.09
Keith Hall No. 2 Canal[2]	0.22	0.04	0.00	0.00	0.22	0.22	0.22
Union Drain	-0.30	0.10	0.26	0.24	-0.20	-0.07	-0.12
The Escape	-0.32	0.07	0.29	0.16	-0.25	-0.04	-0.16
Mosquito Creek	0.29	0.00	0.00	0.00	0.29	0.29	0.29

[1] Water level statistics presented are for the entire length of each drain unless otherwise specified
[2] Increase in median water level for Keith Hall No. 2 Canal only occurs in downstream sections of the drain.

The highest increase in median water level was observed in The Escape and Union Drain where an increase of up to +0.3 m could be expected. It is unlikely that a rise in water level like this would impact existing sugarcane agriculture located on the low-lying floodplain adjacent to Union Drain. Further investigations into the groundwater table and soil hydraulic conductivity (flow potential of the soil) at this location would confirm this and determine if the system can provide sufficient drainage when operating in a cyclic manner.

3.2.5 Relative cost considerations

Implementation

Works required to implement drainage Option 1 involve the following changes to the culverts on Keith Hall No. 1 Canal, Union Drain and The Escape:

- Removal of existing buoyancy gates
- Installation of sluice gates
- Installation of winches to manage sluice gates

First pass estimates indicate that Option 1 would cost from $25,000 to $35,000 including design and implementation. This gives the overall cost for implementation a low relative cost.

Maintenance/management

Since RCC currently manages all end of system infrastructure that would require any changes, there would not be any additional costs associated with general maintenance and upkeep. Note, operation of sluice gates so that they are shut prior to wet events would be a new requirement. While there would be reduced maintenance costs for the general upkeep of the sluice gates, there may be additional management costs for personnel to actively manage the sluice gates before and after wet events.

Introduction of saline tidal water to the drainage network may result in less freshwater weeds across the system. This has potential to reduce costs associated with spraying and removal of weeds. Note, freshwater weeds may also become replaced with salt water tolerant weeds/vegetation. Additional costs may be incurred to manage the growth of salt water tolerant weeds or vegetation such as mangroves. Mangroves in the drainage channel can cause reduced drainage and can be difficult to manage due to clearing regulations. To prevent mangrove growth, floating booms, or nets to limit seed pod transport can be installed.

3.3 Option 2: Cyclic flow (automatic floodgates)

3.3.1 Description

Drainage Option 1 identified that cyclic flow through the Keith Hall drainage network is possible. It also identified that inundation of the low-lying Keith Hall floodplain would likely occur when large volumes of flow are allowed to cycle through the drainage network with varying tide levels. To overcome this issue, drainage Option 2 assessed whether the floodgates on either Keith Hall No. 1 Canal or Union Drain can be modified using an automated system to increase the volume of flow through the system without causing floodplain inundation.

For this option the floodgates on either Keith Hall No. 1 Canal or Union Drain have been modified to automatically open and close based upon the tidal water levels in the river. Technical details on how this has been applied for each floodgate are outlined in Appendix B. Modifying the floodgates in this way means that increased flow volumes can be encouraged to pass through the Keith Hall drainage network without causing inundation of the floodplain. When water levels in the drainage network are low, the floodgates allow tidal water from the estuary to flow into the drainage network. When river water levels reach a certain trigger height, the floodgates can then be programmed to close preventing further water entering the drainage network and floodplain inundation. An example of a floodgate structure that has been implemented elsewhere using this technology is shown in Figure 3.1. Numerical modelling has been completed to determine the optimal trigger level for closing the floodgates.

This drainage option was only considered for dry periods. The hydrology of the floodplain during wet periods should not be impacted provided operational rules for the management of floodgates are implemented (see Appendix D).

Figure 3.1: Example of automatic gates controlled by water level gauges (Kooragang Island, Hunter River)

3.3.2 Numerical model results

Numerical modelling has been used to assess the use of automatic tidal floodgates on either Keith Hall No. 1 Canal or Union Drain. A range of differing trigger water levels were assessed ranging from 0.0 m AHD to 0.45 m AHD to determine trigger levels that would provide the optimal flow through the drainage network. In total, nine configurations of automatic floodgates and trigger levels have been assessed. Table 3.3 shows how each of these configurations performed.

Table 3.3: Assessment of different configurations for drainage Option 2

Configuration	Flow direction[1]	Floodgate closure trigger level (m AHD)	Percentage of flow that travelled through the system[2]
2A – Keith Hall inflow	Clockwise	0.00	None
2B – Keith Hall inflow	Clockwise	0.10	<10%
2C – Keith Hall inflow	Clockwise	0.20	25% to 35%
2D – Keith Hall inflow	Clockwise	0.30	40% to 50%
2E – Union Drain inflow	Counter-clockwise	0.0	<10%
2F – Union Drain inflow	Counter-clockwise	0.15	20% to 30%
2G – Union Drain inflow	Counter-clockwise	0.30	30% to 50%

Configuration	Flow direction[1]	Floodgate closure trigger level (m AHD)	Percentage of flow that travelled through the system[2]
2H – Union Drain inflow	Counter-clockwise	0.45	40% to 60%
2I – Union Drain inflow and The Escape buoyancy gate	Counter-clockwise	0.45	40% to 60%

[1]Clockwise flow is from Keith Hall to Union Drain. Counter-clockwise flow is from Union Drain to Keith Hall.
[2] Note: the existing floodgate configuration (one sluice and one buoyancy gate on the Keith Hall floodgates) does not allow tidal water to flow through the system in a cycle (i.e. currently the percentage of flow travelling through the system is 0%)

3.3.3 Water quality assessment

Changes to water quality for drainage Option 2 are expected to be similar to drainage Option 1, including:

- Increased flow throughout the system preventing nutrient accumulation and enabling flushing to improve overall water quality
- Increased tidal water throughout the system which can neutralise acid generated from acid sulfate soils
- A higher water table elevation would reduce further oxidisation of acid sulfate soils
- A higher water table elevation would reduce the export of acidic groundwater to the drain
- Increased risk of mono-sulfidic black ooze (MBO) being mobilised and removing oxygen from the water column (note, this risk will be highest when tidal flushing is first implemented and the overall accumulation of new MBOs after the initial flushing period will be reduced)
- For some configurations (2A, 2B, 2C and 2D) floodplain drainage can be routed through Union Drain avoiding Mobbs Bay

Model results indicated that drainage Option 2 would result in an increase in the median water level when compared to drainage Option 1. This would mean water quality improvements associated with reduced oxidisation and buffering of acid sulfate soils would be greater for drainage Option 2.

When automatic floodgates are installed on Keith Hall No. 1 Canal, during dry times, floodplain runoff would only discharge from the drainage network via the Union Drain or The Escape floodgates. This is because automatic floodgates can be operated so that no flow is allowed out of the Keith Hall floodgates (i.e. the floodgates remain shut as the tide level falls and only open once the tide level is above the in-drain water level). It is expected that this would improve the overall water quality within Mobbs Bay. However, this solution would result in a significant increase in the distance flow is routed, particularly for the floodplain adjacent to Keith Hall No. 2 Canal. Runoff from this section of floodplain would be required to flow approximately six extra kilometres before discharging from the drainage system via Union Drain and The Escape. This means poor quality water from the section of the floodplain adjacent to Keith Hall No. 2 Canal would likely remain within the drainage network for longer. There is limited data to quantify the water quality within this section of the floodplain and how/if longer retention times may impact the system overall.

For configurations 2E to 2I, floodplain runoff discharging into Mobbs Bay would be increased. Any benefits to water quality within the Keith Hall drainage network (outlined above) should be weighed against the risks associated with, and an overall increase in, discharges into Mobbs Bay.

Similar to drainage Option 1, water quality improvements were targeted for dry periods. Poor water quality associated with floodplain runoff, such as increased nutrient loads or blackwater, is not expected to change. As with the drainage Option 1, no changes to water quality within Mosquito Creek are expected as flushing is limited within Keith Hall No. 1 Canal, Keith Hall No. 2 Canal, Union Drain and The Escape.

3.3.4 Drainage assessment

Automatic floodgates allow for water level controls within the drainage network, ensuring that there is no inundation of the floodplain from the tide. Subsequently, the greatest impact of automatic floodgates on drainage would result from an increased groundwater table. Table 3.4 provides the model results for the automatic floodgate options and the increase in the median water level within the drainage network at different locations within the system (the median water level has been used as an indicator for how groundwater levels may be impacted). Note, increases in the median water levels throughout Keith Hall No. 2 Canal only occur in the downstream sections of the drain. Increases in the median water levels occur throughout the entire length of the other drains.

Table 3.4: Impact of drainage Option 2 on the median in-drain water levels

Drain	Base case median water level (m AHD)	Maximum increase in median water level (m)				Maximum median water level (m AHD)			
Configuration	**Base case**	**2B**	**2D**	**2F**	**2H**	**2B**	**2D**	**2F**	**2H**
Trigger level (m)		**0.10**	**0.30**	**0.15**	**0.45**	**0.10**	**0.30**	**0.15**	**0.45**
Keith Hall No. 1 Canal	-0.10	0.31	0.44	0.04	0.12	0.08	0.21	-0.06	0.02
Keith Hall No. 2 Canal*	0.22	0.31	0.44	0.00	0.01	0.22	0.22	0.22	0.22
Union Drain	-0.30	0.29	0.40	0.37	0.50	-0.01	0.10	-0.02	0.10
The Escape	-0.32	0.23	0.32	0.27	0.36	-0.08	0.00	-0.04	0.05
Mosquito Creek	0.29	0.00	0.00	0.00	0.00	0.29	0.29	0.29	0.29

*Increase in median water level in Keith Hall No. 2 Canal only occurs in downstream sections of the drain.

Model results indicate that there would be a substantial increase in the median water level within the drainage network (up to 0.50 m in Union Drain). This has the potential to raise the groundwater table and any impact to the agricultural productivity would need to be considered (see Appendix E). It is likely that during wet periods a raised groundwater table would impact crop productivity. Careful management of floodgate operational rules could reduce any potential impact to agricultural productivity. For example, cyclic flow could only be permitted once floodplain groundwater levels have dropped to an acceptable level. Further investigation of floodplain groundwater levels would assist in developing operating rules for the floodgates.

3.3.5 Relative cost considerations

Implementation

Automatic floodgates can be retrofitted to existing floodgate structures or a new structure can be built either upstream or downstream of the existing floodgates. Subsequently, the implementation costs would vary depending upon the final floodgate design.

It is estimated that a new structure with automatic tidal floodgates would cost between $350,000 and $625,000. This has been estimated based on the cost to design and construct new floodgates, the cost to add automatic modifications, and the costs to replace existing buoyancy gates with sluices. This gives the overall cost for implementation a medium to high relative cost.

The estimated costs are reduced to between $150,000 and $250,000 if the existing floodgate structures are retrofitted with automatic tide gates. This would bring the overall cost for implementation to a medium relative cost.

Maintenance/management

Automatic floodgates would require significantly more maintenance than the existing floodgate structures at Keith Hall. It is estimated that if the existing floodgates were retrofitted with automatic floodgates maintenance costs would increase by approximately $15,000 per annum. This includes time for regular servicing and manual operation in the event of a malfunction. As such, if new floodgates were constructed there would be additional costs associated with the maintenance of the new structures in addition to the existing ones.

Where existing sluice and buoyance gates are decommissioned, operational costs would be reduced. The automatic floodgates could also be operated remotely, however, operators may need to be on standby in case the automatic floodgates malfunction.

As with drainage Option 1, introduction of tidal water to the drainage network may result in fewer freshwater weeds across the system. This has the potential to reduce costs associated with spraying and removal of weeds. Note, freshwater weeds may also become replaced with salt water tolerant weeds/vegetation. Additional costs may be incurred to manage the growth of salt water tolerant weeds or vegetation such as mangroves. Mangroves in the drainage channel can reduce drainage and be difficult to manage due to clearing regulations. To prevent mangrove growth, floating booms or screens to limit seed pod transport can be installed.

3.4 Option 3: Increased tidal connectivity

3.4.1 Description

There are four sets of floodgates for the Keith Hall drainage network which are responsible for the majority of floodplain drainage, including:

- The Keith Hall No. 1 Culvert floodgates
- The Union Drain floodgates
- The Escape floodgates
- The Mosquito Creek floodgates

Presently, there are a number of modifications that permit tidal flushing into the Keith Hall drainage network. On the Keith Hall No. 1 Canal floodgates there is a sluice gate and a buoyancy gate which are operated as per the "Keith Hall Drainage System Active Floodgate Management Plan" (RCC, 2020) (Figure 3.2). There is a buoyancy gate located on The Escape floodgates which allows controlled tidal flows upstream. There is also a buoyancy gate which has been decommissioned and does not open on the Union Drain floodgates. The Mosquito Creek floodgates currently have a single buoyancy gate that allows limited tidal exchange, however local landowners occasionally open the floodgates to allow larger volumes of tidal water to flow upstream to improve water quality and control freshwater weeds. Field observations found that tidal connectivity allows the growth of mangroves upstream of the Mosquito Creek floodgates.

Figure 3.2: Sluice gate (right) and buoyancy driven tidal gate (left) on the Keith Hall floodgates

Drainage Option 3 investigates whether the tidal connectivity between the estuary and the Keith Hall drainage network can be increased through further modifications to the drainage infrastructure. Subsequently, the replacement of all buoyancy gates with sluice gates following options has been assessed.

Numerical modelling has been used to optimise the design and operation strategy for sluice gates. The optimal opening size of the sluice gates has been determined based upon the project aims. Technical details for how these modifications have been implemented in the numerical model are outlined in Appendix B.

This drainage option was only considered for dry periods. The hydrology of the floodplain during wet periods should not be impacted as long as operational rules for the management of floodgates are implemented (see Appendix D).

3.4.2 Numerical model results

Six configurations have been assessed for increased tidal connectivity between the Keith Hall drainage network and the Richmond River. Numerical model results for these configurations are shown in Table 3.5. Technical detail regarding how sluice gates were implemented within the numerical model is outlined in Appendix B. Note, the median water level has been used as an indicator for influence on the average groundwater level. Depending on the elevation of the floodplain and land use surrounding the drainage network this can have impacts on agricultural productivity (see Appendix E). As an additional check, the 95th percentile water level has also been used as an indicator of the maximum potential groundwater level that would be likely to occur. If the 95th percentile water level is 0.50 m below the floodplain it is unlikely to raise water levels to elevations that may impact sugarcane productivity (see Appendix E).

Table 3.5: Assessment of different configurations for drainage Option 3

Configuration	Increase in median water level above the base case (m)	Is the 95th percentile in-drain water level always 0.50 m below the floodplain?[4]	Floodplain inundation[5]
3A – Keith Hall sluice gates only[1]	0.05 to 0.15	No	None
3B – Mosquito Creek sluice gate only[2]	0.08	No	None
3C – Union Drain sluice gate only[1]	0.01 to 0.25	No	None
3D – The Escape sluice gate only[1]	0.01 to 0.29	No	None
3E – All sluice gates fully open[3]	0.07 to 0.30	No	None
3F – Optimise sluice gates so water level is always 0.50 m below the floodplain[3]	0.06 to 0.29	Yes	None

[1] Increases in the median level occurred in all drains except for Mosquito Creek
[2] Increases in the median water level only occurred within Mosquito Creek
[3] Increases in the median water level occurred throughout the entire drainage network
[4] The 95th percentile water level has been used as an indicator for influence on the groundwater level. If the 95th percentile water level is 0.50 m below the floodplain it is unlikely to raise water levels to elevations that would impact sugarcane productivity
[5] See Appendix B for further information. Inundation is via overtopping of the main channel levees.

3.4.3 Water quality assessment

Changes to water quality for drainage Option 3 is expected to be similar to drainage Options 1 and 2, including:

- Increased flow throughout the system preventing nutrient accumulation and enabling flushing to improve overall water quality
- Increased tidal water throughout the system that can buffer acid generated from acid sulfate soils
- A higher water table elevation would reduce further oxidisation of acid sulfate soils
- A higher water table elevation would reduce the export of acidic groundwater to the drain
- Increased risk of mono-sulfidic black ooze (MBO) being mobilised and removing oxygen from the water column (note, this risk will be highest when tidal flushing is first implemented and the overall accumulation of new MBOs after the initial flushing period will be reduced)

Since tidal flushing would occur throughout Mosquito Creek, so would the changes to water quality outlined above (for configurations 3B, 3E and 3F). This contrasts with drainage Options 1 and 2 which do not result in any tidal flushing or changes to the water quality within Mosquito Creek.

Water quality in Mobbs Bay would be expected to be improved due to increased tidal connectivity within the drainage network. Additional tidal flushing would reduce oxidisation of acid sulfate soils and encourage buffering of acid. Increased water volumes flowing through the drainage network would help to prevent the build-up contaminants such as nutrients and bacteria in the drainage network.

Similar to drainage Options 1 and 2, water quality improvements were targeted for dry periods. Poor water quality associated with floodplain runoff, such as increased nutrient loads or blackwater, is not expected to change.

3.4.4 Drainage assessment

Modification of floodplain drainage infrastructure to install sluice gates would mean that inflows to the floodplain would occur throughout the tidal cycle. The level of this inflow can be controlled by adjusting the sluice gates to have larger or smaller openings. Assessment of numerical model results has been completed to determine how different sluice gate openings would impact floodplain drainage. This assessment has reviewed the potential inundation and the potential impact on groundwater levels. Note, inflow levels are also a function of the tide elevation so the model simulation period included spring tides to ensure higher inflow volumes during these large tides were accounted for.

A 0.35 m^2 sluice gate was simulated for Mosquito Creek in place of the existing buoyancy gate to allow tidal connectivity between the drainage network and the Richmond River (for configurations 3B, 3E and 3F). Modelling indicated that if such a sluice gate were to be installed, there would be no impacts associated with inundation or significant increases in the groundwater table.

For the Keith Hall, Union Drain and The Escape floodgates, the existing windows in the floodgates currently used for the buoyancy gates were simulated to be converted to sluice gates (configurations

3A, 3C, 3D, 3E and 3F) and assessed using the numerical model. The assessment was completed for the opening of individual sluice gates (configurations 3A, 3C, and 3D) and a combination of sluice gates (configurations 3E and 3F). Modelling found that if the sluice gates were fully opened no inundation over the drain banks would occur. This finding held for any combination of sluice gates that were opened/closed across the floodplain infrastructure.

While no floodplain inundation occurs from the installation of sluice gates, increasing the in-drain water levels is likely to increase the groundwater table across the Keith Hall floodplain. Depending upon the scale of groundwater table increase, this can have various impacts on agriculture (see Appendix E). Configuration 3F identified the levels sluice gates could be opened to without risking any significant changes to the groundwater table under areas of the floodplain where sugarcane is currently growing. Sugarcane was selected as it is the land use most likely to be impacted by a raised groundwater table (sugarcane requires the groundwater table to be approximately 0.5 m below the surface to ensure drainage and subsequently productivity (Rudd and Chardon, 1977)). Model results showed that the sluice gates could be opened to the following levels without impacting agricultural productivity:

- Keith Hall floodgates: Two sluice gates opened 0.20 m
- The Escape floodgates: One sluice gate opened 0.05 m
- Union Drain floodgates: One sluice gate 0.20 m wide opened 0.05 m
- Mosquito Creek: One sluice gate fully opened

Table 3.6 outlines the additional connectivity between the Keith Hall drainage network and the Richmond River for the different configurations. These results show that even low-risk options result in over twice as much connectivity between the drainage network and the estuary without impacting agricultural productivity (i.e., configuration 3F). Modelling indicated that present day active management of the floodgates (RCC, 2020) results in approximately 5,800 m^3/day of tidal water flushing through the drainage network that would not occur if the sluice gate and buoyancy gate were closed.

Table 3.6: Additional tidal connectivity for drainage Option 3 compared to the base case

Configuration	Volume of tide allowed into the drainage network (m^3/day)	Increase in volume compared to the base case (base case volumes)*
Base case	5,800	1.0
3A – Keith Hall sluice gates only	20,100	3.5
3B – Mosquito Creek sluice gate only	14,000	2.4
3C – Union Drain sluice gate only	8,000	1.4
3D – The Escape sluice gate only	12,800	2.2
3E – All sluice gates fully open	35,600	6.1

3F – Optimise sluice gates so water level is always 0.50 m below the floodplain	15,600	2.7

* i.e. an increase in volume compared to the base case of '2.0' means that twice as much tidal water enters the drainage network (i.e. 11,600 m^3/day) compared to the existing level of tidal flushing.

It is recommended that a staged opening of sluice gates be considered if any configurations outlined for drainage Option 3 are to be implemented. This would ensure that there are no adverse impacts on the surrounding floodplain.

3.4.5 Relative cost considerations

Implementation
Sluice gates require a window to be cut in a floodgate (if it does not already exist), a sliding gate to be fitted, and a winch to be installed so that the sluice can be safely operated. For drainage Option 3, anywhere between one and four sluice gates may be installed. The cost of this is estimated to be between $15,000 and $50,000. This suggests that the overall cost for implementation is a low relative cost.

Maintenance/management
Since RCC presently manage all of the end of system infrastructure that would require any changes, there would not be any additional costs associated with their general maintenance and upkeep. Removal of buoyancy gates and replacement with sluice gates would mean that there would be reduced maintenance required for their general upkeep. Operation of sluice gates so that they are shut prior to wet events would be required and would result in additional maintenance costs.

Introduction of saline tidal water to the drainage network may result in reduced freshwater weeds across the system. This has the potential to reduce costs associated with spraying and the removal of weeds. However, freshwater weeds may also become replaced with salt water tolerant weeds/vegetation over time. Additional costs may be incurred to manage the growth of salt water tolerant weeds or vegetation such as mangroves. Mangroves in the drainage channel can cause reduced drainage and can be difficult to manage due to clearing regulations. To prevent mangrove growth, floating booms or nets to limit seed pod transport can be installed.

3.5 Option 4: Keith Hall floodgate weight

3.5.1 Description

Upstream water levels at the Keith Hall floodgates are approximately 0.1 m to 0.2 m higher than downstream Richmond River water levels (Appendix A). There are several factors that contribute to this difference in water levels, including:

- The floodgate has an invert at -0.43m AHD preventing drainage lower than this elevation (see Figure 3.3 for invert definition)

- As water passes through the culvert there are energy losses associated with friction and turbulence which effectively hold the water table on the upstream side at a higher level compared to the downstream side (Bos, 1976)
- As water passes through the floodgate, water pressure is required to swing the floodgate flap open. The pressure is related to the water depth so the higher the water level on the upstream side of the floodgates, the higher the pressure. Since the floodgates require a certain level of pressure to open, the upstream side will always have a higher water level compared to the downstream side. If a heavier floodgate flap is installed, more pressure will be required, and the water level on the upstream side of the floodgates will need to be even higher to force the floodgates open compared to a lighter floodgate flap.

These factors result in higher water levels throughout the Keith Hall drainage network (i.e. the 0.1 m to 0.2 m rise in water levels translates up Keith Hall No. 1 and No. 2 Canals). This water level differential occurs at all times as it is caused by the floodgate structure and geometry and occurs for all floodgate structures. Furthermore, despite being unable to completely drain water to the downstream water levels, the existence of a floodgate structure like this provides a net benefit to the drainage of the floodplain compared to if it did not exist, as it prevents water flowing back into the drainage network.

Each of these factors could be individually addressed to increase drainage efficiency through the Keith Hall floodgates. The floodgate invert could be lowered to allow further drainage when the low tide drops below the floodgates invert level. Note, lowering the invert of a floodgate like this is a difficult process and it may be more cost effective to replace the entire structure. Furthermore, Harrison et al. (2021) found that in the near future the Keith Hall floodgates would be impacted by sea level rise so any benefit of this option would be short-lived. Alternatively, a new floodgate design which minimises friction and turbulence could be investigated to reduce the water level difference between upstream and downstream waterways.

Another option to increase drainage efficiency is to install new light weight floodgate flaps to reduce the energy (i.e. water pressure) required to open them. When the water level in the drain lowers, it reaches a level where there is not enough force from the water on the upstream side to push the floodgates open (i.e. the floodgates weight prevents further drainage). If the weight of the floodgates was lighter, then it would require less force to push them open. Additionally, when lighter floodgates are pushed open, they are pushed open further for equivalent water levels (compared to heavier floodgates) meaning more flow can pass through them.

Drainage Option 4 investigates the option of replacing the existing floodgate flaps with light weight flaps (Figure 3.3). Numerical modelling has been completed to determine how the floodgate flap material affects the final stages of drainage and whether the difference between the upstream and downstream water levels can be reduced by changing the flap material. This analysis has been completed for the following floodgate flap materials:

- Aluminium (the current floodgate flap material)
- Stainless steel
- Fibreglass
- High density polyethylene (HDPE)

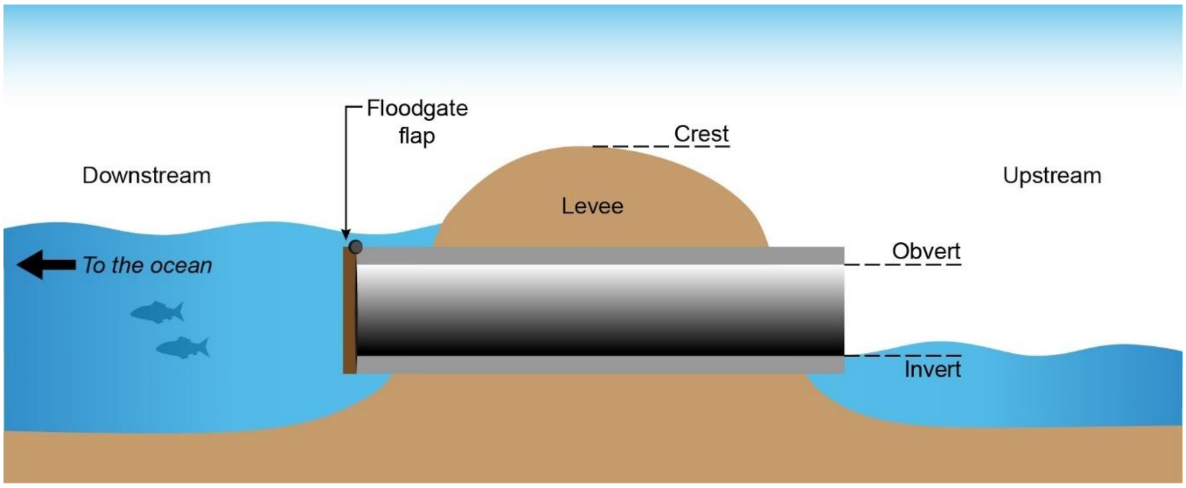


Figure 3.3: Diagram of a floodgate showing the "floodgate flap" which was altered to be made of different materials and therefore lighter in weight for different scenarios

Technical details on how the analysis was completed using the numerical model is specified in Appendix B. The following section outlines the results of numerical modelling and assessment of drainage Option 4 against the project aims.

3.5.2 Numerical model results

Four alternate floodgate materials have been modelled to determine if changing the floodgate material is likely to improve drainage efficiency. Results from the numerical modelling are shown in Figure 3.4. Note, model simulations for each floodgate material assumed that the current active tidal management of the floodgates continue (i.e. one sluice gate and one buoyancy driven tidal gate).

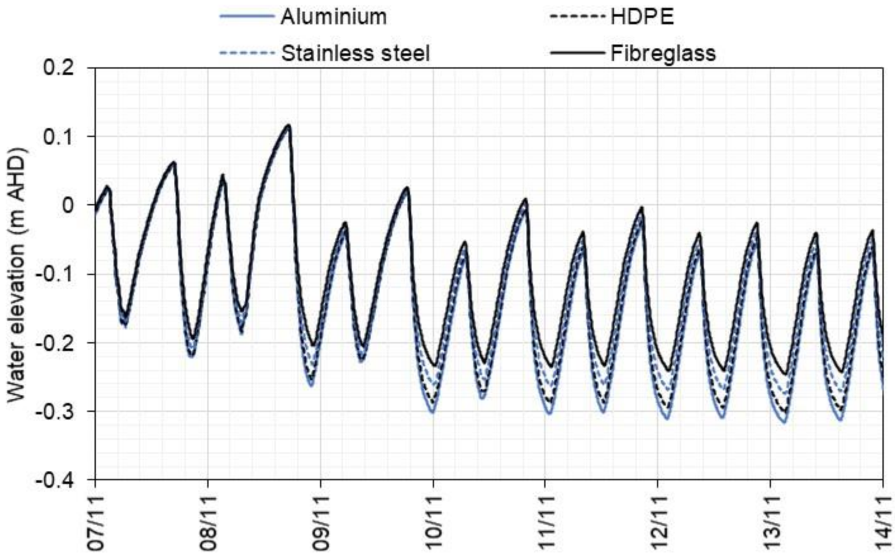


Figure 3.4: Water levels upstream of the Keith Hall floodgates for different floodgate flap materials

As shown in Figure 3.4, different floodgate flap materials have the ability to alter the minimum water level elevation immediately upstream of the Keith Hall floodgates. Differences in water levels up to 75 mm were observed in the model results. Aluminium floodgates were the most effective at reducing the water levels within the drainage network. This is because overall they were the lightest weight. While fibreglass and HDPE are less dense than aluminium, to provide enough strength for a floodgate flap they require a larger mass of material (see Appendix B).

Since the floodgate weight was identified as the key factor in determining the drainage level upstream of the floodgate, an additional test was completed to assess if two half sized flaps hinged separately one on top of the other would provide more efficient drainage than one large floodgate flap. Results of this analysis are shown in Figure 3.5. Installing two smaller floodgates instead of one large floodgate for each culvert provided up to 9 mm of additional drainage relief in the immediate vicinity of the floodgates. For the majority of the Keith Hall drainage network additional drainage relief was minimal (1 to 2 mm).

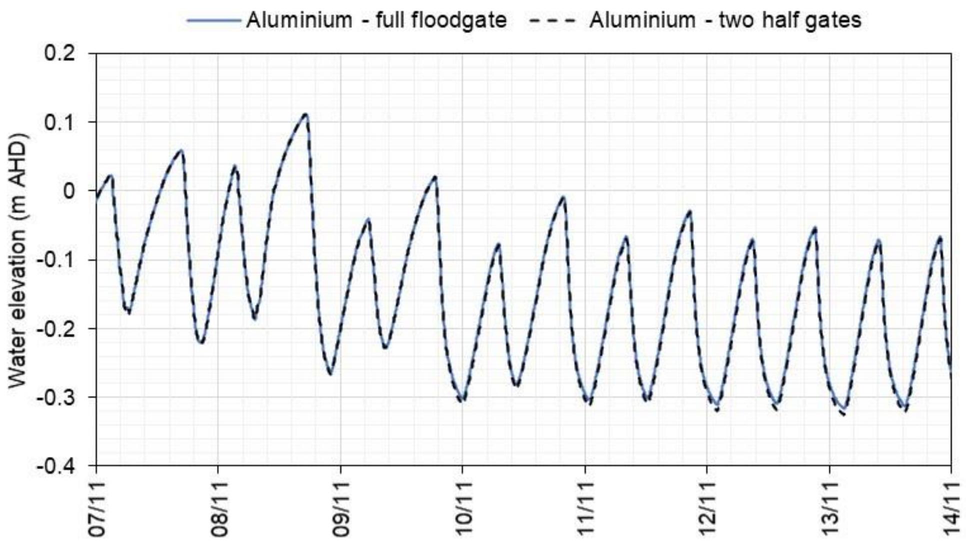


Figure 3.5: Comparison of floodplain drainage provided by one large floodgate versus two smaller floodgates for a single culvert

3.5.3 Water quality assessment

Changes to the floodgate flap design (so there are two smaller floodgate flaps) would result in changes to the low-tide water levels immediately upstream in the drainage network, albeit only slightly (<10 mm in the vicinity of the floodgates). While this level of change would likely be negligible, it is worth understanding the impacts that lowering the drainage networks water table would have on water quality.

Following wet events, the groundwater level remains high while there are lower water levels in the drainage network caused by floodgates. This results in acidified water from acid sulfate soils flowing from the groundwater into the drainage network. The greater the water level difference between the groundwater and in-drain water levels, the greater the export of acidic water. Therefore, any change to the drainage network that results in a lower in-drain water level is likely to have adverse impacts on water quality due to the production and increased export of sulfuric acid from acid sulfate soils. The impacts of acid sulfate soils on water quality are further outlined in Section 2.3.1.

Numerical modelling indicated that aluminium floodgate flaps (the lightest weight option) with two separate flaps per culvert would provide the most efficient drainage. This would result in a slightly lower water table (up to 9 mm at the floodgates) during low tides immediately upstream of the floodgates. There would be some capacity for additional oxidisation and drainage of acid sulfate soils, however, changes of this scale would likely be negligible and off-set by the existing sluice and buoyancy driven tidal gates.

3.5.4 Drainage assessment

Drainage Option 4 investigates modifying the material of the flaps on the Keith Hall floodgates with the objective of increasing discharges during the final stages of low-tide drainage. The purpose of this would be to provide additional in-drain storage to protect the floodplain during rainfall events. Numerical modelling found that minimal changes in water levels (<10 mm) in the vicinity of the Keith Hall floodgates would result from different floodgate flap materials. If this level of change occurred across the drainage network it would correspond to approximately 4,000 m^3 of water (see Appendix D), or less than one millimetre of rainfall across the Keith Hall floodplain. Therefore, the level of additional protection from flooding provided by installing lightweight floodgates can be considered negligible.

Note, further investigations are required to determine how the weight of the floodgate flap affects the first stages of drainage when the floodgate flaps are partially submerged. During this stage of drainage other influences such as the buoyancy (or specific gravity) of the floodgate would need to be considered.

3.5.5 Relative cost considerations

Implementation

Installing new floodgates at Keith Hall would require either the retail purchase of an existing lightweight floodgate or the design and manufacturing costs associated with creating a new floodgate. There would also be costs associated with installation for both options. It is estimated that new floodgates would cost up to $70,000, a medium relative cost.

Maintenance/management

The Keith Hall floodgate flaps are currently manufactured and maintained in-house by RCC. Existing floodgates managed by RCC are marine grade aluminium and stainless steel floodgates, however, stainless steel floodgates are being phased out as marine grade aluminium is lighter weight and more tolerant to the estuarine environment. There are economies of scale and cost efficiencies achieved through having aluminium floodgates across the network of floodgates managed by RCC. Subsequently, changing to fibreglass or HDPE designs would be more costly as RCC would require different material resourcing and need to supply skills and training for staff to manage and maintain the new materials. Note, some floodgate materials are more or less resistant to the harsh marine environment that floodgates are subject to and may require different levels of maintenance.

3.6 Option 5: Keith Hall No. 1 Canal swale

3.6.1 Description

Drainage Option 5 investigates the effectiveness of reshaping a section of Keith Hall No. 1 Canal to be shallow and wide to reduce poor water quality associated with acid sulfate soils. The section of drain to be reshaped is between Union Drain and Keith Hall Lane, as shown in Figure 3.6.

Creating a swale drain is an effective technique to mitigate the impacts of acid sulfate soils (Johnston et al., 2003; Tulau, 2007). Swale drains maintain the effective drain cross-sectional area and drainage capacity of the existing system while reducing groundwater drawdown (Figure 3.7). This means that the groundwater is higher (preventing further oxidisation of acid sulfate soils), and less acid is exported from the floodplain through the drainage network.

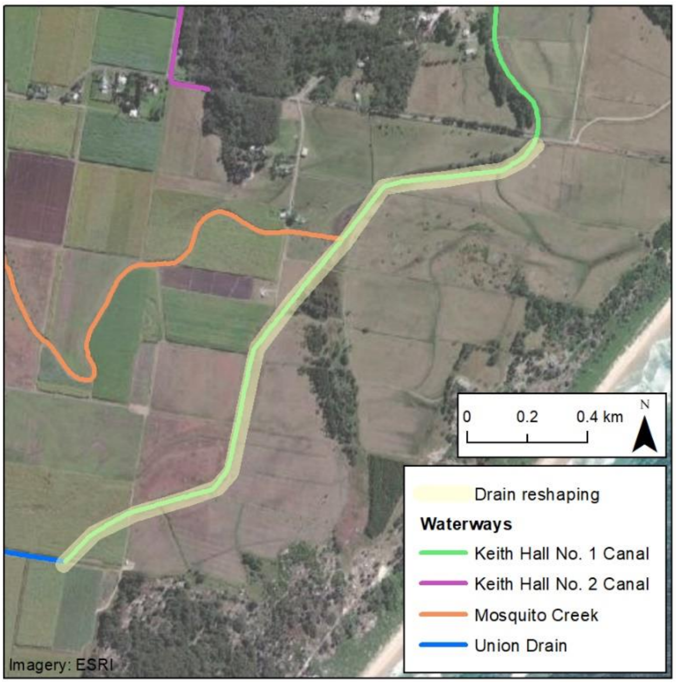


Figure 3.6: Location of drain reshaping on Keith Hall No. 1 Canal

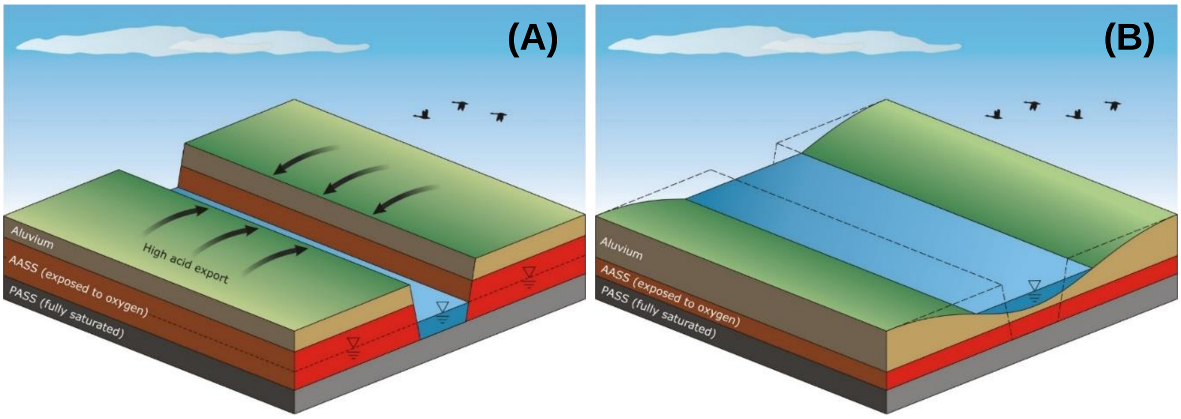


Figure 3.7: Before (A) and after (B) swale drain construction

Technical details for the implementation and assessment of drainage Option 5 are provided in Appendix B.

3.6.2 Numerical model results

Assessment of how constructing a shallow and wide swale drain on the upstream sections of Keith Hall No. 1 Canal would impact the floodplain hydrology was completed using the numerical model. The shape of the swale drain is shown in comparison to the existing canal cross section in Figure 3.8. The drain was redesigned to have a slight gradient towards the Keith Hall floodgates, however, due to the presence of acid sulfate soils this gradient was limited to less than 0.2 m over the length of the drain. Note, a gradient like this could be considered negligible. Due to the environmental conditions and low elevation of the floodplain a more significant fall is not possible without significant disturbance of acid sulfate soils.

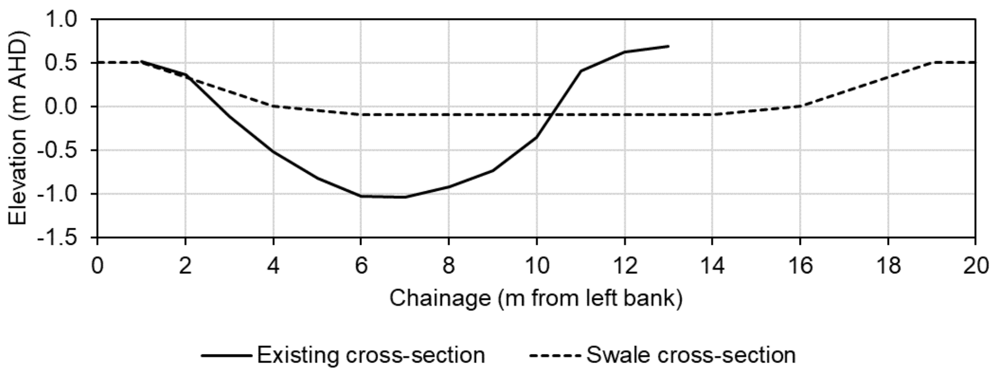


Figure 3.8: Comparison of the existing cross-section with the swale drain cross section

Model results indicated that there would be negligible changes to the flow of water throughout the floodplain. The swale drain behaved as expected during runoff events, being able to provide sufficient drainage equivalent to the previous deep drainage channel. Water levels across the floodplain are shown in Figure 3.9 comparing drainage Option 5 to the base case (i.e., the current floodplain conditions).

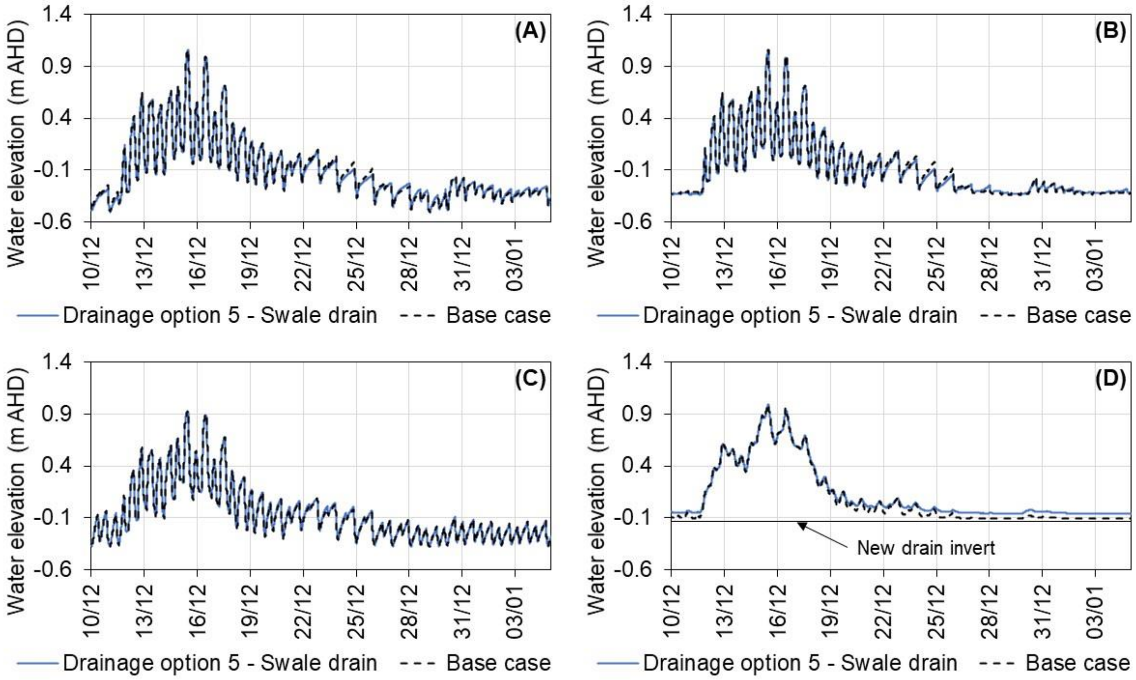


Figure 3.9: Water levels for drainage Option 5 upstream of the Union Drain floodgates (A), upstream of The Escape floodgates (B), at the confluence of Keith Hall No. 1 and No. 2 Canals (C) and at the confluence of Keith Hall No. 1 Canal and Mosquito Creek (D)

The majority of changes to the floodplain hydrology were associated with the new swale drain acting as a *defacto* weir, reducing the connectivity between Keith Hall No. 1 Canal and Union Drain. Overall, this resulted in increased flow discharging through the Keith Hall floodgates and decreased flow discharging through the Union Drain/The Escape floodgates.

3.6.3 Water quality assessment

The strategy of widening and shallowing Keith Hall No 1 Canal specifically focuses on reducing the impacts of poor water quality associated with acid sulfate soils. This is achieved in three ways:

1. The hydraulic gradient and transport of acid from the floodplain to the drainage network is reduced.
2. The groundwater is no longer drained to low levels preventing further oxidisation of acid sulfate soils.
3. Drain maintenance to clear vegetation which involves the placement of acidic sediments on drain banks that can then leech back into the drainage network when vegetation is cleared is reduced.

Acid sulfate soils were observed up to the surface at certain points along the drain alignment, specifically the area adjacent to Mosquito Creek which has been identified as an acid hot spot on the

Keith Hall floodplain (WRL, 2019). Subsequently, an overall reduction in oxidisation and export of acid from acid sulfate would be expected. This would reduce concentrations of heavy metals such as iron and aluminium throughout the Keith Hall drainage network. The overall pH throughout the drainage network would also be expected to increase (improve). Note, since the swale drain is only for a 2 km section of drainage network, it would not reduce the drainage of acid sulfate soils throughout the rest of the drainage system. Subsequently, while there would be improvements by reducing the drainage of acid sulfate soils at a known hot spot, some level of acid sulfate soil drainage, and the environmental impacts associated (low pH and high heavy metal concentrations), would still occur.

Modelling indicated that during dry periods the bottom of the swale drain would likely dry out. This has benefits to water quality as it would prevent the formation mono-sulfidic black ooze (MBO) which requires anaerobic conditions (i.e., no oxygen) (Sullivan et al., 2018a). Furthermore, since the drain would likely dry out, maintenance of weeds within the drainage channel could be managed through slashing as opposed to clearing with an excavator. Stone et al. (1998) noted that when drains are cleared using an excavator there is an increased risk that acidic sediments from the bottom of the drainage channel are mobilised within the waterway, and also placed on the bank will oxidise and result in acidic water leaching back into the drain. Note, this risk can often be mitigated by other management practices such as liming or placing any excavated sediment back into the drain before it can aerate and oxidise.

Depending upon the adjacent land use, a swale drain could result in reduced water quality. During dry periods it may be possible for cattle to walk across and graze within the swale drain. Following runoff events this would result in pathogens from cattle faeces being transported into the downstream waterways. This would be of particular concern at Keith Hall where oysters farming and recreation would be impacted downstream in Mobbs Bay. Where cattle are allowed within the swale drain channels there may also be a higher risk of soil pugging and soil erosion. To mitigate this, it is recommended that the swale drain be fenced from stock access.

3.6.4 Drainage assessment

Numerical model results indicated that drainage efficiency of the swale drain was equivalent to the current deep and narrow drainage channel. This can be seen in Figure 3.9 where the water level was effectively reduced and the floodplain drained following the runoff event on December 12.

Figure 3.10 shows the time it took to drain the floodplain following an inundation event up to 1 m AHD across the floodplain for drainage Option 5 versus the existing base case. Results indicate that it would take an additional one hour for the water level to reduce below the lowest floodplain elevation. While drainage times did increase it was only by a small period and it is not expected that this would significantly impact floodplain drainage.

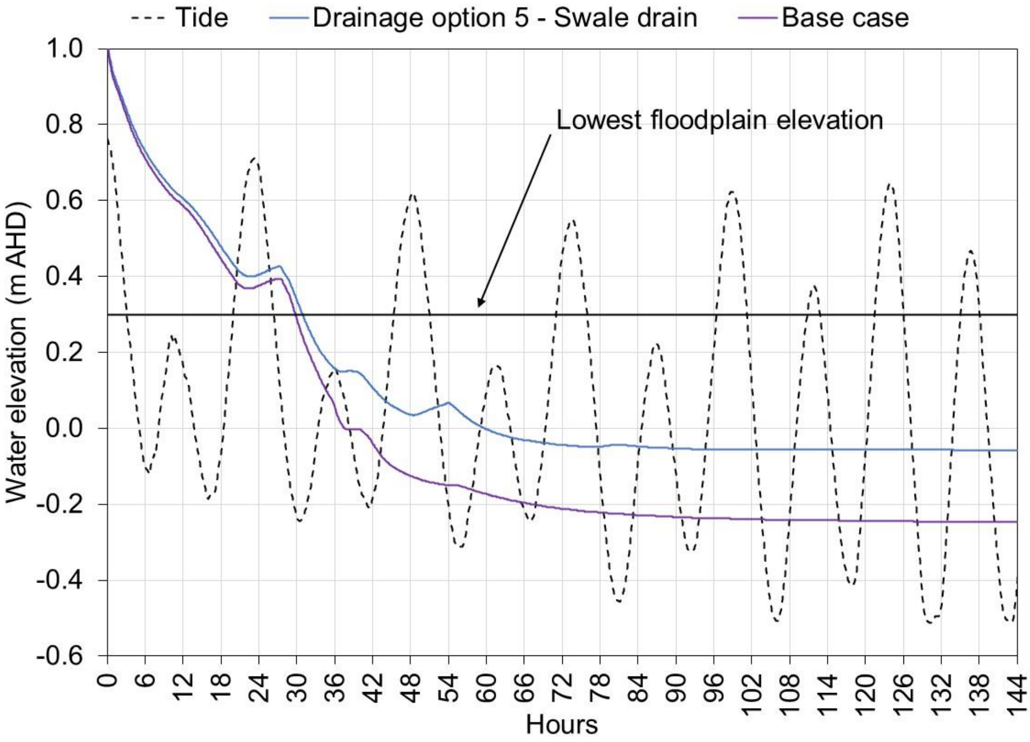


Figure 3.10: Drainage time assessment for Option 5 at the confluence of Mosquito Creek and Keith Hall No. 1 Canal

Construction of a swale drain would result in decreased groundwater drainage compared to the existing deep drainage channel. Given enough time, drainage would occur to the invert of the new swale drain (or the standing water level if higher). However, in comparison to the low tide level (or standing water level) for the current deep drain this is significantly less. A swale drain with an invert at approximately 0 m AHD would mean that the groundwater could only be drained below this elevation through evaporation. While this would benefit water quality where acid sulfate soils are present there is potential for this to impact on agricultural productivity particularly for sugarcane. Analysis of LiDAR topographic data found that there is one low-lying section of floodplain that may be at higher risk (Figure 3.11). A detailed assessment of the floodplain elevation at this location could be completed to inform land raising for this small section of the floodplain. The purpose of this would be to mitigate the impact of an increased water table at this location.

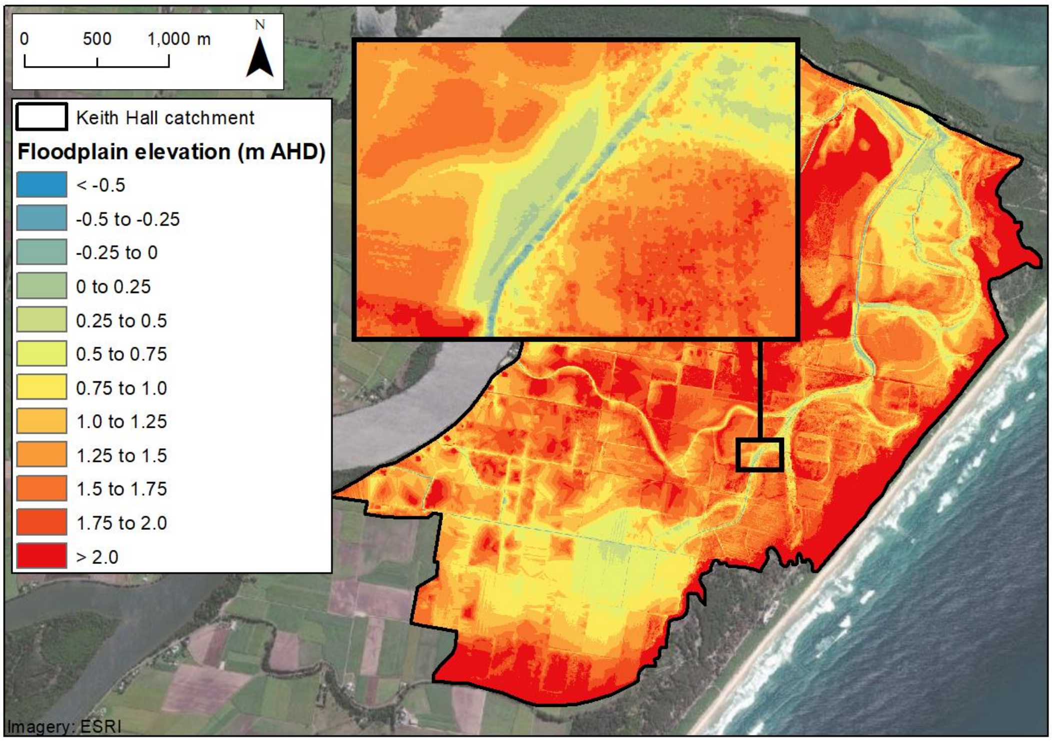


Figure 3.11: Location of low elevation cane field adjacent to Keith Hall No. 1 Canal

Analysis of data available for secondary drains that would flow into the sections of Keith Hall No. 1 Canal upstream of Keith Hall Lane found that their inverts were above 0 m AHD, the proposed invert elevation for the new swale drain. This means secondary drains would not be impacted by changing the shape of Keith Hall No. 1 Canal. Any new secondary drains constructed should follow acid sulfate soil guidelines (Stone et al., 1998) and have an invert higher than the section of swale drain they would connect with.

Exclusion of stock from the swale drain would not be important for its hydraulic function. It is unlikely that allowing stock onto the drain would change the fall of the drain because the redesigned drains slope is relatively flat. Growth of vegetation across the swale drain may result in increased roughness and decrease its efficiency. Subsequently, allowing stock to graze across the swale may improve the drains efficiency.

3.6.5 Relative cost considerations

Implementation

Costs to implement drainage Option 5 include detailed design, site establishment and construction. It is estimated that to reshape the 2 km of Keith Hall No. 1 Canal from Union Drain to Keith Hall Lane costs would total approximately $130,000. Note, during construction additional costs may be incurred associated with import/export of fill and liming of acid sulfate soils. The cost of liming acid sulfate soils depends on the content of acid and frequency of liming required but could be up to $250,000. Subsequently, drainage Option 5 has a medium relative cost.

Maintenance/management
As with all floodplain drains, ongoing maintenance would be required for the swale drain once constructed. Levels of maintenance could be expected to be similar to the existing drainage infrastructure and include management of vegetation in and around the drain.

Where there is no water within the drain, due to the higher invert, the drain can be managed by regular slashing to ensure that drainage is efficient and unobstructed. Fencing may be required to prohibit stock access to the swale drain to meet water quality objectives.

If there are sections of the drain that are continuously filled with shallow water, this may result in an increased need for clearing of weeds and vegetation. This is because in shallow drains light can more easily penetrate to the bottom of the channel (compared to deep drains) allowing vegetation to grow.

3.7 Option 6: Keith Hall No. 2 Canal new drain

3.7.1 Description

Historically, Keith Hall No. 2 Canal would have connected directly to Mobbs Bay independently of Keith Hall No. 1 Canal through its own set of floodgates. This connection no longer exists due to the construction of South Ballina Beach Road and a new east-west channel connecting Keith Hall No. 2 Canal to Keith Hall No. 1 Canal. Drainage Option 6 looks at reconnecting Keith Hall No. 2 Canal directly to Mobbs Bay (Figure 3.12). This would involve:

- Increasing the flow capacity of culverts under South Ballina Beach Road (currently there is one 0.6 m diameter culvert that only allows flows to pass through during high tides)
- Disconnecting Keith Hall No. 2 and No. 1 Canals by infilling the east-west section of drain and creating a swale drain that only allows flow during flood events
- Ensuring that former drain channels between Keith Hall No. 2 and Mobbs Bay are sufficiently sized to allow floodplain drainage

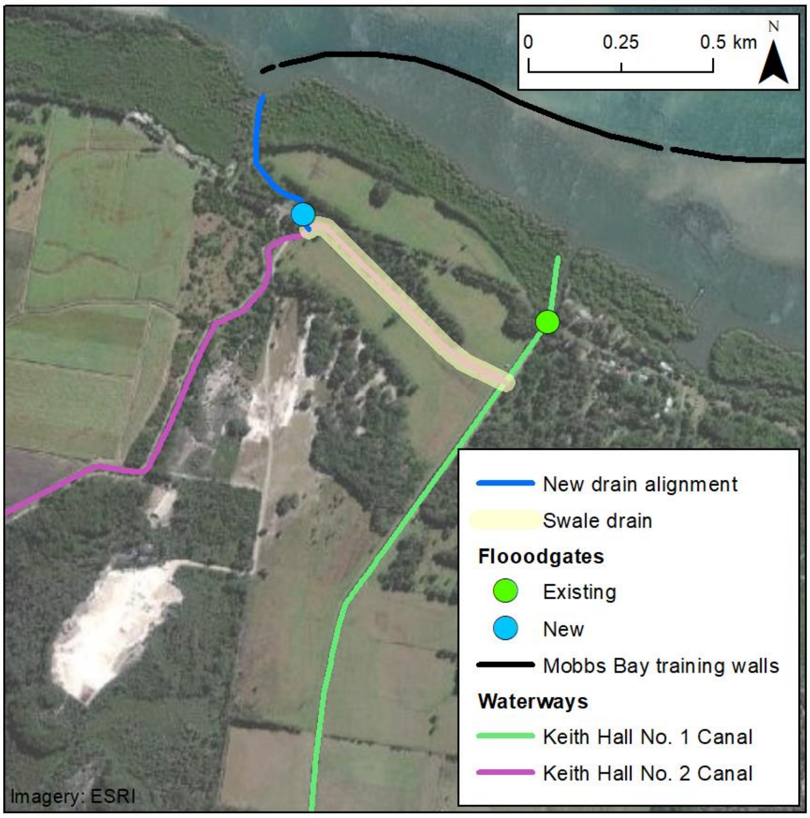


Figure 3.12: Drainage Option 6 – Keith Hall No. 2 Canal new drain

Drainage Option 6 seeks to achieve the project aims in the following ways:

- The elevation of the culverts under South Ballina Beach Road is designed to have an invert level above the acid sulfate soil layer (approximately +0.1 m) to reduce acid drainage
- Water quality improvements for Keith Hall No. 1 and No. 2 Canals can be treated individually
- The invert of a 600 m length of drain is raised reducing groundwater and acid sulfate soil drainage
- A swale drain still remains between Keith Hall No. 1 and No. 2 Canals to ensure sufficient drainage during runoff events to remove water from the floodplain

3.7.2 Numerical model results

Numerical model results for drainage Option 6 are shown in Figure 3.13 at various locations throughout the Keith Hall drainage network. The floodgate structure design was for four rectangular culverts 1.3 m wide, 0.5 m high and with an invert of +0.1 m AHD. Comparison of the base case and drainage Option 6 model results show that there are minimal changes to floodplain drainage. Changes that were observed include:

- An increase in water levels (<0.1 m) within Keith Hall No. 1 Canal and Union Drain during day-to-day conditions
- An increase in water levels (up to 0.6 m) within Keith Hall No. 2 Canal during day-to-day conditions (Figure 3.14)

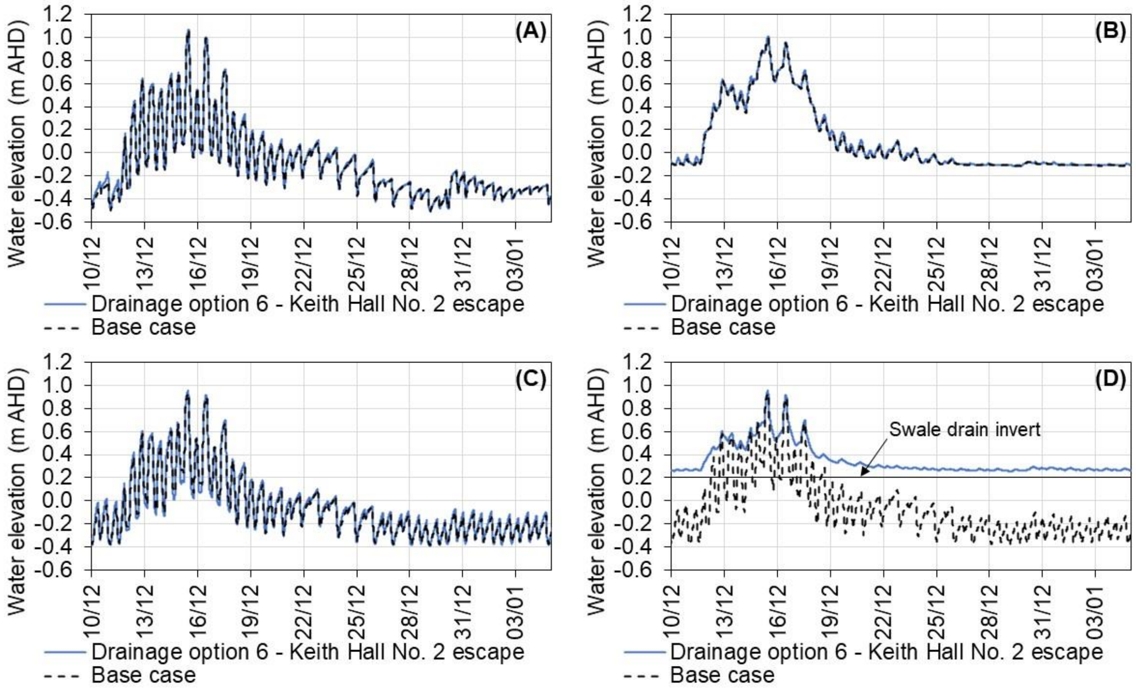


Figure 3.13: Water levels for drainage Option 6 upstream of the Union Drain floodgates (A), at the confluence of Keith Hall No. 1 Canal and Mosquito Creek (B), at the confluence of Keith Hall No. 1 and No. 2 Canals (C), and at the new outlet for Keith Hall No. 2 Canal (D)

An increase in water levels within the Union Drain was associated with tidal flushing that would have previously flowed into Keith Hall No. 2 Canal now flowing to Union Drain via Keith Hall No. 1 Canal. Water levels within Keith Hall No. 2 Canal increased due to the invert of the new floodgates being set at +0.1 m AHD, and the invert of the east-west swale drain being raised to +0.2 m AHD. The location where the raised water levels within Keith Hall No. 2 Canal would occur is shown in Figure 3.14.

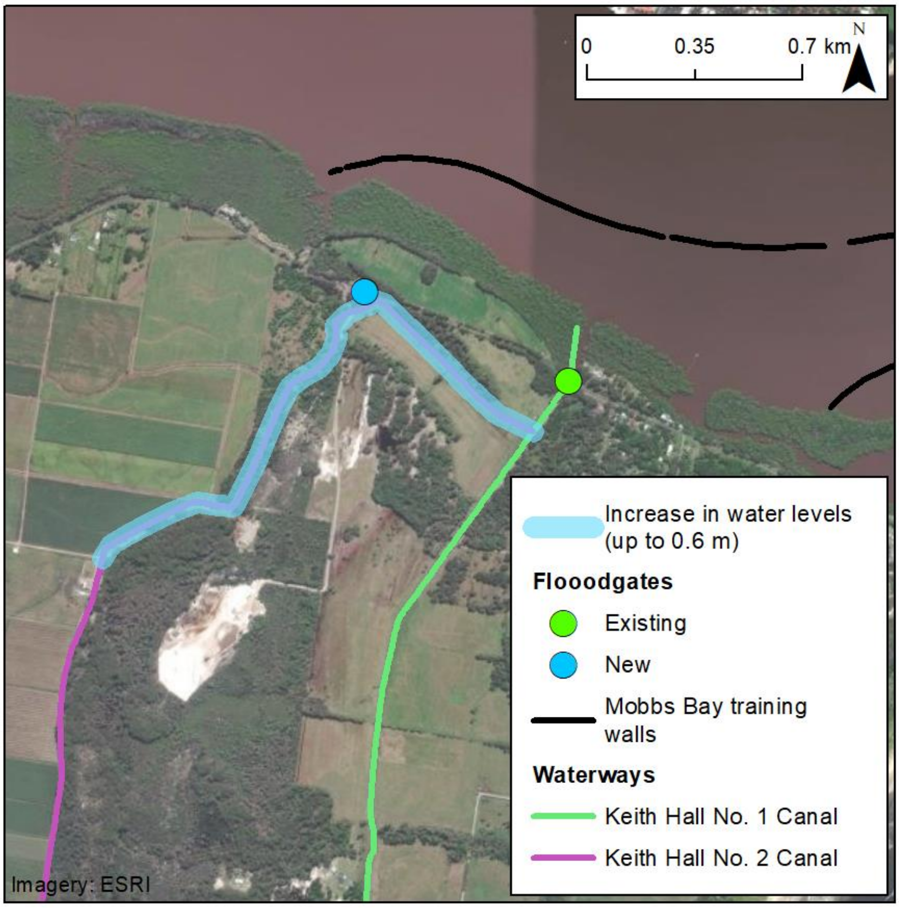


Figure 3.14: Location where there will be an increase in the day-to-day water levels (up to 0.6 m increase) within Keith Hall No. 2 Canal for Option 6

3.7.3 Water quality assessment

Modifications to the drainage network outlined in drainage Option 6 would significantly reduce groundwater drawdown and the export of acid from Keith Hall No. 2 Canal. Analysis of soil profile data indicated that acid sulfate soils along Keith Hall No. 2 Canal range from elevations of +0.1 m AHD on the downstream floodplain (see Appendix A) to +0.4 m AHD on the upstream floodplain (WRL, 2019). The higher invert of the new floodgate (at +0.1 m AHD) and raised invert of the swale drain (+0.2 m AHD) would reduce the export of acid from these soils in two ways:

1. A raised water table would reduce the further oxidisation of potential acid sulfate soils.
2. A raised water table would reduce the hydraulic gradient between the floodplain to Keith Hall No. 2 Canal and subsequently the export of acid sulfate soils.

Note, Option 6 specifically addresses acid sulfate soil drainage via Keith Hall No. 2 Canal. Further investigations would be required to determine the contribution of acid sulfate soils to low-pH water in the Keith Hall drainage network individually from Keith Hall No. 1 and No. 2 Canals.
In addition to reducing the export of acid sulfate soils from Keith Hall No. 2 Canal, drainage Option 6 would provide the opportunity to address water quality issues from Keith Hall No. 1 and No. 2 Canals

separately. Currently, water from both canals combines before discharging into Mobbs Bay. It is possible that poor water quality from one drain is of better or worse quality than the other. By separating the discharge points for each canal there would be an opportunity to manage each as independent drainage systems. For example, changes to Keith Hall No. 2 Canal could be implemented without impacting landowners that are serviced by Keith Hall No. 1 Canal.

Numerical modelling indicated there would be a slight increase in the flushing of Keith Hall No. 1 Canal, The Escape, and Union Drain for Option 6. Increased tidal flushing in these drains would assist to buffer acid sulfate soils and reduce the build-up of nutrients. Note, the level flushing for Option 6 would be significantly less than compared to Options 1, 2 and 3.

Creating a swale drain which cattle can walk across may impact water quality. Where cattle are allowed within the swale drain channels there is also a higher risk of pugging and soil erosion. To mitigate impacts on water quality it is recommended that the swale drain be fenced from stock.

Further improvements to the water quality within Mobbs Bay could occur through the installation of automatic floodgates on the new floodgate outlet. While this has not been numerically modelled, conceptually the automatic floodgates could be operated in such a way as to only discharge during an incoming (flood) tide. This would result in poor quality water from Keith Hall No. 2 Canal discharging directly into the Richmond River and bypassing Mobbs Bay. Subsequently, the sensitive receivers within Mobbs Bay would not be impacted by poor water quality from Keith Hall No. 2 Canal. Design of an automatic floodgate like this would require further investigation of tides and flows to confirm the conceptual understanding. Note, this design would only meaningfully improve water quality with Mobbs Bay if the relative contribution of poor quality water originating from Keith Hall No. 2 Canal was significant, which would require further investigation to quantify.

3.7.4 Drainage assessment

Drainage Option 6 has been assessed to determine if modifications to the Keith Hall drainage network resulted in any changes to:

1. The day-to-day drainage conditions across the floodplain.
2. Drainage conditions following a significant rainfall event.

An increase in the day-to-day water levels within Keith Hall No. 1 Canal and Union Drain was observed for drainage Option 6. Overall, the median water level was raised between 0.02 m and 0.05 m (Table 3.7). A rise in water levels of this scale would not result in any significant impact to agriculture resulting from raised groundwater levels (see Appendix E).

Table 3.7: Changes in dry condition water levels for drainage Option 6

Drain	Base case median water level (m AHD)	Maximum increase in median water level (m)	Option 6 maximum median water level (m AHD)
Keith Hall No. 1 Canal	-0.10	0.02	-0.08
Keith Hall No. 2 Canal	0.22	0.50	0.26
Union Drain	-0.30	0.05	-0.25
The Escape	-0.30	0.03	-0.27
Mosquito Creek	0.29	0.00	0.29

A more substantial increase in day-to-day water levels was observed within Keith Hall No. 2 Canal caused by higher drain and floodgate inverts (see location in Figure 3.14). Modelling indicated that water levels could increase up to 0.64 m, however, the average increase in median water level across the length of the drain was 0.50 m (Table 3.7). Depending upon pasture types, low-lying floodplain land located adjacent to the swale drain mapped as grazing land use may become less productive as the groundwater table increases to within 0.3 m of the ground level (Appendix E). Floodplain surrounding the upstream sections of Keith Hall No. 2 Canal is mapped as sugarcane and has significantly higher elevation (>0.8 m AHD). It is unlikely this land would be impacted by an increased groundwater table.

Following a significant rainfall event, the numerical model results indicated that there would be a negligible increase in drainage times for Keith Hall No. 1 Canal, Union Drain, The Escape, and Mosquito Creek (Figure 3.13). This occurred because water that previously would have travelled up Keith Hall No. 2 Canal from tidal flushing now flowed further into Keith Hall No. 1 Canal. Results also showed that water levels within Keith Hall No. 2 Canal were significantly increased resulting from modifications to the drainage network, however, this did not significantly impede floodplain drainage. Water across the floodplain adjacent to Keith Hall No. 2 Canal was able to recede below the floodplain in less than 48 hours (Figure 3.15). Water levels returned to day-to-day levels within 72 hours.

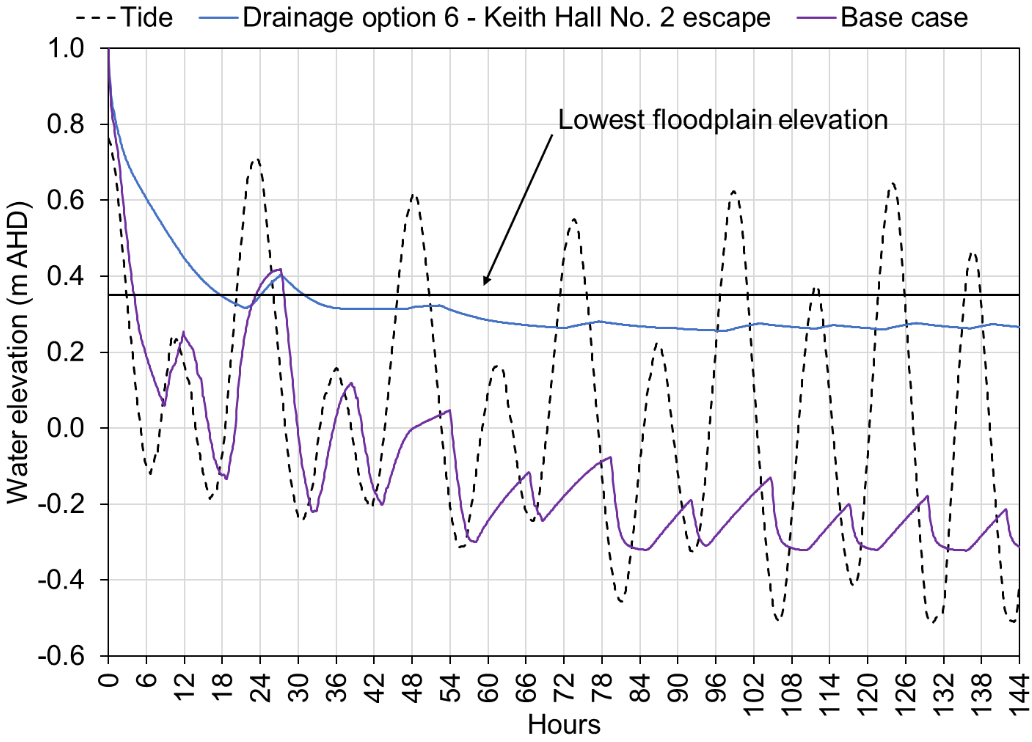


Figure 3.15: Drainage time assessment for Option 6 upstream of the new Keith Hall No. 2 Canal floodgates

3.7.5 Relative cost considerations

Implementation

Costs to implement drainage Option 6 are associated with the detailed design, site establishment and construction of approximately 1 km of reshaped drainage channels and a large floodgate. It is estimated that costs for this would be approximately $500,000 or a high relative cost. Note, this costing does not include any allowance for:

- Additional fill material required to swale the downstream section of Keith Hall No. 2 Canal
- Any costs that may be required for liming of acid sulfate soils excavated from the new drain on the downstream side of Keith Hall No. 2 Canal
- Costs to obtain approvals to disturb existing mangrove habitat within the Richmond River Nature Reserve
- Costs associated with habitat offset requirements for disturbing mangrove habitat downstream of South Ballina Beach Road that may be required during construction of the drain

Maintenance/management

As with all floodplain drains, ongoing maintenance would be required for the drain connecting Keith Hall No. 2 Canal to Mobbs Bay once constructed. It may be necessary to obtain relevant approvals to ensure the downstream channel within the Richmond River Nature Reserve can be regularly maintained so that it does not become obstructed with mangroves.

The new floodgate structure underneath South Ballina Beach Road would also require ongoing maintenance. The level of maintenance could be considered similar to other structures of similar size (such as the existing Keith Hall culverts).

If there are sections of the swale drain that are continuously filled with shallow water, this may result in an increased need for clearing of weeds and vegetation. This is because in shallow drains light can more easily penetrate to the bottom of the channel (compared to deep drains) allowing vegetation to grow.

3.8 Summary of drainage options

A qualitative comparison determining how each drainage option meets the project aims is provided in Table 3.8. Where a number of configurations are available for a drainage option the best-case configuration for meeting project aims has been selected for the assessment. Water quality improvement and drainage efficiency have been assessed relative to the existing floodplain drainage network. The relative cost assessment has been completed as outlined in Appendix B.

Table 3.8: Qualitative comparison of drainage options

Drainage option	Water quality improvement			Drainage efficiency		Relative cost	
	Acid drainage	Blackwater	Nutrients/ bacteria	Day-to-day	Wet event	Implementation	Maintenance
Option 1 - Cyclic flow (existing infrastructure)	Moderate to High	None	Moderate[1]	Improved[2]	None[3]	Low	Minimal change
Option 2 - Cyclic flow (automatic floodgates)	High	None	Moderate[1]	Improved[2,4]	None	Medium to High	Increase
Option 3 - Increased tidal connectivity	High	None	Moderate[1]	Improved[2,4]	None	Low	Minimal change
Option 4 - Keith Hall floodgate weight	Reduced quality	Negligible	None	None	Negligible	Low	No change
Option 5 - Keith Hall No. 1 Canal swale	High	None	None[5]	Improved[6]	Negligible reduction	Medium	Minimal change
Option 6 - Keith Hall No. 2 Canal new drain	High	None	Low[5]	Negligible reduction	Negligible reduction	High	Increase

[1]Improvements of nutrient and bacteria levels are due to increased flushing in dry times only

[2]Drainage improvements assumed due to decrease in freshwater vegetation build up in drainage channel and assumes no saltwater tolerant vegetation grows (e.g. mangroves)

[3]Assumes floodgates are managed to mitigate impacts of wet events

[4]Floodgates need to be managed so that groundwater levels are not increased

[5]Potential for reduced quality if grazing within the swale drain is allowed

[6]Minimal improvements for Union Drain and The Escape only

4 Mobbs Bay conceptual understanding

Summary of Mobbs Bay conceptual understanding:

- The total volume of sediment within Mobbs Bay has remained relatively unchanged despite sediment shifting position throughout the bay
- Flow through Mobbs Bay follows the flow direction of the Richmond River
- Elevation of the training wall ranges from mean sea level to mean high water
- Mobbs Bay is connected to the Richmond River at three locations during low tides
- Mobbs Bay is more likely to be impacted by discharges from the Keith Hall drainage network following rainfall events than during day-to-day conditions

4.1 Preamble

The following section provides a conceptual understanding of the flow and sediment dynamics within Mobbs Bay. This assessment has been completed using field data collected during this and previous studies alongside available aerial imagery. Understanding the physical processes within Mobbs Bay allows for an improved understanding of the water quality issues faced when managing the site.

Physical processes within Mobbs Bay assessed in the following sections include:

- The morphology and development of key features within the bay
- Sediment transport throughout the bay
- The hydrodynamic flow conditions throughout the bay

Following this, a discussion on flushing dynamics within Mobbs Bay is provided based upon the conceptual understanding developed for Mobbs Bay. This discussion specifically focuses on the assimilative capacity of Mobbs Bay, with regards to the retention of poor quality water originating from the Keith Hall drainage network.

4.2 Morphology

Aerial imagery is available for Mobbs Bay from 1958 to 2009 (via NSW Spatial Services) and from 2012 to 2021 (via Nearmap). Figure 4.1 shows the changes that the sediment of Mobbs Bay has undergone since 1958.

The 1958 imagery shows that historically there was no vegetation on the dunes of South Ballina Beach (likely influenced by sand mining that historically occurred). During this time aeolian transport drove sand from the beach and into Mobbs Bay (Witt et al., 2003). The 1971 imagery shows vegetation beginning to grow across the dune system and by 1991 it was well established. At this time there was a spit that connected the inner and outer training walls of Mobbs Bay. Between 1997 and 2009 this spit was eroded in the centre leaving an island within Mobbs Bay. This channel between South Ballina and the Mobbs Bay island still exists today and facilitates flow through Mobbs Bay. Imagery indicates that this channel results in sediment movement towards the west as seen by changes to Mobbs Bay island, and the creation of a sandy beach on the southern side of Mobbs Bay at South Ballina.

Imagery indicates three major connections between Mobbs Bay and the Richmond River:

1. The channel between South Ballina and the Mobbs Bay island
2. A navigation channel immediately to the west of the Mobbs Bay island allowing boats access to Mobbs Bay
3. A channel on the west side of Mobbs Bay between the end of the training wall and the riverbank

Some smaller gaps exist including one opposite Keith Hall No. 1 Canal. The construction of Keith Hall No. 1 and No. 2 Canals can be seen to occur between 1958 and 1971, however, the gap in the training wall appears to pre-date the imagery. Since the construction of Keith Hall No. 1 Canal there does appear to be some erosion or clearing of a channel through the sediment on the southern side of the training wall at this location. Besides this change, the sediment to the south of the western training wall remains relatively unchanged across all the images.

Figure 4.1:Comparison of aerial imagery of Mobbs Bay from 1958 to 2021

4.3 Sediment transport

Bathymetry surveys of Mobbs Bay were completed during field work for this project (Appendix A). This most recent bathymetry data was compared to a historical dataset collected by NSW OEH in 2005. Figure 4.3 to Figure 4.6 show the changes in the bathymetry at four locations in the 15-year period. Note, all surveyed cross sections run from north to south or from the Mobbs Bay training wall to South Ballina (the right bank of the river when looking downstream).

During this 15-year period the channel between the Mobbs Bay island and South Ballina has significantly widened. Figure 4.4 shows this widening has been caused by erosion of the Mobbs Bay island. The cross-section confirms observations from the imagery (Section 4.2) that sediment is moving west and into Mobbs Bay. Accretion can be observed on the sandy beach at the southern side of cross-section N (Figure 4.3) and the northern side of cross-section M (Figure 4.4). There is a deep hole located west of the Mobbs Bay island where there is a gap in the training wall. Cross-section J (Figure 4.5) shows that sediment has begun to fill in this hole.

Except for erosion and accretion around the Mobbs Bay island and channel, the bathymetry has largely remained unchanged over the 15-year period (for example see cross-section F in Figure 4.6). Comparison of total sediment volumes calculated from the 2005 and 2020 surveys indicated that the overall change to sediment volume within Mobbs Bay was minimal and within expected error bounds for the measurements (approximately 1% change). While sediment may have moved around within the bay, the overall volume of sediment has remained unchanged over the 15-year period.

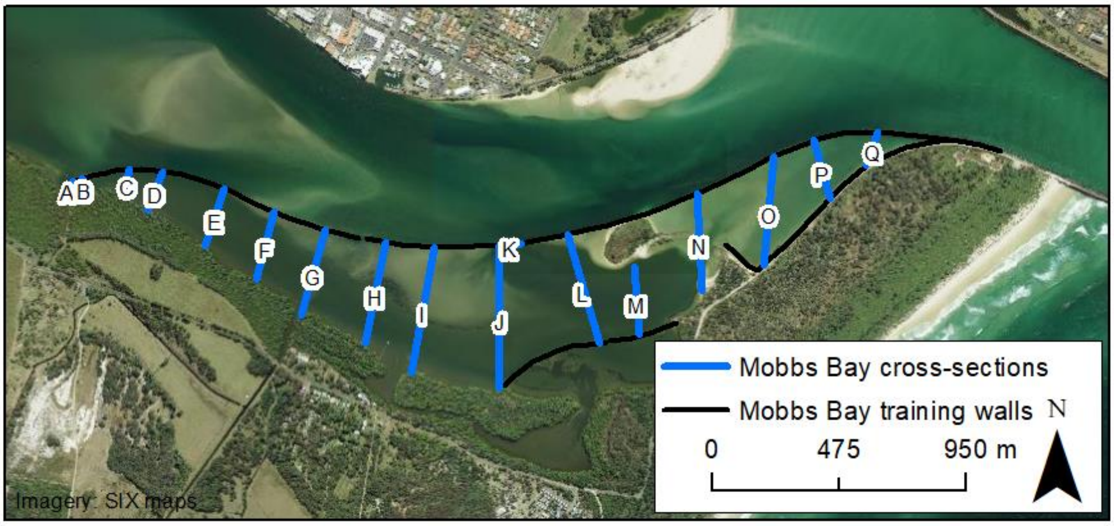


Figure 4.2: Location of bathymetric survey cross-sections in Mobbs Bay

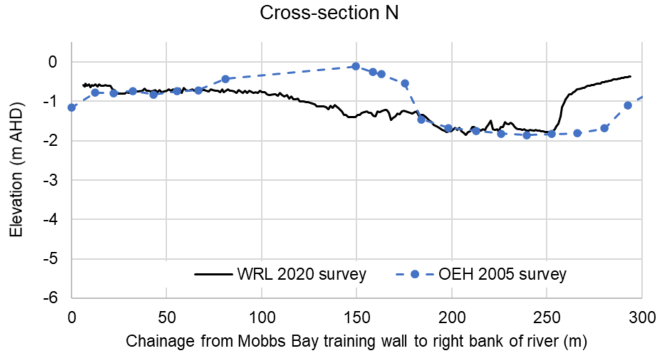


Figure 4.3: Change in bathymetry at cross-section N from 2005 to 2020

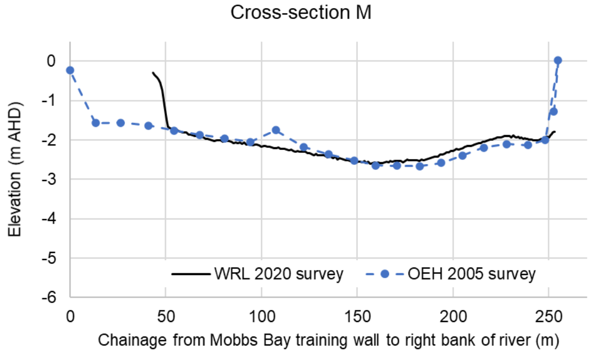


Figure 4.4: Change in bathymetry at cross-section M from 2005 to 2020

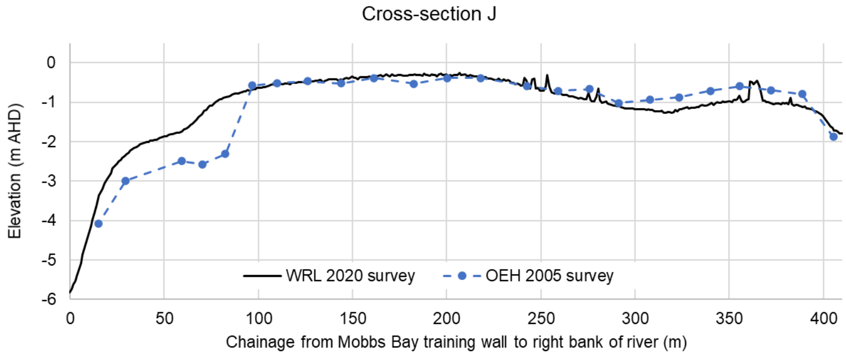


Figure 4.5: Change in bathymetry at cross-section J from 2005 to 2020

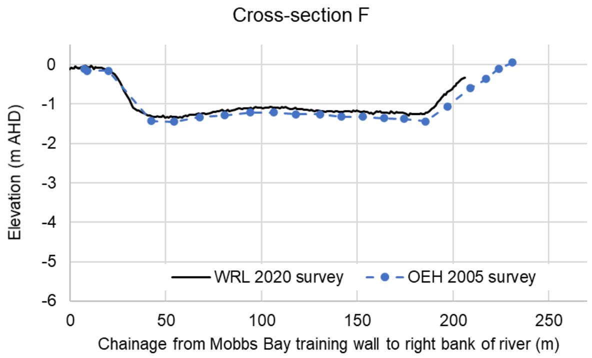


Figure 4.6: Change in bathymetry at cross-section F from 2005 to 2020

Using the bathymetry surveys from 2005 and 2020 an estimate of the volume of water within Mobbs Bay was calculated. Note, since Mobbs Bay is tidal this volume changes with the tide. Volumes for different tide levels are shown in Table 4.1. Analysis of this data indicates that approximately 30,000 m^3 of sediment has moved from above mean sea level to below mean sea level. This confirms observations from the aerial imagery (Section 4.2) that show the Mobbs Bay island decreasing in size while the deep hole at the gap in the training wall to the west of the Mobbs Bay island appears to be filling with sediment (Figure 4.7).

Table 4.1: Volume of water within Mobbs Bay at various tides

Tidal plane[1]	Tide elevation (m AHD[2])	Approximate water volume in Mobbs Bay (2005) (m^3)	Approximate water volume in Mobbs Bay (2020) (m^3)	Approximate change in sediment volume (m^3)	Percent change (%)
I.S.L.W.	-0.925	338,000	277,000	+61,000	18%
M.L.W.S.	-0.648	483,000	433,000	+50,000	10%
M.L.W.	-0.521	561,000	517,000	+44,000	8%
M.L.W.N.	-0.393	648,000	609,000	+39,000	6%
M.S.L.	-0.061	918,000	890,000	+28,000	3%
M.H.W.N.	0.27	1,215,000	1,188,000	+27,000	2%
M.H.W.	0.398	1,331,000	1,304,000	+27,000	2%
M.H.W.S.	0.525	1,445,000	1,418,000	+27,000	2%
H.H.W.S.S.	0.913	1,794,000	1,768,000	+26,000	1%

[1] Tidal planes are as per Couriel et al. (2012). I.S.L.W. = Indian Spring Low Water, M.L.W.S. = Mean Low Water Spring, M.L.W. = Mean Low Water, M.L.W.N. = Mean Low Water Neap, M.S.L. = Mean Sea Level, M.H.W.N. = Mean High Water Neap, M.H.W. = Mean High Water, M.H.W.S. = Mean High Water Spring, H.H.W.S.S. = High High Water Solstice Spring.
[2] AHD = Australian Height Datum.

4.4 Hydrodynamics

4.4.1 Current measurements

During fieldwork, flow current meters were deployed to gain an understanding of the flow dynamics through Mobbs Bay (see Appendix A). Analysis of data provided the following observations:

- The flow through Mobbs Bay generally follows the flow direction of the Richmond River (Figure 4.7 A and B)

- At the change of tide from low to high, flow continues to exit Mobbs Bay for a small period (Figure 4.7 C). This confirmed previous observations for the river by MHL (1995)
- Velocities measured at the western entrance to Mobbs Bay were slightly higher than on the eastern side

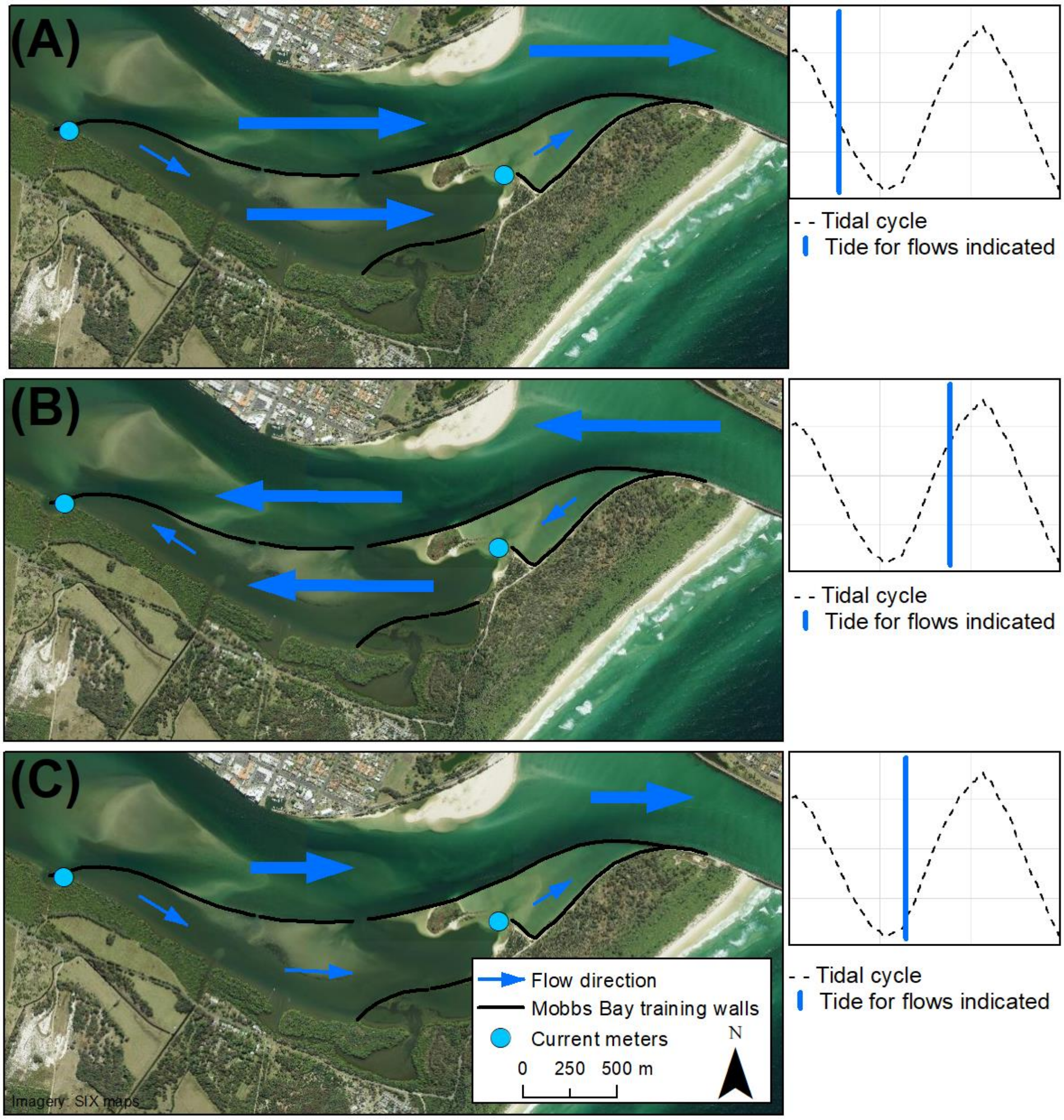


Figure 4.7: Observations of flow behaviour from current measurements for a falling tide (A), a rising tide (B) and a rising tide immediately after a low tide (C)

4.4.2 Training wall elevation

An approximately 3 km long training wall protects the northern side of Mobbs Bay. This training wall is made up of rock rubble that now has a significant growth of oysters on it (Figure 4.8). Elevation of the training wall ranges from mean sea level (-0.06m AHD) to mean high water (+0.40m AHD) (Appendix A). To the west of the Mobbs Bay island, the height of the training wall is relatively uniform averaging +0.21 m AHD. To the east of the Mobbs Bay island, the crest of the training wall has a lower elevation at distances further from the island. The average height of the training wall measurements to the east of the Mobbs Bay Island is -0.14 m AHD. In addition to the height varying across the training wall there are also several gaps in the training wall that allow water to pass through during low tides.

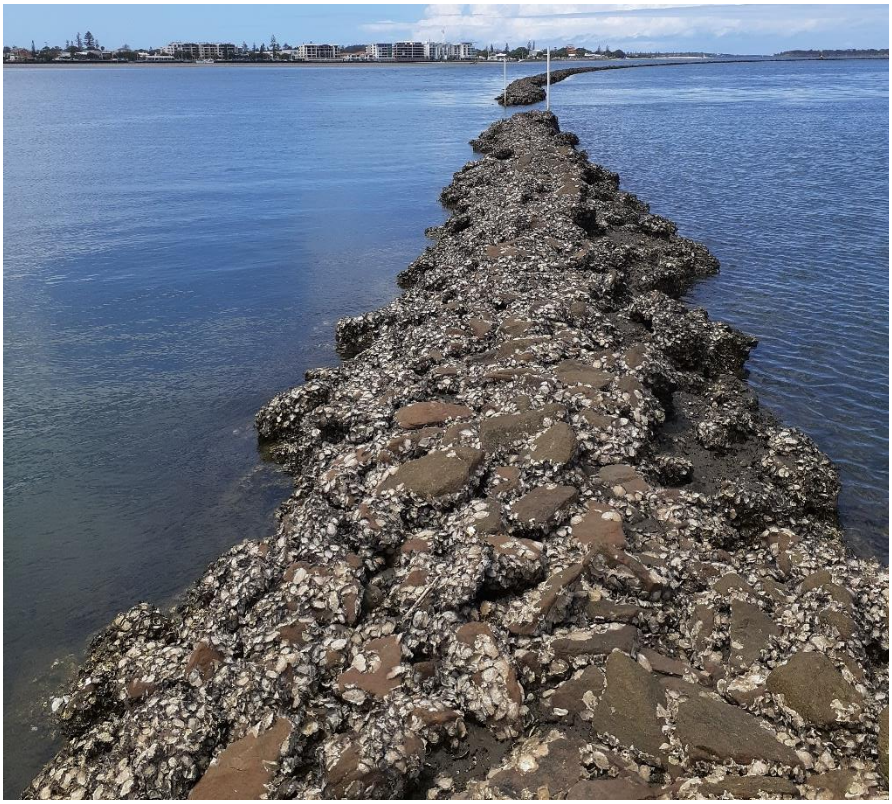
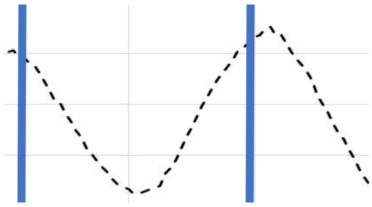
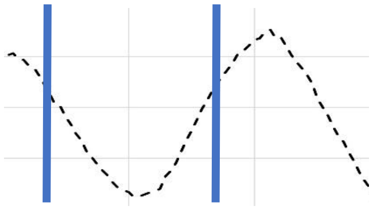
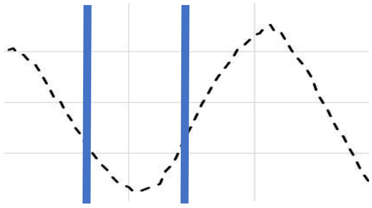
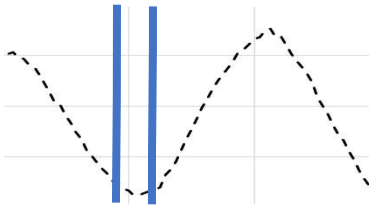


Figure 4.8: Mobbs Bay training wall looking east

Since the Mobbs Bay training wall is in the tidal zone, throughout the tidal cycle it has various impacts for flow throughout Mobbs Bay. Table 4.2 summarises the effects of the training wall on flow through Mobbs Bay for various tides.

Table 4.2: Conditions for flow over and around Mobbs Bay training wall

Tide level	Notes	Tide diagram (blue line indicates tide level)
Above mean high water **(>+0.40 m AHD)**	The tide level is above the crest of the training wall. Water can freely flow over the top of the training wall.	
Between mean high water and mean sea level **(-0.06 to +0.40 m AHD)**	The tide level is below the crest of the training wall west of the Mobbs Bay island where water can only flow to and from the Richmond River through gaps in the training wall. To the east of the Mobbs Bay island water can freely flow over the top of the training wall.	
Between mean sea level and mean low water **(-0.52 to -0.06 m AHD)**	The tide level is below the crest elevation for most of Mobbs Bay training wall. Flow can only flow to and from the Richmond River via gaps in the training wall and over the lowest section of training wall on its far eastern side.	
Below mean low water **(<-0.52 m AHD)**	The tide level is below the crest elevation for the majority of the Mobbs Bay training wall. Flow can only flow to the Richmond River via deep gaps in the training wall and over the lowest section of the training wall on its far eastern side.	

4.5 Flushing dynamics

Floodplain runoff from Keith Hall No. 1 Canal discharges directly into Mobbs Bay. Water quality observations have indicated that this water can often be of poor quality with low acidity levels (e.g., pH <5), low dissolved oxygen levels (e.g. <6.5mg/L), high nutrient levels (e.g. ammonia >0.01mg/L) and high microbial bacteria levels (i.e. classified as high risk for recreation). Poor water quality within Mobbs Bay is of concern as the bay is used for a number of activities which are likely to be impacted including:

- Aquaculture (oyster farming)
- Fishing
- Recreation/swimming

Understanding the flushing dynamics within Mobbs Bay can provide an overview of the potential for poor quality water from the Keith Hall drainage network to affect the bay.

A high-level understanding of flushing dynamics within Mobbs Bay has been developed from the data analysis provided in Sections 4.2 to 4.4. When the water level in Mobbs Bay is lower than the water level in the Keith Hall drainage network, water from the drainage network discharges into Mobbs Bay. This occurs regularly on a falling (ebb) tide. The volume of water discharged from the Keith Hall drainage network is dependent upon several factors including:

- Rainfall/runoff
- Antecedent conditions prior to the rainfall (including groundwater levels
- Flow pathways (i.e., the drainage network and distance water needs to travel to reach Mobbs Bay)
- Flow controls (e.g., floodgates and culverts)

During day-to-day conditions, there is limited flow associated with baseflow (i.e. flow from the groundwater) from the Keith Hall drainage network to Mobbs Bay. Following rainfall events there will be raised water levels within the drainage network and subsequently increased outflows for at least three days (see Appendix D). Table 4.3 shows that larger runoff events would be more likely to impact Mobbs Bay. Furthermore, event-based water quality sampling completed by RCC (Appendix F) indicated that poor quality water is more likely to occur following runoff events than during day-to-day dry weather conditions. However, poor water quality during day-to-day conditions (such as low pH and high metal concentrations from the drainage of acid sulfate soils) is still able to have detrimental impacts on the downstream sensitive receivers, particularly when discharges from the drainage network are not diluted before reaching sensitive receivers within Mobbs Bay (such as the oyster leases downstream of the floodgate outlet). Note, while active floodgate management does help improve day-to-day water quality it is unlikely to improve water quality during events.

The Mobbs Bay training wall governs the level of flushing that occurs within Mobbs Bay, and subsequently has a large influence on the water quality. The current high level of connectivity that occurs between the Richmond River and Mobbs Bay results in regular flushing that improves the water quality within the bay. It is unlikely that a significant change to the volume of flushing within Mobbs Bay would occur without a large section of the training wall being removed (albeit with other potential impacts to the estuary). Note, contributions of poor water quality from the Keith Hall drainage network to Mobbs Bay relate to the location and timing of flushing not necessarily the overall volume of flushing achieved within Mobbs Bay. Furthermore, impacts from the Keith Hall drainage network are likely exacerbated due to the fact there are sensitive receivers immediately downstream of the floodgate outlet and that the drainage network discharges at low tide which limits dilution.

Table 4.3: Estimated runoff volume relative to the volume of water within Mobbs Bay

Runoff condition	Approximate maximum runoff volume per tidal cycle (m^3)*	Runoff volume as a percentage of the mean low water volume of Mobbs Bay (%)	Runoff volume as a percentage of the mean high water volume of Mobbs Bay (%)
Day-to-day (tidal flushing with groundwater inflows)	21,000	4%	2%
12 exceedances per year (12EY)	145,000	26%	11%
Two exceedances per year (2EY)	310,000	55%	23%
1 in 2 year annual exceedance probability (50% AEP)	460,000	82%	35%
1 in 5 year annual exceedance probability (20% AEP)	640,000	114%	48%

*Runoff volume based of maximum rainfall for a 6-hour period assuming no losses due to antecedent conditions. Other factors such as flow pathways and flow controls may also limit actual runoff to Mobbs Bay.

Once water from the Keith Hall drainage network has entered Mobbs Bay there are several factors that influence the retention time of floodplain runoff within the bay, including:

- Volume of rainfall on the floodplain
- Tidal flushing in Keith Hall No. 1 Canal
- Tide elevations
- Flow mixing
- River flow volumes
- Flow through Mobbs Bay
- The ratio of ocean to river water entering Mobbs Bay each tide

Due to these complexities, the impacts of poor water quality discharging from the Keith Hall drainage network to Mobbs Bay cannot be quantitatively determined without further data collection or numerical modelling. However, the following qualitative observations can be concluded from the available data:

- During day-to-day conditions, water within the Keith Hall drainage network is diluted due to tidal flushing. Subsequently, the impacts of poor quality water to Mobbs Bay will be less during dry times than following rainfall events when discharges are not diluted
- Water quality is likely to be better during high tides where there is significantly greater volume of water flushing Mobbs Bay (volume assessment of Mobbs Bay show that over half of the water within Mobbs Bay enters and exits the system each tidal cycle, however, the mixing dynamics of this water with the Richmond River and the ocean have not been determined)

- Locations within Mobbs Bay further away from the Keith Hall floodgate outlet are less likely to be impacted by poor water quality from the drainage network as floodplain runoff becomes increasingly diluted and mixed with estuarine water
- The section of Mobbs Bay to the east of the island is likely to be the least impacted by poor water quality from Keith Hall due to significant levels of flushing throughout the tidal cycle

5 Discussion

5.1 Future floodplain management

Numerical modelling completed for this study assumed that present day conditions across the Keith Hall floodplain and wider Richmond River estuary would remain unchanged. In the future, changes across the floodplain may affect how the floodplain is managed and how different drainage objectives are prioritised.

Heimhuber et al. (2019) identified that estuaries will be significantly affected by climate change. Harrison et al. (2021) assessed the likelihood that floodplain drainage and floodplain infrastructure would be impacted due to sea level rise. This analysis determined that land with an elevation below 0.9 m AHD is at risk of reduced drainage due to sea level rise in the near future (2050). In the far future (2100), this elevation rises to any land below 1.4 m AHD. Their study also found that floodplain infrastructure would only be able to drain effectively less than 50% of the time in the far future (Figure 5.1).

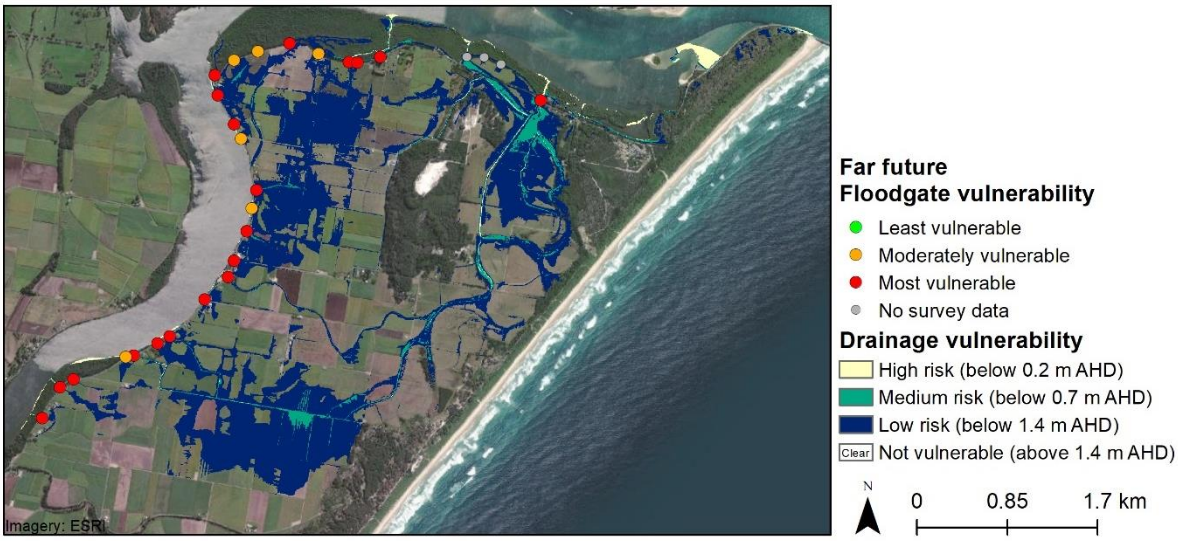


Figure 5.1: Floodplain infrastructure and drainage vulnerability in the far future (2100) (Harrison et al., 2021)

In addition to sea level rise, changes in the future land use of the floodplain may also have implications for the management of the Keith Hall drainage network. Subsequently, it is important that the design life of drainage options be considered prior to implementation. This would ensure that changes to conditions across the floodplain in the future would not render modifications to the drainage network redundant.

5.2 Mitigation measures

Numerical modelling utilises a mathematical approximation of the physical world to determine the likely outcomes of changes to the floodplain. Due to this approximation, there is an accuracy range in calculations (e.g., for impacts to groundwater) that can be mitigated through further on-ground actions. When implementing drainage options, a risk based approach should be taken to ensure that options proposed do not result in negative outcomes. By implementing mitigation measures, risk of adverse impacts from on-ground works may be significantly reduced:

Examples of mitigation measures that could be enacted include:

- Staged opening of sluice gates to allow on-ground verification that water levels are not inundating the floodplain
- Infilling of known levee low points
- Installing additional floodgate flaps on secondary culverts
- Monitoring of groundwater levels throughout the floodplain

5.3 Simultaneous drainage options

Each of the drainage options considered in this study was assessed independent of one another. Despite this, it is possible one or more of the drainage options could be implemented simultaneously. If this were to occur, there may be different changes to drainage and water quality than what has been presented in this study.

5.4 Drain bank slumping

Local landowners have identified that the slumping of drain banks, particularly adjacent to Union Drain, is an ongoing issue. Slumping of the banks can be exacerbated by:

- Steep banks
- Lack of bank vegetation
- Flood events through compressed banks

Driving heavy machinery on the bank has the potential to compact the soil and reduce hydraulic conductivity. This means when rainfall events occur the connectivity of the drain to the groundwater under the floodplain is reduced. Occasionally cracks can occur within these compressed banks. Where there are cracks slumping may be more likely to occur as the cracks form weaknesses in the bank. Following a rainfall event these cracks become flow paths that exacerbate bank slumping. Note, steep banks and lack of existing vegetation within the current drainage system are also likely causes for slumping.

It is unlikely that tidal inundation within the drainage channel is a significant cause of bank slumping. Modelling indicated that the velocities created in the drain due to tidal flushing were not high enough to cause erosion/slumping. While tidal water may kill freshwater vegetation that could encourage slumping, when vegetation dies their roots can remain and work to hold the bank intact. Growth of vegetation on banks may also help to reduce slumping. Note, the risk of bank slumping could also be mitigated through reshaping of drainage channels to reduce the steepness of banks.

5.5 Groundwater levels

Increasing the water level within the drainage network will also result in an overall increase in the groundwater table across the floodplain, particularly during wet periods. This has potential to impact on the agricultural productivity of land. This study has only assessed the change in water levels within the drainage network and has only discussed the impacts of management options on groundwater at a conceptual level (Appendix E). Further site specific research is required to understand the connectivity of the drainage network and groundwater and groundwater recharge following rainfall events.

6 Recommendations

Improving water quality discharging from the Keith Hall drainage network has been identified as a priority to ensure that the environmental and recreational benefits of Mobbs Bay are fully realised. A strategic approach for improving water quality is required. However, the drainage network is valuable for floodplain users as it prevents nuisance flooding, lowers groundwater levels and improves the agricultural productivity of the land.

In addition to the long-term maintenance of the drainage network, the following study aims were developed :

1. Reduce any downstream impact on Mobbs Bay and the Richmond River from water quality leaving Keith Hall No. 1 Canal
2. Improve drainage efficiency and reduce the impact of floodplain inundation, particularly along Keith Hall No. 1 Canal where build-up of sediment and vegetation can occur
3. Reduce maintenance of the Keith Hall drainage network for Rous County Council

Six options for modifying the drainage network were identified in consultation with floodplain landowners with the purpose of achieving these study aims. Each of the drainage options was then numerically modelled and the model results assessed against the project aims.

All drainage options except for Option 4 (Keith Hall floodgate weight) resulted in improved water quality. Drainage Option 5 (Keith Hall No. 1 Canal swale) resulted in the greatest improvement for floodplain drainage as the connectivity between Keith Hall No. 1 Canal and Union Drain was reduced, improving drainage within Union Drain. The relative costs for implementation of drainage options varied greatly from low (<$100,000) to high (>$500,000) with the costs for ongoing maintenance also varying from option to option.

Drainage Option 3 (increased tidal connectivity) was identified as the most feasible option for implementation. Increased tidal connectivity would result in buffering of acid sulfate soils, while increased flow in the drainage network would help flush the system preventing the build-up of nutrients and bacteria. Drainage efficiency could be expected to be improved during day-to-day conditions as tidal water would help to prevent the growth of freshwater vegetation (provided growth of saltwater tolerant vegetation is also managed). This option also has a low relative cost for implementation and ongoing maintenance will be similar to the current level required for the system.

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Appendix A Data synthesis

A1 Preamble

The following appendix summarises, and where applicable analyses, field data that was collected over the duration of the Keith Hall Drainage Options Study. Data has been collected for the development of a one-dimensional numerical model of the Keith Hall drainage network, to provide insight and knowledge to further understand water quality issues across the floodplain, and for the development of a conceptual understanding of Mobbs Bay. Data collected included:

- Drainage channel cross-sections
- Floodplain structure dimension and elevation measurements
- Topographic data to verify accuracy of LiDAR measurements
- Discrete one-off water quality measurements
- Continuous long-term water level and water quality measurements
- Soil profiles
- Hydraulic conductivity measurements
- Flow and velocity measurements within the drainage network and Mobbs Bay
- Training wall elevations
- Bathymetric survey of Mobbs Bay

Throughout the field investigations, elevation and position data was collected using Trimble R10 global navigation satellite system (GNSS) equipment. All position measurements were collected using the geocentric datum of Australia 1994 (GDA94) and all elevation measurements were collected using the Australian Height Datum (AHD) 1971. Real time kinematic (RTK) positioning was utilised whereby GNSS position measurements captured by the Trimble equipment were compared in real time to GNSS position measurements captured by continuously operating reference stations (CORS), specifically CORSnet-NSW operated by the NSW Spatial Services, to improve accuracy. Accuracy of the Trimble equipment had a root mean square (RMS) error of 0.018 m for vertical measurements and 0.011 m for horizontal measurements. In addition to the base RMS measurement accuracy, factors such as geographic location and atmospheric activity can also increase the error. During survey, the Trimble equipment records the horizontal and vertical precision of each measurement including this additional error. Taking this into account, all vertical measurements had a precision within 0.06 m and all horizontal measurements had a precision within 0.03 m.

A2 Drainage channel cross-sections

A total of 109 cross-sections were measured throughout the Keith Hall Drainage system between 26 and 30 October 2020. Cross-section measurements were taken for the following waterways:

- Keith Hall No. 1 Canal (11 cross-sections)
- Unions Drain (26 cross-sections)
- Mosquito Creek (38 cross-sections)
- The Escape (12 cross-sections)

- Secondary drainage channels (22 cross-sections)

These cross-section measurements supplement an existing dataset collected by WRL (2019) who previously surveyed Keith Hall No. 1 Canal and Keith Hall No. 2 Canal in February 2019. In September 2019 a section of the Keith Hall No. 1 Canal had weeds mechanically cleared from it (Figure A.1). A repeat survey was completed for this section of Keith Hall No. 1 Canal. The impacts of the vegetation clearing on the drain invert is shown in Figure A.2. Differences in the two cross-sections where the largest changes were observed (at chainages 2920 and 3065) are shown in Figure A.3 for comparison. The difference between the invert levels for these two cross-sections is due to sediment build up associated with dense weed growth in this section of the drain.

Invert measurements for Mosquito Creek, The Escape and Union Drain are presented in Figure A.4, Figure A.5 and Figure A.6 respectively. Chainage has been measured as metres from the end-of-system floodgates which discharge to the Richmond River. The invert elevation for each floodgate structure is also presented for the relevant drainage channels. A detailed dataset outlining cross-section locations and cross-section profiles, including cross-sections measured for side channels, can be found in Appendix C.

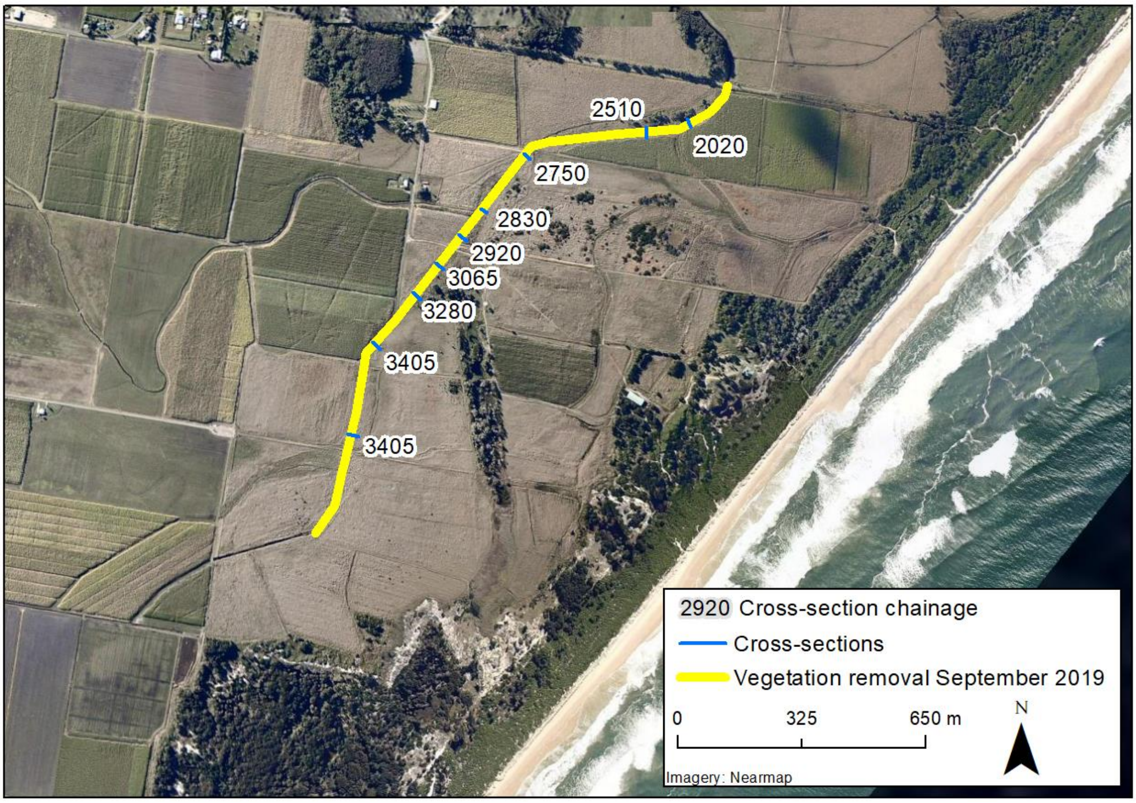


Figure A.1: Location of mechanical vegetation removal completed in September 2019

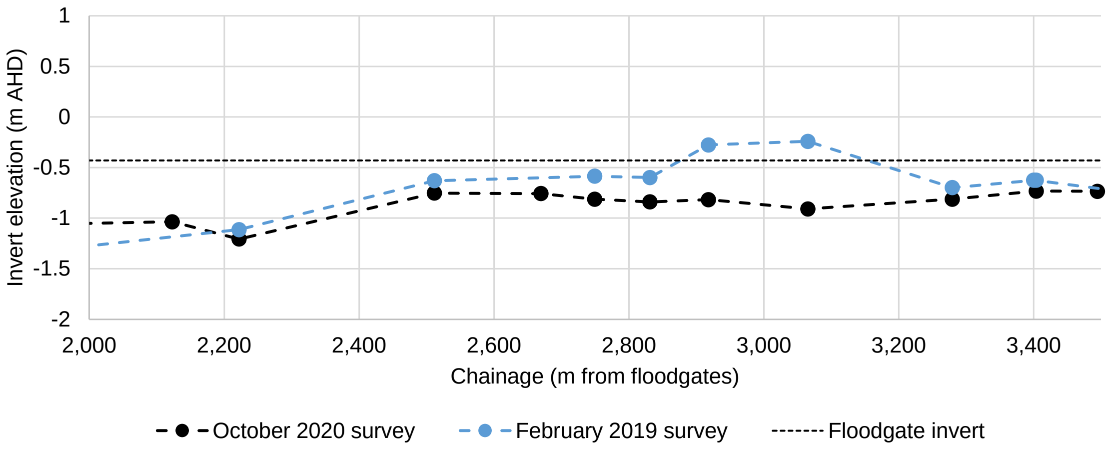


Figure A.2: Difference between the invert of Keith Hall No. 1 Canal in February 2019 and October 2020 for chainages 2000 to 3500

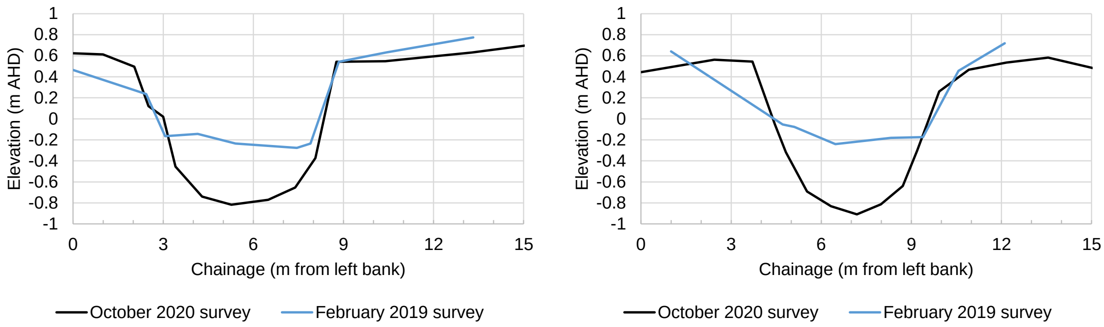


Figure A.3 – Difference in cross-section profiles at chainage 2920 (left) and 3065 (right) between February 2019 and October 2020 following mechanical drain clearing

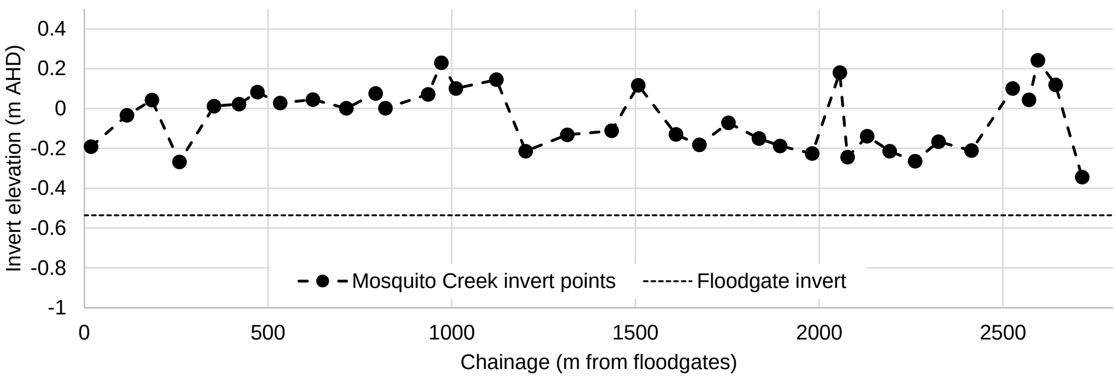


Figure A.4: Invert elevation measurements for Mosquito Creek

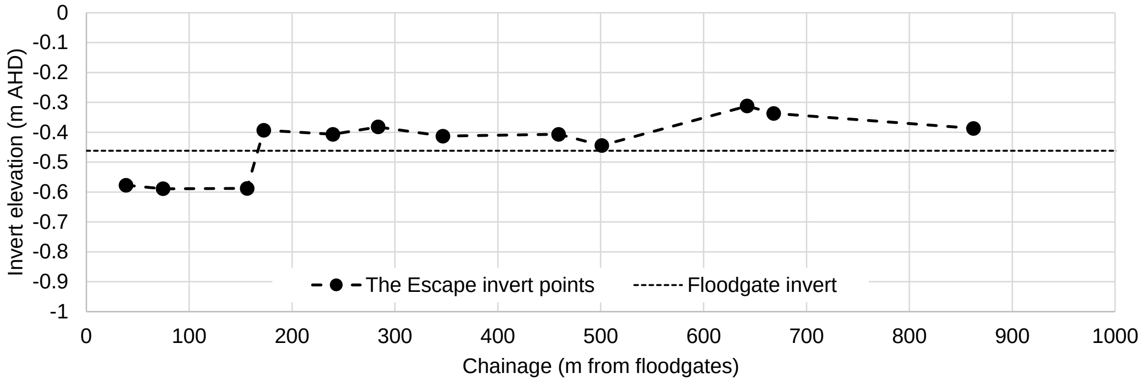


Figure A.5: Invert elevation measurements for The Escape

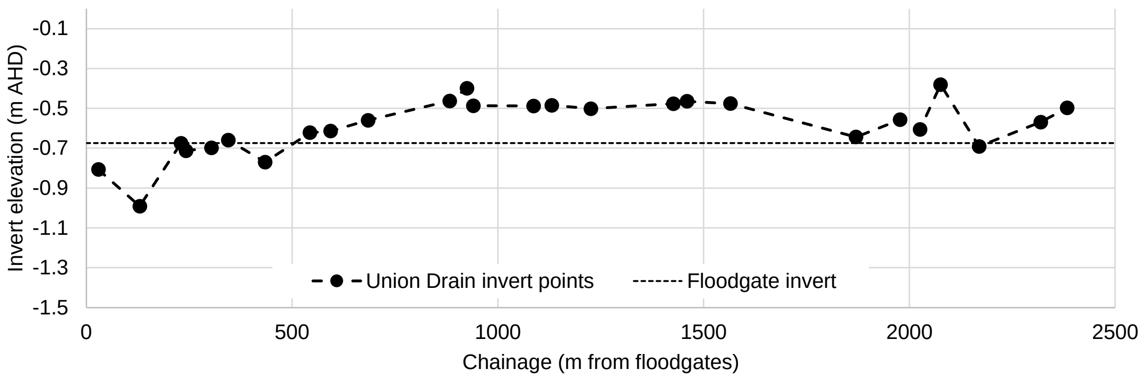


Figure A.6: Invert elevation measurements for Union Drain

A3 Floodplain structure measurements

A total of 29 in-drain structures were surveyed throughout the Keith Hall Drainage network between 26 and 30 October 2020. This data supplements existing data collected for the Keith Hall Drainage system by WRL (2019) and Harrison et al. (2021). Locations of structure surveys are shown in Figure A.7.

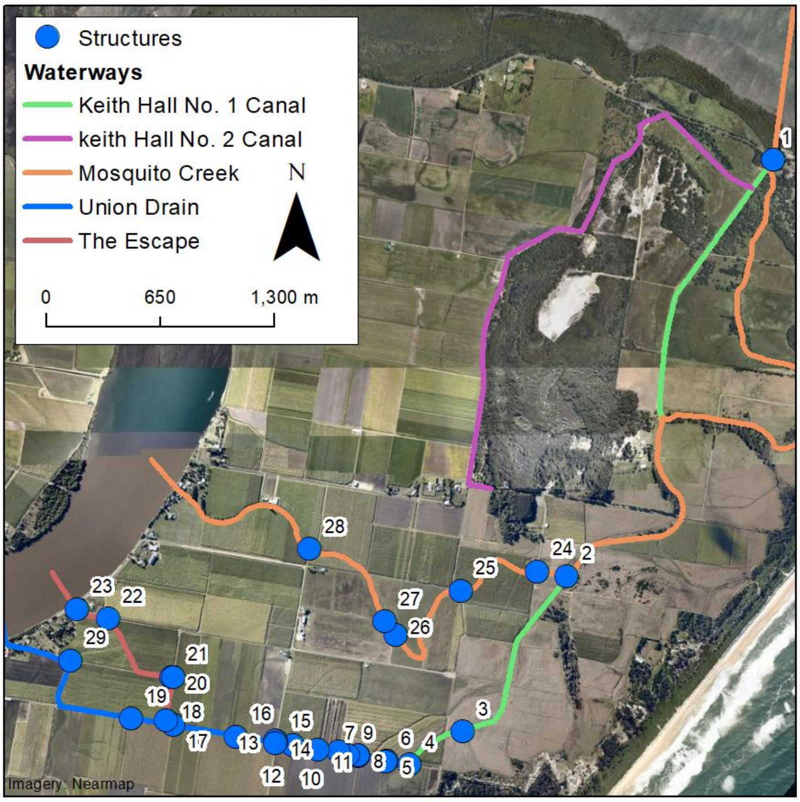


Figure A.7: Structures surveyed within the Keith Hall drainage network.

Structure ID numbers displayed in Figure A.7 correspond to the Structure ID column detailing individual structure measurements in Table A.1.

Table A.1: Measurements of structures within the Keith Hall drainage network

Structure ID	Easting* (m)	Northing* (m)	Structure type	Number of cells	Invert (m AHD)	Obvert (m AHD)	Diameter (m)	Width (m)	Height (m)	Notes
1	554563	6805011	Sluice	1	-0.28	0.01		0.33	0.29	On far left floodgate flap on Keith Hall floodgates (0010-030). Height is at time of inspection (general conditions) but may change.
1	554563	6805011	Auto-tidal gate	1	-0.28	0.22		0.35	0.50	On second floodgate flap from the right on the Keith Hall floodgates (0010-030).
2	553521	6802943	Culvert	1	-0.54	0.36	0.9			Connection between Mosquito Creek and Keith Hall No. 1 Canal.
3	552995	6802168	Culvert	1	-0.02	0.28	0.3			Side drain on Keith Hall No. 1 Canal.
4	552728	6802006	Culvert	1	-0.58	0.62	1.2			Corrugated pipe.
5	552615	6802024	Culvert	2	-0.69	0.21	0.9			
6	552610	6802021	Culvert	1	-0.40	0.20	0.6			Side drain on Union Drain.
7	552473	6802049	Culvert	2	-0.53	0.22	0.75			

Structure ID	Easting* (m)	Northing* (m)	Structure type	Number of cells	Invert (m AHD)	Obvert (m AHD)	Diameter (m)	Width (m)	Height (m)	Notes
8	552472	6802053	Culvert	1	-0.08	0.32	0.4			Side drain on Union Drain.
9	552421	6802053	Culvert	2	-0.28	0.17	0.45			Side drain on Union Drain.
10	552374	6802071	Culvert	1	-0.22	0.38	0.6			Side drain on Union Drain.
11	552268	6802080	Culvert	1	-0.35	0.10	0.45			Side drain on Union Drain.
12	552144	6802103	Culvert	1	-0.11	0.34	0.45			Side drain on Union Drain.
13	552061	6802122	Culvert	3	-0.63	0.27	0.9			
14	552058	6802129	Culvert	1	-0.10	0.35	0.45			Side drain on Union Drain.
15	552058	6802114	Culvert	1	-0.03	0.42	0.45			Side drain on Union Drain.
16	551862	6802149	Culvert	1	-0.04	0.26	0.3			Side drain on Union Drain.
17	551546	6802207	Culvert	1	-0.90	0.30	1.2			One of two culverts.
17	551546	6802207	Culvert	1	-1.01	0.49	1.5			One of two culverts.
18	551513	6802229	Culvert	1	-0.66	0.54	1.2			Connection between The Escape and Union Drain.
19	551337	6802239	Culvert	1	0.04	0.64	0.6			Side drain on Union Drain.
20	551541	6802445	Culvert	1	-0.52	0.68	1.2			One of two culverts.

Structure ID	Easting* (m)	Northing* (m)	Structure type	Number of cells	Invert (m AHD)	Obvert (m AHD)	Diameter (m)	Width (m)	Height (m)	Notes
20	551541	6802445	Culvert	1	-0.59	0.17	0.75			One of two culverts.
21	551547	6802448	Culvert	1	0.03	0.43	0.4			Side drain on The Escape.
22	551223	6802739	Culvert	1	-0.23	0.67	0.9			Side drain on The Escape.
23	551069	6802789	Auto-tidal gate	1	-0.51					Dimensions not measured.
24	553375	6802964	Culvert	1	0.23	1.13	0.9			Bottom of culvert infilled with ~0.25m of sediment.
25	552988	6802871	Culvert	1	-0.23	0.37	0.6			
26	552661	6802650	Culvert	1	-0.68	0.82	1.5			
27	552609	6802719	Culvert	1	-0.03	0.57	0.6			
28	552233	6803082	Culvert	1	-0.13	1.07	1.2			
29	551036	6802531	Culvert	2	-1.18	0.62	1.8			

*GDA 94 MGA 56 coordinates

A4 Topographic LiDAR confirmation survey

Light detection and ranging (LiDAR) technology has been used to measure the topography (or surface elevation) of the Keith Hall floodplain and create a digital elevation model (DEM) with a 1 m by 1 m resolution. This data was collected in June/July 2010 by the NSW Department of Finance, Services and Innovation. While LiDAR technology can measure the topography over a large scale it is unable to measure the ground surface correctly when it is covered by water or vegetation (such as fully grown sugarcane). To assess the accuracy of the LiDAR measurements, ground truthing surveys were completed. In total 121 individual topographic measurements were taken to verify the existing LiDAR measurements. These datapoint supplement existing data collected by WRL (2019). Comparison between LiDAR measurements and ground truthing measurements collected between 27 and 29 October 2020 are shown in Figure A.8.

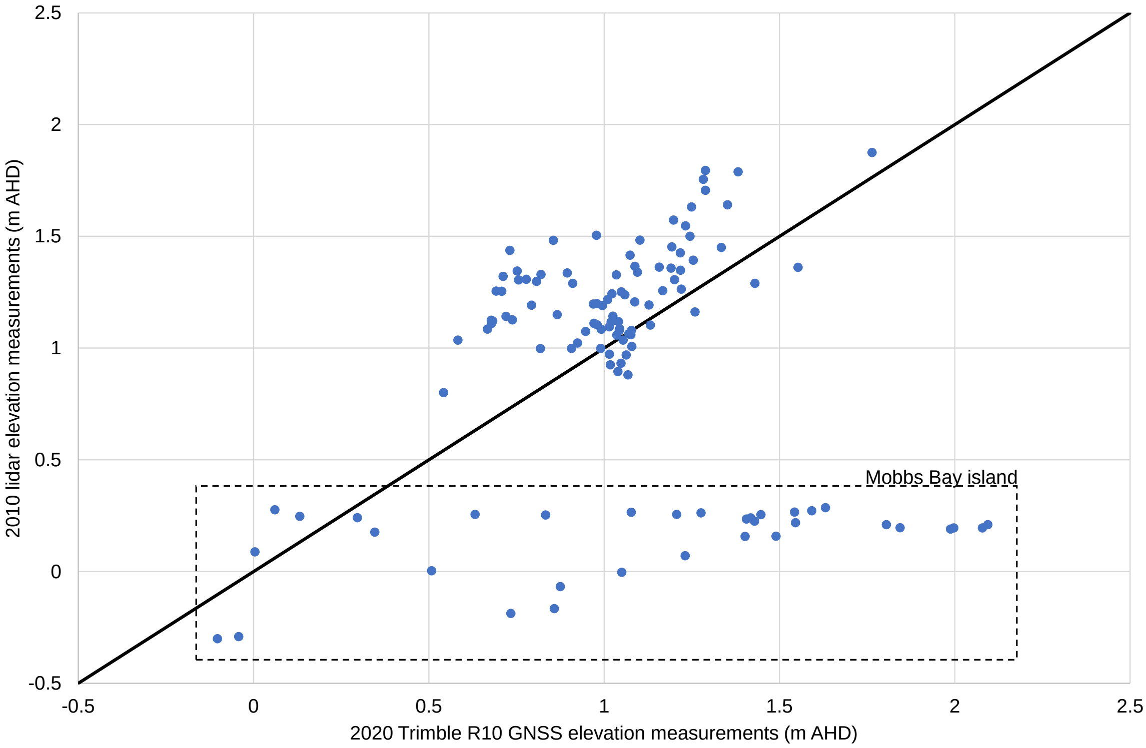


Figure A.8: Comparison between 2010 LiDAR and 2020 topographic survey measurements

Results indicate that on average the LiDAR measurements are 0.2 m higher than measurements surveyed in 2020. This is expected as the ground truthing survey will have a lower elevation when compared to LiDAR which is biased through measuring the top of vegetation or water. Another noteworthy feature of the ground truthing survey is the change in elevation for Mobbs Bay island. Aerial imagery confirms that sand has accreted on the island since the 2010 LiDAR survey at the location where GNSS elevation measurements were taken.

A5 Spot water quality measurements

Spot water quality measurements were observed across the Keith Hall drainage network between 26 and 29 October 2020 using a calibrated YSI EXO2 water quality sonde. Table A.2 summarises the water quality measurements observed. Of these measurements, salinity, pH and dissolved oxygen are presented spatially in Figure A.9, Figure A.10 and Figure A.11, respectively. These water quality measurements supplement existing data collected by WRL (2019) and ongoing monitoring completed by Rous County Council.

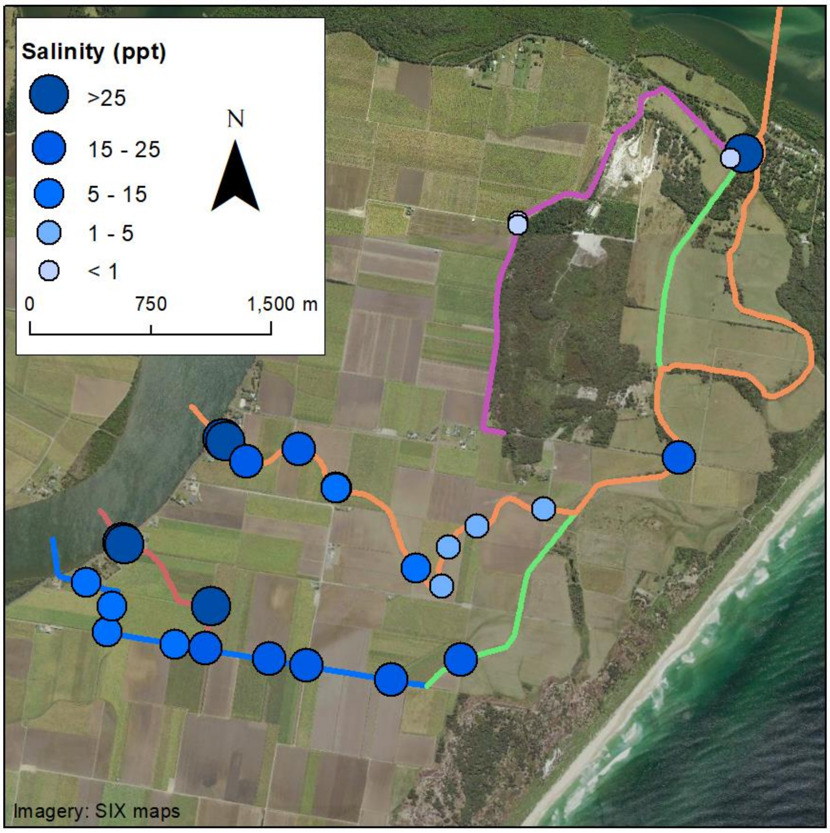


Figure A.9: Spot salinity measurements in the Keith Hall drainage network

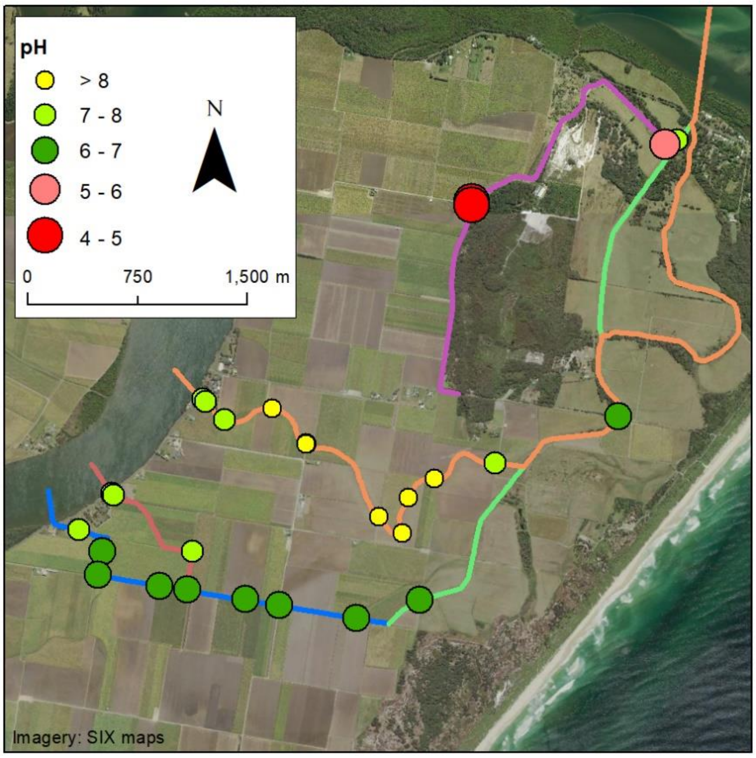


Figure A.10:Spot pH measurements in the Keith Hall drainage network

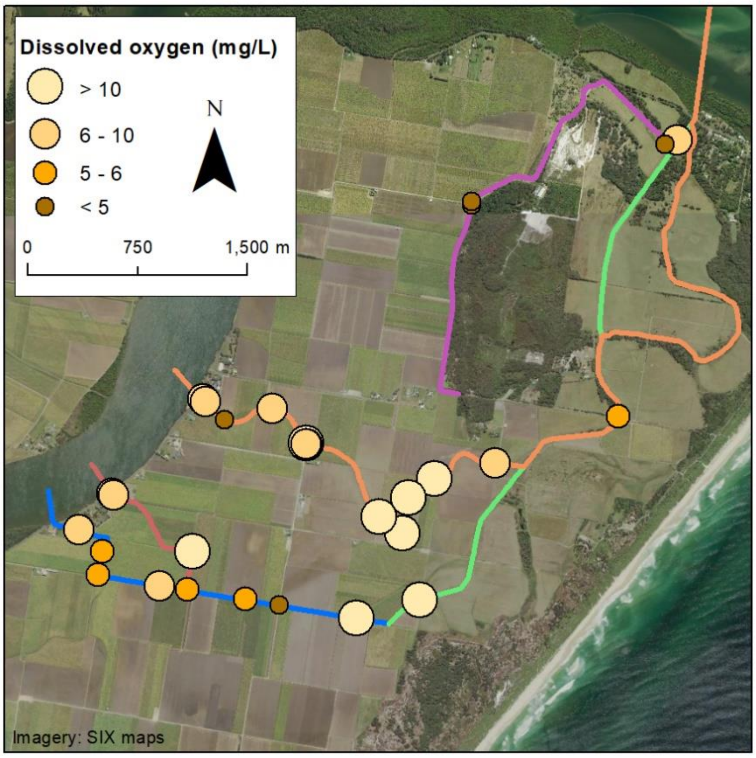


Figure A.11: Spot dissolved oxygen measurements in the Keith Hall drainage network

Table A.2: Spot water quality measurements

Date	Time	Location/notes	Temperature (°C)	Dissolved oxygen (%)	Dissolved oxygen (mg/L)	Specific conductivity (µS/cm)	Salinity(ppt)	pH	Oxidation reduction potential (mV)	Turbidity (NTU)	Blue-green algae (ug/L)	Chlorophyll a (ug/L)	Fluorescent dissolved organic matter (QSU)
26/10/2020	1:10:24 PM	Within K_{sat} P1.	22.3	21	1.8	12	0.0	5.2	69.3	993.7	3.1	6.2	7.4
26/10/2020	4:17:08 PM	At the confluence of Keith Hall No. 1 Canal and Keith Hall No. 2 Canal.	26.9	94	6.5	42,522	27.3	7.0	21.8	39.0	0.9	22.2	111.1
27/10/2020	8:37:59 AM	Keith Hall No. 2 Canal at the water level logger.	20.8	19	1.7	249	0.1	4.2	125.6	6.9	0.6	19.9	144.6
27/10/2020	8:40:00 AM	Keith Hall No. 2 Canal upstream of culvert where logger is installed.	21.0	19	1.7	247	0.1	4.1	115.1	7.5	0.7	20.9	147.4
27/10/2020	9:31:47 AM	Keith Hall No. 1 Canal at Keith Hall Lane downstream of the culverts.	22.3	77	5.9	34,478	21.7	6.5	123.3	73.7	5.0	64.1	93.6
28/10/2020	3:09:31 PM	At the logger just downstream of the junction at Keith Hall No. 1 Canal and Union Drain.	28.7	154	10.7	29,678	18.3	6.2	76.7	24.5	2.2	40.8	195.3
28/10/2020	3:52:17 PM	At Union Drain adjacent to where the soil profile KH_P4 was taken.	29.0	167	11.7	26,495	16.1	6.6	12.1	20.2	3.9	102.6	212.3
29/10/2020	8:49:06 AM	Upstream of cross-section UD_08.	23.0	51	4.0	25,366	15.5	6.4	100.0	34.9	2.7	46.9	206.9
29/10/2020	8:54:50 AM	At cross-section UD_09.	23.9	71	5.5	25,105	15.3	6.5	87.0	34.6	4.2	65.7	186.3
29/10/2020	9:10:56 AM	At the confluence of Union Drain and The Escape.	24.3	71	5.4	25,046	15.3	6.6	42.9	29.6	5.7	69.8	190.3
29/10/2020	9:45:46 AM	At cross-section UD_14.	25.4	84	6.3	24,603	14.9	6.7	77.3	25.1	2.1	34.6	188.2
29/10/2020	10:11:36 AM	At cross-section UD_18.	24.5	78	5.9	24,660	15.0	6.8	76.3	21.6	5.4	53.0	200.6
29/10/2020	10:22:53 AM	At cross-section UD_19.	24.5	75	5.8	22,968	13.9	6.9	51.5	21.5	5.2	47.9	195.6
29/10/2020	11:26:59 AM	At cross-section UD_24.	25.4	100	7.6	22,887	13.8	7.2	43.2	8.0	1.7	33.6	199.2
29/10/2020	11:40:47 AM	At cross-section TE_02.	26.0	150	10.3	46,812	30.4	7.5	-47.8	8.4	0.9	24.4	85.1

Date	Time	Location/notes	Temperature (°C)	Dissolved oxygen (%)	Dissolved oxygen (mg/L)	Specific conductivity (µS/cm)	Salinity(ppt)	pH	Oxidation reduction potential (mV)	Turbidity (NTU)	Blue-green algae (ug/L)	Chlorophyll a (ug/L)	Fluorescent dissolved organic matter (QSU)
29/10/2020	12:53:01 PM	Upstream of The Escape floodgates (0310-031).	26.0	93	6.2	52,820	34.8	7.6	55.3	8.4	0.0	1.7	22.4
29/10/2020	12:54:39 PM	Downstream of The Escape floodgates (0310-031) and upstream of the road.	25.8	95	6.3	53,045	35.0	7.6	39.1	8.3	0.0	1.6	21.9
29/10/2020	1:50:03 PM	At cross-section MC_04.	31.0	105	7.7	3,466	1.8	7.8	-52.4	79.3	7.0	121.0	144.8
29/10/2020	2:02:18 PM	At culvert MC_C2.	29.8	217	16.2	4,621	2.5	9.1	-113.3	42.0	5.4	45.6	160.1
29/10/2020	2:30:24 PM	At cross-section MC_14.	30.0	189	14.1	5,476	2.9	8.8	-82.4	17.0	1.2	15.5	174.0
29/10/2020	2:36:25 PM	At cross-section MC_17.	32.4	313	22.2	7,891	4.3	9.6	-114.1	28.8	32.4	49.7	151.1
29/10/2020	2:42:11 PM	At cross-section MC_19.	29.9	284	20.7	11,247	6.4	9.4	-116.4	24.5	2.8	24.5	142.9
29/10/2020	3:18:30 PM	At cross-section MC_28 prior to rainfall.	28.8	219	15.7	23,058	13.9	8.4	-66.9	12.3	10.7	175.1	164.0
29/10/2020	5:36:57 PM	At cross-section MC_28 after rainfall - water became turbid.	27.4	83	6.1	21,536	12.9	8.1	-36.8	42.9	5.0	103.9	150.3
29/10/2020	5:38:21 PM	At cross-section MC_27 after rainfall - water became turbid.	27.3	85	6.3	21,549	12.9	8.1	-59.1	66.0	4.4	62.6	146.7
29/10/2020	5:48:19 PM	At cross-section MC_32.	25.6	110	8.2	26,540	16.2	8.2	-34.3	24.3	4.6	86.9	141.7
29/10/2020	6:04:13 PM	At cross-section MC_36.	21.6	47	4.0	27,992	17.3	7.3	-283.8	84.7	2.7	46.5	70.2
29/10/2020	6:11:50 PM	Upstream of the Mosquito Creek floodgates (0290-031).	23.1	89	6.4	46,014	29.9	7.3	-97.3	16.4	0.8	4.7	25.0
29/10/2020	6:12:40 PM	Downstream of the Mosquito Creek floodgates (0290-031).	23.9	95	6.7	47,458	30.9	7.5	-94.6	8.1	0.5	5.3	13.0

A6 Long-term water level and quality measurements

Water level and quality monitoring equipment was installed at Keith Hall from October 2020 to April 2021. Locations of monitoring equipment is shown in Figure A.12. Specifications of monitoring equipment and installation details are shown in Table A.3. Note, several loggers (ID: 2, 3, 6, 7 and 8) malfunctioned during deployment. This meant that for some instances data was not available for the entire period from October 2020 to April 2021. Water level data collected is shown in Figure A.13, specific conductivity data is shown in Figure A. 14, and other water quality data is shown in Figure A.15.

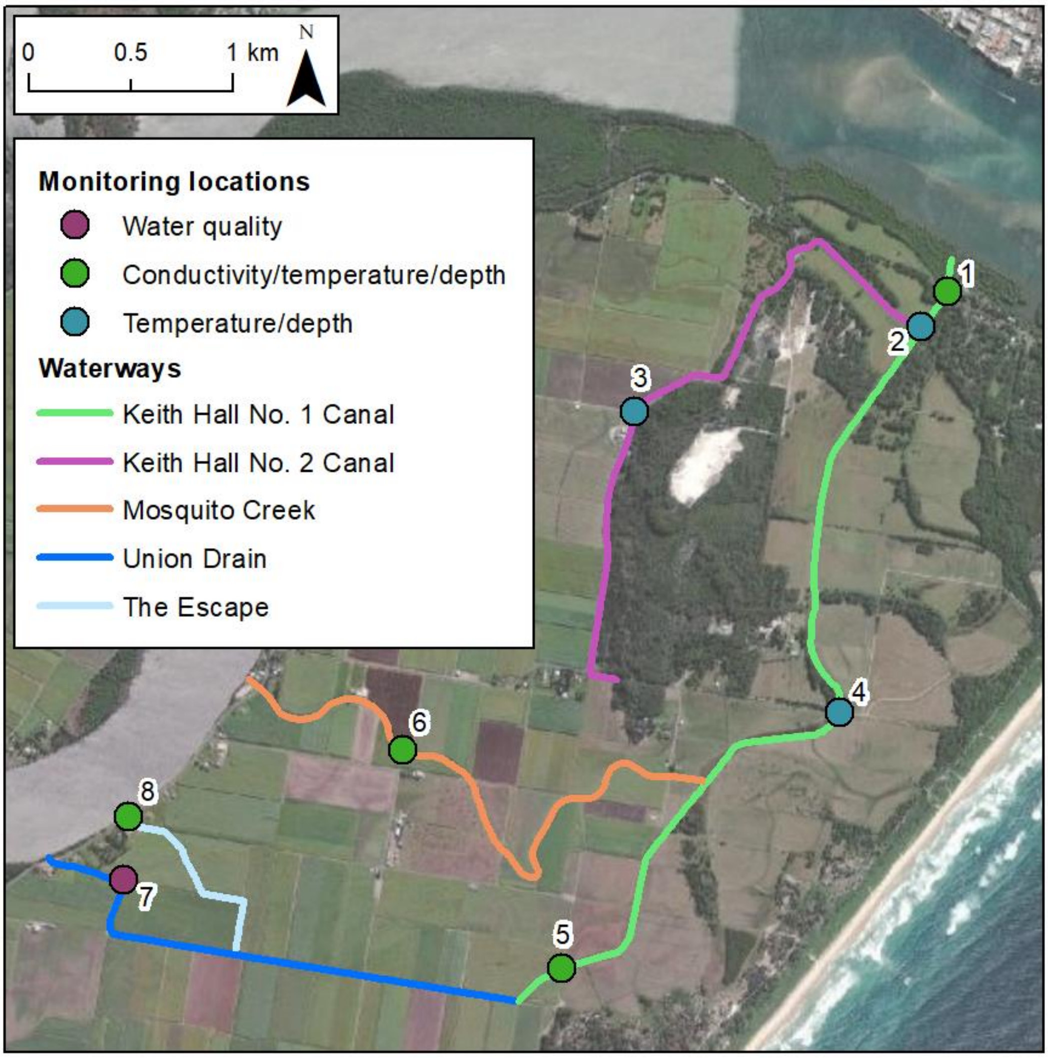


Figure A.12: Location of long-term water level and water quality monitoring equipment

Table A.3: Water level and water quality logger information

ID	Description	Instrument	Easting (m) (MGA56 GDA94)	Northing (m) (MGA56 GDA94)	Date deployed	Date downloaded	Notes
1	Downstream of the Keith Hall floodgates	Solinst Levelogger LTC	6805025.2	554568.3	26/10/2020	15/04/2021	Timestamp on logger drifted but was able to be corrected in post-processing.
2	At the confluence of Keith Hall No. 1 and Keith Hall No. 2 Canals	Heron DipperLog Nano	6804875.4	554453.9	26/10/2020	5/11/2020	Logger malfunctioned from the 5/11/2020. Data infilled using information from RCC logger where available.
3	Downstream of a culvert on Keith Hall No. 2 Canal	Heron DipperLog Nano	6804519.0	553230.9	27/10/2020	15/04/2021	
4	In Keith Hall No. 1 Canal Downstream of Keith Hall Lane	Heron DipperLog Nano	6803235.5	554100.4	27/10/2020	15/04/2021	
5	Upstream of a Culvert on Keith Hall No 1 Canal near its confluence with Union Drain	Solinst Levelogger LTC	6802148.3	552906.2	28/10/2020	15/04/2021	Blockage in channel believed to increase water levels following December rainfall event.
6	Downstream of a culvert in Mosquito Creek	Solinst Levelogger LTC	6803084.8	552230.8	29/10/2020	1/11/2020	Logger malfunctioned and only recorded 3 days of data.

ID	Description	Instrument	Easting (m) (MGA56 GDA94)	Northing (m) (MGA56 GDA94)	Date deployed	Date downloaded	Notes
7	Downstream of a bridge in Union Drain	In-situ Aquatroll 500	6802532.6	551033.0	29/10/2020	15/04/2021	Water level measurements OK. Water quality measurements failed throughout deployment period.
8	On the downstream side of River Drive where The Escape meets the Richmond River.	Solinst Levelogger LTC	6802805.8	551053.6	29/10/2020	1/11/2020	Logger malfunctioned and only recorded 3 days of data.

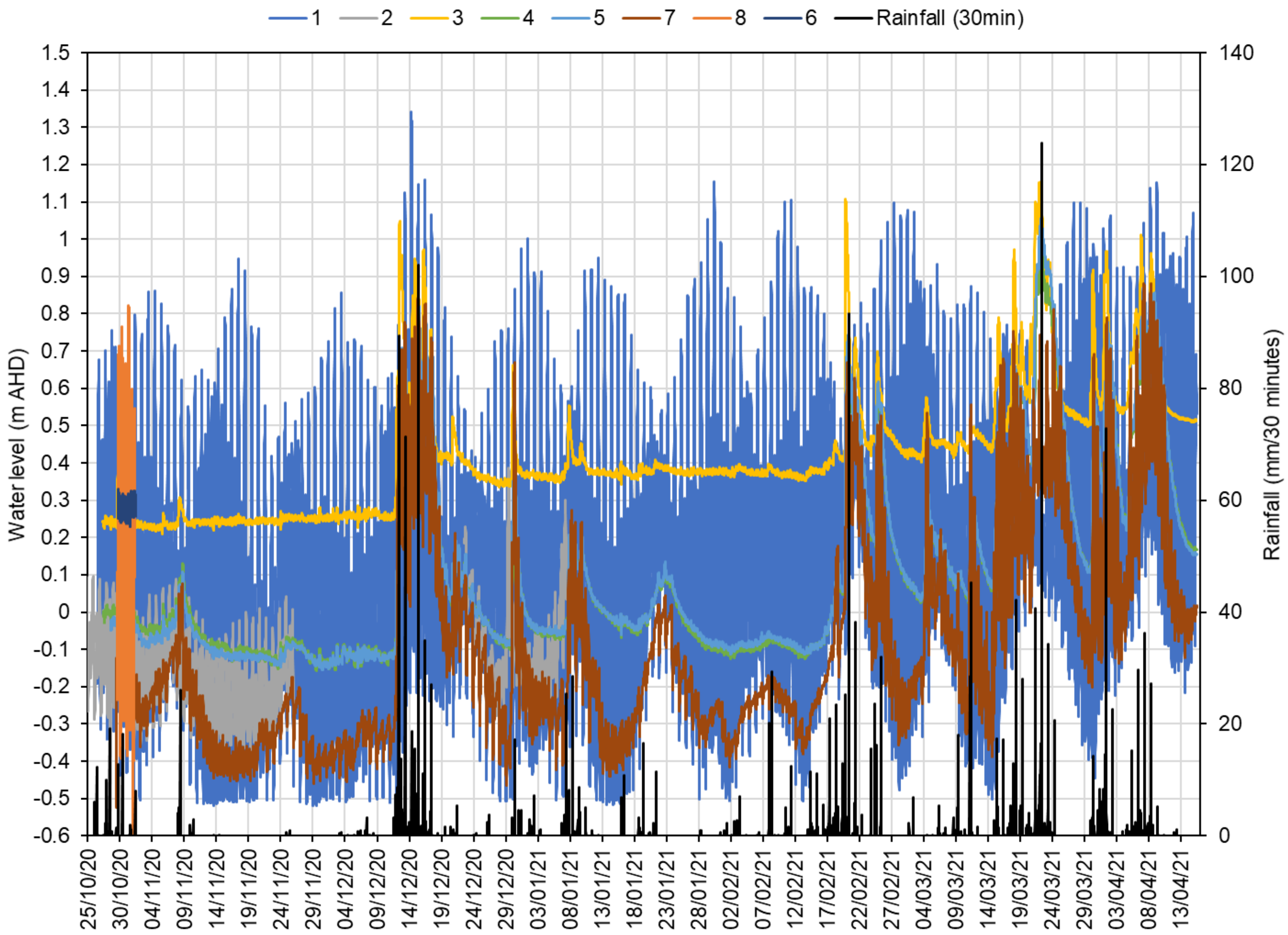


Figure A.13: Water level data

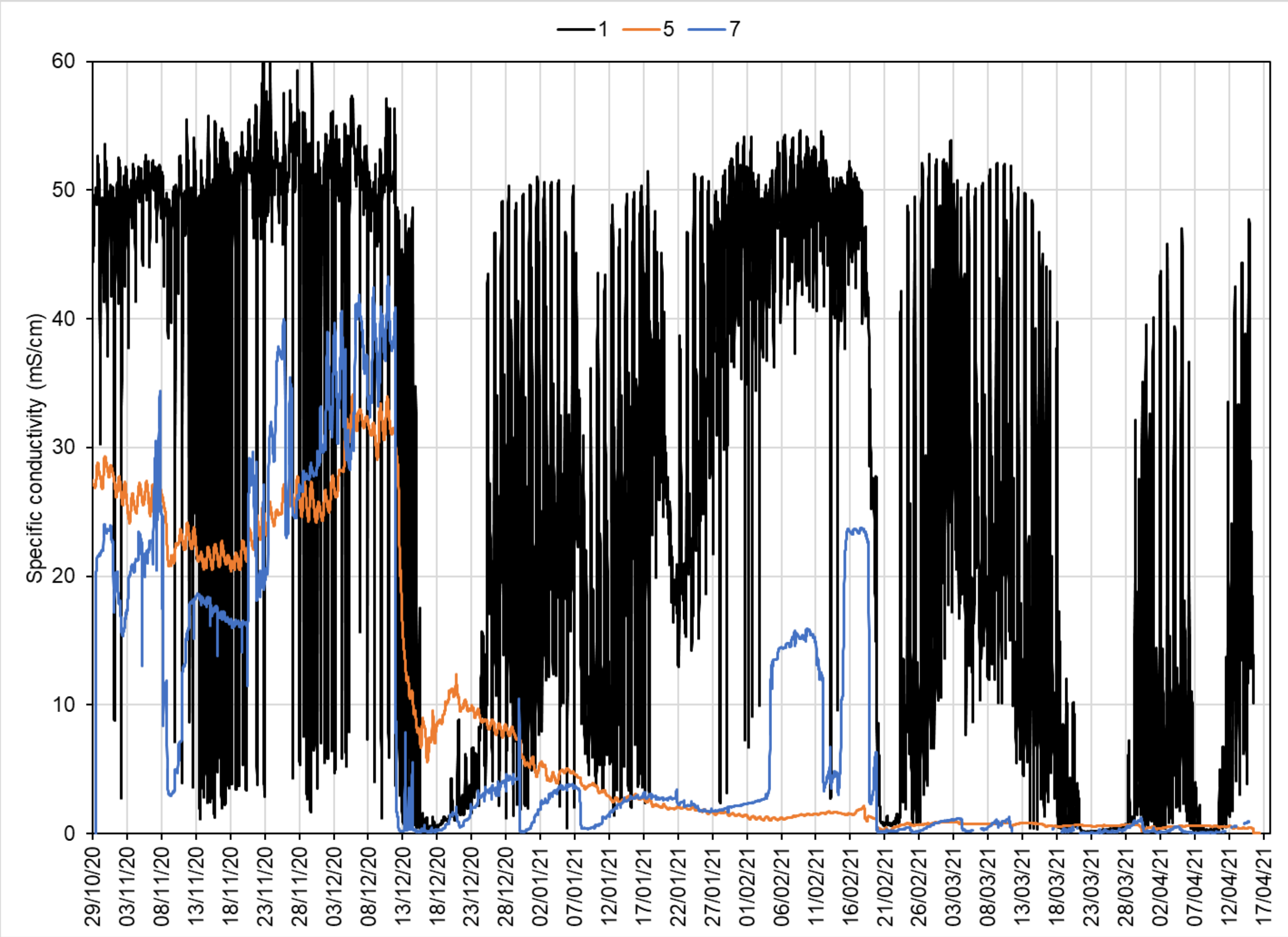


Figure A. 14: Specific conductivity data

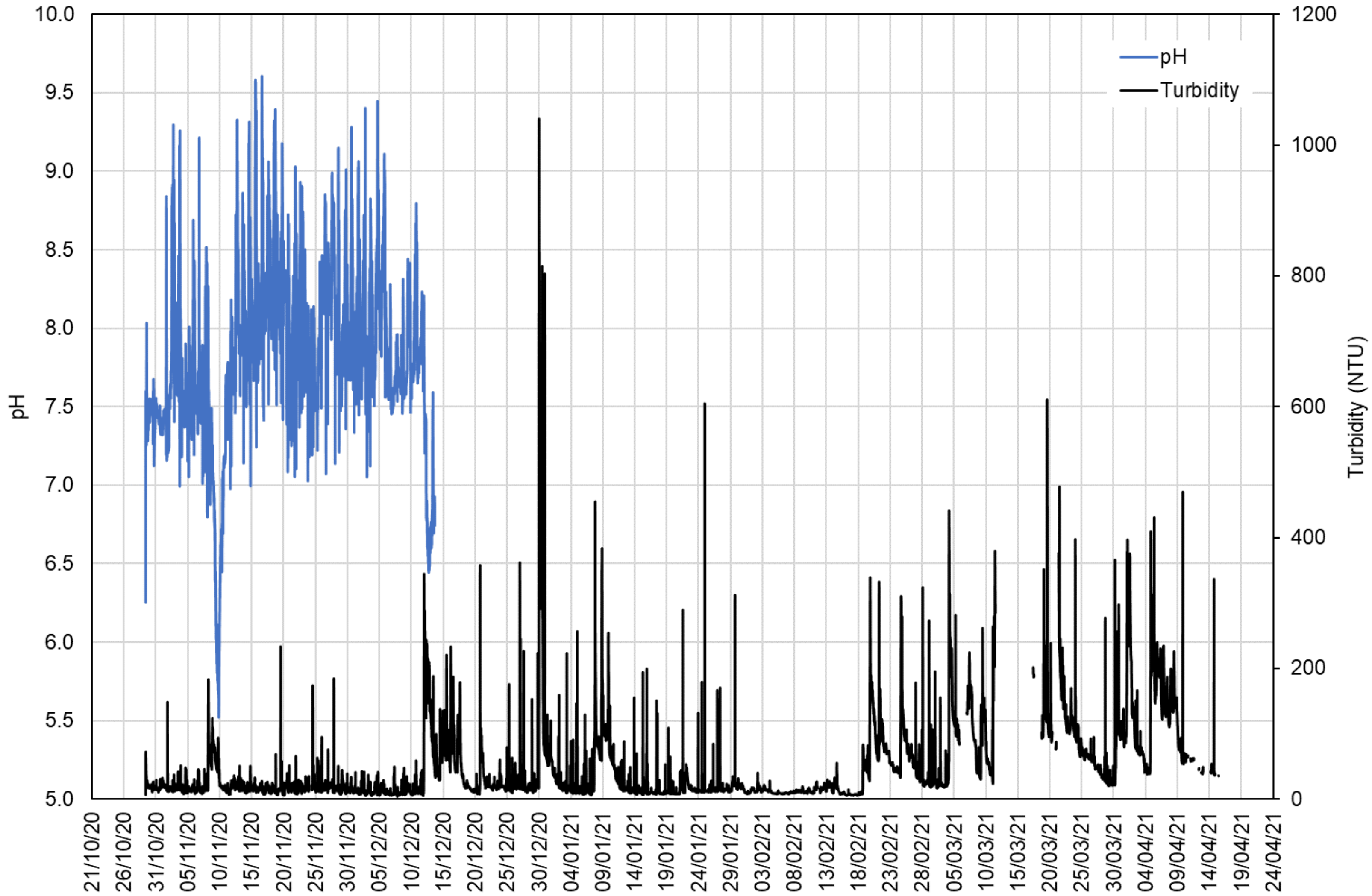


Figure A.15: pH and turbidity water quality data collected in Union Drain (Site ID: 7)

At the same time this equipment was installed, RCC also had a water quality sonde measuring continuously in Keith Hall No. 1 Canal upstream of the floodgates (ID: 2). Throughout the monitoring program RCC also collected event based water quality samples in Keith Hall No. 1 Canal upstream of the floodgates and Mobbs Bay downstream of the floodgates. RCC data can be found in Appendix F).

A7 Soil profiles

Five soil profiles were sampled across the Keith Hall floodplain to determine the presence of acid sulfate soils. Locations of the soil profiles is shown in Figure A.16. Soil profile log information is also presented from Figure A.17 to Figure A.21. This data supplements existing soil profile information collected by WRL (2019) and the NSW Government Soil and Land Information Systems (SALIS) data available on eSPADE.

Actual and potential acid sulfate soils contain oxidised or un-oxidised reduced inorganic sulphur and can be identified as per Sullivan et al. (2018b). An indicator of actual acid sulfate soils is when their pH is below 4. For soil with a pH above 4, indicators of potential acid sulfate soil are: a pH_{fox} below 3, a large difference between the soil pH and pH_{fox} and a reaction rate of 5.

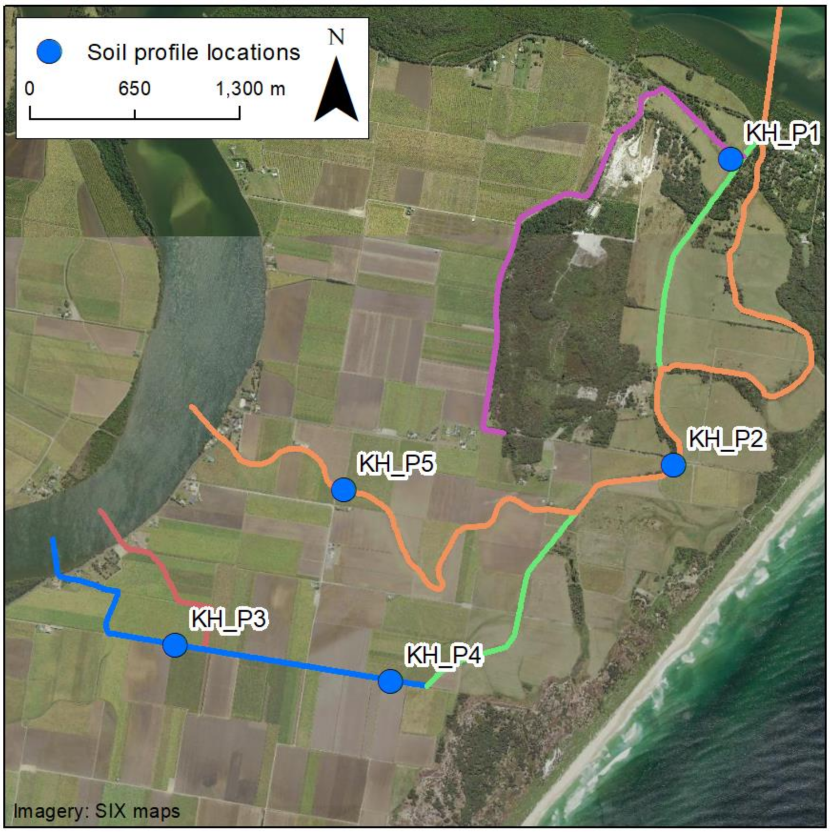


Figure A.16: Soil profile locations

Soil profile details:

Project Number: 2020031 Profile ID: P1
River/estuary: Richmond Sample date: 26/10/20
Easting: 554388 Sampled by: TAT GL
Northing: 6804859.1

Ground elevation (m AHD): 0.41
Hydraulic conductivity (m/d): 3.1

Water quality:

Surface water EC (µS/cm): Not available
Surface water pH: Not available
Groundwater EC (µS/cm): 12.1
Groundwater pH: 5.23

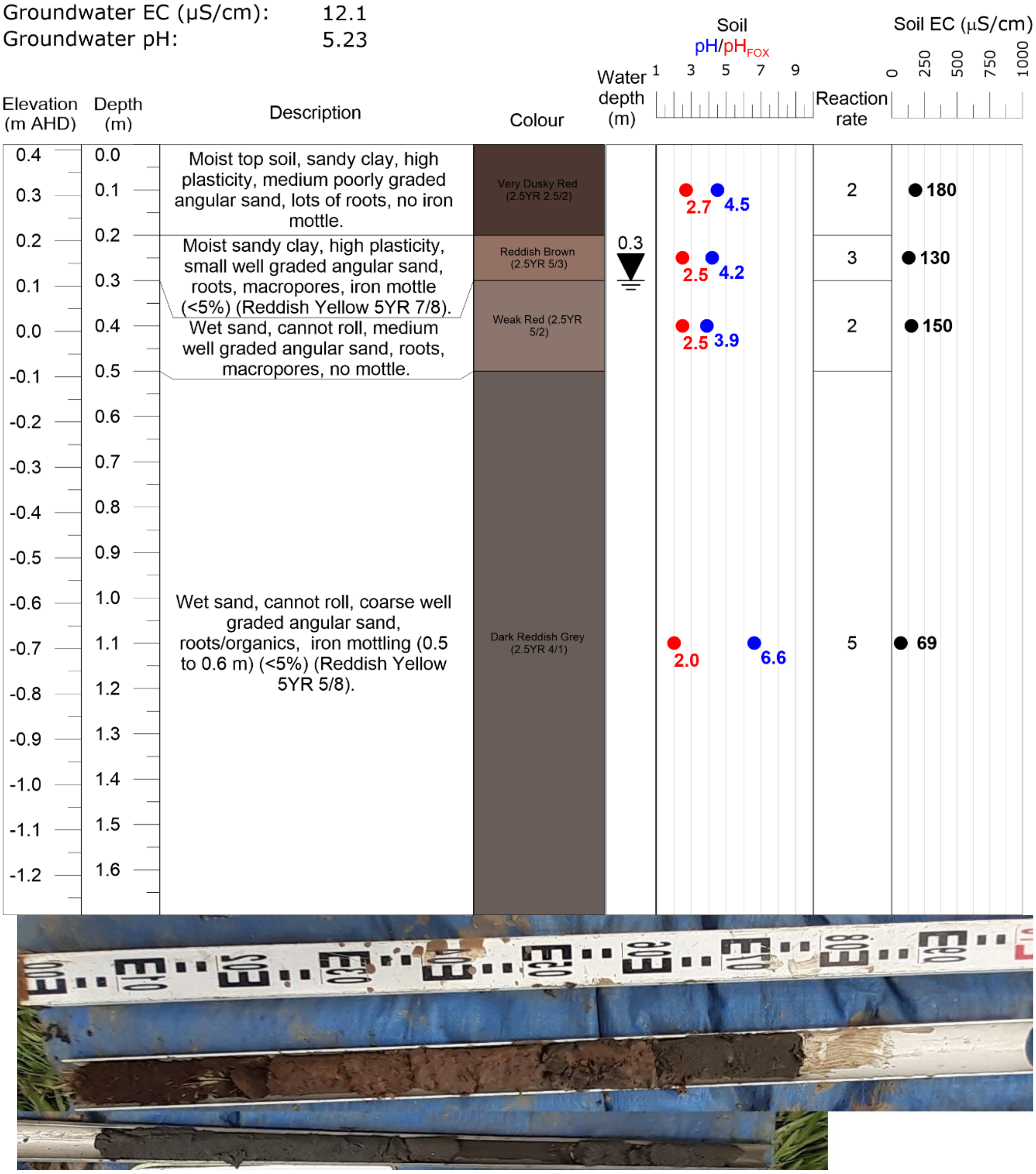


Figure A.17: Soil profile KH_P1

Soil profile details:

Project Number:	2020031	Profile ID:	P2
River/estuary:	Richmond	Sample date:	27/10/20
Easting:	554035.6	Sampled by:	TAT GL
Northing:	6803201.2		

Ground elevation (m AHD): 0.44
Hydraulic conductivity (m/d): 4

Water quality:

Surface water EC (µS/cm): Not available
Surface water pH: Not available
Groundwater EC (µS/cm): Not available
Groundwater pH: Not available

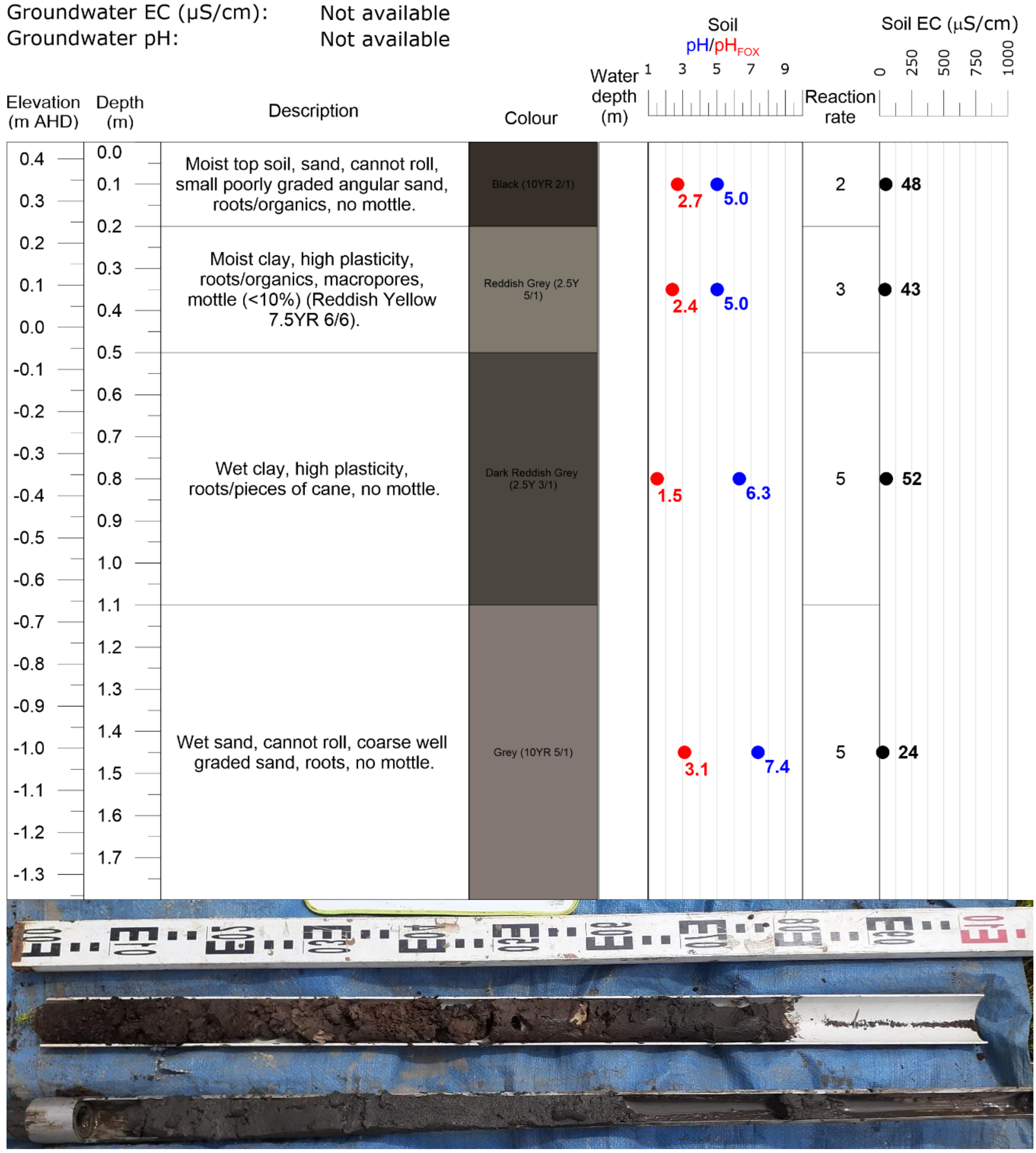


Figure A.18: Soil profile KH_P2

Soil profile details:

Project Number:	2020031	Profile ID:	P3
River/estuary:	Richmond	Sample date:	30/10/20
Easting:	551349.1	Sampled by:	TAT GL
Northing:	6802237.3		

Ground elevation (m AHD): 0.88
Hydraulic conductivity (m/d): Not available

Water quality:

Surface water EC (µS/cm): 25,433
Surface water pH: 7.09
Groundwater EC (µS/cm): Not available
Groundwater pH: Not available

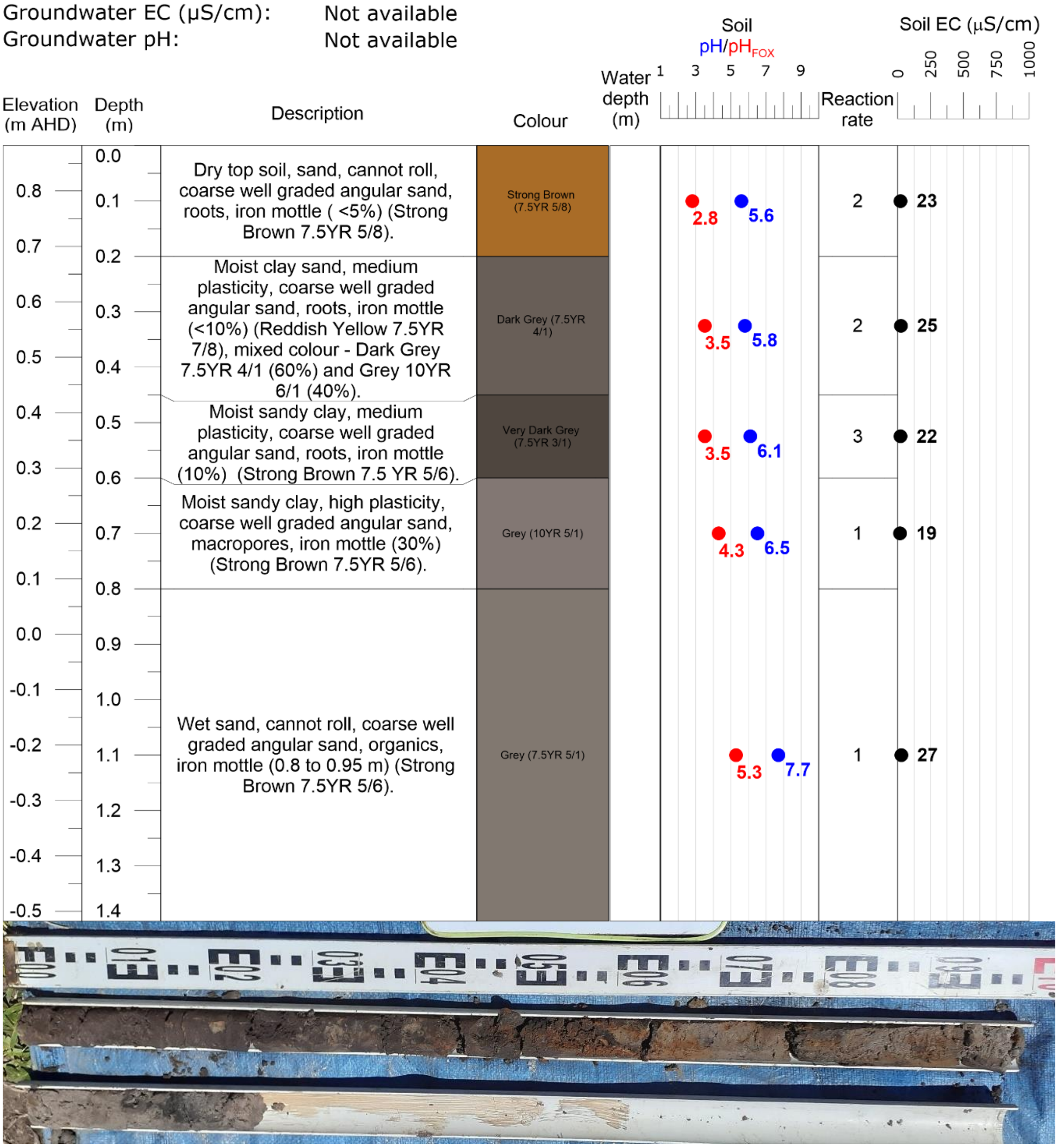


Figure A.19: Soil profile KH_P3

Soil profile details:

Project Number:	2020031	Profile ID:	P4
River/estuary:	Richmond	Sample date:	28/10/20
Easting:	552521	Sampled by:	TAT GL
Northing:	6802037.3		

Ground elevation (m AHD):	0.59
Hydraulic conductivity (m/d):	Not available

Water quality:

Surface water EC (µS/cm):	26,495
Surface water pH:	6.62
Groundwater EC (µS/cm):	Not available
Groundwater pH:	Not available

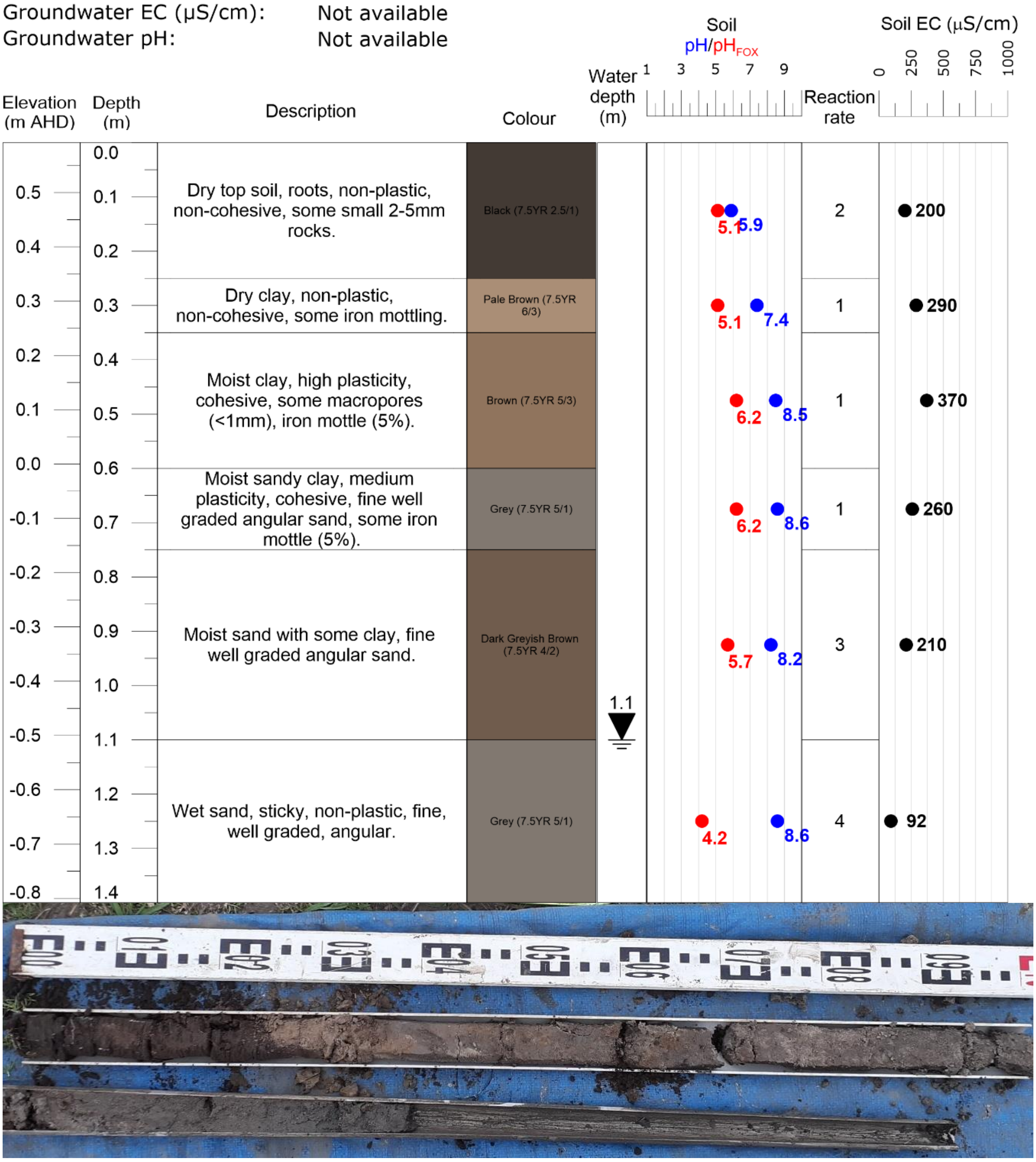


Figure A.20:Soil profile KH_P4

Soil profile details:

Project Number:	2020031	Profile ID:	P5
River/estuary:	Richmond	Sample date:	29/10/20
Easting:	552267.8	Sampled by:	TAT GL
Northing:	6803074.9		

Ground elevation (m AHD): 1.25
Hydraulic conductivity (m/d): Not available

Water quality:

Surface water EC (µS/cm): Not available
Surface water pH: Not available
Groundwater EC (µS/cm): Not available
Groundwater pH: Not available

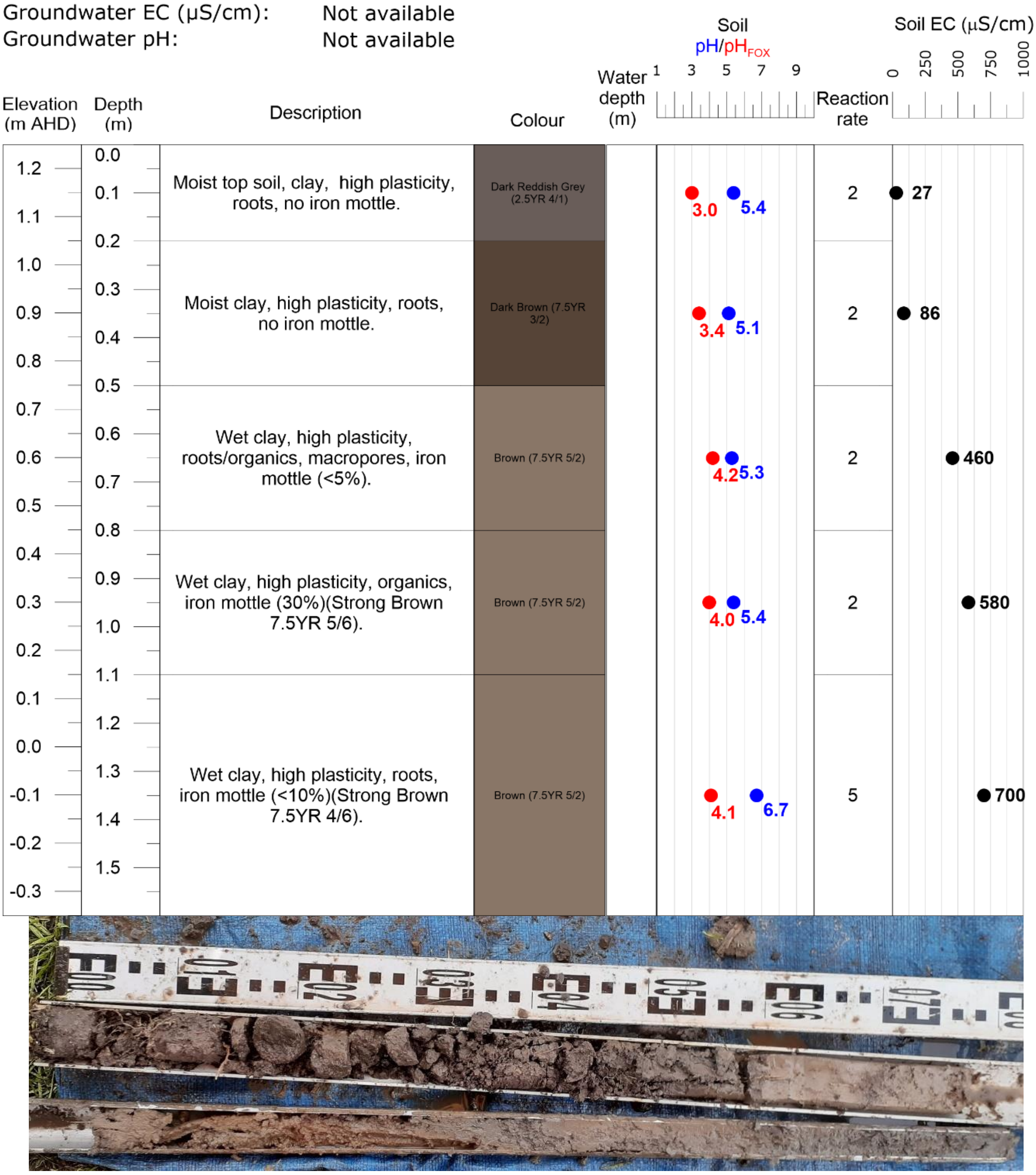


Figure A.21:Soil profile KH_P5

A8 Hydraulic conductivity

Hydraulic conductivity data was measured adjacent to soil profiles KH_P1 and KH_P2. Measurements were observed using the pit bailing method as outlined by Johnston et al. (2009) (Figure A.22). Discrete hydraulic conductivity values were determined using the Bouwer and Rice (1983) method taking into consideration a square pit using shape factors as outlined by Boast and Langebartel (1984). Table A.4 outlines the hydraulic conductivity measurements collected during field investigations and compared with measurements collected by WRL (2019) using the same method. All hydraulic conductivity measurements were rated as moderate risk according to the Johnston and Slavich (2003) criteria.

Figure A.22: Pit used to measure hydraulic conductivity adjacent to KH_P2

Table A.4: Hydraulic conductivity measurements on the Keith Hall floodplain

Pit ID	Easting (m) (GDA 94 MGA 56)	Northing (m) (GDA 94 MGA 56)	Hydraulic conductivity (m/day)	Hydraulic conductivity risk rating*
KH_P1	554388	6804859	3.1	Moderate
KH_P2	554066	6803201	4.0	Moderate
WRL (2019) 1	553094	6804132	10.0	Moderate
WRL (2019) 2	553504	6802882	10.8	Moderate

*As per Johnston and Slavich (2003)

A9 Velocity measurements

Marotte high sampling (HS) current meters (JCU, 2020) were deployed within Mobbs Bay at the locations shown in Figure A.23 from 28-30 October 2020. During this time, they continuously measured flow velocity and current direction. Comparison of the half-hourly averaged velocities with the water levels measured downstream of the Keith Hall floodgates is shown in Figure A.24.

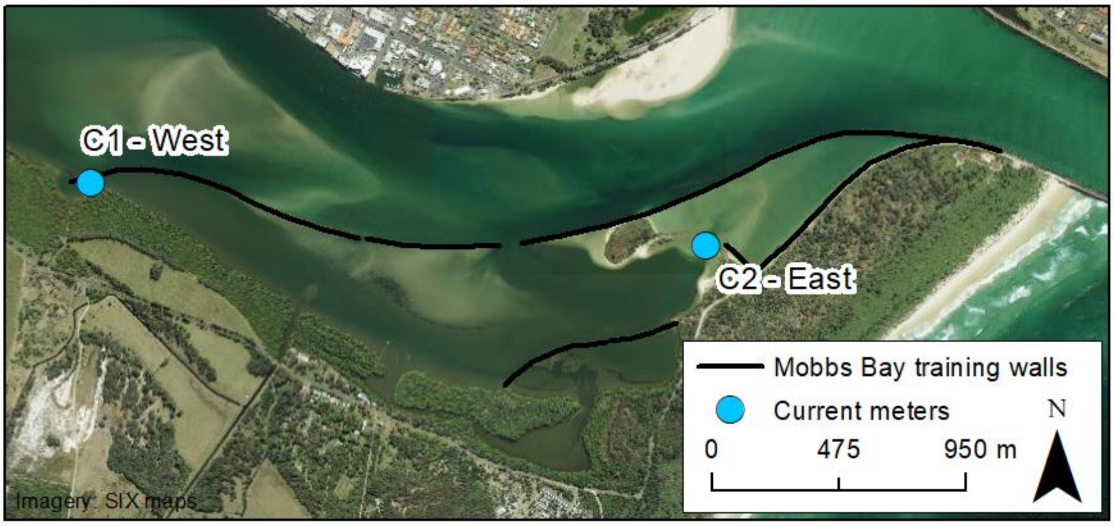


Figure A.23: Location of current meters within Mobbs Bay

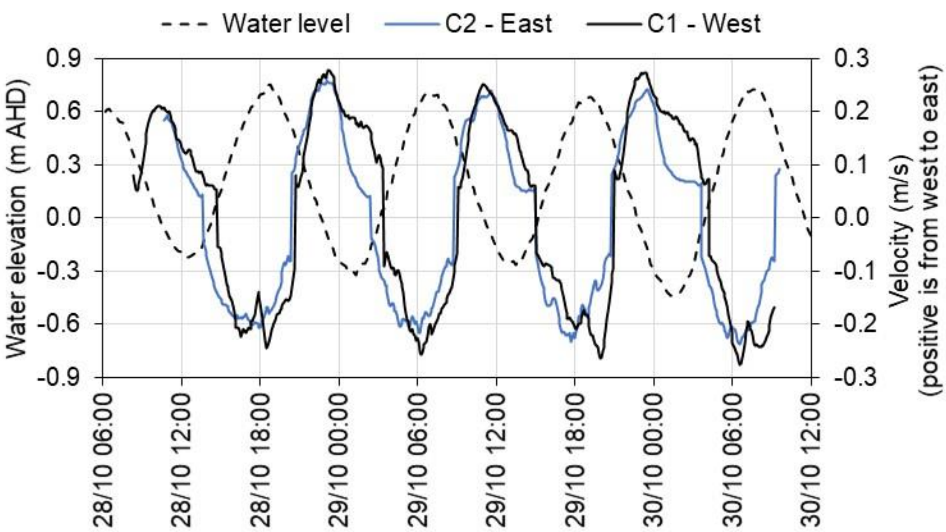


Figure A.24: Velocity measurements within Mobbs Bay

A10 Mobbs Bay training wall elevations

Measurements of the crest elevation of Mobbs Bay training wall were taken on 28 October 2020 to help develop a conceptual understanding of Mobbs Bay. In total, 641 elevation measurements were observed. As shown in Figure A.25, the crest elevation of Mobbs Bay training wall varies depending on the placement of individual armour units. Subsequently, to ascertain the crest elevation, numerous measurements were taken of the crest along the training wall. Using this method an indicative elevation for different sections of the training wall could be inferred. Elevation measurements across the training wall are shown in Figure A.26. Note, the survey to the west of Mobbs Bay island was far more detailed when compared to the survey to the east. This was due to limited accessibility to the training wall on the eastern side where it was significantly impacted by waves.

Figure A.25: Mobbs Bay training wall looking west

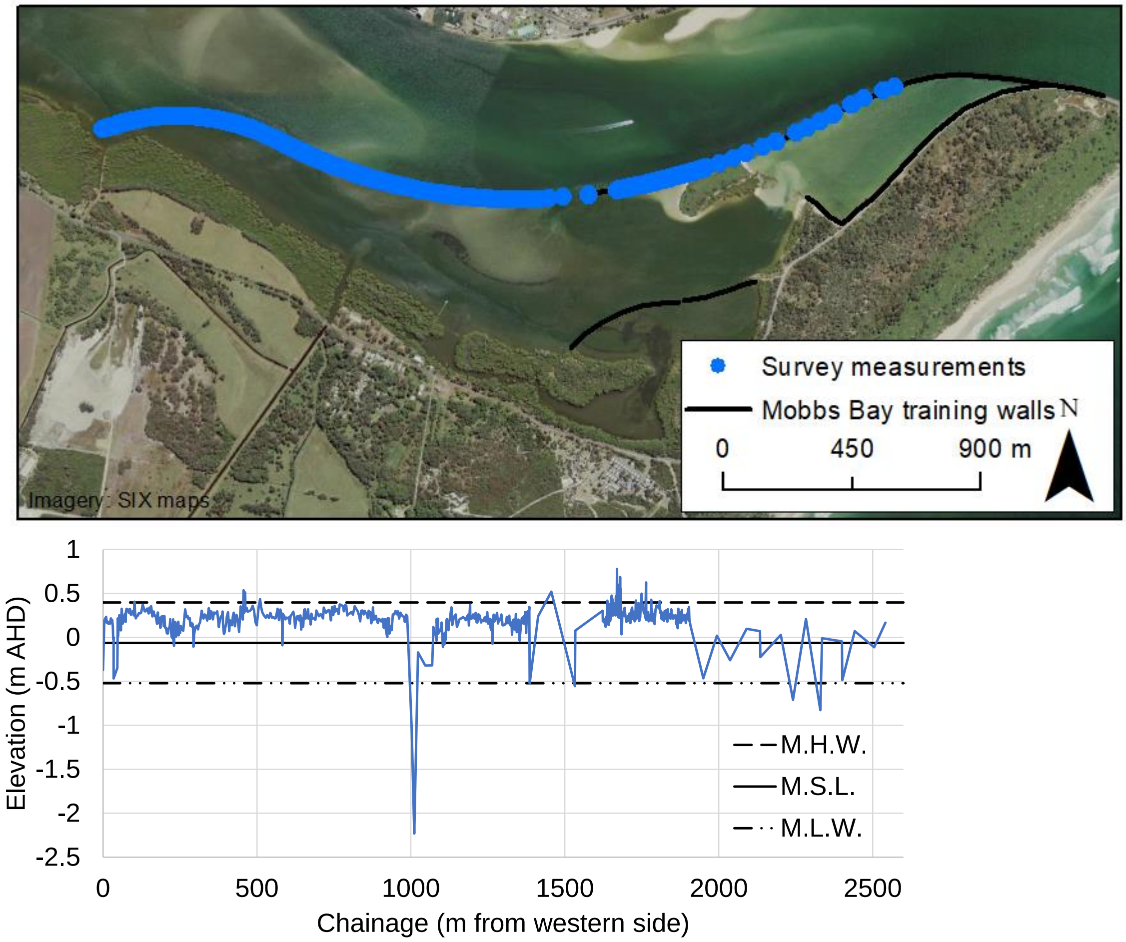


Figure A.26: Elevation measurements of Mobbs Bay training walls

The training wall crest elevation is predominantly located between mean sea level (MSL) and the mean high water neap (MHWN). On average, the elevation of the crest of the training wall to the east of the island has a lower elevation (-0.14 m AHD) when compared to the western side (0.21 m AHD). Table A.5 outlines the percentage of crest measurements that are above each tidal plane.

Table A.5: Percentage of Mobbs Bay training wall crest measurements above each tidal plane

Tidal plane	Elevation (m AHD)	Percent of training wall crest measurements above tidal plane
ISLW	-0.925	100%
MLWS	-0.648	99%
MLW	-0.521	99%
MLWN.	-0.393	99%
MSL.	-0.061	96%
MHWN	0.27	28%
MHW	0.398	4%
MHWS	0.525	1%
H.H.W.S.S.	0.913	0%

A11 Mobbs Bay bathymetric survey

A bathymetric survey was completed within Mobbs Bay using a CEESCOPE hydrographic survey system on 28 October 2020. The CEESCOPE system can measure depths to an accuracy of 15 mm. When combined with the Trimble R10 GNSS to determine bathymetry elevation accuracy becomes 33 mm. Note, factors such as geographic location and atmospheric activity can also increase this error.

Seventeen bathymetric cross-sections were measured within Mobbs Bay in addition to opportunistic measurements that were observed while travelling between cross-sections (Figure A.27). Historical survey data for Mobbs Bay bathymetric was collected on 1 May 2005 by the NSW Office of Environment and Heritage (OEH, now Environment, Energy and Science (EES) within the Department of Planning Industry and Environment). Cross-section profiles, including a comparison between the 2005 survey and the recent 2020 survey are presented in Appendix C.

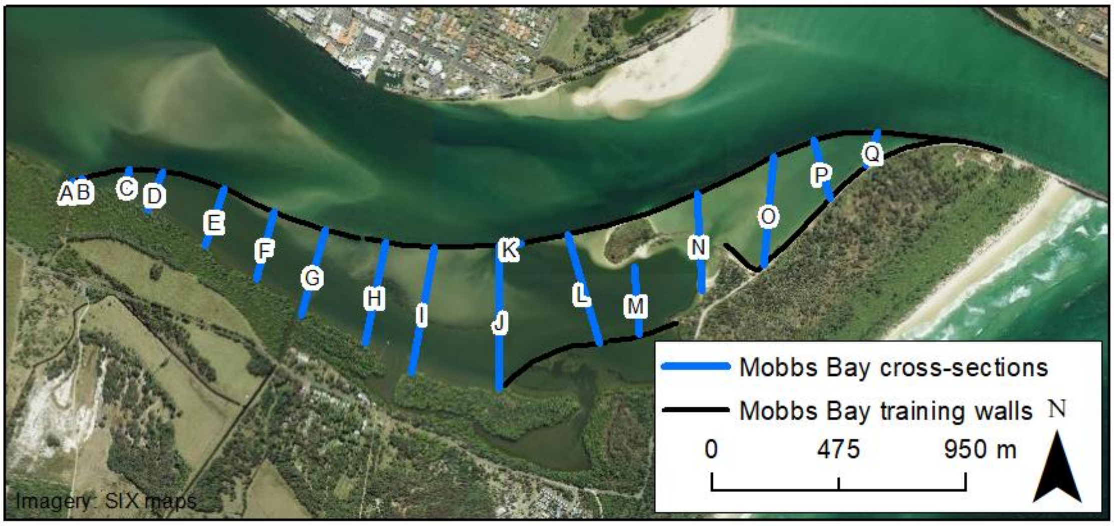


Figure A.27: Location of bathymetric survey cross-sections in Mobbs Bay

Appendix B Numerical modelling

B1 Preamble

A one-dimensional (1D) numerical model was developed for the Keith Hall drainage network using the MIKE 1D software package (DHI, 2019). Empirical data outlined in Appendix A was used to develop and hydrodynamically verify the numerical model. Using this verified model, each drainage option was then simulated to determine its effectiveness at achieving the project aims. The following appendix outlines technical details relevant to the numerical model development, validation, scenario simulations, and analysis of model data.

B2 Model development

B2.1 Numerical model grid

The numerical model grid consisted of 1D grid points at which discharge and water level calculations are made. Each water level grid point has a specified cross-section that determines the channel geometry for calculations. In total 121 cross-section measurements were used to develop the model grid. To provide increased computational accuracy these cross-sections were interpolated on a 10 m spacing.

At certain locations throughout the model there were hydraulic control structures, such as weirs and culverts. These were simulated in the numerical model using the MIKE-1D engine at the respective discharge grid points in the model domain. Measurements of each structure were used as input to the MIKE-1D engine which then calculated discharge based on the relative water levels of the bounding water level grid points. For floodgate structures where there were modifications, such as sluice gates or buoyancy driven tidal gates, which required the structure to open and close based on conditions such as water levels and predicted weather events, the MIKE HYDRO River Control Module was used.

B2.2 Boundary conditions

Both upstream (catchment) and downstream boundary (tide) conditions were used for model simulations. Water level data collected downstream of the Keith Hall floodgates was used as a downstream water level boundary. Short-term data collected downstream of The Escape confirmed that there was a small difference in the tide times between the Keith Hall floodgates and those located on the west of the floodplain (Figure B.1). Subsequently, the long-term tidal data collected downstream of the Keith Hall floodgates was used as the tidal boundary for the discharge points on the west of the Keith Hall floodplain with an offset of one hour (behind).

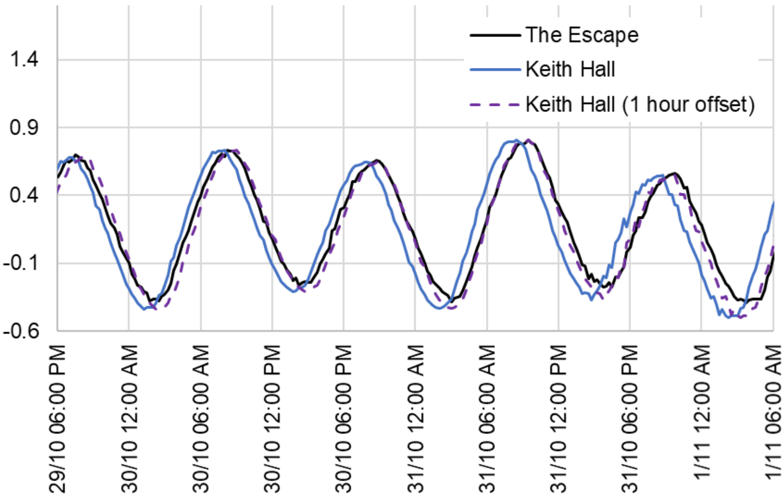


Figure B.1: Time lag between water levels in Mobbs Bay at the Keith Hall floodgates and the Richmond River at The Escape floodgates

Couriel et al. (2012) completed a tidal data analysis for the Richmond River at Ballina. They found that the average tide ranged from -0.925 m AHD to 0.913 m AHD. Analysis of tide data collected for the modelled period ranged from -0.52 m AHD to 0.94 m AHD (during dry times). The difference in measured low-tide data (-0.52 m AHD) versus the Indian Spring Low Water (-0.925 m AHD for the Richmond River at Ballina) level was caused by water level measurement instrumentation missing the lowest tide measurements. High tide observations, including the High High Water Solstice Spring tides (0.913 m AHD for the Richmond River at Ballina), were accurately represented in measured water level data. Using this dataset in the model is not expected to impact model results as the low tide cut off elevation for instrument measurements (-0.52 m AHD) is below the sill level for the Keith Hall No. 1 Canal culverts (-0.43 m AHD). When the water level is below this level outflow from the culverts will be controlled by tailwater conditions as the culverts act like a broad crested weir.

There was no catchment gauging information available for the study site. Subsequently, an uncalibrated Australian Water Balance Model (AWBM) (Boughton, 2004) was used to determine the catchment inflows for the site (Figure B.2). The Keith Hall drainage network was split into four smaller catchments (Figure B.3). Using input rainfall and evaporation data provided by the Bureau of Meteorology (BOM) collected at the Ballina Airport Automatic Weather Station (AWS, station ID: 58198), the AWBM was run for each of the four catchments. Runoff calculated from the AWBM for each catchment was then input into the model as a distributed source along the length of the drainage network. Model parameters for the AWBM were taken from literature and are shown in Table B.1.

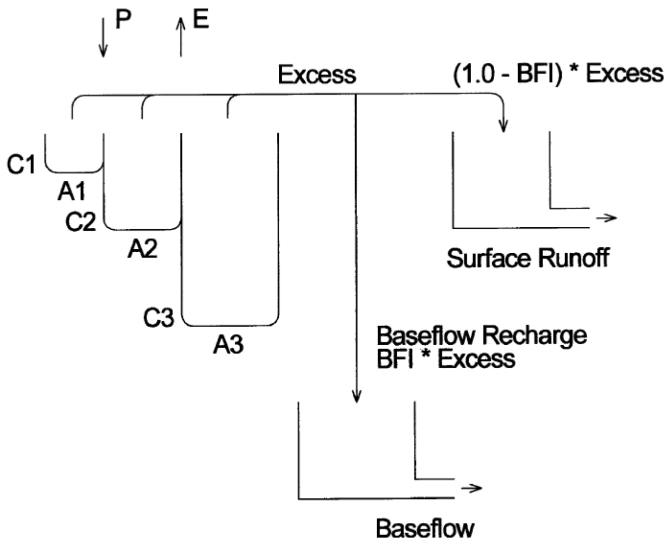


Figure B.2: Australian Water Balance Model (AWBM) diagram (Boughton, 2004)

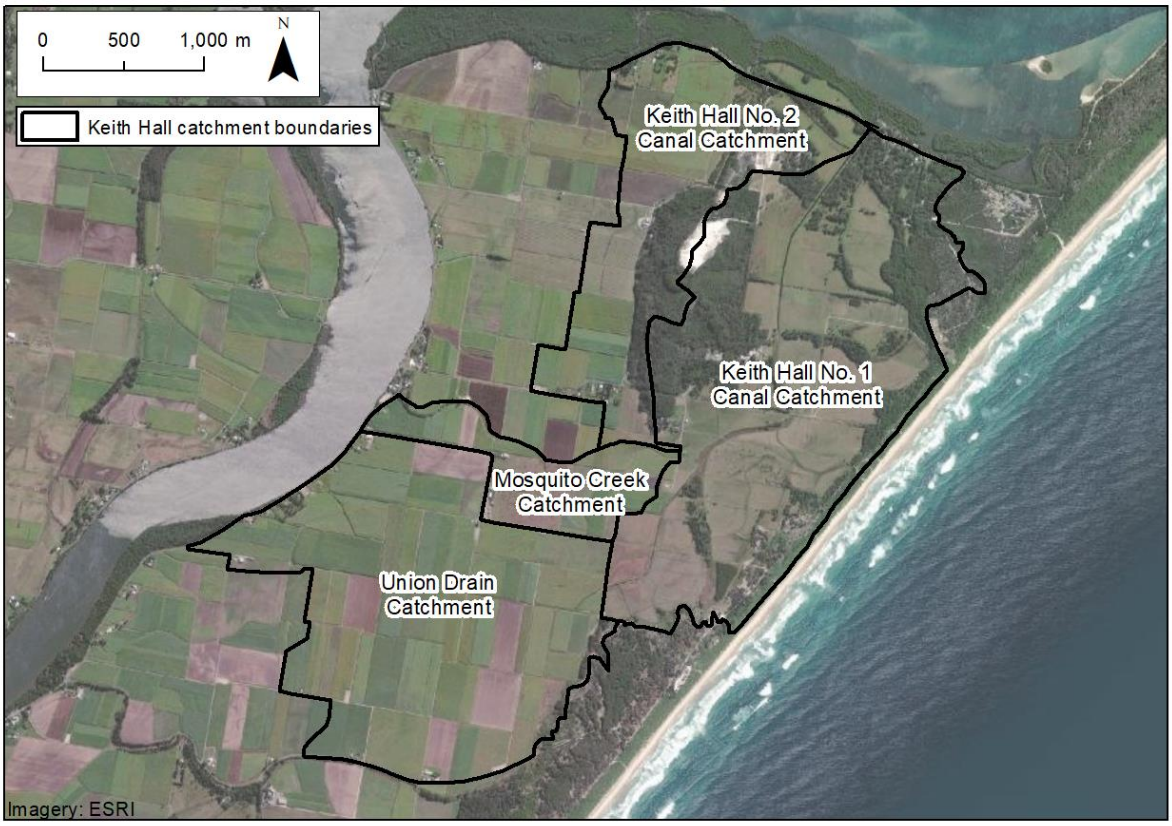


Figure B.3: Delineation of four smaller catchment areas for the Keith Hall drainage network

Table B.1: AWBM model parameters used for rainfall runoff routing

Model parameter	Value	Source
A1	0.134	Boughton and Chiew (2003)
A2	0.433	Boughton and Chiew (2003)
A3	0.433	Boughton and Chiew (2003)
RC	4.2	Boughton and Chiew (2003)
BFI	0.25	Boughton and Chiew (2003)
K_{base}	0.99	Boughton and Chiew (2003)
Ave	150	Boughton and Chiew (2007)
C1	11.25	Boughton and Chiew (2003)
C2	114.3	Boughton and Chiew (2003)
C3	228.6	Boughton and Chiew (2003)
K_{surf}	0.35	Boughton and Chiew (2007)

Observations from water level loggers indicated that flow behaviour across the floodplain occurred on a sub-daily time scale. The AWBM however was designed to run on a daily timestep which would not provide sufficient temporal accuracy for calculating runoff. Furthermore, while rainfall data was provided on a half-hourly timestep, evaporation data was only provided on a daily timestep.

To provide sufficient temporal accuracy, the AWBM was run on a half hourly timestep. To provide evaporation data for each AWBM timestep, evaporation data was averaged across the entire period for each day. While this meant that evaporation would technically be introduced in timesteps that occur during night, the overall error from this was considered to be within the error margins for the calculations.

Assessment of the runoff calculated from the AWBM run on a half-hourly timestep indicated that there were small but negligible changes in the total runoff volume for the study site as compared to the daily model. Running the model on a half-hourly timestep resulted in a responsive routing of water from rainfall to runoff with the peaks of runoff events occurring in intense and short durations which did not match with water level observations. To overcome this a 12-hour moving average was applied to the runoff series.

A comparison of daily, half-hourly and half-hourly with a 12-hour moving average as calculated by the AWBM is shown in Figure B.4. This shows how the different manipulations on the timeseries has affected the overall runoff. The total volume of runoff calculated using each method was within 5-10% of each other.

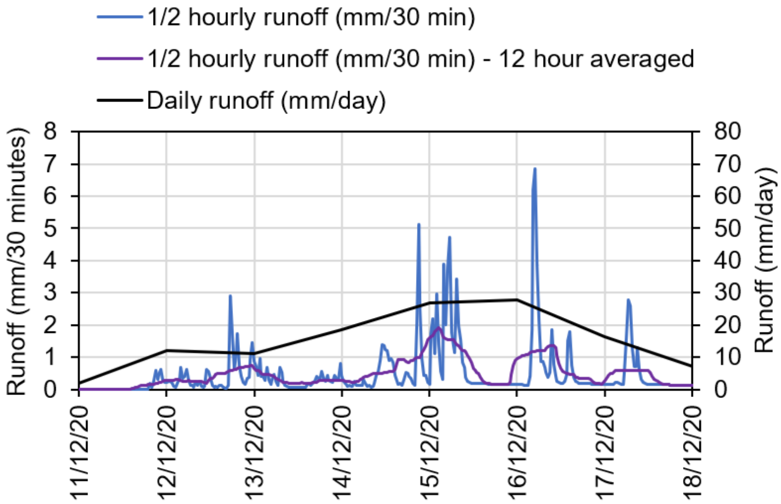


Figure B.4: Comparison of alternate methods for calculating runoff using the AWBM

B2.3 Floodplain storage

Water level data observations indicated that during rainfall events water is able to inundate low-lying sections of floodplain. When this occurs water is held on the floodplain for a longer period which recharges the groundwater and slows the overall transport of water from the catchment to the estuary. To simulate this in the numerical model, a stage-volume relationship was created for the four smaller catchments (see Figure B.3) across the Keith Hall drainage network using LiDAR data (see Appendix A). For each of these catchments a side channel was then built within the model domain which contained the stage-storage relationship calculated. This meant when water levels in the drain reached levels that the floodplain would begin to inundate, that the volume of water on the floodplain would be correctly simulated within the model. These side channels were given a Manning's n of 0.10 to simulate the gradual drainage of the floodplain when it is inundated.

B3 Model verification

Following development of the numerical model, simulations were completed to verify that the numerical model realistically simulated the Keith Hall floodplain. To complete this verification, model results were compared to water level measurements collected across the floodplain.

During the verification process a number of modifications were made to the model to improve the correlation between measured and modelled results. Changes that were implemented included:

- Adjustment of Manning's n roughness coefficient throughout the model domain
- Creation of a weir on Keith Hall No. 2 Canal to simulate raised water levels
- Inclusion of additional groundwater inflows

Field observations of the drainage network allowed for channel roughness (represented in the model as Manning's n) to be adjusted. Across the model domain a global value for Manning's n of 0.04 was adopted with the exceptions outlined in Table B.2. The dense vegetation observed on Mosquito Creek (Manning's n of 0.10) is shown compared to the relatively efficient channel of Keith Hall No. 1 Canal (Manning's n of 0.10) in Figure B.5.

Table B.2: Manning's n coefficient values selected across the model domain

Drain	Location	Manning's n	Description
Mosquito Creek	Immediately upstream of the floodgates	0.07	Mangrove roots
Mosquito Creek	Approximately 1.5 km upstream of the floodgates	0.10	Dense overgrown vegetation
Union Drain	Upstream of Keith Hall No. 1 Drain	0.10	Dense overgrown vegetation
Union Drain	Immediately upstream of the floodgates	0.07	Grass and vegetation growing
Keith Hall No. 1 Canal	For 1 km downstream of Keith Hall Lane	0.07	Grass and vegetation growing
The Escape	Entire length	0.07	Grass and vegetation growing

Figure B.5: Dense vegetation in the channel on Mosquito Creek represented by a Manning's n of 0.10 (A) and a clear channel on Keith Hall No. 1 Canal represented by a Manning's n of 0.04 (B)

During verification simulations it was observed that the water levels within Keith Hall No. 2 Canal were significantly lower than measured water levels. Since the cross-sections were collected in 2019 when there was a significant volume of water in the channel it is possible a blockage existed that was underwater or has been created since the survey. This requires further investigation. To represent this blockage a weir was inserted in the model approximately 400 m downstream of the location where water levels were monitored (see Figure A.12 in Appendix A). This effectively simulated the blockage in Keith Hall No. 2 Canal.

Since there were no flow measurements available for the Keith Hall drainage network there was no way of verifying the calculated catchment inflows. During simulations, assessment of modelled versus measured water levels found that there was some baseflow that was missing, particularly sourced from areas in the drainage network surrounding Keith Hall No. 1 Canal. To overcome this, a constant baseflow was added to the model as a distributed source for the major drainage channels. Introducing a groundwater inflow source like this improved the modelled water levels when compared to measured water levels.

Modelled water levels were compared to measured water levels at five locations throughout the model domain for wet and dry periods. Figure B.6 to Figure B.10 show the comparison of modelled versus measured water levels for the verified model. Note, there was no data available for the logger located at the confluence of Keith Hall No. 1 Canal and Keith Hall No. 2 Canal for the start of the wet event and within Keith Hall No. 2 Canal following the wet event. Data within Mosquito Creek was only available for a short period (three days) during which there was a good correlation between modelled and measured data (water levels during dry periods were measured and modelled to be approximately 0.3 m AHD).

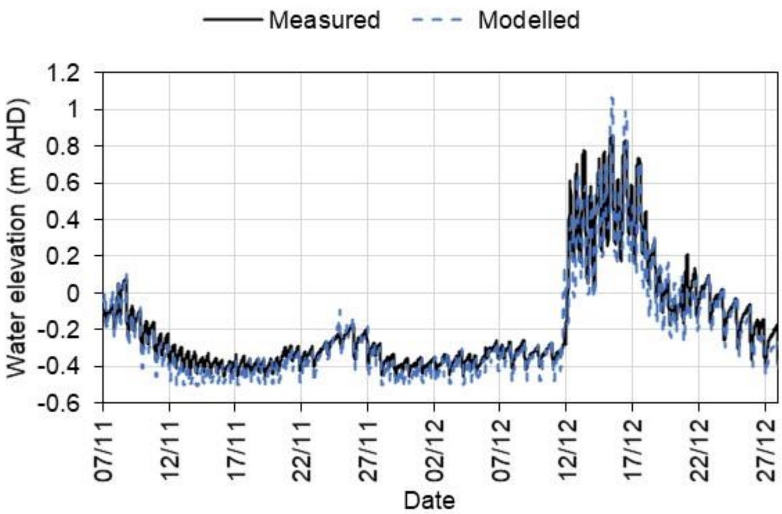


Figure B.6: Model verification results for Union Drain (location ID: 7)

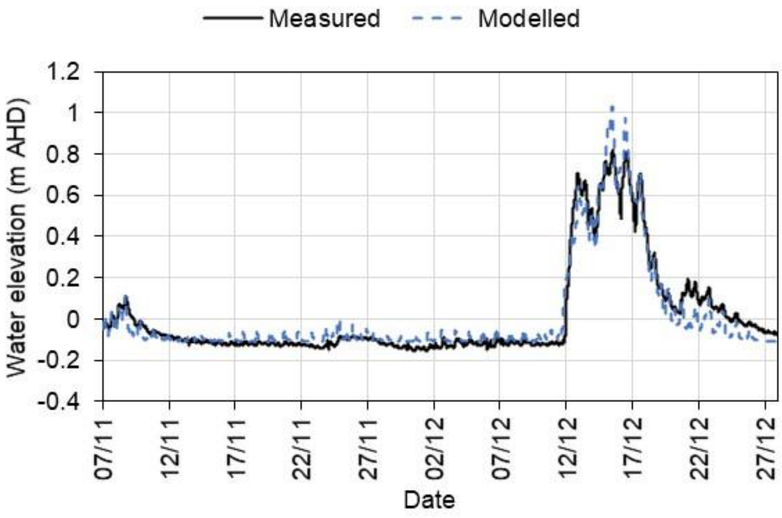


Figure B.7: Model verification results for Keith Hall No. 1 Canal near Union Drain (location ID: 5)

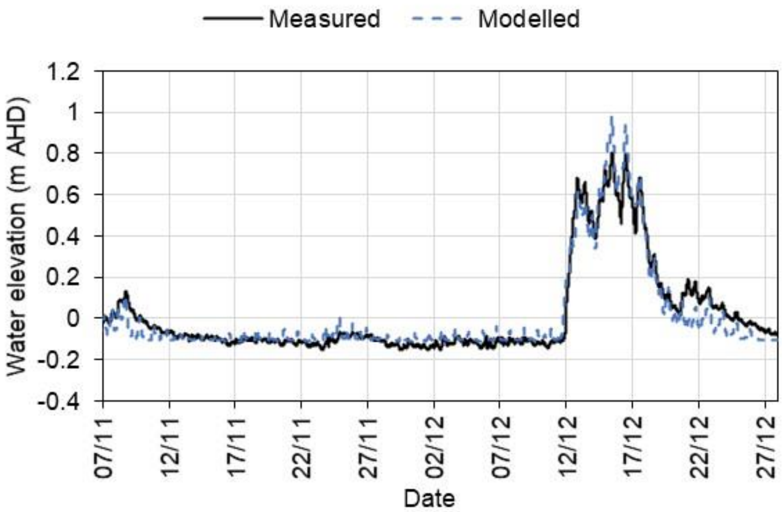


Figure B.8: Model verification results for Keith Hall No. 1 Canal at Keith Hall Lane (location ID: 4)

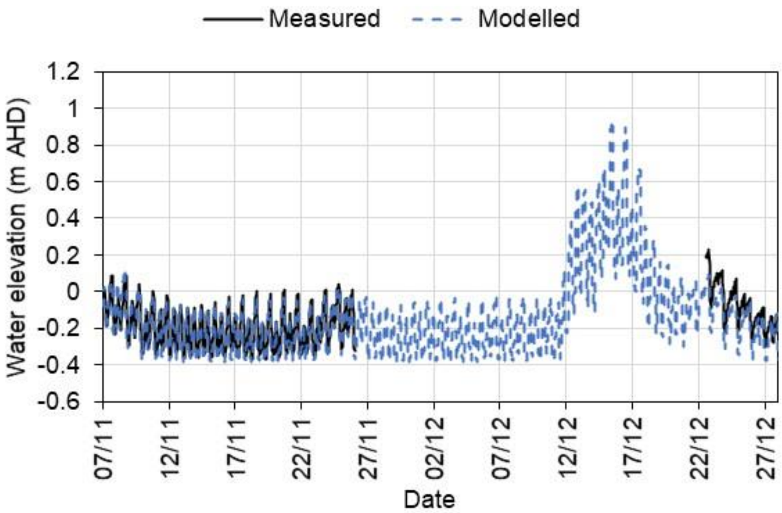


Figure B.9: Model verification results for Keith Hall No. 1 Canal at its confluence with Keith Hall No. 2 Canal (location ID: 2)

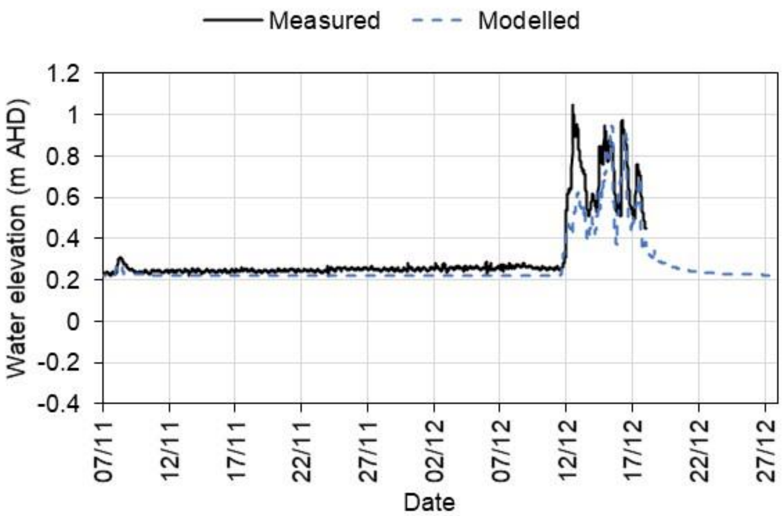


Figure B.10: Model verification results for Keith Hall No. 2 Canal (location ID: 3)

B4 Model scenario development

Numerical models allow for the simulation of changes to the drainage network to be assessed without any physical on-ground works needing to be constructed. The verified numerical model of the Keith Hall drainage network was used to assess six options for modifying the drainage network to achieve the project aims. The following section describes how drainage options were implemented in the numerical model to assess their effectiveness.

B4.1 Base case

A base case model simulation was run to provide a baseline to which different drainage option scenarios could be compared. The base case was run using the validated numerical model for the period from 7 November 2020 to 7 January 2021. This period included a dry period (November) and a wet period (December). So that there were no errors with the simulation period associated with instabilities during the start-up process of the model simulation, the simulation period was extended to begin on 1 November 2020 (i.e., for a 7 day 'warm up').

This simulation included the operational rules described by RCC (2020) for the management of the sluice gate on the Keith Hall culverts. The sluice gate was opened during the dry period and closed during the wet period from 11 December 2020.

B4.2 Option 1: Cyclic flow (existing infrastructure)

Five configurations were tested for this scenario. Each configuration involved small scale modifications of the floodgate structures located on Keith Hall No. 1 Canal, The Escape and Union Drain. Table B.3 summarises the five configurations.

Table B.3: Option 1 Cyclic flow (existing infrastructure) floodgate configurations

Option	Keith Hall floodgates	Union Drain floodgates	The Escape floodgates
1A	All floodgates shut; Sluice gate fully open; Buoyancy gate removed (with hole allowing flow in).	All floodgates shut; Buoyancy gate permanently shut.	All floodgates shut; Buoyancy gate permanently shut.
1B	One floodgate completely open; All remaining floodgates shut.	All floodgates shut; Buoyancy gate permanently shut.	All floodgates shut; Buoyancy gate permanently shut.
1C	All floodgates shut; Buoyancy gate permanently shut; Sluice gate shut.	Buoyancy gate removed (with hole allowing flow in).	Buoyancy gate removed (with hole allowing flow in).
1D	All floodgates shut; Buoyancy gate permanently shut; Sluice gate shut.	Buoyancy gate removed (with hole allowing flow in).	No change.
1E	All floodgates shut; Buoyancy gate permanently shut; Sluice gate shut.	One gate completely open All remaining gates shut.	No change.

Option 1 was run for the dry period from 7 November 2020 to 7 December 2020 with a 7-day model warmup period starting on 1 November 2020. Catchment inflows for each model run were the same as per the base case. This simulation period shows the maximum extent and volume of tidal water that will enter into the drainage network. During wet periods characterised by an increased groundwater table, but not necessarily flooding, fresh catchment flows exiting the system will limit the extent to which saline tidal water can enter the drainage network. Note, wetter periods like this were not considered for this scenario as its purpose was to understand the extent of tidal flushing possible.

B4.3 Option 2: Cyclic flow (automatic floodgates)

Automated floodgates have been simulated on the Keith Hall drainage network using the MIKE HYDRO River Control Module. A total of nine simulations were completed to determine how the installation of automatic floodgates would affect the drainage network (Table B.4). Each configuration involved the modification of the Keith Hall floodgates (on Keith Hall No. 1 Canal) or the Union Drain floodgates. Modification involved replacing the existing floodgate flaps with automatically controlled sluice gates. These gates were then triggered to close based upon the downstream water level elevation (i.e., when the downstream water level reached the trigger level the sluice gate would shut until the water fell below that level again). The sluice gates moved at a rate of 0.05 m/s when closing. During simulations none of the existing buoyancy or sluice gates were included unless specified. Since only rectangular culverts can be simulated, the Union Drain culverts were simulated as the biggest rectangular opening that would fit on the existing circular culvert.

Table B.4: Summary of configurations for drainage Option 2 (automatic floodgates)

Configuration	Floodgate closure trigger downstream water level (m AHD)	Description
2A – Keith Hall inflow	0.00	Same culverts as existing Keith Hall floodgates (6 culverts 1.23 m wide by 1.22 m high)
2B – Keith Hall inflow	0.10	Same culverts as existing Keith Hall floodgates (6 culverts 1.23 m wide by 1.22 m high)
2C – Keith Hall inflow	0.20	Same culverts as existing Keith Hall floodgates (6 culverts 1.23 m wide by 1.22 m high)
2D – Keith Hall inflow	0.30	Same culverts as existing Keith Hall floodgates (6 culverts 1.23 m wide by 1.22 m high)
2E – Union Drain inflow	0.0	3 culverts 0.85 m wide by 0.85 m high with an invert of -0.535 m AHD
2F – Union Drain inflow	0.15	3 culverts 0.85 m wide by 0.85 m high with an invert of -0.535 m AHD

Configuration	Floodgate closure trigger downstream water level (m AHD)	Description
2G – Union Drain inflow	0.30	3 culverts 0.85 m wide by 0.85 m high with an invert of -0.535 m AHD
2H– Union Drain inflow	0.45	3 culverts 0.85 m wide by 0.85 m high with an invert of -0.535 m AHD
2I – Union Drain inflow and The Escape buoyancy gate	0.45	3 culverts 0.85 m wide by 0.85 m high with an invert of -0.535 m AHD. The Escape buoyancy gate was modelled as per the base case.

Option 2 was run for the dry period from 7 November 2020 to 7 December 2020 with a 7-day model warmup period starting on 1 November 2020. Catchment inflows for each model run were the same as per the base case. This simulation period shows the maximum extent and volume of tidal water that will enter into the drainage network. During wet periods characterised by an increased groundwater table, but not necessarily flooding, fresh catchment flows exiting the system will limit the extent to which saline tidal water can enter the drainage network. Note, wetter periods like this were not considered for this scenario as its purpose was to understand the extent of tidal flushing possible.

B4.4 Option 3: Increased tidal connectivity

Six configurations were modelled for drainage Option 3. Generally, these model scenarios involved removing the existing buoyancy driven tidal gates on floodgates and allowing uncontrolled flow through the window in the floodgate flap during higher tides. Specifications for each configuration are shown in Table B.5. Note, the size of the window on Mosquito Creek was not measured and would need to be verified to ensure it matches with the modelled dimensions.

In addition to testing if the sluice gates could be completely opened, an optimisation test was completed to determine how far open the sluice windows should be allowed to ensure that the median water level (used as an indicator for the groundwater level) would remain 0.5 m below the floodplain. Multiple simulations were completed until the results showed that the water table was sufficiently low in the drainage network. Results presented in Table B.5 are for the last run of this optimisation, that is, the case where the median water level was always 0.5 m below the floodplain elevation. Floodplain elevations are as per Section B5.

Table B.5: Description of drainage Option 3 configurations (increased tidal connectivity)

Configuration	Description*
3A – Keith Hall sluice gates only	Two windows with an invert of -0.28 m AHD. One 0.35 m wide and 0.5 m high. One 0.33 m wide and 0.5m high.
3B – Mosquito Creek sluice gate only	One window with an invert of -0.34 m AHD, 0.35 m wide and 0.35 m high.
3C – Union Drain sluice gate only	One window with an invert of -0.36 m AHD, 0.3 m wide and 0.35 m high.
3D – The Escape sluice gate only	One window with an invert of -0.51 m AHD, 0.35 m wide and 0.50 m high.
3E – All sluice gates fully open	Same as configurations 3A, 3B, 3C and 3D combined.
3F – Optimise sluice gates so water level is always 0.5 m below the floodplain	Same as configurations 3A, 3B, 3C and 3D combined except with vertical sluice openings set to: Keith Hall floodgates: Two sluice gates opened 0.20 m The Escape floodgates: One sluice gate opened 0.05 m Union Drain floodgates: One sluice gate 0.20 m wide opened 0.05 m Mosquito Creek: One sluice gate fully opened

*If not otherwise specified, conditions were as per the base case.

Option 3 was run for the dry period from 7 November 2020 to 7 December 2020 with a 7-day model warmup period starting on 1 November 2020. Catchment inflows for each model run were the same as per the base case. This simulation period shows the maximum extent and volume of tidal water that will enter into the drainage network. During wet periods characterised by an increased groundwater table, but not necessarily flooding, fresh catchment flows exiting the system will limit the extent to which saline tidal water can enter the drainage network. Note, wetter periods like this were not considered for this scenario as its purpose was to understand the extent of tidal flushing possible.

B4.5 Option 4: Keith Hall floodgate weight

When the low tide elevation drops below the apron of the Keith Hall floodgates, flow through the culverts is controlled by the upstream water levels. When this is the case, flow through the culverts can be approximated using the broad crested weir equation (Equation 1) (Bos, 1976).

$$Q = C_D A_c \sqrt{2g(H - h_c)} \quad (1)$$

Where:

Q = Flow out of the structure (m^3/s)
C_D = Discharge coefficient
A_c = Area at the point of critical flow depth (m^2)
g = Acceleration due to gravity (m/s^2)
H = Total upstream head (m)
h_c = Critical flow depth (m)

The discharge coefficient (C_D) takes into consideration the complex nature of flows including factors such as viscosity, turbulence and velocity distribution which are not accurately represented in the theoretical derivation of flow (Bos, 1976). Due to its complexity, the discharge coefficient (C_D) is usually determined experimentally for different structures (Felder and Chanson, 2012). The MIKE 1D numerical model accounts for the discharge coefficient (C_D) through a number of loss coefficients (DHI, 2019).

When a hinged floodgate is added to a culvert the calculation of flow is further complicated as new losses are introduced. Observational evidence suggests that the weight of floodgate flaps generally only impacts drainage on small systems and that there are minimal impacts on drains with large floodgate infrastructure, such as at Keith Hall (Rampano, 2009). A number of researchers have looked at determining the head loss related to a hinged floodgate. SCS (1971) provided a loss coefficient for circular floodgates based on a number of laboratory tests. They found that for a light floodgate with a diameter ranging from 0.2 m to 1.2 m that head losses could be up to 30 mm depending upon the flow rate. SCS (1971) did not however specify what the specifications of a 'light' floodgate were and other literature quoting the same laboratory tests has identified that heavy floodgates may result in higher losses (Mueller, 2019).

Laboratory tests have also been completed by Burrows and Emmonds (1988), Burrows et al. (1997) and Replogle and Wahlin (2003) for circular floodgates. Burrows and Emmonds (1988) completed their experiments with a partially submerged floodgate (i.e., the tailwater level was above the floodgate invert). They concluded that a heavy floodgate could result in twice as much head loss through a culvert than if there was no floodgate. Burrows et al. (1997) completed similar experiments but also tested a range of outflow conditions from free overflow to partially submerged. They also found that an increased floodgate weight resulted in additional losses. From their model results, Burrows et al. (1997) also developed an empirical formulation relating discharge to the weight and angle of a floodgate flap. Replogle and Wahlin (2003) completed additional experiments that assessed how the weight of floodgate flaps impacted losses focussing on the initial angle of the floodgate. Their study concluded that there were two separate forces working to open a floodgate, namely the hydrostatic and hydrodynamic forces. Initial opening of the floodgate was found to be governed by the hydrostatic pressure required to move a floodgate. Once the gate was opened and water began to flow, the hydrodynamic pressure increased and was able to effectively keep a floodgate open despite the weight of a floodgate.

Upon review of laboratory research, Pennington (2010) concluded that the best method for accounting for losses associated with floodgate structures in numerical models is to use manufacturer specifications for loss. They noted that while often this loss is only associated with free outflow conditions, it will generally improve model calculations. While this is useful for new design situations where manufacturer specifications may be available, modelling existing floodgate systems where there are floodgates without manufacturer specifications still presents a challenge.

Raemy and Hagar (1998) (see also Hagar, 2010) investigated the use of a floodgate structure in a rectangular channel to ensure a constant upstream water level. They noted that when flow through a floodgate structure could be represented as an orifice flow and subsequently calculated using Equation 2 as per Bos (1976).

$$\boldsymbol{Q = C_D b a\sqrt{2gh}} \qquad 2$$

Where:

- Q = Flow out of the structure (m^3/s)
- C_D = Discharge coefficient
- b = Channel width (m)
- a = Depth at the gate (m)
- g = Acceleration due to gravity (m/s^2)
- h = Approach inflow depth (m)

They determined that the discharge coefficient (C_D) was a function of the floodgate opening angle (δ) as shown in Equation 3.

$$\boldsymbol{C_D = 0.60(1 + 0.23\theta - 0.16\theta^2)} \qquad 3$$

Where:

- C_D = Discharge coefficient
- θ = floodgate opening angle (radians)

Complexity in determining the discharge arises as the floodgate opening angle (θ) is dependent upon the hydrodynamic pressure on the floodgate which varies as the floodgate opens. To overcome this, Raemy and Hagar (1998) completed experiments to determine the relationship between the hydrostatic and hydrodynamic pressure exerted on the floodgate from the upstream water. This relationship is shown in Equation 4.

$$\mu = \frac{M_d}{M_s} = 1 - \sqrt{\frac{L}{h}} tan\theta \qquad 4$$

Where:

- μ = Moment ratio of the hydrostatic and hydrodynamic moments
- M_d = Hydrodynamic moment (Nm)
- M_S = Hydrostatic moment (Nm)

L = Floodgate length (m)
h = Approach inflow depth (m)
θ = Floodgate opening angle (degrees)

The hydrostatic moment is easily calculated as per Equation 5. When the floodgate is open, for any given upstream water level Raemy and Hagar (1998) determined that the floodgate must reach an equilibrium whereby the hydrodynamic moment equals the restoring moment of the floodgate weight, assuming at this time the hydrostatic pressure becomes negligible. This can be calculated as per Equation 6.

$$M_S = 0.5\rho g b h^2 \left(L - \frac{1}{3}h\right) cos\theta \qquad 5$$

$$M_d = 0.5gGLsin\theta \qquad \mathbf{6}$$

Where:

M_d = Hydrodynamic moment (Nm)
M_S = Hydrostatic moment (Nm)
ρ = Density of water (kg/m^3)
g = Acceleration due to gravity (m/s^2)
b = Channel width (m)
h = Approach flow depth (m)
L = Floodgate length (m)
θ = Floodgate opening angle (degrees)
G = Floodgate weight (kg)

By combining Equations 4, 5 and 6, the floodgate opening angle (θ) can be determined as per equation 7.

$$\theta = tan^{-1}\left(\left(\frac{gGL}{\rho g b h^2\left(L - \frac{1}{3}h\right)} + \sqrt{\frac{L}{h}}\right)^{-1}\right) \qquad 7$$

Where:

θ = Floodgate opening angle (degrees)
G = Floodgate weight (kg)
L = Floodgate length (m)
ρ = Density of water (kg/m^3)
g = Acceleration due to gravity (m/s^2)
b = Channel width (m)
h = Approach flow depth (m)

Utilising equations 2, 3 and 7 a stage discharge relationship can be created for floodgates with different floodgate weights. Subsequently, numerical modelling has been completed using this stage discharge relationship within the MIKE 1D modelling software to assess the impacts of different floodgate weights.

Note, while a theoretical calculation of floodgate losses is presented here, there are a number of errors introduced due to the complexity of the actual flow conditions and assumptions required to numerically model them. Results presented here are indicative of what may occur if the floodgates at Keith Hall are modified. For increased accuracy it is recommended that either physical modelling or field tests be completed.

Numerical modelling of floodgates has been completed for four alternate floodgate materials. A number of assumptions have been made based on material density and off-the-shelf products available. Floodgate weight specifications are outlined in Table B.6. Note, while some materials such as fibreglass and high density polyethylene (HDPE) have a lower density, existing designs for floodgates with such materials indicate a larger volume is required to ensure floodgate strength. While a floodgate may be strong enough to withstand forces associated with hydrostatic pressure, other considerations may be needed for the construction of floodgates including wave loads and ability to withstand impacts from debris (particularly during floods). Furthermore, additional material associated with mounting floodgates or the installation of modifications to the floodgates may need to be considered. Incorporating these considerations into the design weight of a floodgate would change the outcomes of modelling.

Table B.6: Floodgate material specifications and dimensions (per floodgate flap)

Material	Floodgate dimension (m)			Density (kg/m^3)	Weight (Kg)	Assumptions
	Height	Width	Thickness			
Aluminium	1.22	1.23	0.010	2,650	40	Marine plate 5083 as per Ullrich (2020)
Stainless steel	1.22	1.23	0.008	8,000	96	316L grade steel as per Aalco (2020)
Fibreglass	1.22	1.23	0.100	1,050	158	Based on density for fibreglass floodgate products manufactured by Humes (2020)
High density polyethylene (HDPE)	1.22	1.23	0.040	950	57	Based on density for HDPE floodgate products manufactured by Spirolite (2020)

Modelling of floodgate weight assumes that flow through the culvert is not impacted by downstream water levels. This assumption only holds when the downstream water level reduces to below the invert level of the floodgate. When downstream water levels are above the invert of the floodgate, raised water levels and buoyancy of the floodgate flap will influence discharge volumes.

Option 4 was run for the dry period from 7 November 2020 to 7 January 2021 with a 7-day model warmup period starting on 1 November 2020. Catchment inflows for each model run were the same as per the base case.

B4.6 Option 5: Keith Hall No. 1 Canal swale

Drainage Option 5 involves reshaping the upstream section of Keith Hall No. 1 Canal from Keith Hall Lane to Union Drain to be a shallow and wide (swale) drain. Design of the swale drain for this section of the floodplain was completed as per Stone et al. (1998) to ensure there would be sufficient floodplain drainage. Cross sections for the upstream (at Union Drain), middle (at Mosquito Creek) and downstream sections of the new drain are shown in Figure B.11 to Figure B.13 The drain was approximately 20 m wide, 0.5 m deep and had a flat slope of 0.2 m over the 2 km length. This was to minimise its interaction with acid sulfate soils (Figure B.14). Batter slopes were at an angle of no more than 1 vertical to 5 horizontal.

Culverts throughout the section of drain that would be reshaped remained as is. In the model a wider and deeper cross-section was inserted upstream and downstream of culverts to ensure numerical stability in the calculations.

Option 5 was run for the dry period from 7 November 2020 to 7 January 2021 with a 7-day model warmup period starting on 1 November 2020. Catchment inflows for each model run were the same as per the base case as were all floodgate operational rules. An additional drainage test was also completed to assess how quickly the floodplain would drain if water started at an initial elevation of 1 m AHD.

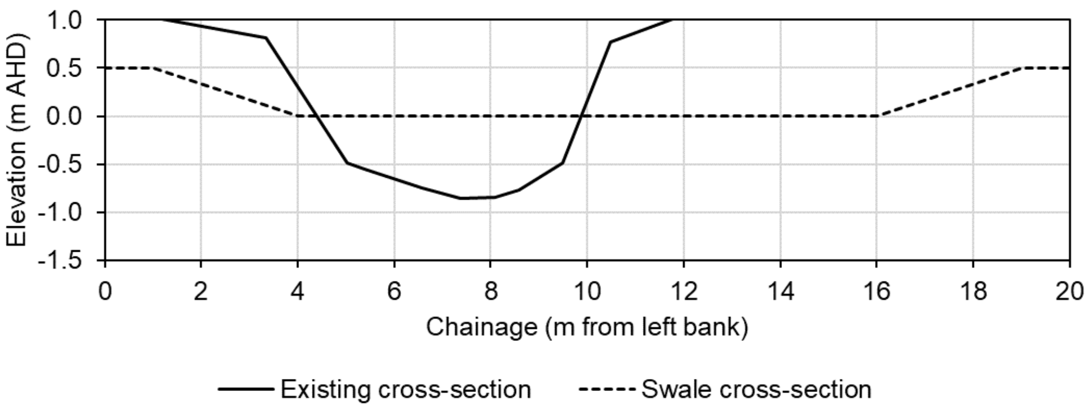


Figure B.11: Swale drain cross-section at Union Drain

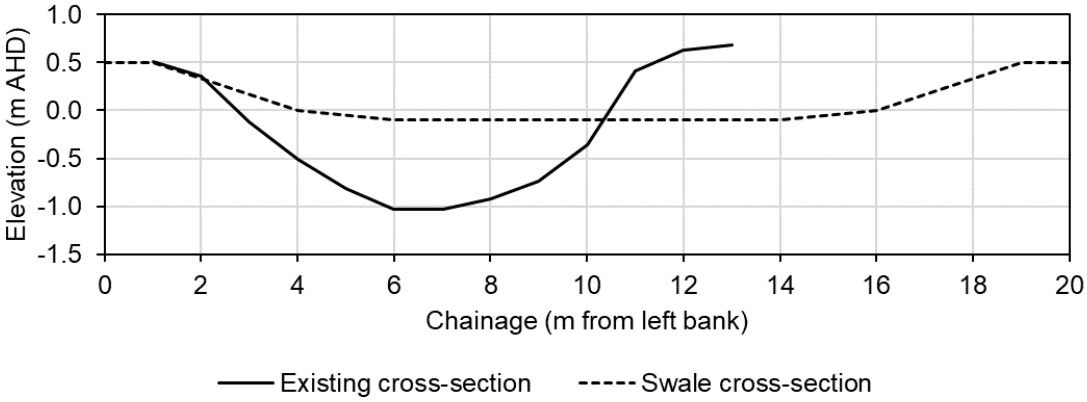


Figure B.12: Swale drain cross-section at Mosquito Creek

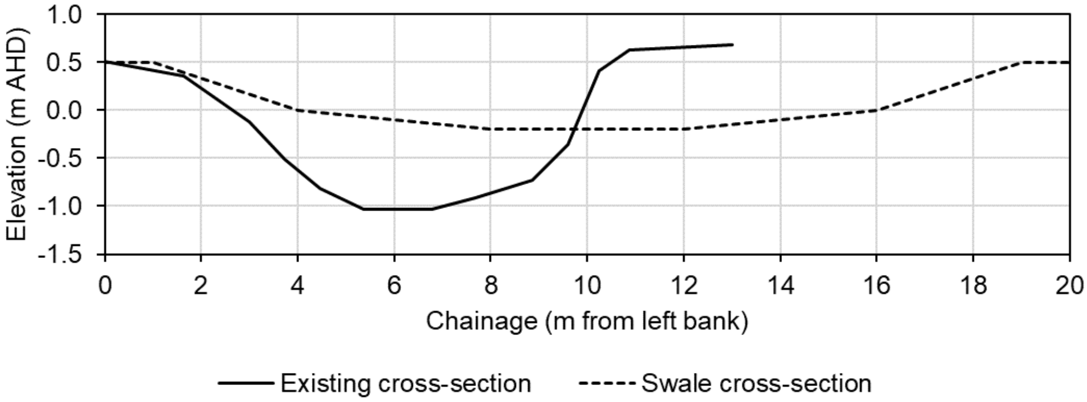


Figure B.13: Swale drain cross-section at Keith Hall Lane

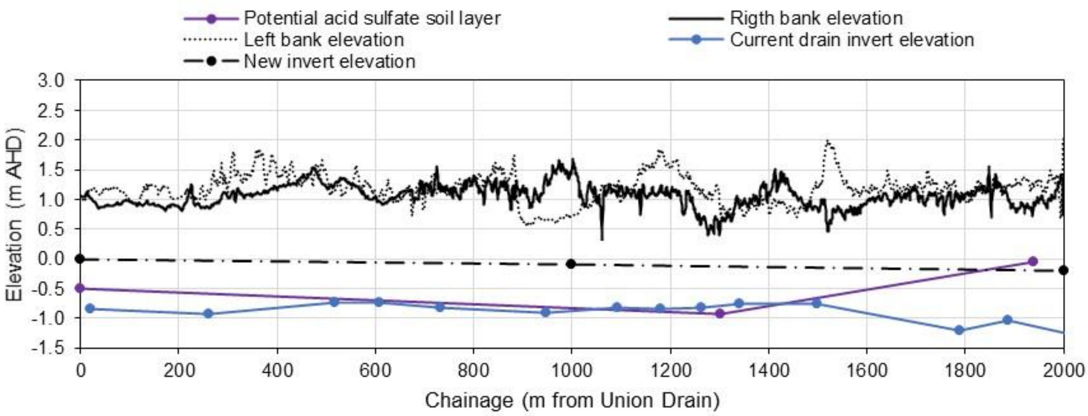


Figure B.14: Swale drain invert with respect to drain features

B4.7 Option 6: Keith Hall No. 2 Canal new drain

Drainage Option 6 involved the most significant changes to the floodplain drainage network. This included:

- Increasing the flow capacity of culverts under South Ballina Beach Road
- Disconnecting Keith Hall No. 2 and No. 1 Canals by infilling the east-west section of drain and creating a shallower drain that only allows flow during flood events.
- Ensuring that former drain channels between Keith Hall No. 2 and Mobbs Bay are sufficiently sized to allow floodplain drainage

Design of the culverts underneath South Ballina Beach Road and the downstream channel were completed as per Stone et al. (1998) to ensure that they would supply adequate discharge capacity for floodplain runoff. Subsequently, utilising the east-west section of Keith Hall No. 2 Canal is not required. Despite this, the east-west section of Keith Hall No. 2 Canal has only been partially infilled to ensure there is redundancy to the new outlet design under South Ballina Beach Road.

Infilling of the east-west section of Keith Hall No. 2 Canal was completed in the numerical model simply by editing cross-sections so that their invert was at 0.20 m AHD. No widening of this drain was completed and the existing banks of Keith Hall No. 2 Canal remained as is.

The new channel that connects Keith Hall No. 2 Canal to Mobbs Bay was designed to have an invert of +0.1 m AHD. The side slopes of the channel were designed to be no greater than 1 vertical in 5 horizontal. A representative cross-section is shown in Figure B.15.

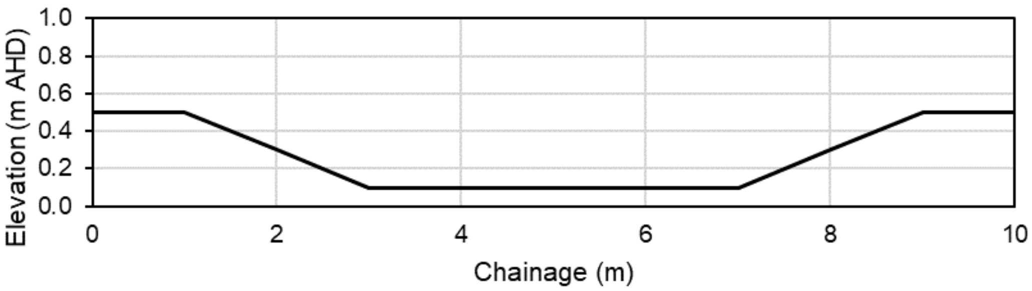


Figure B.15: Representative cross-section connecting Keith Hall No. 2 Canal to Mobbs Bay

The floodgate underneath South Ballina Beach Road was designed using the Mike 1D software to ensure sufficient flow would pass through to facilitate floodplain runoff. The final design was for four rectangular culverts 1.3 m wide, 0.5 m high and with an invert of +0.1 m AHD.

Option 6 was run for the dry period from 7 November 2020 to 7 January 2021 with a 7-day model warmup period starting on 1 November 2020. Catchment inflows for each model run were the same as per the base case as were all floodgate operational rules. An additional drainage test was also completed to assess how quickly the floodplain would drain if water started at an initial elevation of 1 m AHD.

B5 Scenario assessment

To determine if each of the drainage options achieves the project aims a number of techniques have been used. The following section provides additional details regarding some of these techniques, including:

- Identification of whether water levels would inundate the floodplain
- Comparison of water levels to a base case (i.e., the current drainage network without modifications)
- Comparison of water level statistics (e.g., 95th percentile, median, 5th percentile)
- Review of model output files

The elevation at which the Keith Hall floodplain first becomes inundated has been analysed using LiDAR data provided by the NSW Department of Finance, Services and Innovation (see Appendix A). Secondary drains that are adjacent to the main trunk drainage system were not considered during the analysis, however, a map of 53 potential locations where these drains connect to the main trunk drainage system is provided in Figure B.16. These locations should be assessed during detailed designs of any drainage options and may require small floodgates to prevent inundation. Only points where water might flow over a drains levee bank onto the floodplain were identified as inundation points. The lowest points, or locations where inundation would first occur for each drain in the Keith Hall drainage network have been summarised in Table B.7 and Figure B.17. For levees surrounding The Escape it was observed during fieldwork that LiDAR observations were incorrect in some areas and adjustments have been made as required. Otherwise, it has been assumed that the LiDAR data for levees is correct and no adjustments have been made to the LiDAR data.

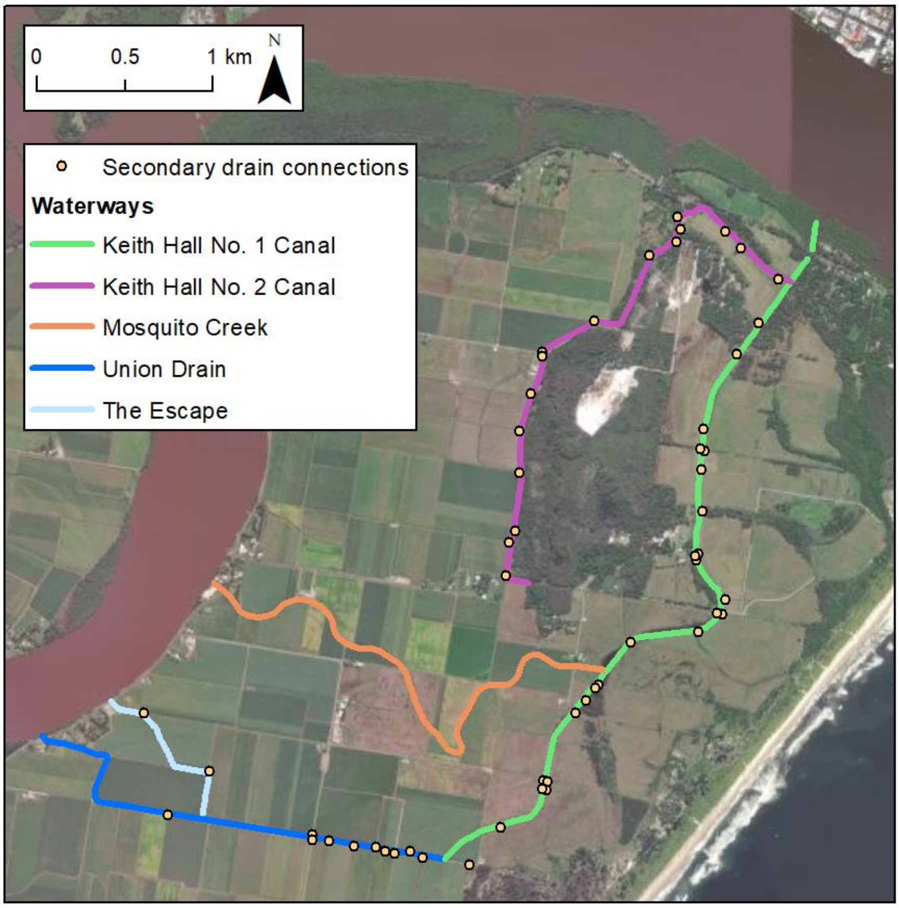


Figure B.16: Locations identified where secondary drains connect to the Keith Hall Drainage Network

Table B.7: Lowest elevation at which floodplain inundation occurs for the Keith Hall drainage network (see Figure B.17)

Drain	Bank*	Figure B.17 location ID	First inundation (m AHD)	Location
Keith Hall No. 1 Canal	Left	1	0.30	Floodplain downstream of Keith Hall Lane
Keith Hall No. 1 Canal	Right	2	0.40	Floodplain upstream of Keith Hall Lane
Keith Hall No. 2 Canal	Left	3	0.35	Floodplain just upstream of Keith Hall No. 1 Canal
Keith Hall No. 2 Canal	Right	4	0.50	Floodplain just upstream of Keith Hall No. 1 Canal
Union Drain	Left	5	0.45	Floodplain near Keith Hall No.1 Canal

Drain	Bank*	Figure B.17 location ID	First inundation (m AHD)	Location
Union Drain	Right	6	0.55	Floodplain near Keith Hall No.1 Canal
The Escape	Left	7	0.75	Floodplain near the middle of The Escape
The Escape	Right	8	0.65	Floodplain near Union Drain
Mosquito Creek	Left	9	0.75	Floodplain near Keith Hall No. 1 Canal
Mosquito Creek	Right	10	0.65	Floodplain near Keith Hall No. 1 Canal

*Left bank and right bank refer to the side of the water way when looking downstream towards the floodgate.

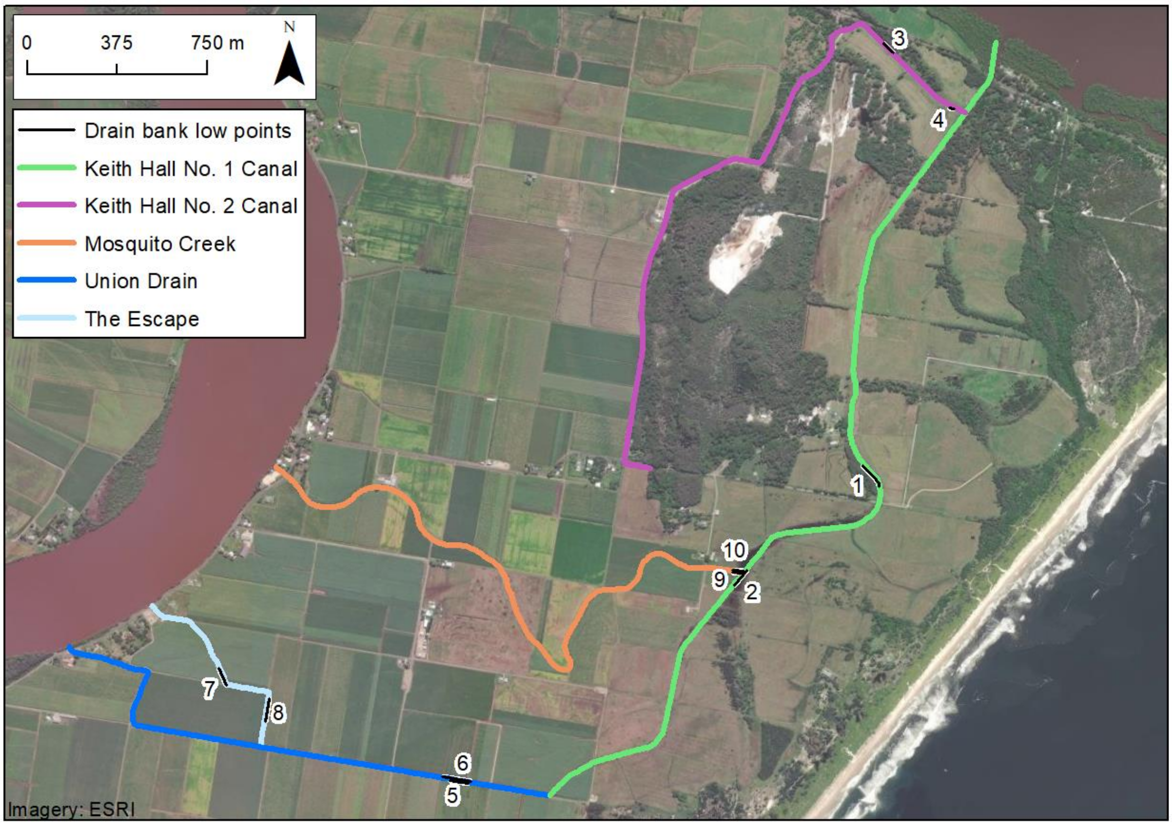


Figure B.17: Location where inundation first occurs for each of the drains in the Keith Hall drainage network (see Table B.7)

While Table B.7 notes the level of first inundation, often at these elevations inundation of the floodplain is only localised. LiDAR data indicates that significant inundation of the floodplain is unlikely to occur until water levels reach 0.6 m AHD. When water levels reach this height multiple locations across the floodplain are likely to become inundated including a significant proportion of the low-lying floodplain adjacent to the upstream section of Union Drain. Note, land surrounding Mosquito Creek has a slightly higher elevation compared to the rest of the floodplain and LiDAR data indicated it is only likely to experience significant inundation when water levels reach 1.2 m AHD.

For assessing the impact of floodplain inundation, a classification scheme has been developed with the impact of floodplain inundation rating as either minimal, moderate or major. Table B.8 summarises what these classifications mean for management across the floodplain.

Table B.8: Classification system for impact of floodplain inundation

Classification	Description
Minimal	Inundation of the floodplain occurs only rarely and the locations where inundation occurs are unlikely to have an impact on land use
Moderate	Where inundation of the floodplain occurs modifications such as the construction of floodgates, construction of levees or wet pasture management of the floodplain could be implemented to minimise risk to current land use
Major	Inundation across the floodplain is extensive and would impact existing land use

To assist in evaluating each drainage option, 14 locations were selected across the Keith Hall drainage network for a detailed assessment of water levels (Figure B.18). At each of these locations water levels were able to be compared between the base case and the potential drainage options for the simulation period. Additionally, at each of these locations statistics were also determined for water levels including the 95th percentile, 50th percentile (median), 5th percentile and mean water levels for the duration of the simulation period. These timeseries comparisons and statistics were used to determine the overall scale at which drainage options would impact the water table across the drainage network.

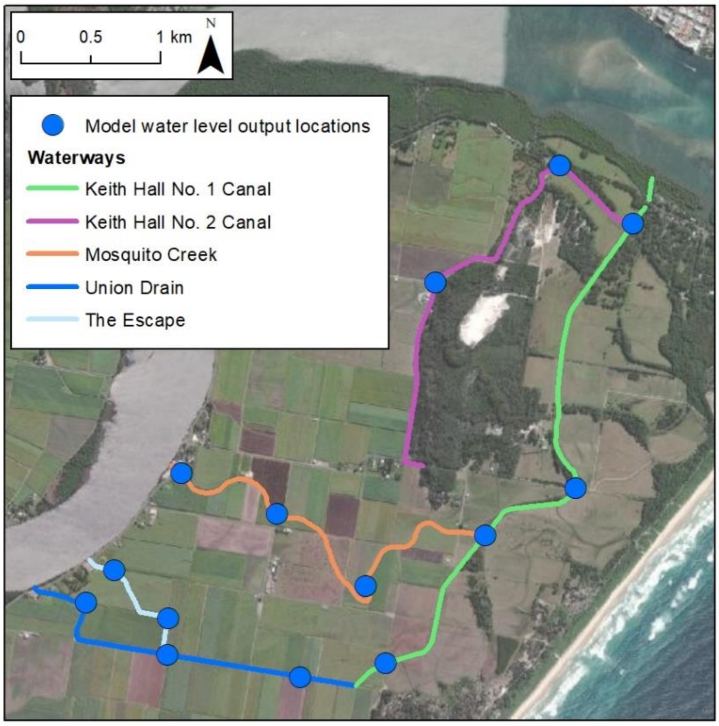


Figure B.18: Locations where base case water levels were to scenario water levels and where statistics for water levels were calculated

In addition to these techniques, drainage options were also assessed through the review of MIKE-1D model result files. Following each simulation, a number of detailed result files are created which specify water level, discharge, velocity and volume information for the entire drainage network over the simulation period. Where a detailed understanding of the hydrology is needed at a particular point in the drainage network, these model result files have been interrogated to assess the effectiveness of different drainage options.

B6 Relative cost assessment

Relative costs for on-ground implementation of drainage options have been based on the engineering costs identified by Rayner et al. (2021) (see Table B.9). Note, costs identified only consider the engineering costs for implementation and do not consider other costs such as those associated with loss of agricultural productivity. Furthermore, costs associated with additional studies that may be required to implement on-ground works such as an environmental impact statement (EIS), review of environmental factors (REF) or additional flood studies have not been accounted for.

Table B.9: Indicative costs for various drainage options as per Rayner et al. (2021)

Management Option	Design cost	Implementation	Maintenance (per annum)
Weir	$10,000 to $30,000	$10,000 to $200,000	$5,000 to $15,000
Floodgate modification	$5,000 to $25,000	$10,000 to $30,000 per gate	$1,000 to $15,000
Liming	$5,000 to $10,000	$30/m^3 acid soil per application (dependent on acid content)	Dependent on required repetition of liming
New/relocated culvert	$5,000 to $25,000	$70,000 to $120,000 per culvert	$1,000 to $10,000
Drain infilling	$10,000 to $20,000	Equipment establishment ($10,000) + unit rate ($14,000/500 m)	None
Drain reshaping	$10,000 to $20,000	Equipment establishment ($10,000) + unit rate ($25,000/500 m)	Ongoing drain maintenance
Permeable Reactive Barrier (PRB)	$20,000 to $80,000	$15,000 to $200,000/100 m	$25,000
Wet pasture	$10,000 to $20,000	Potential: Structure relocation + land acquisition + drain infilling	None
Land raising	Design and potential flood impact assessment.	Equipment establishment + fill + daily rate	None
Full remediation	$40,000 to $200,000	Land acquisition (per ha) + drain infilling + drain reshaping + infrastructure removal + infrastructure relocation	Land management (fire control, pests, fencing etc.)

Based on the costs for implementation of infrastructure detailed in Table B.9, each drainage option has been assigned the following relative costs:

- Low: Upfront capital cost of implementation of on-ground works was estimated to be less than $50,000

- Medium: Upfront capital cost of implementation of on-ground works was estimated to be less than $500,000 but greater than $50,000
- High: Upfront capital cost of implementation of on-ground works was estimated to be greater than $500,000

Appendix C Cross-section data

Cross-section data has been collected throughout the Keith Hall floodplain drainage network (109 in total) and at various locations throughout Mobbs Bay (17 in total) (Figure C.1). Table C.1 outlines the locations of each of the cross-sections surveyed during the field investigations. Figures showing the elevation measurements for each cross-section are then presented. For cross-sections measured within Mobbs Bay (with a cross-section ID prefix of “MB”), bathymetry measurements have been compared to historical survey data collected in 2005 (see Appendix A for further information).

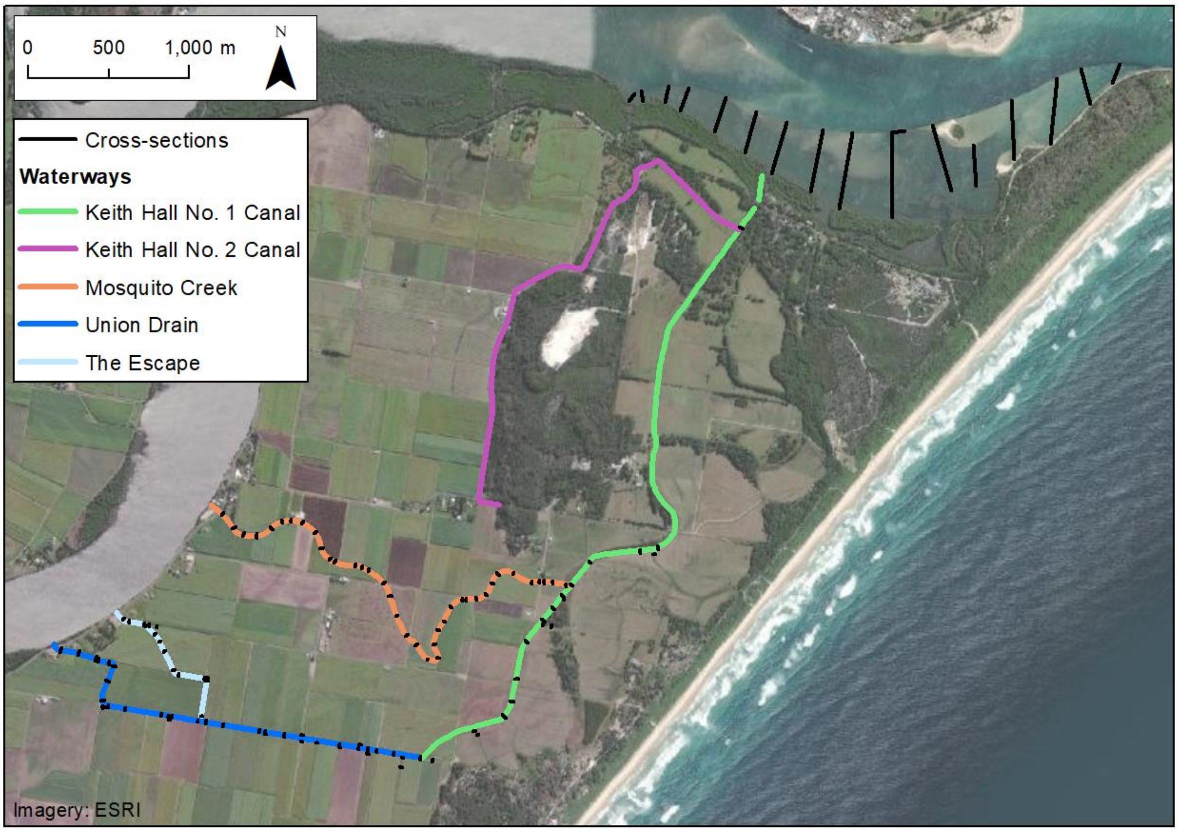


Figure C.1: Location of cross-section measurements

Table C.1: Coordinates for the start and end of each cross-section profile

Cross-section ID	**Coordinates (GDA 1994 MGA 56)**			
	Start easting (m)	Start northing (m)	End easting (m)	End northing (m)
KH1_01	554004.0	6803154.6	554011.8	6803136.2
KH1_02	553909.5	6803138.0	553912.1	6803112.8

Cross-section ID	Coordinates (GDA 1994 MGA 56)			
	Start easting (m)	Start northing (m)	End easting (m)	End northing (m)
KH1_03	553628.1	6803077.7	553643.3	6803064.3
KH1_04	553528.7	6802953.1	553543.4	6802943.1
KH1_05	553477.6	6802893.6	553495.7	6802878.0
KH1_06	553425.1	6802829.9	553444.5	6802814.8
KH1_07	553371.6	6802761.7	553391.5	6802746.1
KH1_08	553278.3	6802648.3	553296.9	6802632.5
KH1_09	553220.9	6802439.2	553245.2	6802434.1
KH1_10	553194.0	6802317.4	553218.0	6802312.8
KH1_11	553155.5	6802243.4	553176.0	6802226.2
KH1_12	554459.8	6804885.1	554478.0	6804871.1
KH1S1_1	553977.9	6803107.3	553995.6	6803107.7
KH1S2_1	553493.2	6802861.8	553495.1	6802874.1
KH1S3_1	553375.6	6802726.8	553380.7	6802739.6
KH1S3_2	553422.5	6802715.0	553426.0	6802730.0
KH1S4_1	552994.6	6802152.9	553010.2	6802161.0
KH1S4_2	553012.2	6802130.5	553025.4	6802138.3
MC_01	553505.8	6802951.2	553503.3	6802937.2
MC_02	553435.0	6802967.7	553432.3	6802950.7
MC_03	553386.8	6802973.4	553384.8	6802954.3
MC_04	553360.8	6802956.1	553362.6	6802971.4
MC_05	553317.6	6802954.3	553317.4	6802969.3
MC_06	553212.4	6803002.9	553222.6	6803015.8
MC_07	553139.7	6803001.8	553128.7	6803013.4

Cross-section ID	Coordinates (GDA 1994 MGA 56)			
	Start easting (m)	Start northing (m)	End easting (m)	End northing (m)
MC_08	553108.4	6802952.9	553093.4	6802958.5
MC_09	553074.0	6802889.7	553063.3	6802901.6
MC_10	553014.5	6802864.0	553012.8	6802881.6
MC_11	552959.7	6802859.4	552960.4	6802877.5
MC_12	552940.9	6802861.2	552937.5	6802877.4
MC_13	552883.7	6802825.2	552873.3	6802834.4
MC_14	552846.2	6802748.4	552832.9	6802755.4
MC_15	552814.4	6802699.5	552800.3	6802708.0
MC_16	552791.5	6802627.3	552776.4	6802624.8
MC_17	552811.7	6802550.0	552798.1	6802553.5
MC_18	552746.3	6802541.3	552752.6	6802549.4
MC_19	552678.5	6802620.9	552691.6	6802629.8
MC_20	552628.0	6802671.0	552640.6	6802681.3
MC_21	552572.9	6802781.0	552587.4	6802786.7
MC_22	552534.9	6802887.5	552552.9	6802890.9
MC_23	552503.1	6802957.0	552518.2	6802964.3
MC_24	552423.7	6803026.0	552432.5	6803037.5
MC_25	552388.7	6803040.3	552393.0	6803054.1
MC_26	552354.2	6803049.6	552357.5	6803063.7
MC_27	552241.3	6803071.1	552248.3	6803088.8
MC_28	552215.4	6803085.3	552226.3	6803097.7
MC_29	552164.2	6803150.5	552180.9	6803153.7
MC_30	552133.1	6803230.2	552146.3	6803239.8

Cross-section ID	Coordinates (GDA 1994 MGA 56)			
	Start easting (m)	Start northing (m)	End easting (m)	End northing (m)
MC_31	552065.9	6803282.9	552074.7	6803299.9
MC_32	552009.1	6803292.1	552008.0	6803311.0
MC_33	551960.2	6803288.2	551957.0	6803305.3
MC_34	551907.0	6803256.0	551894.8	6803268.7
MC_35	551820.8	6803209.5	551818.6	6803231.2
MC_36	551743.4	6803215.9	551751.9	6803238.0
MC_37	551684.8	6803257.6	551705.9	6803268.6
MC_38	551626.2	6803331.9	551639.3	6803345.2
TE_01	551506.8	6802241.7	551519.0	6802240.8
TE_02	551537.4	6802433.0	551551.3	6802432.7
TE_03	551529.3	6802440.6	551530.8	6802452.4
TE_04	551389.2	6802462.0	551392.1	6802477.0
TE_05	551353.9	6802489.4	551367.8	6802495.5
TE_06	551305.7	6802589.8	551318.7	6802597.6
TE_07	551281.4	6802649.2	551294.1	6802654.0
TE_08	551256.5	6802683.2	551268.4	6802691.4
TE_09	551210.1	6802730.7	551221.3	6802740.3
TE_10	551200.7	6802736.2	551202.8	6802751.4
TE_11	551119.8	6802748.4	551122.2	6802764.0
TE_12	551084.5	6802765.1	551096.1	6802778.9
TES1_1	551553.2	6802450.4	551544.2	6802453.0
TES2_1	551228.7	6802732.0	551230.3	6802743.9
TES2_2	551270.6	6802725.3	551272.3	6802736.4

Cross-section ID	Coordinates (GDA 1994 MGA 56)			
	Start easting (m)	Start northing (m)	End easting (m)	End northing (m)
UD_01	552706.7	6801999.6	552709.4	6802019.7
UD_02	552769.1	6801990.9	552773.7	6802006.6
UD_03	552559.5	6802028.0	552561.7	6802042.4
UD_04	552466.6	6802043.4	552469.8	6802058.8
UD_05	552417.9	6802050.2	552419.8	6802066.9
UD_06	552370.0	6802060.1	552371.9	6802075.3
UD_07	552264.1	6802077.6	552266.8	6802092.3
UD_08	551963.0	6802128.8	551967.5	6802146.8
UD_09	551859.2	6802148.4	551863.2	6802161.7
UD_10	551827.4	6802151.4	551829.0	6802169.5
UD_11	551629.1	6802185.3	551632.1	6802202.8
UD_12	551535.9	6802200.7	551538.1	6802219.8
UD_13	551492.7	6802210.3	551494.6	6802224.7
UD_14	551332.5	6802236.1	551334.4	6802251.1
UD_15	551291.0	6802244.1	551293.6	6802260.0
UD_16	551095.6	6802276.8	551098.0	6802293.8
UD_17	551005.5	6802290.5	551008.2	6802309.2
UD_18	550965.4	6802329.5	550986.2	6802332.8
UD_19	550991.8	6802439.1	551011.0	6802430.0
UD_21	551028.5	6802520.1	551049.6	6802511.7
UD_22	551010.3	6802525.2	551011.3	6802546.6
UD_23	550935.7	6802545.5	550946.5	6802569.3
UD_24	550841.9	6802577.9	550849.9	6802599.7

Cross-section ID	Coordinates (GDA 1994 MGA 56)			
	Start easting (m)	Start northing (m)	End easting (m)	End northing (m)
UD_25	551347.3	6802233.4	551351.1	6802251.3
UD_26	550947.6	6802540.3	550956.7	6802561.7
UD_27	550743.4	6802593.7	550750.3	6802618.4
UDS01_1	552601.1	6802013.9	552615.3	6802013.1
UDS01_2	552593.0	6801962.9	552608.0	6801960.7
UDS02_1	552411.5	6802036.8	552428.1	6802034.1
UDS03_1	552383.0	6802083.3	552370.9	6802085.5
UDS04_1	552260.7	6802071.8	552271.8	6802069.4
UDS05_1	552137.2	6802096.0	552147.8	6802094.4
UDS06_1	552066.8	6802135.4	552054.7	6802137.2
UDS07_1	552053.0	6802104.8	552061.6	6802103.1
UDS08_1	551856.3	6802144.2	551865.8	6802143.3
UDS09_1	551329.9	6802223.4	551343.3	6802221.5
UDS10_1	550983.5	6802292.5	551000.9	6802295.2
UDS11_1	550973.6	6802302.2	550976.3	6802288.8
MB_A	553893.8	6805611.7	553893.8	6805611.7
MB_B	553925.3	6805623.3	553925.3	6805623.3
MB_C	554081.2	6805647.8	554081.2	6805647.8
MB_D	554189.3	6805641.7	554189.3	6805641.7
MB_E	554391.4	6805584.5	554391.4	6805584.5
MB_F	554554.6	6805508.9	554554.6	6805508.9
MB_G	554723.1	6805448.8	554723.1	6805448.8
MB_H	554919.4	6805407.9	554919.4	6805407.9

Cross-section ID	Coordinates (GDA 1994 MGA 56)			
	Start easting (m)	Start northing (m)	End easting (m)	End northing (m)
MB_I	555081.9	6805391.5	555081.9	6805391.5
MB_J	555290.1	6805393.0	555290.1	6805393.0
MB_K	555293.0	6805393.1	555293.0	6805393.1
MB_L	555517.8	6805429.1	555517.8	6805429.1
MB_M	555736.0	6805322.7	555736.0	6805322.7
MB_N	555945.1	6805562.0	555945.1	6805562.0
MB_O	556196.2	6805683.5	556196.2	6805683.5
MB_P	556329.3	6805733.3	556329.3	6805733.3
MB_Q	556539.8	6805759.0	556539.8	6805759.0

ID Codes: KH1 = Keith Hall No. 1 Canal, KH1S = a side drain on Keith Hall No. 1 Canal, MC = Mosquito Creek, TE = The Escape, TES = a side drain on The Escape, UD = Union Drain, UDS = a side drain on Union Drain, and MB = Mobbs Bay.

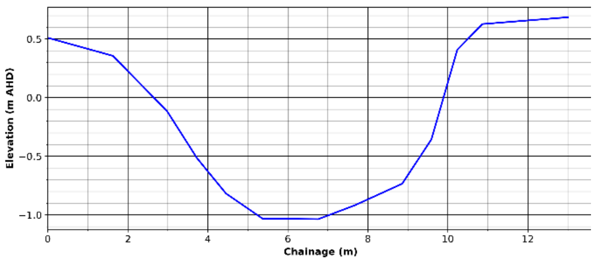


Figure C. 2: Cross-section KH1_01

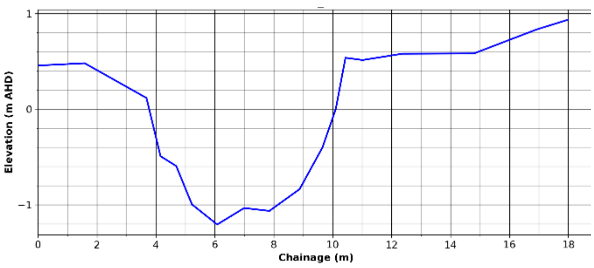


Figure C. 3: Cross-section KH1_02

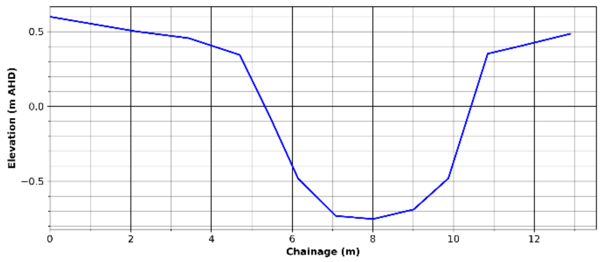


Figure C. 4: Cross-section KH1_03

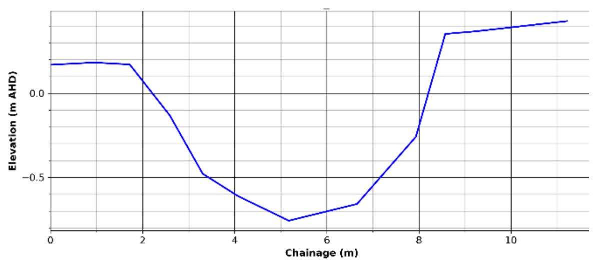


Figure C. 5: Cross-section KH1_04

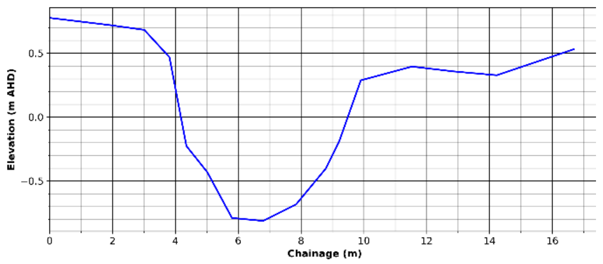


Figure C. 6: Cross-section KH1_05

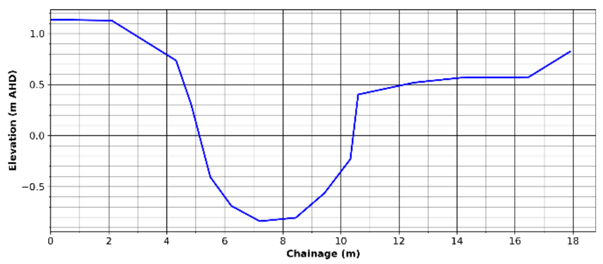


Figure C. 7: Cross-section KH1_06

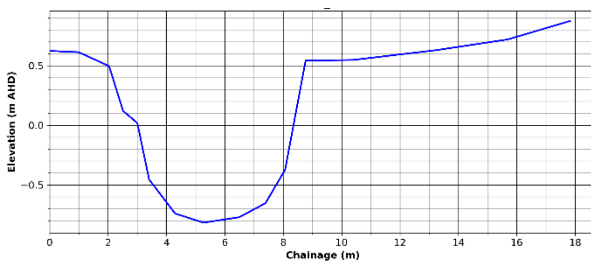


Figure C. 8: Cross-section KH1_07

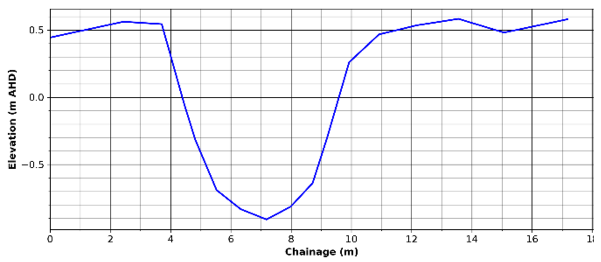


Figure C. 9: Cross-section KH1_08

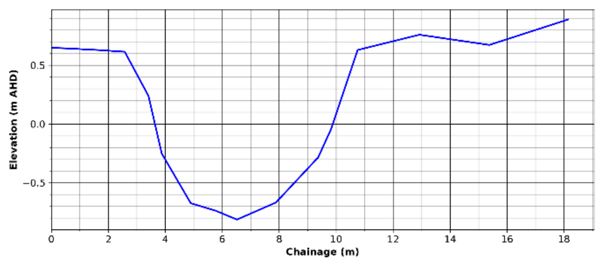


Figure C. 10: Cross-section KH1_09

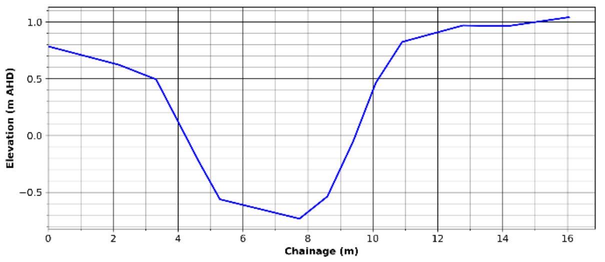


Figure C. 11: Cross-section KH1_10

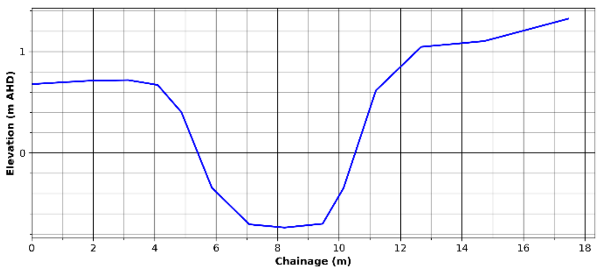


Figure C. 12: Cross-section KH1_11

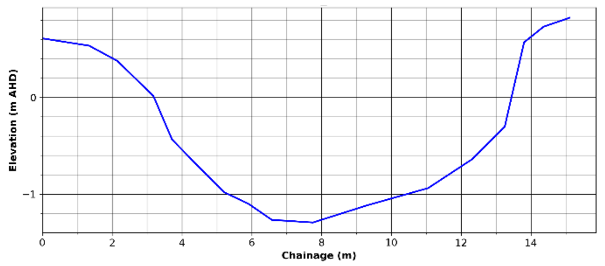


Figure C. 13: Cross-section KH1_12

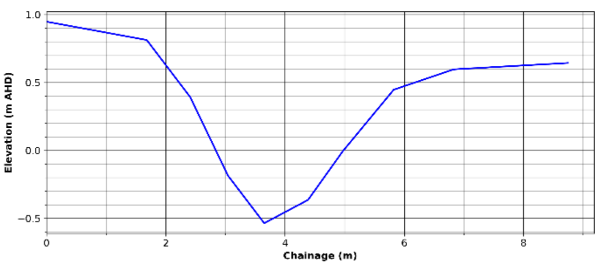


Figure C. 14: Cross-section KH1S1_1

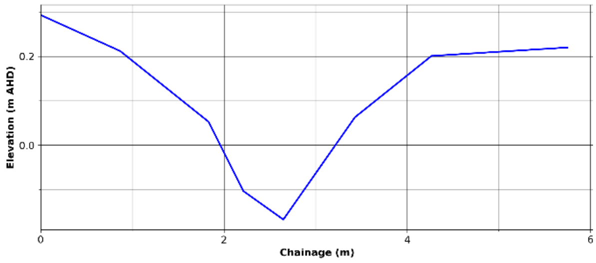


Figure C. 15: Cross-section KH1S2_1

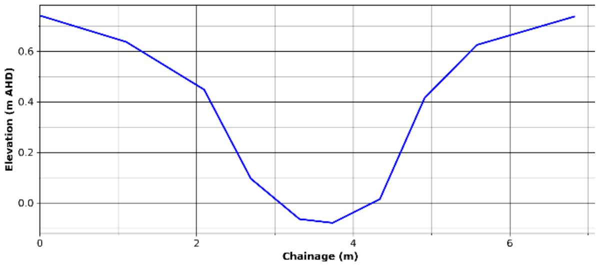


Figure C. 16: Cross-section KH1S3_1

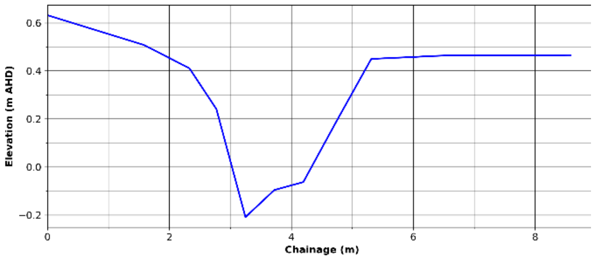


Figure C. 17: Cross-section KH1S3_2

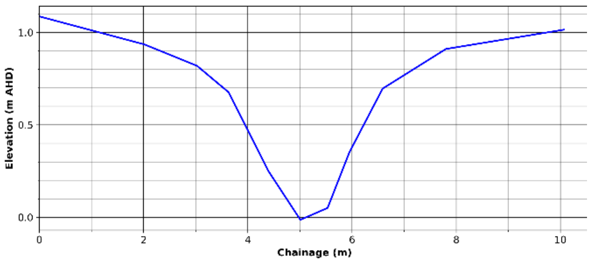


Figure C. 18: Cross-section KH1S4_1

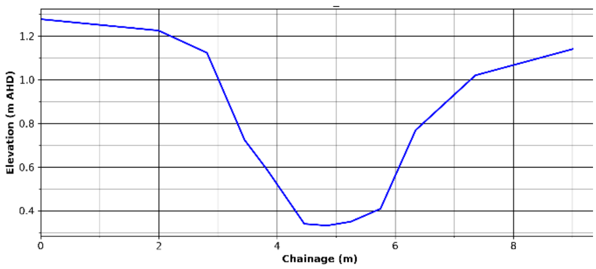


Figure C. 19: Cross-section KH1S4_2

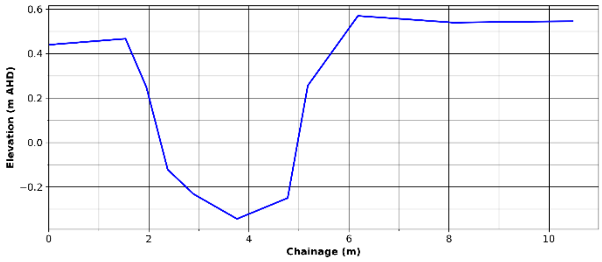


Figure C. 20: Cross-section MC_01

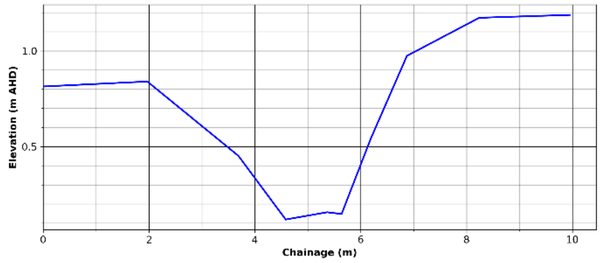


Figure C. 21: Cross-section MC_02

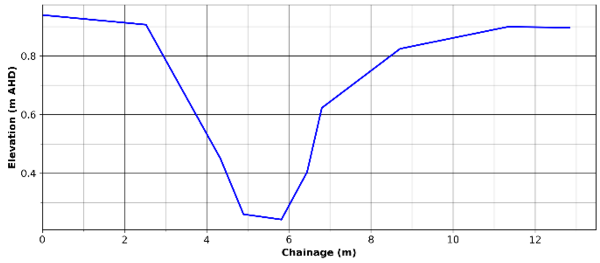


Figure C. 22: Cross-section MC_03

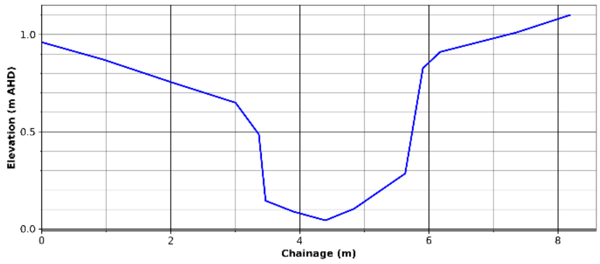


Figure C. 23: Cross-section MC_04

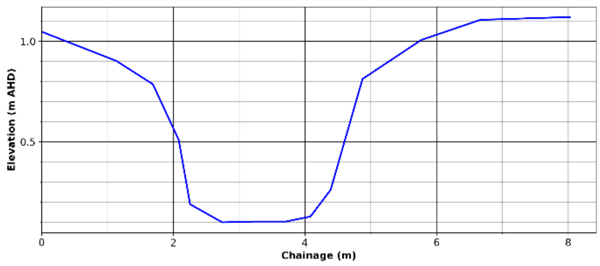


Figure C. 24: Cross-section MC_05

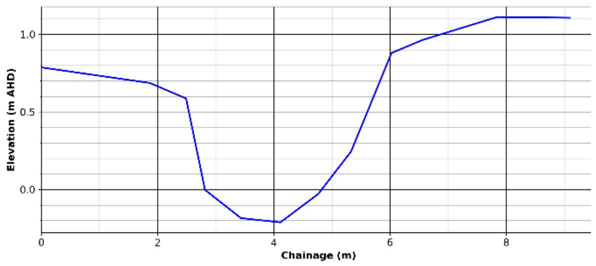


Figure C. 25: Cross-section MC_06

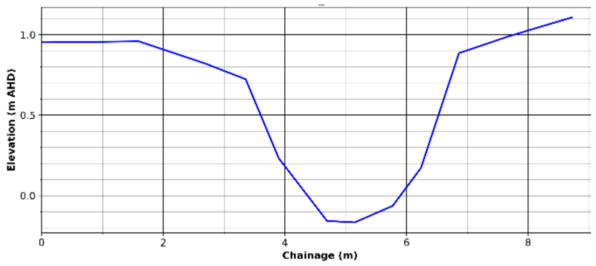


Figure C. 26: Cross-section MC_07

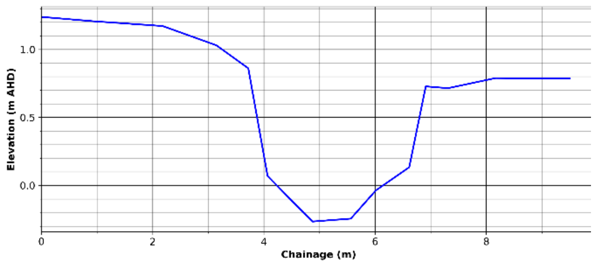


Figure C. 27: Cross-section MC_08

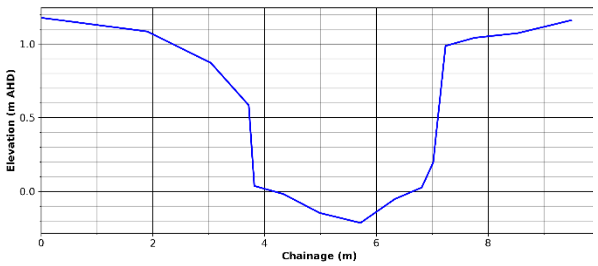


Figure C. 28: Cross-section MC_09

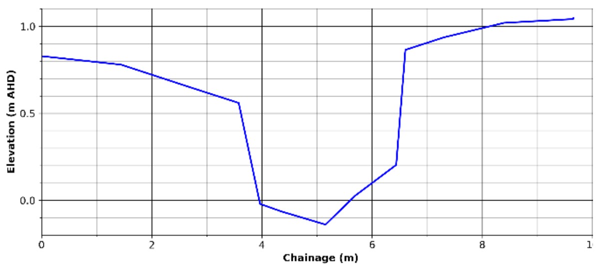


Figure C. 29: Cross-section MC_10

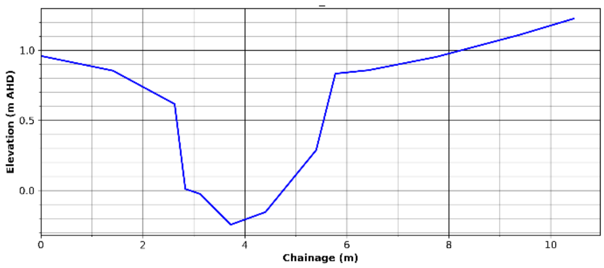


Figure C. 30: Cross-section MC_11

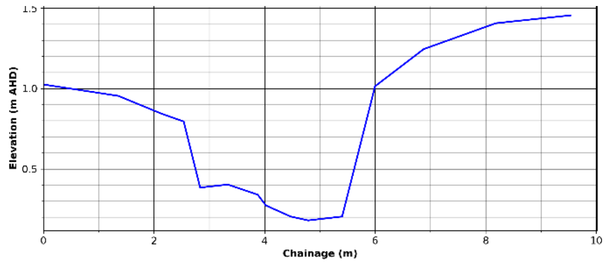


Figure C. 31: Cross-section MC_12

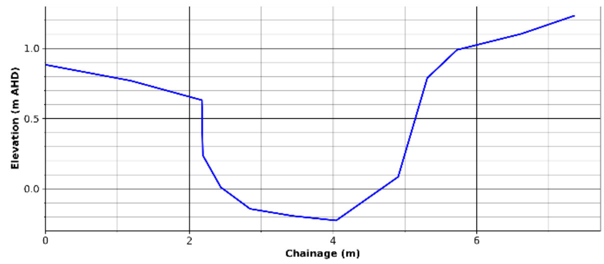


Figure C. 32: Cross-section MC_13

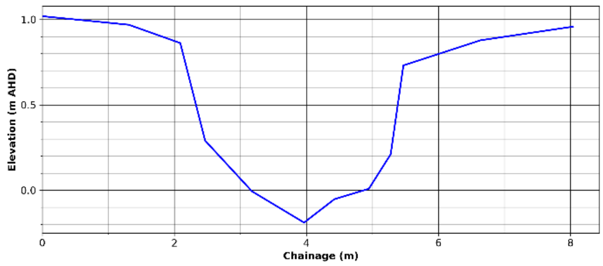


Figure C. 33: Cross-section MC_14

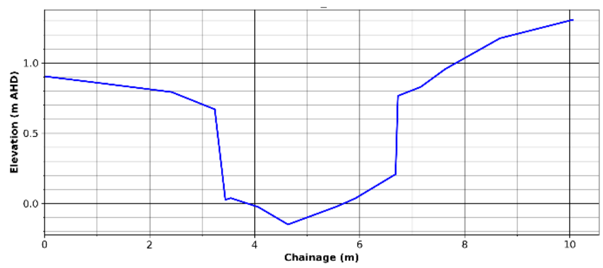


Figure C. 34: Cross-section MC_15

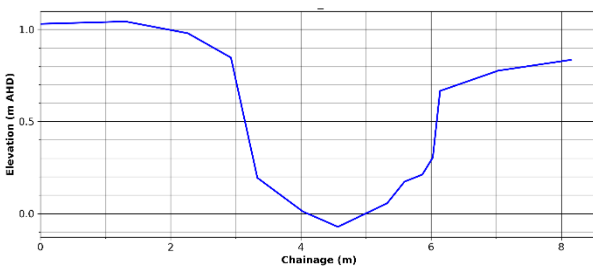


Figure C. 35: Cross-section MC_16

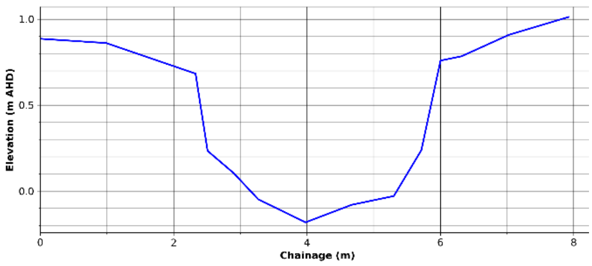


Figure C. 36: Cross-section MC_17

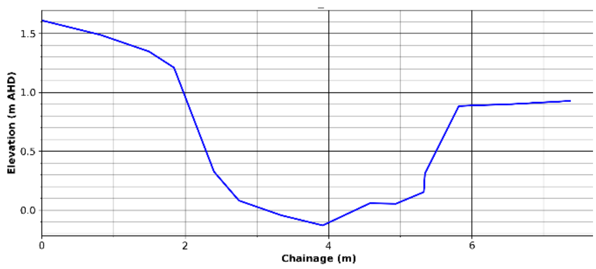


Figure C. 37: Cross-section MC_18

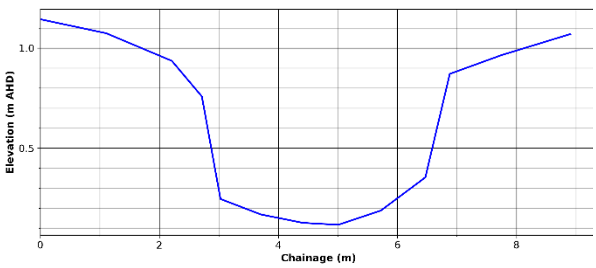


Figure C. 38: Cross-section MC_19

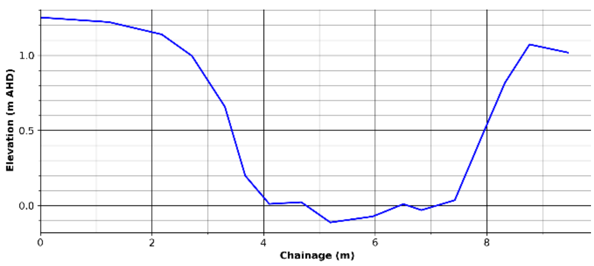


Figure C. 39: Cross-section MC_20

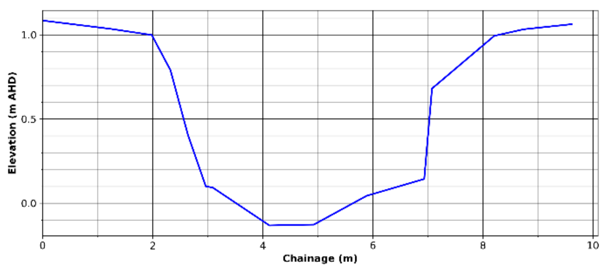


Figure C. 40: Cross-section MC_21

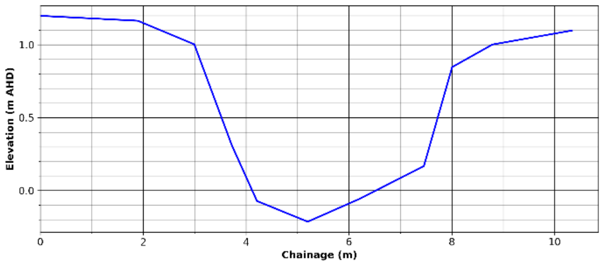


Figure C. 41: Cross-section MC_22

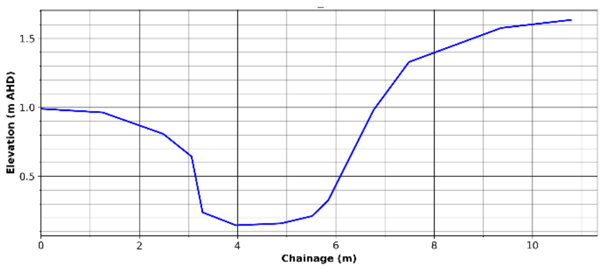


Figure C. 42: Cross-section MC_23

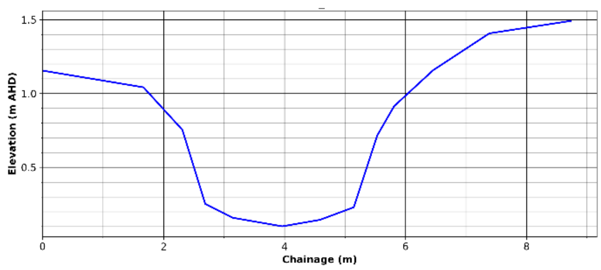


Figure C. 43: Cross-section MC_24

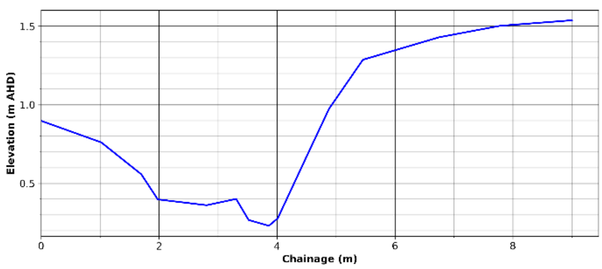


Figure C. 44: Cross-section MC_25

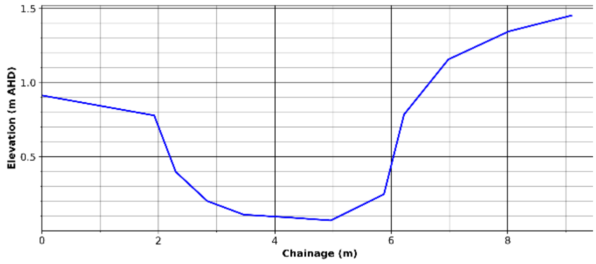


Figure C. 45: Cross-section MC_26

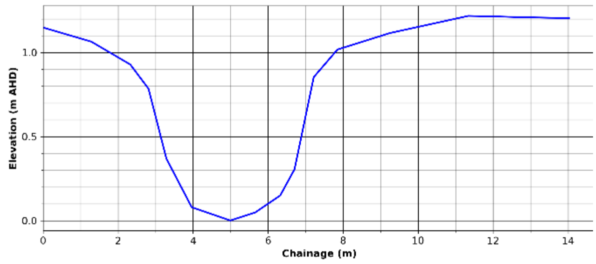


Figure C. 46: Cross-section MC_27

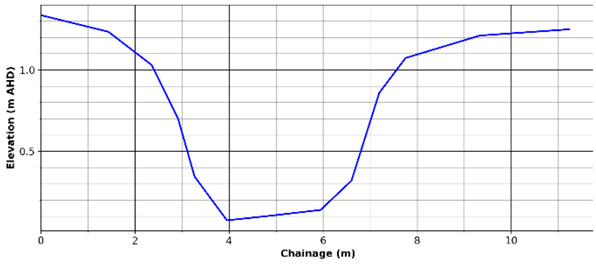


Figure C. 47: Cross-section MC_28

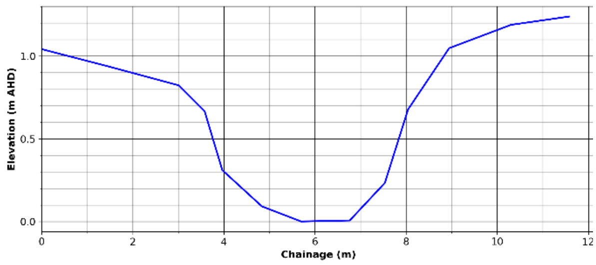


Figure C. 48: Cross-section MC_29

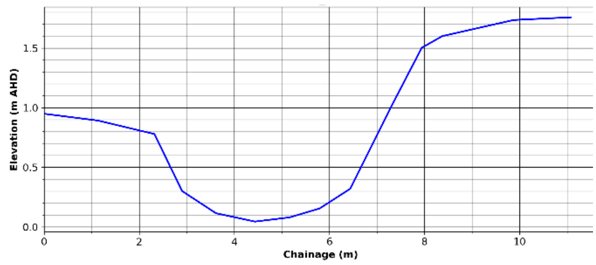


Figure C. 49: Cross-section MC_30

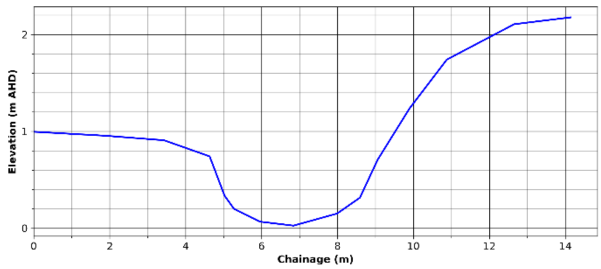


Figure C. 50: Cross-section MC_31

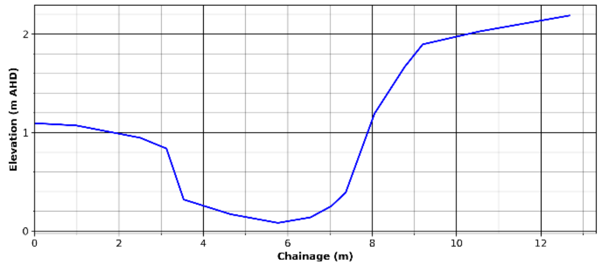


Figure C. 51: Cross-section MC_32

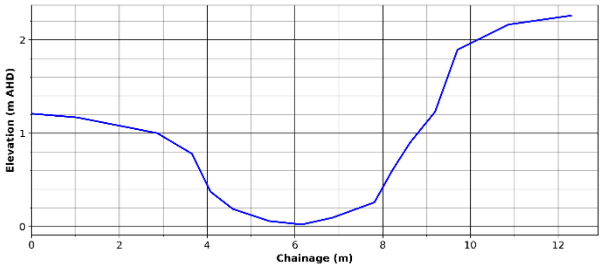


Figure C. 52: Cross-section MC_33

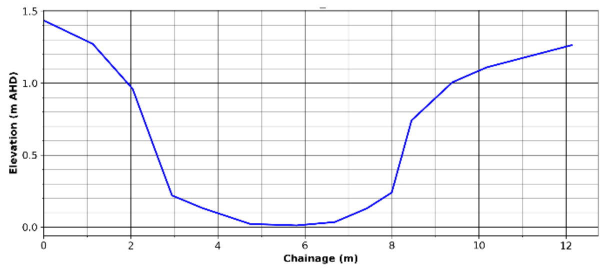


Figure C. 53: Cross-section MC_34

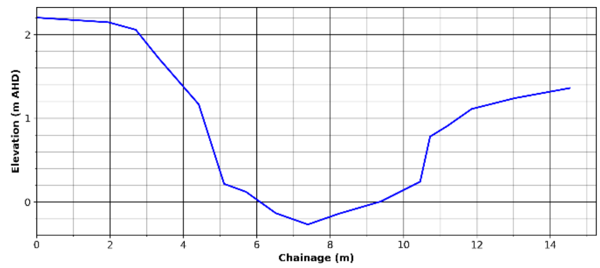


Figure C. 54: Cross-section MC_35

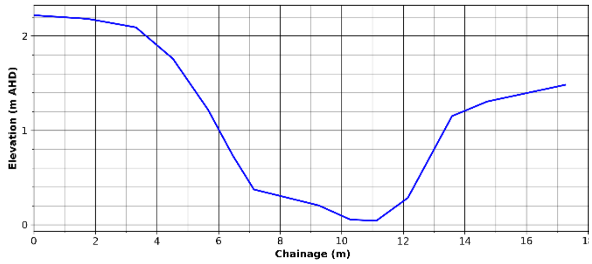


Figure C. 55: Cross-section MC_36

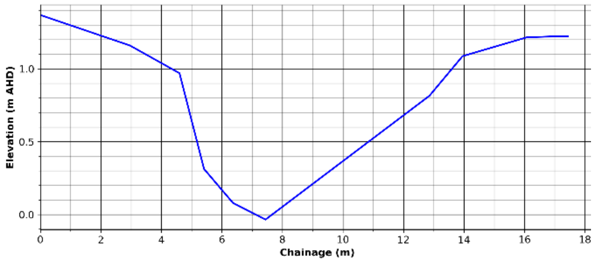


Figure C. 56: Cross-section MC_37

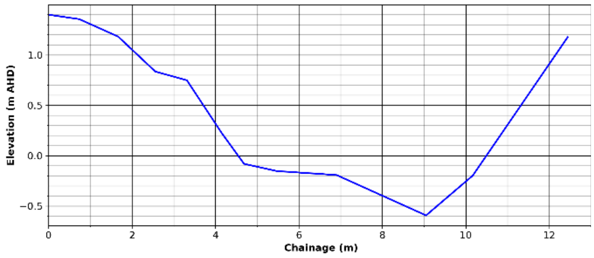


Figure C. 57: Cross-section MC_38

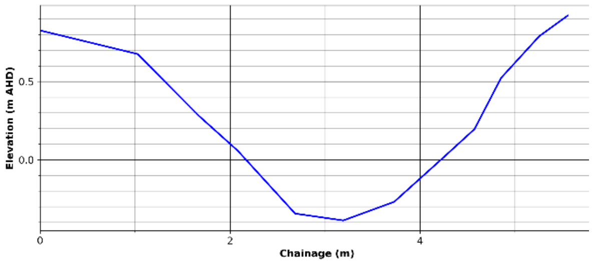


Figure C. 58: Cross-section TE_01

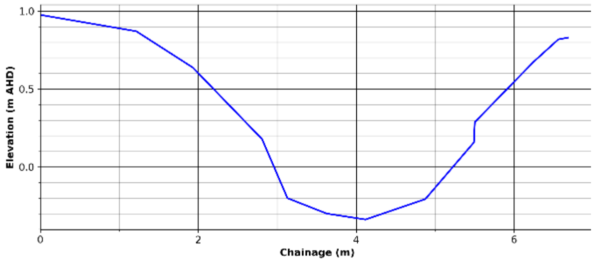


Figure C. 59: Cross-section TE_02

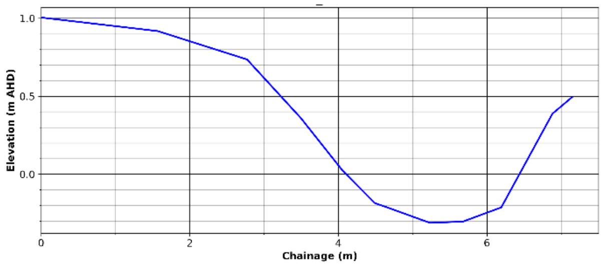


Figure C. 60: Cross-section TE_03

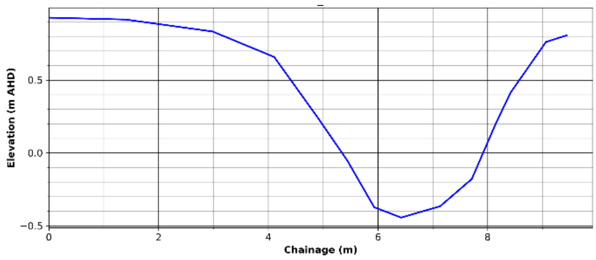


Figure C. 61: Cross-section TE_04

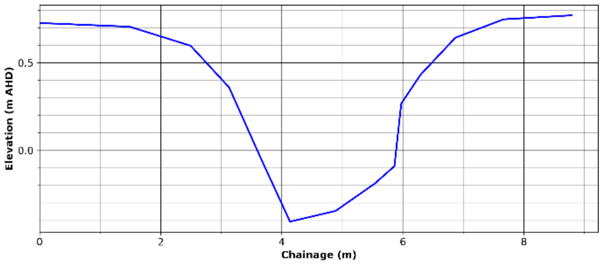


Figure C. 62: Cross-section TE_05

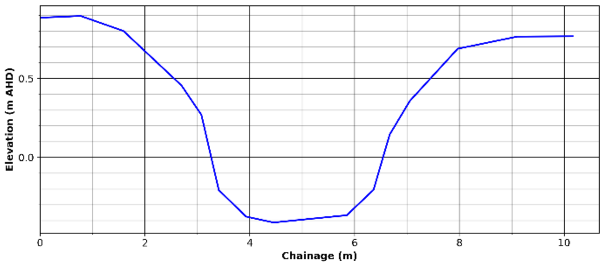


Figure C. 63: Cross-section TE_06

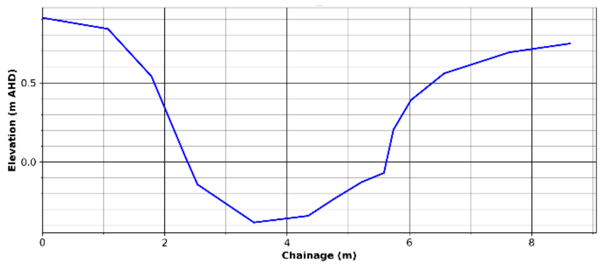


Figure C. 64: Cross-section TE_07

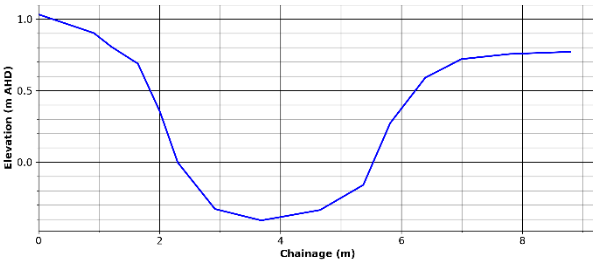


Figure C. 65: Cross-section TE_08

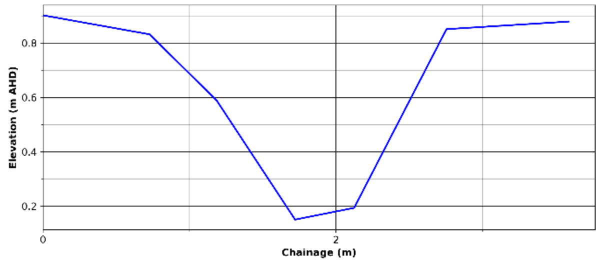


Figure C. 70: Cross-section TES1_1

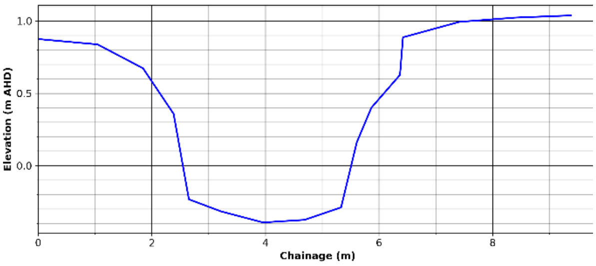


Figure C. 66: Cross-section TE_09

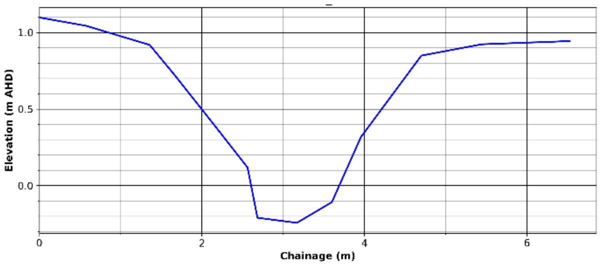


Figure C. 71: Cross-section TES2_1

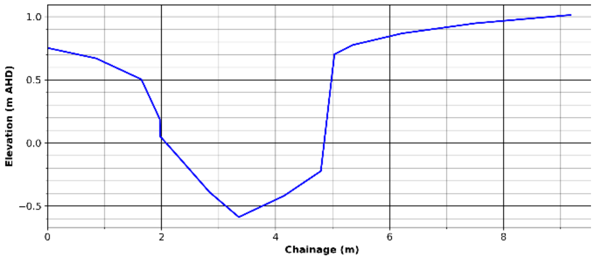


Figure C. 67: Cross-section TE_10

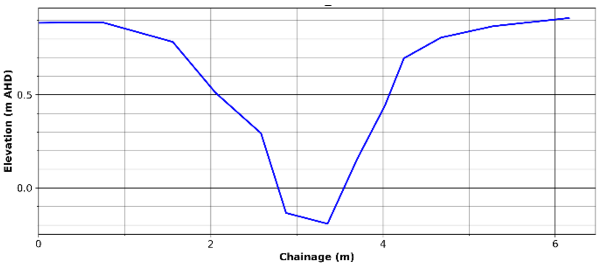


Figure C. 72: Cross-section TES2_2

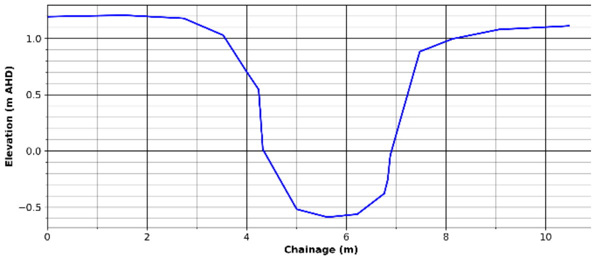


Figure C. 68: Cross-section TE_11

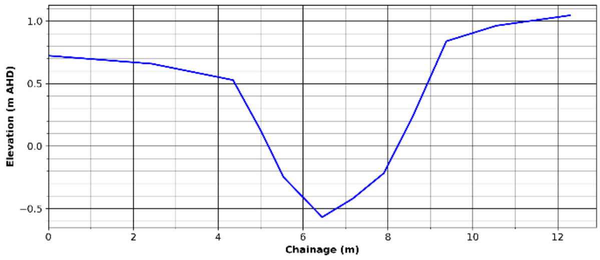


Figure C. 73: Cross-section UD_01

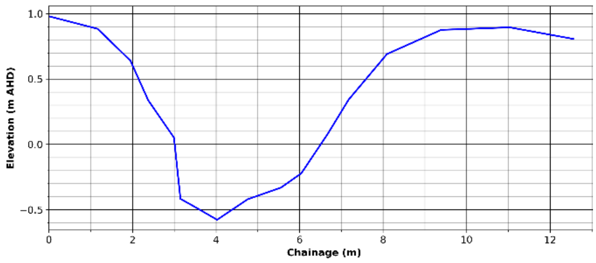


Figure C. 69: Cross-section TE_12

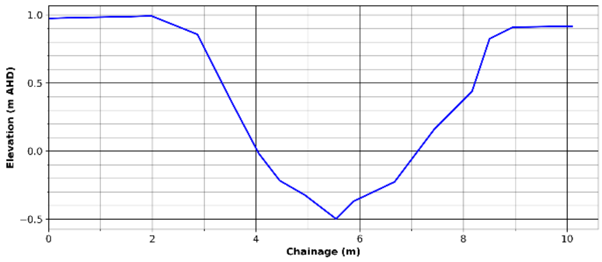


Figure C. 74: Cross-section UD_02

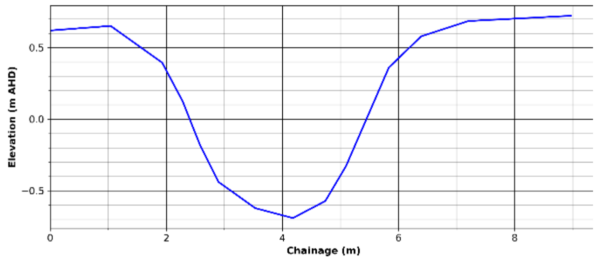


Figure C. 75: Cross-section UD_03

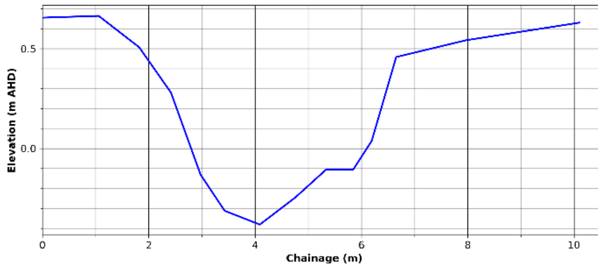


Figure C. 76: Cross-section UD_04

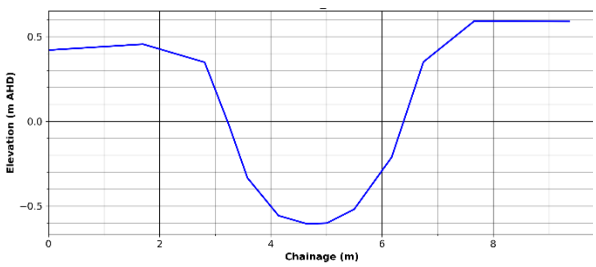


Figure C. 77: Cross-section UD_05

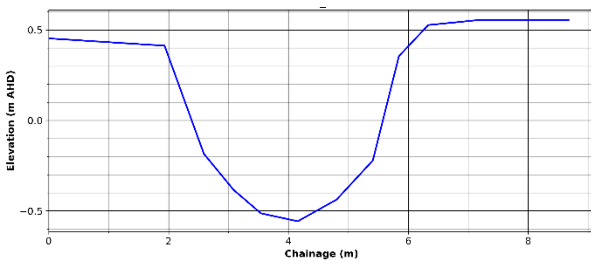


Figure C. 78: Cross-section UD_06

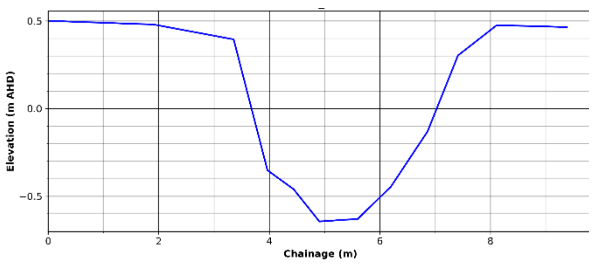


Figure C. 79: Cross-section UD_07

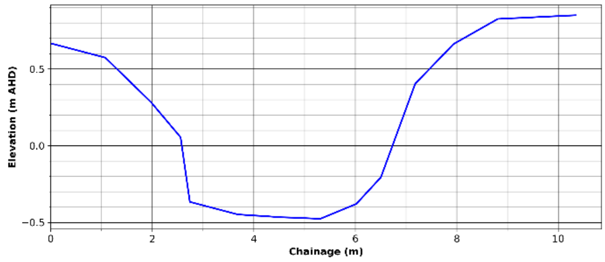


Figure C. 80: Cross-section UD_08

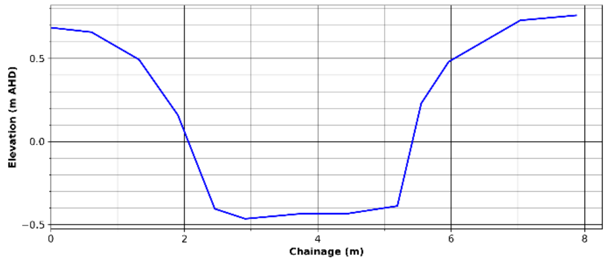


Figure C. 81: Cross-section UD_09

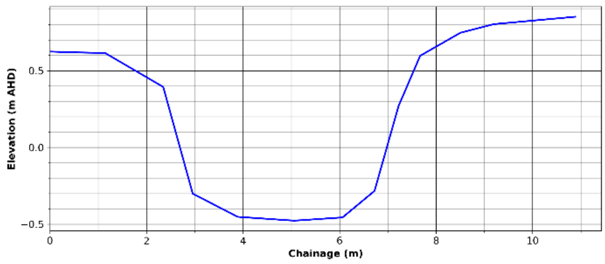


Figure C. 82: Cross-section UD_10

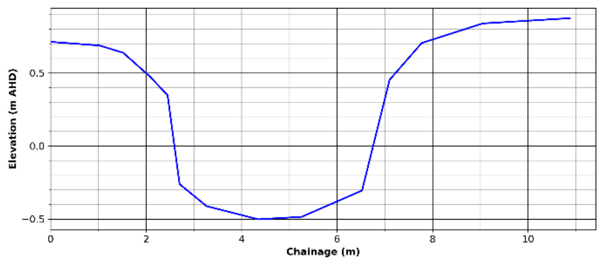


Figure C. 83: Cross-section UD_11

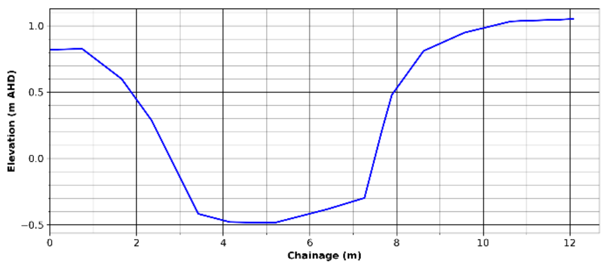


Figure C. 84: Cross-section UD_12

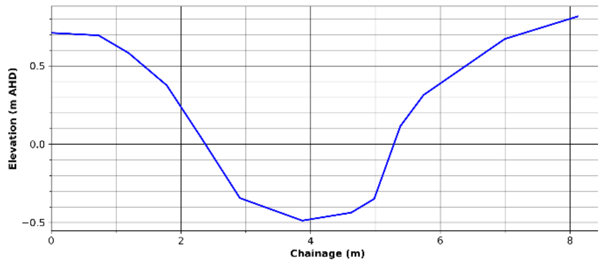


Figure C. 85: Cross-section UD_13

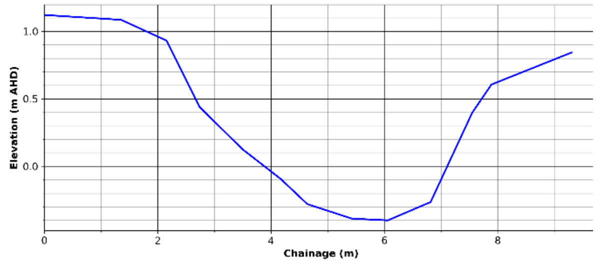


Figure C. 86: Cross-section UD_14

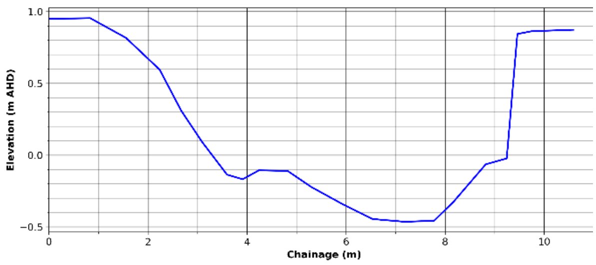


Figure C. 87: Cross-section UD_15

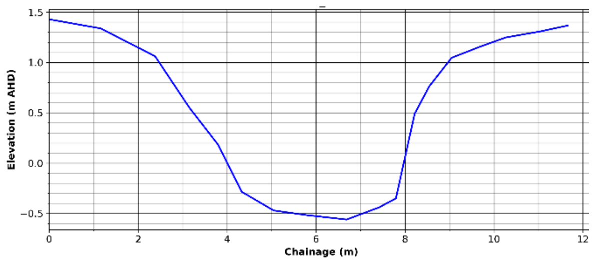


Figure C. 88: Cross-section UD_16

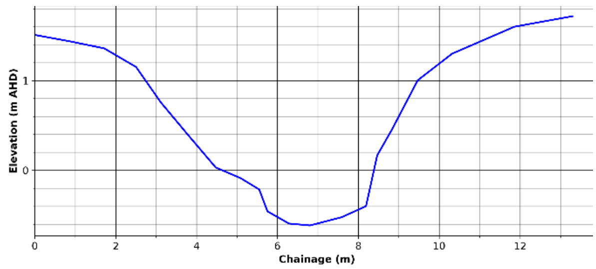


Figure C. 89: Cross-section UD_17

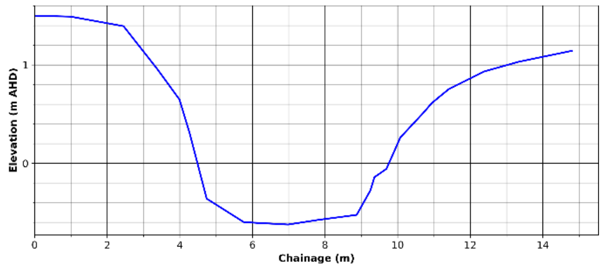


Figure C. 90: Cross-section UD_18

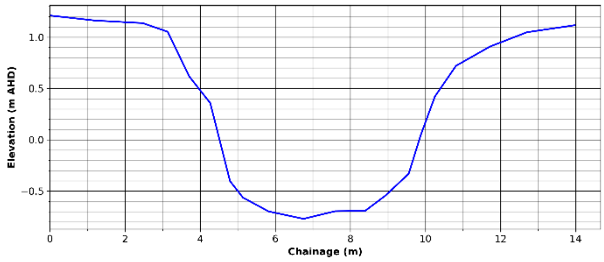


Figure C. 91: Cross-section UD_19

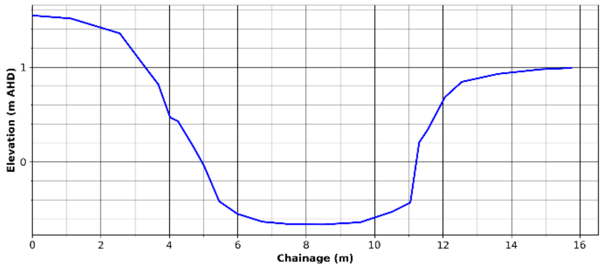


Figure C. 92: Cross-section UD_21

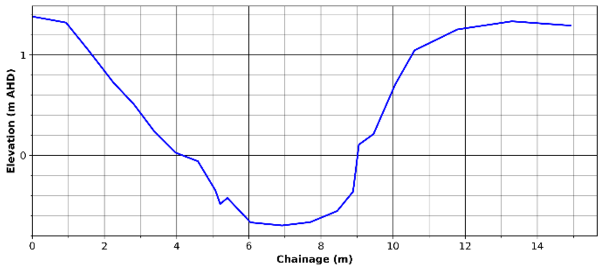


Figure C. 93: Cross-section UD_22

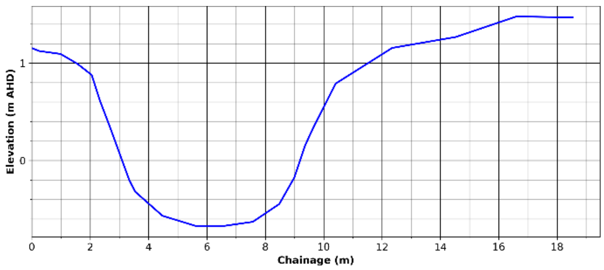


Figure C. 94: Cross-section UD_23

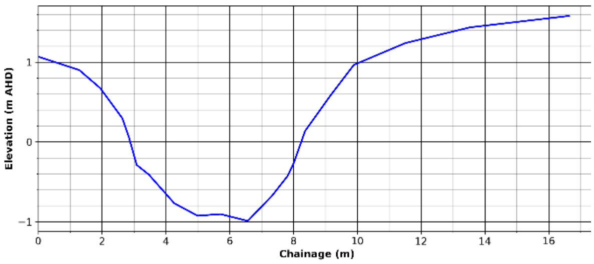


Figure C. 95: Cross-section UD_24

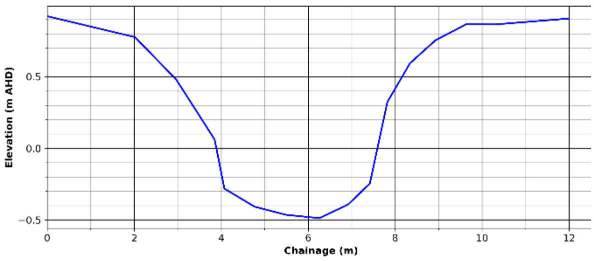


Figure C. 96: Cross-section UD_25

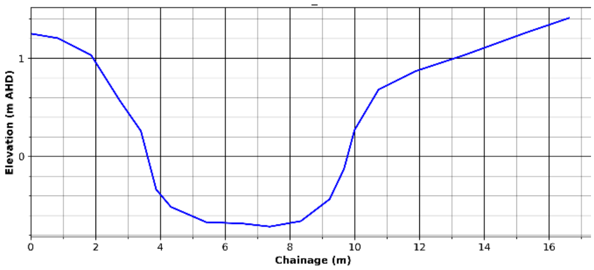


Figure C. 97: Cross-section UD_26

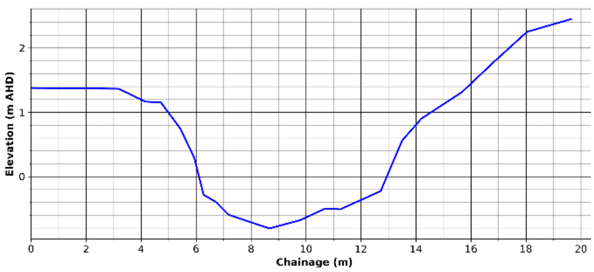


Figure C. 98: Cross-section UD_27

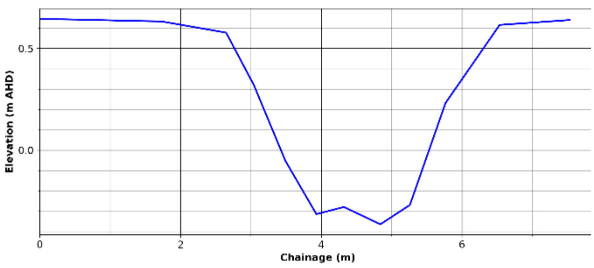


Figure C. 99: Cross-section UDS01_1

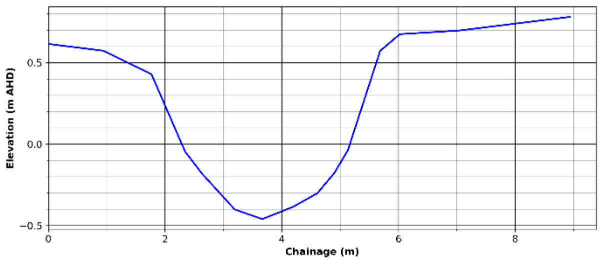


Figure C. 100: Cross-section UDS01_2

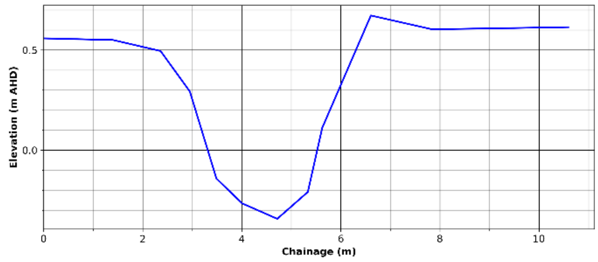


Figure C. 101: Cross-section UDS02_1

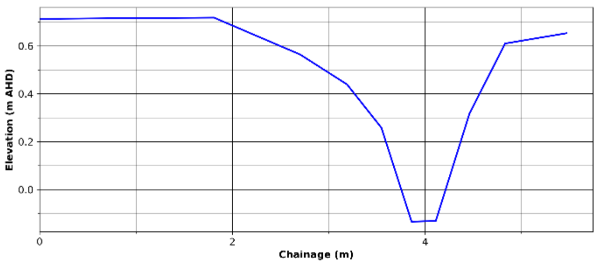


Figure C. 102: Cross-section UDS03_1

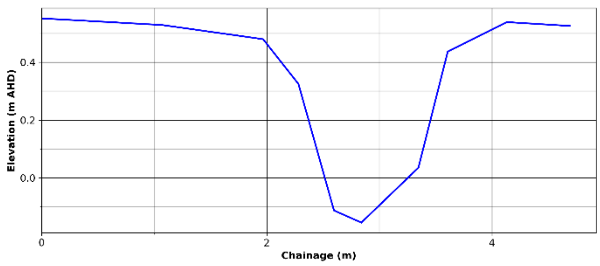


Figure C. 103: Cross-section UDS04_1

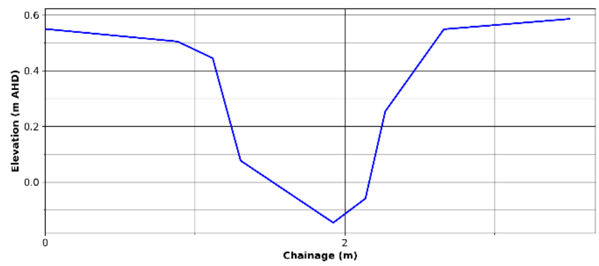


Figure C. 104: Cross-section UDS05_1

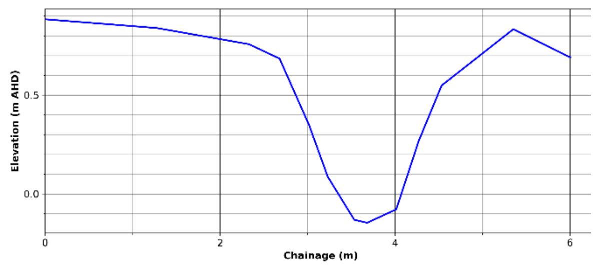


Figure C. 105: Cross-section UDS06_1

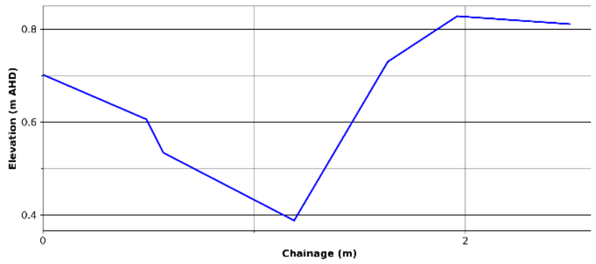


Figure C. 106: Cross-section UDS07_1

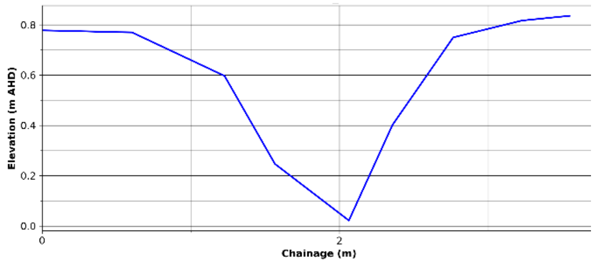


Figure C. 107: Cross-section UDS08_1

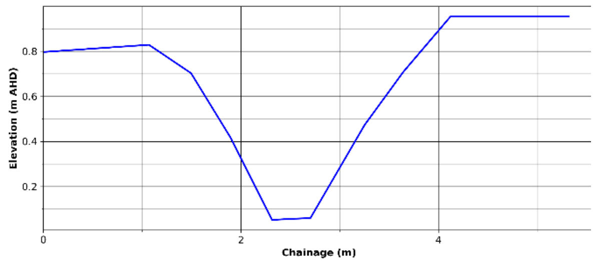


Figure C. 108: Cross-section UDS09_1

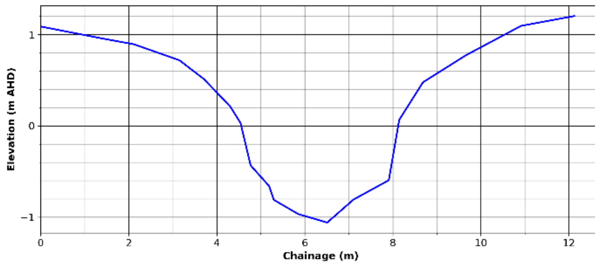


Figure C. 109: Cross-section UDS10_1

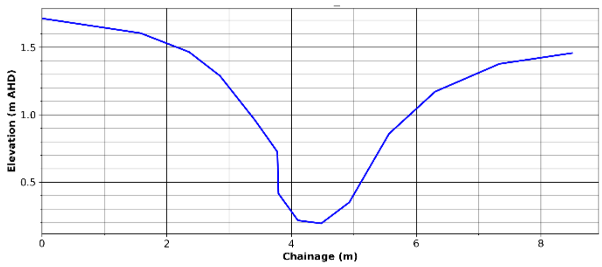


Figure C. 110: Cross-section UDS11_1

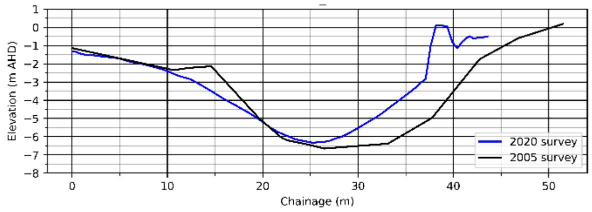


Figure C. 111: Cross-section MB_A

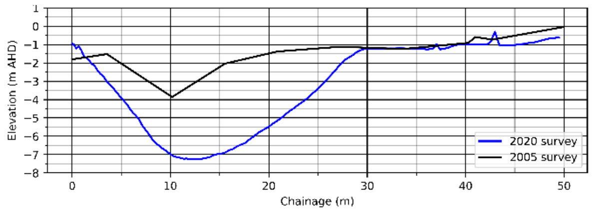


Figure C. 112: Cross-section MB_B

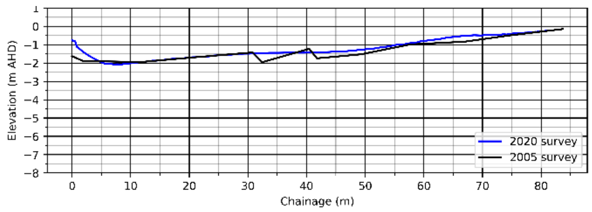


Figure C. 113: Cross-section MB_C

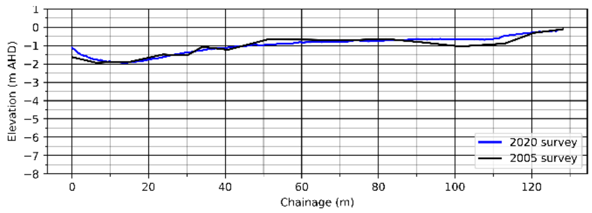


Figure C. 114: Cross-section MB_D

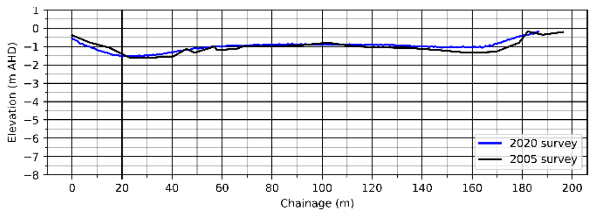


Figure C. 115: Cross-section MB_E

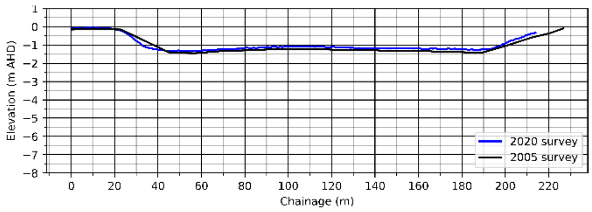


Figure C. 116: Cross-section MB_F

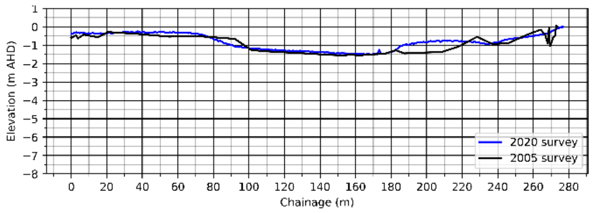


Figure C. 117: Cross-section MB_G

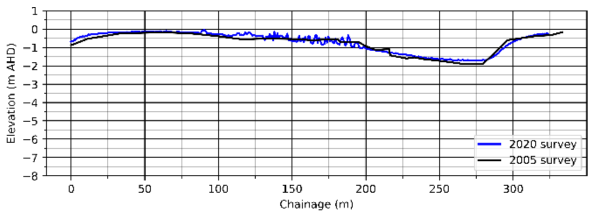


Figure C. 118: Cross-section MB_H

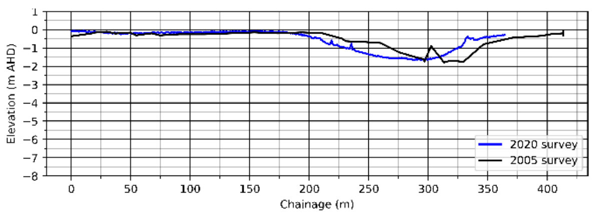


Figure C. 119: Cross-section MB_I

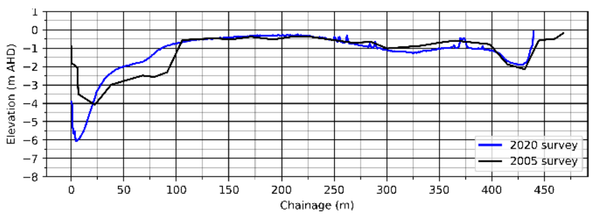


Figure C. 120: Cross-section MB_J

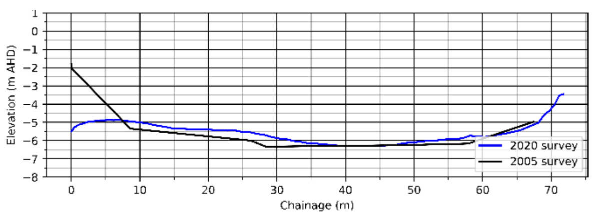


Figure C. 121: Cross-section MB_K

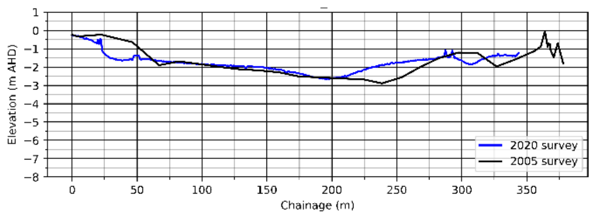


Figure C. 122: Cross-section MB_L

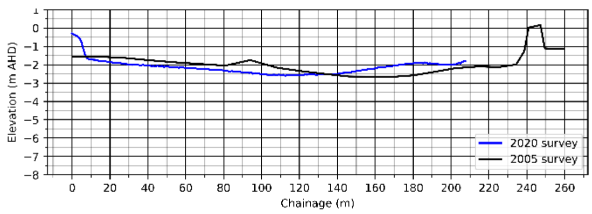


Figure C. 123: Cross-section MB_M

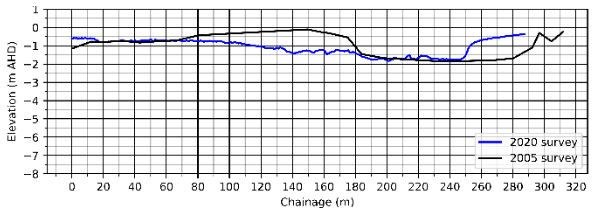


Figure C. 124: Cross-section MB_N

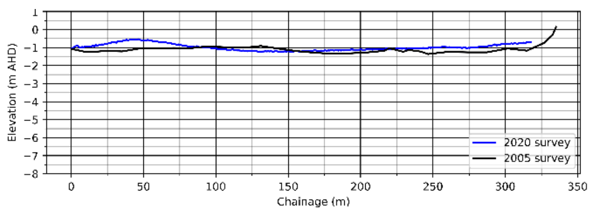


Figure C. 125: Cross-section MB_O

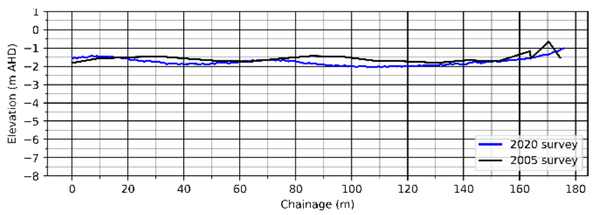


Figure C. 126: Cross-section MB_P

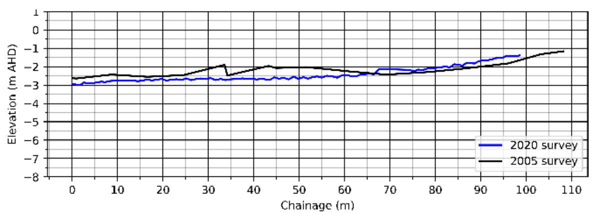


Figure C. 127: Cross-section MB_Q

Appendix D Drainage timing sensitivity tests

Raising the water level inside the Keith Hall drainage network has potential to impact on flooding by reducing the capacity of the drain to store the initial runoff following a rainfall event. A number of sensitivity tests have been completed using the numerical model (Appendix B) and analysed alongside drainage volume information to determine how increased water levels in the drainage network may affect nuisance flooding. The following section summarises these findings which have been used to inform the assessment of drainage management options.

A stage volume relationship has been created for the Keith Hall drainage network as well as the floodplain (Figure D.1). This was created from cross-section data collected for the drainage network (Appendix A and Appendix C) and LiDAR data provided by the NSW Department of Finance, Services and Innovation (Figure D.2).

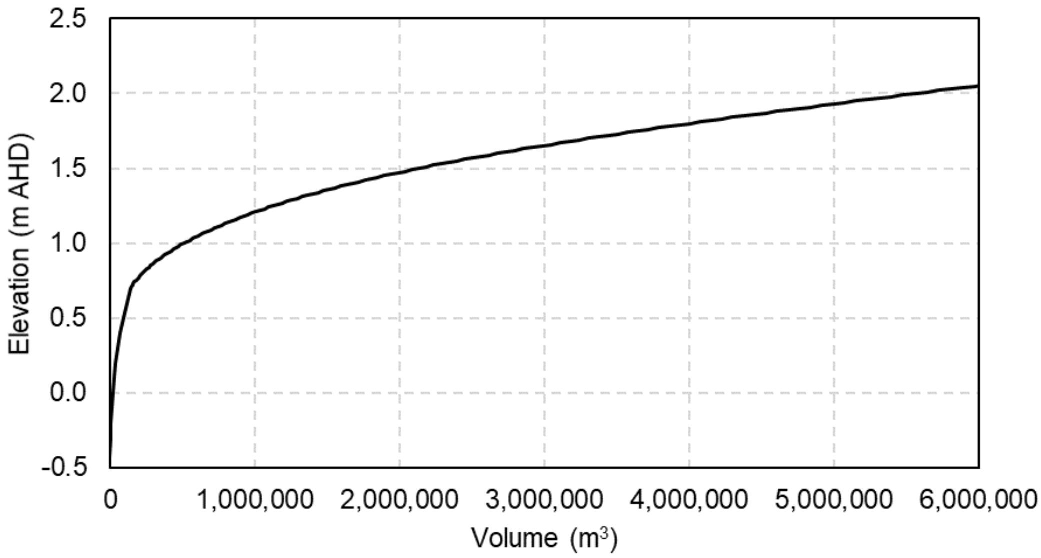


Figure D.1: Stage (elevation) versus volume relationship for the Keith Hall floodplain

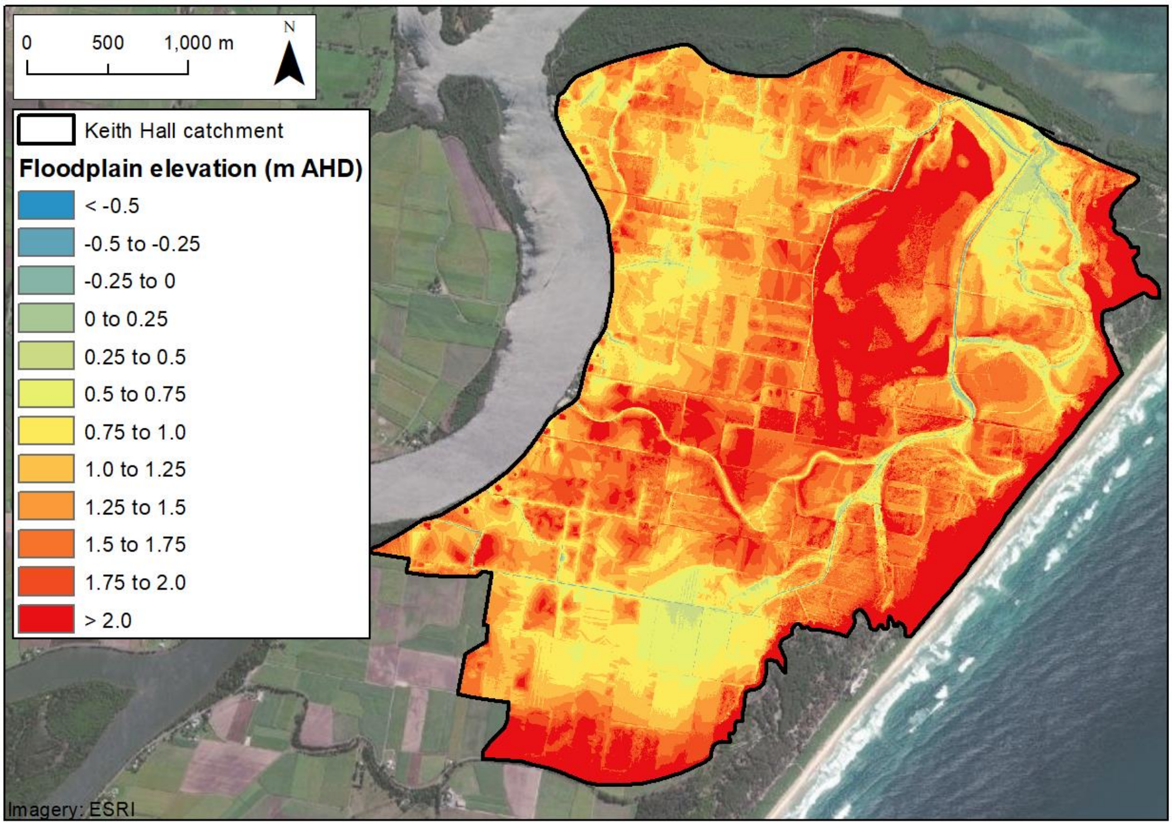


Figure D.2: Elevation of the Keith Hall floodplain (corrected by 0.2 m as per Appendix A)

The numerical model was run to determine how long it takes the network to drain when the starting water level is 0 m AHD, 0.5 m AHD or 1 m AHD. Simulations were completed so that drainage occurred during a neap tide when there is the smallest tidal amplitude and highest low tide elevation. This was done as neap tides are the most likely to prolong drainage across the floodplain. Results show that for the drainage network to completely drain it takes approximately two to three days. The time for drainage across the floodplain varied based on:

- Distance from floodgates
- Tide levels (i.e., spring or neap)
- Constrains in the drainage network (e.g., culverts and weeds)

Figure D.3 shows the time it takes the floodplain to drain at the confluence of Mosquito Creek and Keith Hall No. 1 Canal. This is in the centre of the floodplain and one of the locations that takes the longest to drain.

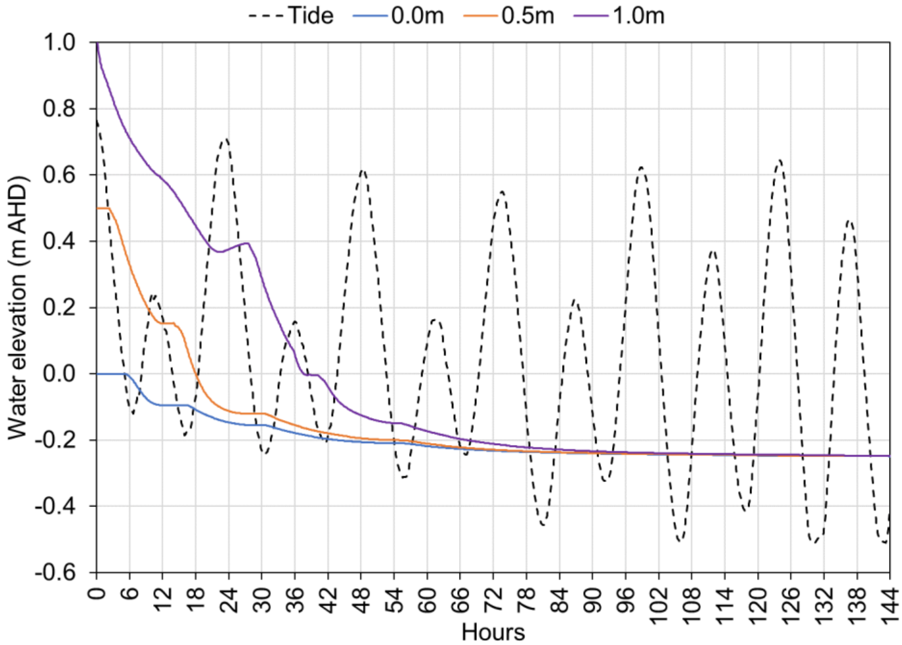


Figure D.3: Floodplain drainage times for different initial water levels at the confluence of Mosquito Creek and Keith Hall No. 1 Drain

Results of this analysis show that to mitigate impacts of allowing raised water levels within the drainage network on flooding, a protocol could be set in place whereby the floodgates and/or sluice gates are shut two to three days (48 to 72 hours) prior to large rainfall events. This would allow the floodplain enough time to drain, even during a neap tidal cycle.

There are a number of factors to consider when determining what constitutes a 'large' rainfall event, including:

- Individual risk profiles for owners of agriculturally productive land
- Rainfall volume
- Volume of water within the drainage network
- Catchment runoff routing (how far water needs to travel to reach the drainage system)
- The downstream water level (within the Richmond River)
- Antecedent conditions (is the floodplain dry or wet prior to rainfall)
- Tidal dynamics (low/ high tide, spring/neap tide)
- Floodplain structures (such as weirs or culverts)
- Management of floodplain structures (e.g. the active floodgate management plan (RCC, 2020))

For example, the influence of antecedent conditions can be seen by comparing the difference between a 343 mm rainfall event in December 2020 that occurred over 6 days with prior dry conditions, compared to a 219 mm event in March 2021 that occurred over 4 days with much wetter conditions beforehand. Despite a lower rainfall volume, the March event produced significantly more inundation of the Keith Hall floodplain.

Along with these factors the risk profile of private landowners needs to be considered. For some landowners, inundation for short durations may be acceptable while for other land owners any inundation might be unacceptable. Analysis of the stage volume for the floodplain indicates that 10 mm of rainfall over a 12 hour duration may cause some level of ponding on the floodplain. However, this type of event is very frequent, occurring more than once every month on average (BOM, 2016) and will rarely actually result in floodplain inundation Subsequently, setting a closure level at 10 mm would be extremely conservative, require significant resourcing to manage, and likely cause poor water quality as the drainage network becomes flushed less frequently. Therefore, it is recommended that consultation with local landowners be used to inform a suitable risk analysis to determine when the sluice gate should be closed. A suitable risk assessment should consider community and environmental values. This may include the environmental and community values of Mobbs Bay, the receiving waters of the Keith Hall drainage network.

The optimal time to reopen the sluice gates following a flood event should also be considered. This will depend upon the time it takes for the groundwater table to lower. It may be required to allow drainage of the floodplain for periods longer than 3 days to ensure that the groundwater table can be lowered sufficiently so that it does not impact agriculture. This is discussed further in Appendix E.

Appendix E Impact of water levels on agricultural productivity

Drainage options investigated during this study focus on modifying the floodplain hydrology which has potential to impact on the agricultural productivity of the floodplain. The following investigation provides a high-level discussion based on data collected and literature available for how changes to hydrology may affect a number of agricultural practices that are known to occur on the Keith Hall floodplain. Note, while a high-level discussion is provided here, it is recommended that an agricultural scientist be consulted to provide an informed assessment of the impacts changes to the floodplain hydrology would have on agriculture and different farming practices.

One of the major changes to hydrology that will occur through the implementation of drainage options is an increased water table within the drainage network. This has potential to increase the groundwater table and impact the agricultural productivity of the floodplain (Rudd and Chardon, 1977). Understanding how an increase for in-drain water levels would impact the groundwater table is complex. Johnston et al. (2004) found that during wet times the groundwater table on a coastal floodplain is generally raised and flowing into the drainage network, while during dry times the drainage network flows the opposite way into the groundwater. They also found that the degree of this connectivity is dependent upon the hydraulic conductivity of the underlying soil with a high hydraulic conductivity resulting in a larger interaction between surface water and groundwater.

During field investigations hydraulic conductivity measurements adjacent to Keith Hall No. 1 Canal and Keith Hall No. 2 Canal were classified as moderate (Appendix A). Measurements of water levels in October 2020 (with 20-30 mm of rainfall in the week prior) showed that the groundwater table in the floodplain was similar to the water level elevation in the drain for Keith Hall No. 1 Canal. Measurements from February 2019, during a dry period, showed that the groundwater table adjacent to Keith Hall No. 1 Canal was lower indicating that water was moving from the drain into the groundwater. February 2019 measurements of the groundwater table adjacent to Keith Hall No. 2 Canal also indicated that water was moving from the drain to the groundwater. This is consistent with the observations of interaction of the groundwater and surface water outline by Johnston et al. (2004).

No hydraulic conductivity measurements were available adjacent to Union Drain, however, soil profiles sampled in October 2020 indicated that there was a wet sand layer that is likely to have medium to high hydraulic conductivity located between -0.1 m and -0.5 m AHD (Appendix A). At the time of measurement, the water level in Union Drain was also measured to be -0.1 m AHD suggesting that the groundwater table is similar to the surface water table during day-to-day conditions. Observations of local landowners has confirmed that sand lenses along Union Drain effectively transport water from the drain to the floodplain via the groundwater.

Currently, there is insufficient data to effectively determine the scale and extent of interaction between the surface water in the Keith Hall drainage network and the groundwater in the adjacent floodplain. Preliminary investigations indicate that the two are linked with a medium to high hydraulic conductivity. Subsequently, any changes to the water level in the drainage network should also consider impacts to the groundwater table and how this may affect existing land use. Further investigations are required to fully understand the extent and nature of the linkage between the groundwater and surface water at Keith Hall.

Land use across the Keith Hall floodplain mapped in 2017 by the NSW Department of Planning, Industry and Environment (DPIE, 2020) is shown in Figure E.1. The predominant land use across the floodplain is sugarcane. Grazing and minimal land use are the next largest land uses. During field investigations completed in April 2021 it was also noted that large proportions of the floodplain mapped as sugarcane land use is now being used for macadamia farming. Each of these industries are impacted differently by changes to floodplain hydrology and groundwater. A brief literature discussion is provided for how each of these land uses may be impacted by drainage options.

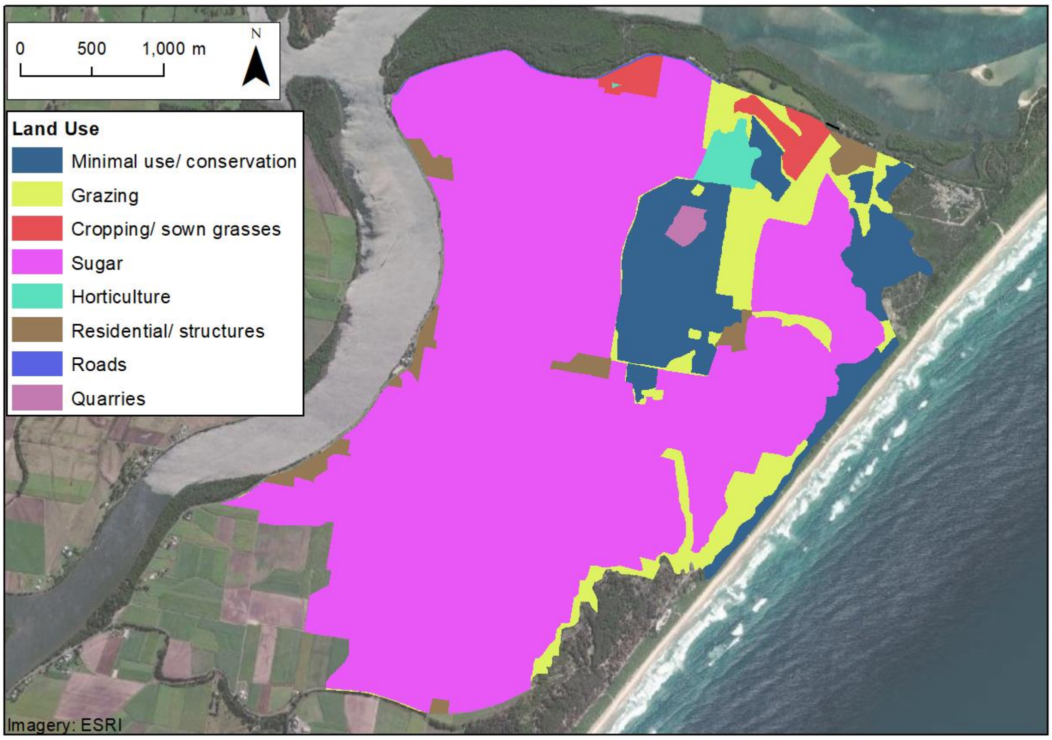


Figure E.1: Keith Hall floodplain land use (DPIE, 2020)

E1 Salt water

When introducing salt water from the estuary to the floodplain drainage network there is potential for this to impact on agriculture (Glamore, 2003). Many vegetation species (such as macadamias) are intolerant to salt and should any inundation of the floodplain or infiltration of groundwater occur this could drastically affect the productivity of the land. On the other hand, benefits of salt water can be associated with management of freshwater weeds in drainage channels and encouraging the growth of coastal wetland vegetation.

E2 Livestock grazing

Depending upon pasture types there may be different tolerances to groundwater levels. Some pastures may tolerate waterlogging, however, for improved pasture the water table is required to be between 0.3 m and 0.6 m below the ground surface and subject to a maximum of two days of waterlogging during wet periods (Stone et al. 1998).

When the water table is increased on low-lying floodplain areas there can be a heightened risk of soil pugging (Wegscheidl and Layden, 2011). This is where livestock hooves or feet sink into wet soil compressing it which can have impacts such as decreased vegetation growth for grazing as the soil structure is destroyed (Eldridge, 2004). Often this can be managed through practices such as fencing and wet pasture management.

E3 Sugarcane

Research has indicated that sugarcane requires a groundwater table to be at least 0.5 m below the ground surface (Rudd and Chardon, 1977). If any modifications to the floodplain increase the water table above this, there is potential that agricultural productivity of sugarcane could be impacted.

E4 Macadamia

Guidance on macadamia farming recommends that plants should not be grown on floodplains that are located below 1.5 m AHD (Bright, 2020). Large proportions of the Keith Hall floodplain fall within this category (Figure E.2). Note, often macadamias are planted on 0.6m high mounds for drainage (Bright, 2020) and this may assist with raising them above the required elevation. Literature recommends that macadamias be planted in soils that are free draining (Bright, 2020) with the depth of free draining soil recommended ranging from 0.75 m (DAF, 2004) to 2.0 m (Quinlan and Wilk, 2005).

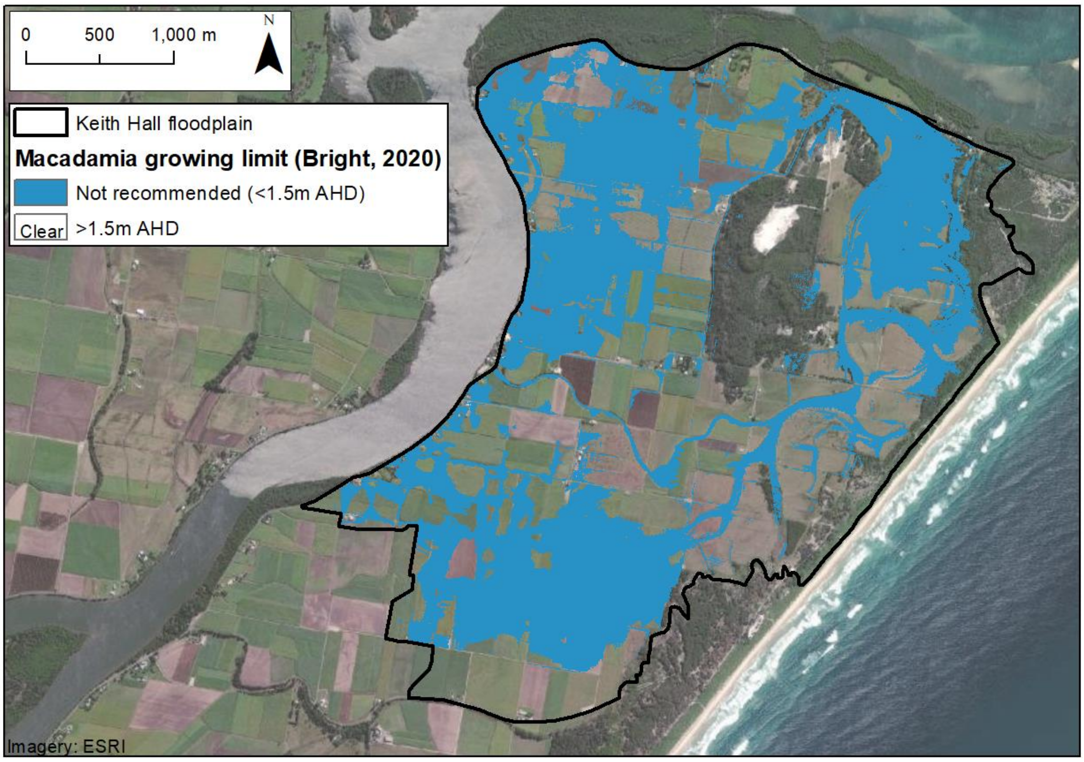
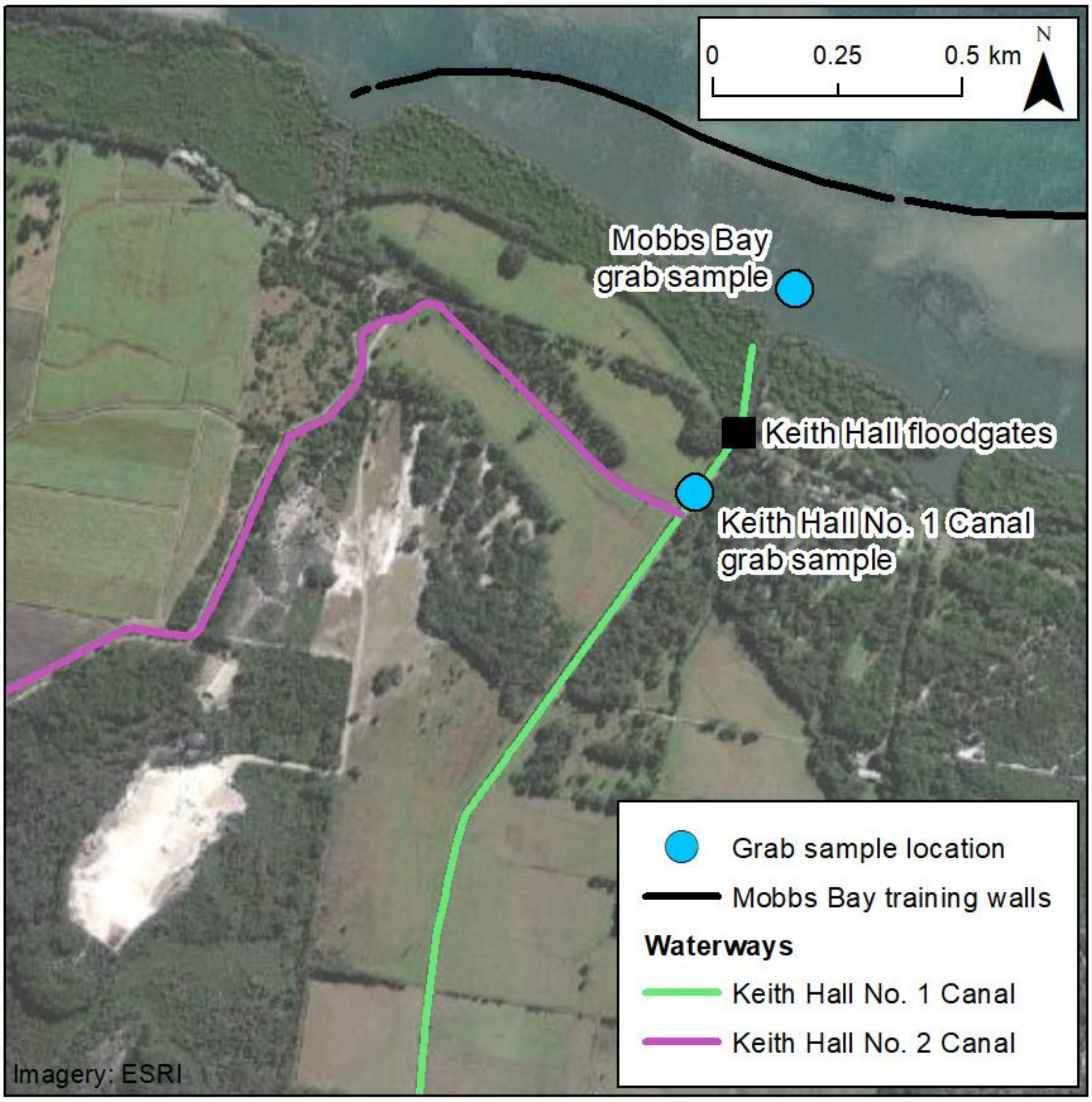


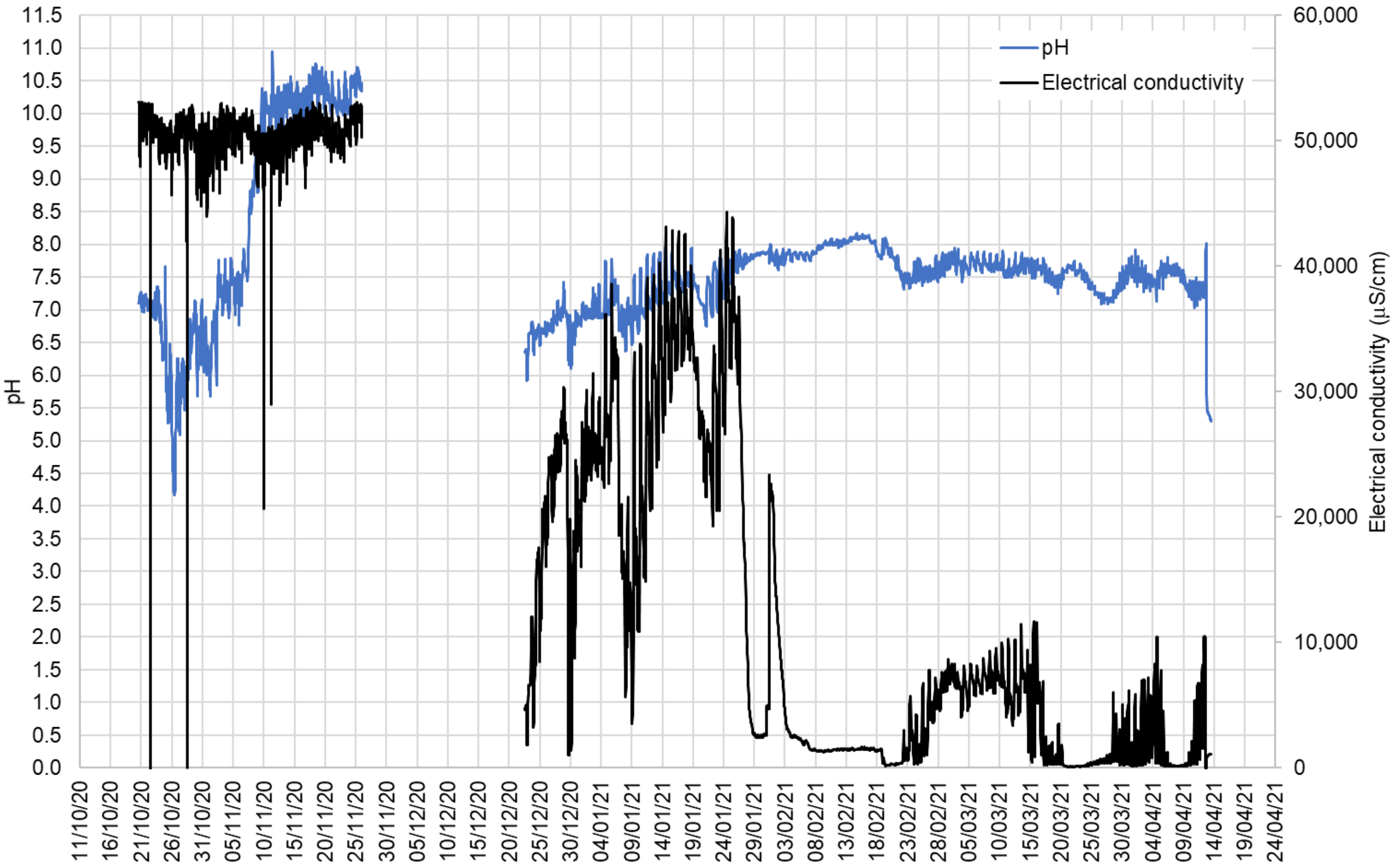
Figure E.2: Extent of Keith Hall floodplain below 1.5m AHD – the limit recommended for growing macadamia (as per Bright, 2020)

Appendix F Rous County Council water quality monitoring

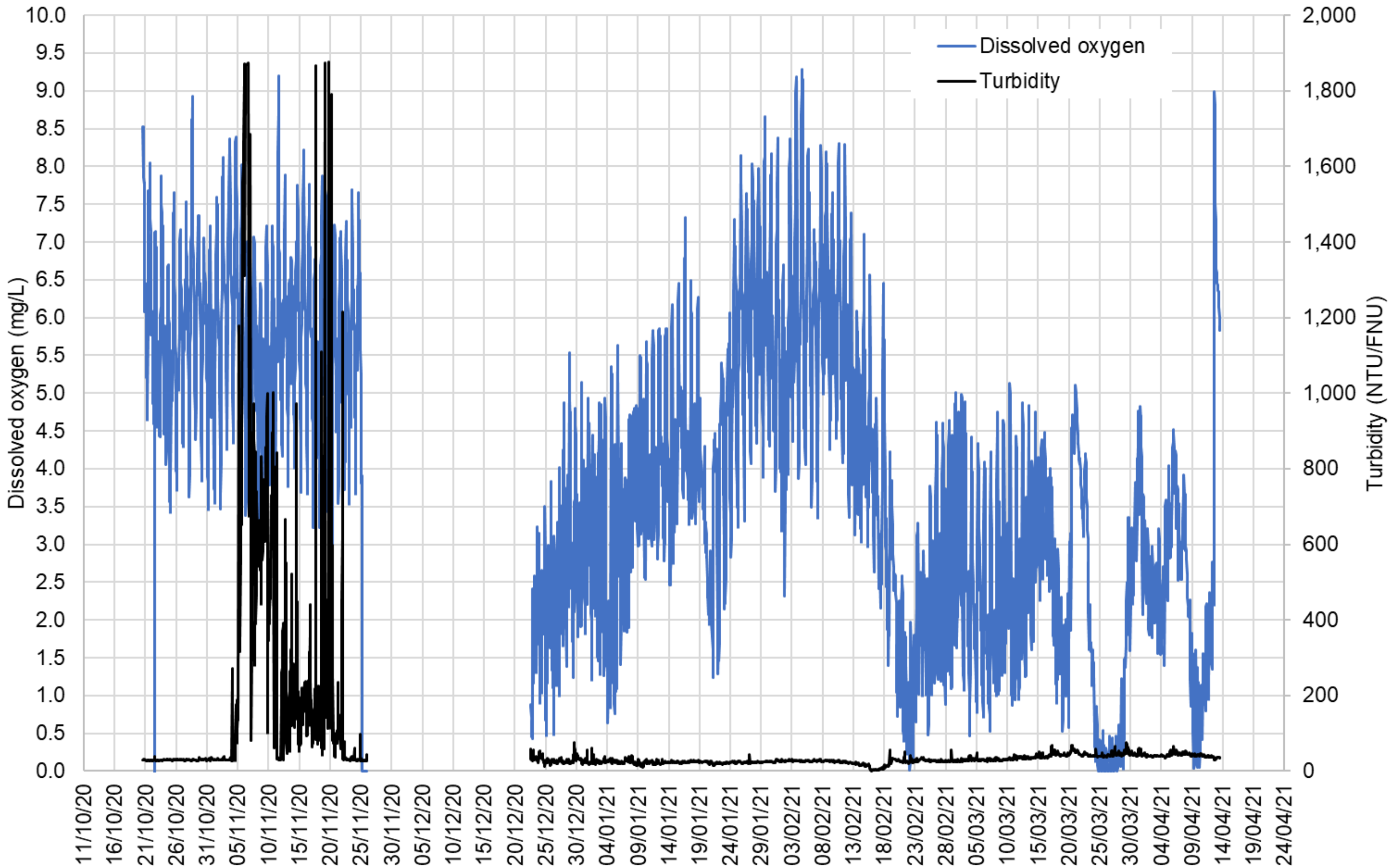
RCC completed event based sampling and long-term monitoring throughout the Keith Hall drainage network from November 2020 to April 2021. Locations where event based monitoring grab samples were taken are shown in Figure F.1. Figure F.2 and Figure F.3 show the long term monitoring data. Grab sample data tables are provided at the end of this section.



F.1: RCC grab sample sites



F.2: Long-term measurements of pH and electrical conductivity in Keith Hall No. 1 Canal (same monitoring site as the grab sample)



F.3: Long-term measurements of dissolved oxygen and turbidity in Keith Hall No. 1 Canal (same monitoring site as the grab sample)

RESULTS OF WATER ANALYSIS

2 samples supplied by Rous County Council on 16/10/2020. Lab Job No. J9543.

Samples submitted by Chrisy Clay. Your Job: Mobbs Bay, Keith Hall Drain

PO Box 230 LISMORE NSW 2480

Parameter	Methods reference	Sample 1 Mobbs Bay 16/10/20	Sample 2 Keith Hall Drain 16/10/20
	Job No.	*J9543/1*	*J9543/2*
pH	APHA 4500-H^+-B	7.96	7.59
Conductivity (EC) (dS/m)	APHA 2510-B	51.7	48.8
Total Dissolved Salts (mg/L)	** Calculation using EC x 680	35,156	33,184
Total Suspended Solids (mg/L)	GFC equiv. filter - APHA 2540-D	28	11
Bicarbonate (Alkalinity) (mg/L $CaCO_3$ equivalent)	** Total Alkalinity - APHA 2320	120	100
Acidity (mg/L CaCO3)	** -to pH 5.5 - APHA 2320	0	0
Acidity (mg/L CaCO3)	** -to pH 7.0 - APHA 2320	0	0
Acidity (mg/L CaCO3)	** -to pH 8.3 - APHA 2320	23	23
Biochemical Oxygen Demand$_5$ (mg/L O_2)	APHA 5210-B	1.6	1.5
Chemical Oxygen Demand (mg/L O_2)	** APHA 5220-D	100	110
Total Oils and Grease (mg/L)	APHA 5520-D (hexane extractable)	<2	<2
Total Phosphorus (mg/L P)	In house method W4	0.07	0.06
Phosphate (mg/L P)	APHA 4500 P-G	0.011	0.009
Total Nitrogen (mg/L N)	In house method W4	0.23	0.30
Total Kjeldahl Nitrogen (mg/L N)	** Calculation: TN – NOx	0.22	0.29
Nitrate (mg/L N)	APHA 4500 NO_3^--F	0.016	0.008
Nitrite (mg/L N)	APHA 4500 NO_2^--I	<0.005	<0.005
Ammonia (mg/L N)	APHA 4500 NH_3-H	0.023	0.059
Chloride (mg/L)	APHA 3125 ICPMS *note 1&2	17,300	16,900
Sulfate (mg/L SO_4^{2-})	APHA 3125 ICPMS *note 1&2	2,660	2,410
Chloride/Sulfate Ratio	** Calculation	6.5	7.0
Total Coliforms (cfu/100 ml)	** APHA 9222-B	390	256
E.Coli (cfu/100 ml)	** ColiBlue Membrane Filtration	44	128
Enterococci (cfu/100 ml)	** subcontracted NSW Health Pathology 377523867	83	84
Silver (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.01	<0.01
Aluminium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.028	0.064
Arsenic (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.003	0.003
Cadmium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Chromium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Copper (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	0.008
Iron (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.016	0.042
Manganese (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.010	0.018
Nickel (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.003	0.002
Lead (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Selenium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.002	0.002
Zinc (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.002	0.004
Mercury (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.0005	<0.0005
Lithium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.176	0.154
Beryllium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Boron (mg/L)	** Dissolved - APHA 3125 ICPMS *note 1&2	4.07	3.77
Silicon (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.448	0.393
Vanadium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.006	0.003
Cobalt (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Strontium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	8.49	7.72
Molybdenum (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.006	0.007
Antimony (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Barium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.009	0.010
Thallium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Bismuth (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Thorium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Uranium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.002	0.002
Calcium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	448	394
Magnesium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	1,260	1,090
Potassium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	371	337
Sodium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	11,000	9,750
Chloride (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	17,300	15,800
Sulfur (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	879	798
Phosphorus (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.09	0.12

Notes:

1. Total metals - samples digested with nitric acid; Total available (acid soluble/ extractable) metals - samples acidified with nitric acid to pH <2;
   Dissolved metals - samples filtered through 0.45µm cellulose acetate and then acidified with nitric acid prior to analysis
2. Metals and salts analysed by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
3. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 µg/L (micrograms per litre) = 1000 ppb (part per billion).
4. For conductivity 1 dS/m = 1 mS/cm = 1000 µS/cm.
5. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
6. Analysis conducted between sample arrival date and reporting date.
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11. Results relate only to the samples tested.
12. This report was issued on 26/10/2020.

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checked: ....
Graham Lancaster
Laboratory Manager

RESULTS OF WATER ANALYSIS

2 samples supplied by Rous County Council on 25/11/2020. Lab Job No. K1010.
Samples submitted by Chrisy Clay. Your Job: PO 14458
PO Box 230 LISMORE NSW 2480

Parameter	Methods reference	Sample 1 Keith Hall	Sample 2 Mobbs Bay
	Job No.	*K1010/1*	*K1010/2*
pH	APHA 4500-H$^+$-B	7.63	7.89
Conductivity (EC) (dS/m)	APHA 2510-B	46.080	53.330
Total Dissolved Salts (mg/L)	** Calculation using EC x 680	31,334	36,264
Total Suspended Solids (mg/L)	GFC equiv. filter - APHA 2540-D	9	13
Bicarbonate (Alkalinity) (mg/L $CaCO_3$ equivalent)	** Total Alkalinity - APHA 2320	127	133
Acidity (mg/L CaCO3)	** -to pH 5.5 - APHA 2320	0	0
Acidity (mg/L CaCO3)	** -to pH 7.0 - APHA 2320	0	0
Acidity (mg/L CaCO3)	** -to pH 8.3 - APHA 2320	26	22
Tannin and Lignin (mg/L)	** Inhouse	3.0	3.0
Biochemical Oxygen Demand$_5$ (mg/L O_2)	APHA 5210-B	3.0	3.0
Chemical Oxygen Demand (mg/L O_2)	** APHA 5220-D	100 (interference)	180 (interference)
Total Oils and Grease (mg/L)	APHA 5520-D (hexane extractable)	3	3
Total Phosphorus (mg/L P)	In house method W4	<0.01	<0.01
Phosphate (mg/L P)	APHA 4500 P-G	<0.005	<0.005
Total Nitrogen (mg/L N)	In house method W4	0.58	0.33
Total Kjeldahl Nitrogen (mg/L N)	** Calculation: TN – NOx	0.58	0.33
Nitrate (mg/L N)	APHA 4500 NO_3^--F	<0.005	0.006
Nitrite (mg/L N)	APHA 4500 NO_2^--I	<0.005	<0.005
Ammonia (mg/L N)	APHA 4500 NH_3-H	0.009	<0.005
Chloride (mg/L)	APHA 3125 ICPMS *note 1&2	16,750	19,412
Sulfate (mg/L SO_4^{2-})	APHA 3125 ICPMS *note 1&2	2,164	2,596
Chloride/Sulfate Ratio	** Calculation	7.7	7.5
Total Coliforms (cfu/100 ml)	** APHA 9222-B	52,000	520,020
Enterococci (cfu/100ml)	subcontracted	>200	14
E.Coli (cfu/100 ml)	** ColiBlue Membrane Filtration	<1	<1
Silver (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.010	<0.010
Aluminium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.068	0.019
Arsenic (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.002	0.002
Cadmium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Chromium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Copper (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Iron (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.109	0.013
Manganese (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.027	0.013
Nickel (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.001	<0.001
Lead (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Selenium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.002	<0.002
Zinc (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.002	0.001
Mercury (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.0005	<0.0005
Lithium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.131	0.160
Beryllium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Boron (mg/L)	** Dissolved - APHA 3125 ICPMS *note 1&2	3.51	4.12
Silicon (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	1.39	1.20
Vanadium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.003	0.004
Cobalt (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.001	<0.001
Strontium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	7.252	8.525
Molybdenum (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.008	0.010
Antimony (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Barium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.012	0.009
Thallium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001	<0.001
Bismuth (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.001	0.001
Thorium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.003	0.002
Uranium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.002	0.002
Calcium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	368	419
Magnesium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	1,067	1,251
Potassium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	324	365
Sodium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	9,162	10,932
Bromide (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	61.7	73.1

Notes:

1. Total metals - samples digested with nitric acid; Total available (acid soluble/ extractable) metals - samples acidified with nitric acid to pH <2;
   Dissolved metals - samples filtered through 0.45µm cellulose acetate and then acidified with nitric acid prior to analysis
2. Metals and salts analysed by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
3. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 µg/L (micrograms per litre) = 1000 ppb (part per billion).
4. For conductivity 1 dS/m = 1 mS/cm = 1000 µS/cm.
5. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
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11. Results relate only to the samples tested.
12. This report was issued on 08/12/2020.

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checked: ....
Graham Lancaster
Laboratory Manager

RESULTS OF WATER ANALYSIS

1 sample supplied by Rous County Council on 14/12/2020. Lab Job No. K1731.
Samples submitted by Chrisy Clay. Your Job: PO 14458
PO Box 230 LISMORE NSW 2480

Parameter	Methods reference	Sample 1 Keith Hall Drain
	Job No.	*K1731/1*
pH	APHA 4500-H^+-B	4.68
Conductivity (EC) (dS/m)	APHA 2510-B	1.409
Total Dissolved Salts (mg/L)	** Calculation using EC x 680	958
Total Suspended Solids (mg/L)	GFC equiv. filter - APHA 2540-D	27
Bicarbonate (Alkalinity) (mg/L $CaCO_3$ equivalent)	** Total Alkalinity - APHA 2320	1
Acidity (mg/L CaCO3)	** -to pH 5.5 - APHA 2320	6
Acidity (mg/L CaCO3)	** -to pH 7.0 - APHA 2320	13
Acidity (mg/L CaCO3)	** -to pH 8.3 - APHA 2320	22
Tannin and Lignin (mg/L)	** Inhouse	2.60
Biochemical Oxygen Demand$_5$ (mg/L O_2)	APHA 5210-B	2.2
Chemical Oxygen Demand (mg/L O_2)	** APHA 5220-D	44
Total Organic Carbon (mg/L)	APHA 5310-B	15.9
Total Oils and Grease (mg/L)	APHA 5520-D (hexane extractable)	3
Total Phosphorus (mg/L P)	In house method W4	0.13
Phosphate (mg/L P)	APHA 4500 P-G	0.011
Total Nitrogen (mg/L N)	In house method W4	2.99
Total Kjeldahl Nitrogen (mg/L N)	** Calculation: TN – NOx	0.58
Nitrate (mg/L N)	APHA 4500 NO_3^--F	2.375
Nitrite (mg/L N)	APHA 4500 NO_2^--I	0.033
Ammonia (mg/L N)	APHA 4500 NH_3-H	0.580
Chloride (mg/L)	APHA 3125 ICPMS*note 1&2	432
Sulfate (mg/L SO_4^{2-})	APHA 3125 ICPMS*note 1&2	102
Chloride/Sulfate Ratio	** Calculation	4.3
Total Coliforms (cfu/100 ml)	** APHA 9222-B	680
E.Coli (cfu/100 ml)	** ColiBlue Membrane Filtration	390
Enterococci (cfu/100 ml)	** Membrane Filtration	450
Silver (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.010
Aluminium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	1.65
Arsenic (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Cadmium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Chromium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Copper (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Iron (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.317
Manganese (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.094
Nickel (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.014
Lead (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Selenium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.002
Zinc (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.063
Mercury (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.0005
Lithium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.013
Beryllium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Boron (mg/L)	** Dissolved - APHA 3125 ICPMS*note 1&2	0.13
Silicon (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	6.67
Vanadium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.001
Cobalt (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.016
Strontium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.227
Molybdenum (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.001
Antimony (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Barium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.010
Thallium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Bismuth (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Thorium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Uranium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Calcium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	19.6
Magnesium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	31.4
Potassium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	11.1
Sodium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	211.0
Bromide (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	1.1

Notes:

1. Total metals - samples digested with nitric acid; Total available (acid soluble/ extractable) metals - samples acidified with nitric acid to pH <2;
   Dissolved metals - samples filtered through 0.45μm cellulose acetate and then acidified with nitric acid prior to analysis
2. Metals and salts analysed by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
3. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 μg/L (micrograms per litre) = 1000 ppb (part per billion).
4. For conductivity 1 dS/m = 1 mS/cm = 1000 μS/cm.
5. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
6. Analysis conducted between sample arrival date and reporting date.
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11. Results relate only to the samples tested.
12. This report was issued on 14/01/2021.

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Graham Lancaster
Laboratory Manager

RESULTS OF WATER ANALYSIS

1 sample supplied by Rous County Council on 18/12/2020. Lab Job No. K1855.
Samples submitted by Chrisy Clay. Your Job: RCC PO14458
PO Box 230 LISMORE NSW 2480

Parameter	Methods reference	Sample 1 Keith Hall Drain
	Job No.	K1855/1
pH	APHA 4500-H+-B	5.94
Conductivity (EC) (dS/m)	APHA 2510-B	0.418
Total Dissolved Salts (mg/L)	** Calculation using EC x 680	284
Total Suspended Solids (mg/L)	GFC equiv. filter - APHA 2540-D	20
Bicarbonate (Alkalinity) (mg/L $CaCO_3$ equivalent)	** Total Alkalinity - APHA 2320	9
Acidity (mg/L CaCO3)	** -to pH 5.5 - APHA 2320	0
Acidity (mg/L CaCO3)	** -to pH 7.0 - APHA 2320	7
Acidity (mg/L CaCO3)	** -to pH 8.3 - APHA 2320	12
Tannin and Lignin (mg/L)	** Inhouse	4.50
Biochemical Oxygen Demand$_5$ (mg/L O_2)	APHA 5210-B	2.6
Chemical Oxygen Demand (mg/L O_2)	** APHA 5220-D	81
Dissolved Organic Carbon (mg/L)	APHA 5310-B	23
Total Oils and Grease (mg/L)	APHA 5520-D (hexane extractable)	3
Total Phosphorus (mg/L P)	In house method W4	0.20
Phosphate (mg/L P)	APHA 4500 P-G	0.035
Total Nitrogen (mg/L N)	In house method W4	0.98
Total Kjeldahl Nitrogen (mg/L N)	** Calculation: TN – NOx	0.94
Nitrate (mg/L N)	APHA 4500 NO_3^--F	0.035
Nitrite (mg/L N)	APHA 4500 NO_2^--I	0.006
Ammonia (mg/L N)	APHA 4500 NH_3-H	0.132
Chloride (mg/L)	APHA 3125 ICPMS*note 1&2	91
Sulfate (mg/L SO_4^{2-})	APHA 3125 ICPMS*note 1&2	34
Chloride/Sulfate Ratio	** Calculation	2.7
Total Coliforms (cfu/100 ml)	** APHA 9222-B	4,800
E.Coli (cfu/100 ml)	** ColiBlue Membrane Filtration	120
Enterococci (cfu/100 ml)	** Membrane Filtration	100
Silver (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Aluminium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.489
Arsenic (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.001
Cadmium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Chromium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.001
Copper (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.001
Iron (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.783
Manganese (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.060
Nickel (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.006
Lead (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Selenium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Zinc (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.025
Mercury (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.0005
Lithium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.005
Beryllium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Boron (mg/L)	** Dissolved - APHA 3125 ICPMS*note 1&2	0.05
Silicon (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	5.17
Vanadium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.001
Cobalt (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.006
Strontium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.069
Molybdenum (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.001
Antimony (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Barium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.005
Thallium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Bismuth (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Thorium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Uranium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Calcium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	7.0
Magnesium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	8.3
Potassium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	4.7
Sodium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	57
Bromide (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.33

Notes:

1. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 µg/L (micrograms per litre) = 1000 ppb (part per billion).
2. For conductivity 1 dS/m = 1 mS/cm = 1000 µS/cm.
3. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
4. Analysis conducted between sample arrival date and reporting date.
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Graham Lancaster
Laboratory Manager

RESULTS OF WATER ANALYSIS

1 sample supplied by Rous County Council on 22/12/2020. Lab Job No. K1953.
Samples submitted by Chrisy Clay. Your Job: RCC PO14458
PO Box 230 LISMORE NSW 2480

Parameter	Methods reference	Sample 1 Keith Hall Drain 21/12/20
	Job No.	*K1953/1*
pH	APHA 4500-H^+-B	5.34
Conductivity (EC) (dS/m)	APHA 2510-B	1.142
Total Dissolved Salts (mg/L)	** Calculation using EC x 680	777
Total Suspended Solids (mg/L)	GFC equiv. filter - APHA 2540-D	28
Bicarbonate (Alkalinity) (mg/L $CaCO_3$ equivalent)	** Total Alkalinity - APHA 2320	5
Acidity (mg/L CaCO3)	** -to pH 5.5 - APHA 2320	1
Acidity (mg/L CaCO3)	** -to pH 7.0 - APHA 2320	15
Acidity (mg/L CaCO3)	** -to pH 8.3 - APHA 2320	11
Tannin and Lignin (mg/L)	** Inhouse	4.00
Biochemical Oxygen Demand$_5$ (mg/L O_2)	APHA 5210-B	2.4
Chemical Oxygen Demand (mg/L O_2)	** APHA 5220-D	78
Total Oils and Grease (mg/L)	APHA 5520-D (hexane extractable)	<2
Total Phosphorus (mg/L P)	In house method W4	0.12
Phosphate (mg/L P)	APHA 4500 P-G	<0.005
Total Nitrogen (mg/L N)	In house method W4	1.03
Total Kjeldahl Nitrogen (mg/L N)	** Calculation: TN – NOx	1.01
Nitrate (mg/L N)	APHA 4500 NO_3^--F	0.008
Nitrite (mg/L N)	APHA 4500 NO_2^--I	0.008
Ammonia (mg/L N)	APHA 4500 NH_3-H	0.376
Chloride (mg/L)	APHA 3125 ICPMS*note 1&2	299
Sulfate (mg/L SO_4^{2-})	APHA 3125 ICPMS*note 1&2	81
Chloride/Sulfate Ratio	** Calculation	3.7
Total Coliforms (cfu/100 ml)	** APHA 9222-B	5,200
E.Coli (cfu/100 ml)	** ColiBlue Membrane Filtration	470
Enterococci (cfu/100 ml)	** inhouse Membrane Filtration	480
Silver (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Aluminium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.661
Arsenic (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Cadmium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Chromium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Copper (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Iron (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	2.79
Manganese (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.100
Nickel (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.009
Lead (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Selenium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.002
Zinc (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.026
Mercury (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.0005
Lithium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.011
Beryllium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Boron (mg/L)	** Dissolved - APHA 3125 ICPMS*note 1&2	0.10
Silicon (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	6.89
Vanadium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.001
Cobalt (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.011
Strontium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.186
Molybdenum (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Antimony (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Barium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.009
Thallium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Bismuth (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Thorium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Uranium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Calcium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	14.7
Magnesium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	23.4
Potassium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	8
Sodium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	172
Bromide (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	1.1

Notes:

1. Total metals - samples digested with nitric acid; Total available (acid soluble/ extractable) metals - samples acidified with nitric acid to pH <2;
   Dissolved metals - samples filtered through 0.45µm cellulose acetate and then acidified with nitric acid prior to analysis
2. Metals and salts analysed by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
3. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 µg/L (micrograms per litre) = 1000 ppb (part per billion).
4. For conductivity 1 dS/m = 1 mS/cm = 1000 µS/cm.
5. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
6. Analysis conducted between sample arrival date and reporting date.
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Graham Lancaster
Laboratory Manager

RESULTS OF WATER ANALYSIS

1 sample supplied by Rous County Council on 4/01/2021 . Lab Job No. K2085.
Samples submitted by Chrisy Clay. Your Job: PO 14458
PO Box 230 LISMORE NSW 2480

Parameter	Methods reference	Sample 1 Keith Hall Drain
	Job No.	*K2085/1*
pH	APHA 4500-H^+-B	6.81
Conductivity (EC) (dS/m)	APHA 2510-B	14.460
Total Dissolved Salts (mg/L)	** Calculation using EC x 680	9,833
Total Suspended Solids (mg/L)	GFC equiv. filter - APHA 2540-D	24
Bicarbonate (Alkalinity) (mg/L $CaCO_3$ equivalent)	** Total Alkalinity - APHA 2320	52
Acidity (mg/L CaCO3)	** -to pH 5.5 - APHA 2320	0
Acidity (mg/L CaCO3)	** -to pH 7.0 - APHA 2320	1
Acidity (mg/L CaCO3)	** -to pH 8.3 - APHA 2320	10
Tannin and Lignin (mg/L)	** Inhouse	4.90
Biochemical Oxygen Demand$_5$ (mg/L O_2)	APHA 5210-B	1.6
Chemical Oxygen Demand (mg/L O_2)	** APHA 5220-D	30.0
Total Oils and Grease (mg/L)	APHA 5520-D (hexane extractable)	<2
Total Phosphorus (mg/L P)	In house method W4	0.08
Phosphate (mg/L P)	APHA 4500 P-G	0.009
Total Nitrogen (mg/L N)	In house method W4	0.63
Total Kjeldahl Nitrogen (mg/L N)	** Calculation: TN – NOx	0.61
Nitrate (mg/L N)	APHA 4500 NO_3^--F	0.009
Nitrite (mg/L N)	APHA 4500 NO_2^--I	0.012
Ammonia (mg/L N)	APHA 4500 NH_3-H	0.164
Chloride (mg/L)	APHA 3125 ICPMS*note 1&2	5,258
Sulfate (mg/L SO_4^{2-})	APHA 3125 ICPMS*note 1&2	729
Chloride/Sulfate Ratio	** Calculation	7.2
Total Coliforms (cfu/100 ml)	** APHA 9222-B	390
E.Coli (cfu/100 ml)	** ColiBlue Membrane Filtration	96
Enterococci (cfu/100 ml)	** inhouse Membrane Filtration	98
Silver (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.010
Aluminium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.146
Arsenic (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Cadmium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Chromium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Copper (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Iron (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.575
Manganese (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.112
Nickel (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.002
Lead (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Selenium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.002
Zinc (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.006
Mercury (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.0005
Lithium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.058
Beryllium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Boron (mg/L)	** Dissolved - APHA 3125 ICPMS*note 1&2	1.21
Silicon (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	5.63
Vanadium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.002
Cobalt (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.003
Strontium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	2.088
Molybdenum (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.003
Antimony (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Barium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.014
Thallium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	<0.001
Bismuth (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.001
Thorium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.002
Uranium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	0.001
Calcium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	124
Magnesium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	350
Potassium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	106
Sodium (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	2,989
Bromide (mg/L)	Dissolved - APHA 3125 ICPMS*note 1&2	17.1

Notes:

1. Total metals - samples digested with nitric acid; Total available (acid soluble/ extractable) metals - samples acidified with nitric acid to pH <2;
   Dissolved metals - samples filtered through 0.45µm cellulose acetate and then acidified with nitric acid prior to analysis
2. Metals and salts analysed by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
3. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 µg/L (micrograms per litre) = 1000 ppb (part per billion).
4. For conductivity 1 dS/m = 1 mS/cm = 1000 µS/cm.
5. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
6. Analysis conducted between sample arrival date and reporting date.
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Laboratory Manager

RESULTS OF WATER ANALYSIS

2 samples supplied by Rous County Council on 9/03/2021 . Lab Job No. K4480.
Samples submitted by Chrisy Clay. Your Job: RCC PO 14458
PO Box 230 LISMORE NSW 2480

Parameter	Methods reference	Sample 1 Keith Hall Drain	Sample 2 Mobbs Bay
	Job No.	*K4480/1*	*K4480/2*
pH	APHA 4500-H^+-B	6.02	7.17
Conductivity (EC) (dS/m)	APHA 2510-B	5.638	32.288
Total Dissolved Salts (mg/L)	** Calculation using EC x 680	3,834	21,956
Total Suspended Solids (mg/L)	GFC equiv. filter - APHA 2540-D	10	40
Bicarbonate (Alkalinity) (mg/L $CaCO_3$ equivalent)	** Total Alkalinity - APHA 2320	17	75
Acidity (mg/L CaCO3)	** -to pH 5.5 - APHA 2320	0	0
Acidity (mg/L CaCO3)	** -to pH 7.0 - APHA 2320	7	0
Acidity (mg/L CaCO3)	** -to pH 8.3 - APHA 2320	10	9
Tannin and Lignin (mg/L)	** Inhouse	4.3	2.0
Biochemical Oxygen Demand$_5$ (mg/L O_2)	APHA 5210-B	2.0	0.9
Chemical Oxygen Demand (mg/L O_2)	** APHA 5220-D	57	51
Total Oils and Grease (mg/L)	APHA 5520-D (hexane extractable)	6	3
Total Phosphorus (mg/L P)	In house method W4	0.14	0.05
Phosphate (mg/L P)	APHA 4500 P-G	0.009	0.014
Total Nitrogen (mg/L N)	In house method W4	<0.1	<0.01
Total Kjeldahl Nitrogen (mg/L N)	** Calculation: TN – NOx	<0.01	<0.01
Nitrate (mg/L N)	APHA 4500 NO_3^--F	<0.005	0.015
Nitrite (mg/L N)	APHA 4500 NO_2^--I	0.014	<0.005
Ammonia (mg/L N)	APHA 4500 NH_3-H	0.247	0.246
Chloride (mg/L)	APHA 3125 ICPMS [*note 1&2]	1,861	12,229
Sulfate (mg/L SO_4^{2-})	APHA 3125 ICPMS [*note 1&2]	286	1,580
Chloride/Sulfate Ratio	** Calculation	6.5	7.7
Total Coliforms (cfu/100 ml)	** APHA 9222-B	1,520	416
E.Coli (cfu/100 ml)	** ColiBlue Membrane Filtration	148	72
Enterococci	** Inhouse Membrane Filtration	448	252
Silver (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.010	<0.010
Aluminium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.446	0.054
Arsenic (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001	0.003
Cadmium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001	<0.001
Chromium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001	<0.001
Copper (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001	<0.001
Iron (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	1.21	0.129
Manganese (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.062	0.042
Nickel (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.003	0.001
Lead (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001	<0.001
Selenium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.002	<0.002
Zinc (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.010	<0.010
Mercury (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.0005	<0.0005
Lithium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.022	0.104
Beryllium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001	<0.001
Boron (mg/L)	** Dissolved - APHA 3125 ICPMS [*note 1&2]	0.46	2.55
Silicon (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	4.92	3.08
Vanadium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001	0.002
Cobalt (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.004	0.002
Strontium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.760	4.600
Molybdenum (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001	0.005
Antimony (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001	<0.001
Barium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.007	0.010
Thallium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001	<0.001
Bismuth (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001	<0.001
Thorium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001	0.001
Uranium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001	0.002
Calcium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	47	270
Magnesium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	119	746
Potassium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	44	242
Sodium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	997	6,513

Notes:

1. Total metals - samples digested with nitric acid; Total available (acid soluble/ extractable) metals - samples acidified with nitric acid to pH <2;
   Dissolved metals - samples filtered through 0.45μm cellulose acetate and then acidified with nitric acid prior to analysis
2. Metals and salts analysed by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
3. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 μg/L (micrograms per litre) = 1000 ppb (part per billion).
4. For conductivity 1 dS/m = 1 mS/cm = 1000 μS/cm.
5. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
6. Analysis conducted between sample arrival date and reporting date.
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Graham Lancaster
Laboratory Manager

RESULTS OF WATER ANALYSIS

1 sample supplied by Rous County Council on 23/03/2021. Lab Job No. K4996.
Samples submitted by Chrisy Clay. Your Job: RCC PO14458
PO Box 230 LISMORE NSW 2480

Parameter	Methods reference	Sample 1 Keith Hall Drain
	Job No.	*K4996/1*
pH	APHA 4500-H+-B	5.86
Conductivity (EC) (dS/m)	APHA 2510-B	0.200
Total Dissolved Salts (mg/L)	** Calculation using EC x 680	136
Total Suspended Solids (mg/L)	GFC equiv. filter - APHA 2540-D	34
Bicarbonate (Alkalinity) (mg/L $CaCO_3$ equivalent)	** Total Alkalinity - APHA 2320	10
Acidity (mg/L CaCO3)	** -to pH 5.5 - APHA 2320	0
Acidity (mg/L CaCO3)	** -to pH 7.0 - APHA 2320	16
Acidity (mg/L CaCO3)	** -to pH 8.3 - APHA 2320	29
Tannin and Lignin (mg/L)	** Inhouse	3.70
Biochemical Oxygen Demand$_5$ (mg/L O_2)	APHA 5210-B	1.5
Chemical Oxygen Demand (mg/L O_2)	** APHA 5220-D	52.0
Total Oils and Grease (mg/L)	APHA 5520-D (hexane extractable)	<2
Total Phosphorus (mg/L P)	In house method W4	0.14
Phosphate (mg/L P)	APHA 4500 P-G	0.022
Total Nitrogen (mg/L N)	In house method W4	0.85
Total Kjeldahl Nitrogen (mg/L N)	** Calculation: TN – NOx	0.85
Nitrate (mg/L N)	APHA 4500 NO_3^--F	<0.005
Nitrite (mg/L N)	APHA 4500 NO_2^--I	0.013
Ammonia (mg/L N)	APHA 4500 NH_3-H	0.015
Chloride (mg/L)	APHA 3125 ICPMS *note 1&2	59
Sulfate (mg/L SO_4^{2-})	APHA 3125 ICPMS *note 1&2	4
Chloride/Sulfate Ratio	** Calculation	14.2
Total Coliforms (cfu/100 ml)	** APHA 9222-B	2,660
E.Coli (cfu/100 ml)	** ColiBlue Membrane Filtration	208
Enterococci (cfu/100ml)	** APHA Inhouse	568
Silver (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.010
Aluminium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.597
Arsenic (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Cadmium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Chromium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.001
Copper (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.001
Iron (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	1.27
Manganese (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.030
Nickel (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Lead (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Selenium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.002
Zinc (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.009
Mercury (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.0005
Lithium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.003
Beryllium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Boron (mg/L)	** Dissolved - APHA 3125 ICPMS *note 1&2	0.11
Silicon (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	4.67
Vanadium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.001
Cobalt (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.003
Strontium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.036
Molybdenum (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Antimony (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Barium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.003
Thallium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Bismuth (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.001
Thorium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.003
Uranium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Calcium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	3.8
Magnesium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	4.3
Potassium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	2.8
Sodium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	21.8
Bromide (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.26

Notes:

1. Total metals - samples digested with nitric acid; Total available (acid soluble/ extractable) metals - samples acidified with nitric acid to pH <2;
   Dissolved metals - samples filtered through 0.45μm cellulose acetate and then acidified with nitric acid prior to analysis
2. Metals and salts analysed by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
3. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 μg/L (micrograms per litre) = 1000 ppb (part per billion).
4. For conductivity 1 dS/m = 1 mS/cm = 1000 μS/cm.
5. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
6. Analysis conducted between sample arrival date and reporting date.
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12. This report was issued on 01/04/2021.

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Graham Lancaster
Laboratory Manager

RESULTS OF WATER ANALYSIS

1 sample supplied by Rous County Council on 25/03/2021. Lab Job No. K5085.
Samples submitted by Chrisy Clay. Your Job: PO-14458
PO Box 230 LISMORE NSW 2480

Parameter	Methods reference	Sample 1 Keith Hall Drain
	Job No.	*K5085/1*
pH	APHA 4500-H^+-B	5.64
Conductivity (EC) (dS/m)	APHA 2510-B	0.415
Total Dissolved Salts (mg/L)	** Calculation using EC x 680	282
Total Suspended Solids (mg/L)	GFC equiv. filter - APHA 2540-D	22
Bicarbonate (Alkalinity) (mg/L $CaCO_3$ equivalent)	** Total Alkalinity - APHA 2320	12
Acidity (mg/L CaCO3)	** -to pH 5.5 - APHA 2320	0
Acidity (mg/L CaCO3)	** -to pH 7.0 - APHA 2320	33
Acidity (mg/L CaCO3)	** -to pH 8.3 - APHA 2320	59
Tannin and Lignin (mg/L)	** Inhouse	6.60
Biochemical Oxygen Demand$_5$ (mg/L O_2)	APHA 5210-B	5.0
Chemical Oxygen Demand (mg/L O_2)	** APHA 5220-D	111.0
Total Oils and Grease (mg/L)	APHA 5520-D (hexane extractable)	15
Total Phosphorus (mg/L P)	In house method W4	0.22
Phosphate (mg/L P)	APHA 4500 P-G	0.027
Total Nitrogen (mg/L N)	In house method W4	1.18
Total Kjeldahl Nitrogen (mg/L N)	** Calculation: TN – NOx	1.18
Nitrate (mg/L N)	APHA 4500 NO_3^--F	<0.005
Nitrite (mg/L N)	APHA 4500 NO_2^--I	0.040
Ammonia (mg/L N)	APHA 4500 NH_3-H	0.082
Chloride (mg/L)	APHA 3125 ICPMS [*note 1&2]	81
Sulfate (mg/L SO_4^{2-})	APHA 3125 ICPMS [*note 1&2]	32
Chloride/Sulfate Ratio	** Calculation	2.5
Total Coliforms (cfu/100 ml)	** APHA 9222-B	4,480
E.Coli (cfu/100 ml)	** ColiBlue Membrane Filtration	250
Enterococci (cfu/100ml)	** APHA Inhouse	210
Silver (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Aluminium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.697
Arsenic (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.001
Cadmium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Chromium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.001
Copper (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.001
Iron (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	6.41
Manganese (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.073
Nickel (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.006
Lead (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Selenium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.002
Zinc (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.019
Mercury (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.0005
Lithium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.006
Beryllium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Boron (mg/L)	** Dissolved - APHA 3125 ICPMS [*note 1&2]	0.10
Silicon (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	5.91
Vanadium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.001
Cobalt (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.007
Strontium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.081
Molybdenum (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.001
Antimony (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Barium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.008
Thallium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Bismuth (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Thorium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.010
Uranium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Calcium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	7.6
Magnesium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	8.4
Potassium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	3.7
Sodium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	61.4
Bromide (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.36

Notes:

1. Total metals - samples digested with nitric acid; Total available (acid soluble/ extractable) metals - samples acidified with nitric acid to pH <2;
   Dissolved metals - samples filtered through 0.45μm cellulose acetate and then acidified with nitric acid prior to analysis
2. Metals and salts analysed by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
3. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 μg/L (micrograms per litre) = 1000 ppb (part per billion).
4. For conductivity 1 dS/m = 1 mS/cm = 1000 μS/cm.
5. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
6. Analysis conducted between sample arrival date and reporting date.
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Graham Lancaster
Laboratory Manager

RESULTS OF WATER ANALYSIS

1 sample supplied by Rous County Council on 30/03/2021. Lab Job No. K5180.
Samples submitted by Chrisy Clay. Your Job: RCC PO 14458
PO Box 230 LISMORE NSW 2480

Parameter	Methods reference	Sample 1 Keith Hall Drain
	Job No.	*K5180/1*
pH	APHA 4500-H⁺-B	5.70
Conductivity (EC) (dS/m)	APHA 2510-B	0.821
Total Dissolved Salts (mg/L)	** Calculation using EC x 680	558
Total Suspended Solids (mg/L)	GFC equiv. filter - APHA 2540-D	31
Bicarbonate (Alkalinity) (mg/L $CaCO_3$ equivalent)	** Total Alkalinity - APHA 2320	13
Acidity (mg/L CaCO3)	** -to pH 5.5 - APHA 2320	0
Acidity (mg/L CaCO3)	** -to pH 7.0 - APHA 2320	20
Acidity (mg/L CaCO3)	** -to pH 8.3 - APHA 2320	41
Tannin and Lignin (mg/L)	** Inhouse	6.10
Biochemical Oxygen Demand$_5$ (mg/L O_2)	APHA 5210-B	2.4
Chemical Oxygen Demand (mg/L O_2)	** APHA 5220-D	93.0
Total Oils and Grease (mg/L)	APHA 5520-D (hexane extractable)	3
Total Phosphorus (mg/L P)	In house method W4	0.13
Phosphate (mg/L P)	APHA 4500 P-G	0.022
Total Nitrogen (mg/L N)	In house method W4	1.08
Total Kjeldahl Nitrogen (mg/L N)	** Calculation: TN – NOx	1.06
Nitrate (mg/L N)	APHA 4500 NO_3^--F	<0.005
Nitrite (mg/L N)	APHA 4500 NO_2^--I	0.023
Ammonia (mg/L N)	APHA 4500 NH_3-H	0.288
Chloride (mg/L)	APHA 3125 ICPMS *note 1&2	170
Sulfate (mg/L SO_4^{2-})	APHA 3125 ICPMS *note 1&2	64
Chloride/Sulfate Ratio	** Calculation	2.6
Total Coliforms (cfu/100 ml)	** APHA 9222-B	1,622
E.Coli (cfu/100 ml)	** ColiBlue Membrane Filtration	102
Enterococci	Inhouse	60
Silver (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Aluminium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.704
Arsenic (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.002
Cadmium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Chromium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.001
Copper (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Iron (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	5.65
Manganese (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.086
Nickel (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.006
Lead (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Selenium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.002
Zinc (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.024
Mercury (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.0005
Lithium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.009
Beryllium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Boron (mg/L)	** Dissolved - APHA 3125 ICPMS *note 1&2	0.20
Silicon (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	7.21
Vanadium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.002
Cobalt (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.007
Strontium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.143
Molybdenum (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.003
Antimony (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Barium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.007
Thallium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Bismuth (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Thorium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Uranium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001

Notes:

1. Total metals - samples digested with nitric acid; Total available (acid soluble/ extractable) metals - samples acidified with nitric acid to pH <2;
   Dissolved metals - samples filtered through 0.45μm cellulose acetate and then acidified with nitric acid prior to analysis
2. Metals and salts analysed by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
3. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 μg/L (micrograms per litre) = 1000 ppb (part per billion).
4. For conductivity 1 dS/m = 1 mS/cm = 1000 μS/cm.
5. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
6. Analysis conducted between sample arrival date and reporting date.
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Graham Lancaster
Laboratory Manager

RESULTS OF WATER ANALYSIS

1 sample supplied by Rous County Council on 1/04/2021 . Lab Job No. K5291.
Samples submitted by Chrisy Clay. Your Job: RCC PO 14458
PO Box 230 LISMORE NSW 2480

Parameter	Methods reference	Sample 1 Keith Hall Drain
	Job No.	*K5291/1*
pH	APHA 4500-H$^+$-B	6.12
Conductivity (EC) (dS/m)	APHA 2510-B	0.469
Total Dissolved Salts (mg/L)	** Calculation using EC x 680	319
Total Suspended Solids (mg/L)	GFC equiv. filter - APHA 2540-D	11
Bicarbonate (Alkalinity) (mg/L $CaCO_3$ equivalent)	** Total Alkalinity - APHA 2320	10
Acidity (mg/L CaCO3)	** -to pH 5.5 - APHA 2320	0
Acidity (mg/L CaCO3)	** -to pH 7.0 - APHA 2320	13
Acidity (mg/L CaCO3)	** -to pH 8.3 - APHA 2320	29
Tannin and Lignin (mg/L)	** Inhouse	4.50
Biochemical Oxygen Demand$_5$ (mg/L O_2)	APHA 5210-B	2.0
Chemical Oxygen Demand (mg/L O_2)	** APHA 5220-D	54
Total Oils and Grease (mg/L)	APHA 5520-D (hexane extractable)	<2
Total Phosphorus (mg/L P)	In house method W4	0.12
Phosphate (mg/L P)	APHA 4500 P-G	0.008
Total Nitrogen (mg/L N)	In house method W4	0.92
Total Kjeldahl Nitrogen (mg/L N)	** Calculation: TN – NOx	0.93
Nitrate (mg/L N)	APHA 4500 NO_3^--F	0.014
Nitrite (mg/L N)	APHA 4500 NO_2^--I	0.014
Ammonia (mg/L N)	APHA 4500 NH_3-H	0.184
Chloride (mg/L)	APHA 3125 ICPMS [*note 1&2]	104
Sulfate (mg/L SO_4^{2-})	APHA 3125 ICPMS [*note 1&2]	32
Chloride/Sulfate Ratio	** Calculation	3.2
Total Coliforms (cfu/100 ml)	** APHA 9222-B	1,330
E.Coli (cfu/100 ml)	** ColiBlue Membrane Filtration	760
Enterococci	Inhouse	490
Silver (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Aluminium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.614
Arsenic (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.001
Cadmium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Chromium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.001
Copper (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.001
Iron (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	2.592
Manganese (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.053
Nickel (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.005
Lead (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Selenium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.002
Zinc (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.020
Mercury (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.0005
Lithium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.006
Beryllium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Boron (mg/L)	** Dissolved - APHA 3125 ICPMS [*note 1&2]	0.04
Silicon (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	7.93
Vanadium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.001
Cobalt (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.005
Strontium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.077
Molybdenum (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Antimony (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Barium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.004
Thallium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Bismuth (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Thorium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.001
Uranium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001

Notes:

1. Total metals - samples digested with nitric acid; Total available (acid soluble/ extractable) metals - samples acidified with nitric acid to pH <2;
   Dissolved metals - samples filtered through 0.45μm cellulose acetate and then acidified with nitric acid prior to analysis
2. Metals and salts analysed by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
3. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 μg/L (micrograms per litre) = 1000 ppb (part per billion).
4. For conductivity 1 dS/m = 1 mS/cm = 1000 μS/cm.
5. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
6. Analysis conducted between sample arrival date and reporting date.
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12. This report was issued on 15/04/2021.

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Graham Lancaster
Laboratory Manager

RESULTS OF WATER ANALYSIS

1 sample supplied by Rous County Council on 8/04/2021 . Lab Job No. K5509.
Samples submitted by Chrisy Clay. Your Job: RCC PO14458
PO Box 230 LISMORE NSW 2480

Parameter	Methods reference	Sample 1 Keith Hall Drain
	Job No.	*K5509/1*
pH	APHA 4500-H^+-B	5.97
Conductivity (EC) (dS/m)	APHA 2510-B	0.222
Total Dissolved Salts (mg/L)	** Calculation using EC x 680	151
Total Suspended Solids (mg/L)	GFC equiv. filter - APHA 2540-D	15
Bicarbonate (Alkalinity) (mg/L $CaCO_3$ equivalent)	** Total Alkalinity - APHA 2320	11
Acidity (mg/L CaCO3)	** -to pH 5.5 - APHA 2320	0
Acidity (mg/L CaCO3)	** -to pH 7.0 - APHA 2320	14
Acidity (mg/L CaCO3)	** -to pH 8.3 - APHA 2320	27
Tannin and Lignin (mg/L)	** Inhouse	0.90
Biochemical Oxygen Demand$_5$ (mg/L O_2)	APHA 5210-B	2.3
Chemical Oxygen Demand (mg/L O_2)	** APHA 5220-D	51
Total Oils and Grease (mg/L)	APHA 5520-D (hexane extractable)	2
Total Phosphorus (mg/L P)	In house method W4	0.30
Phosphate (mg/L P)	APHA 4500 P-G	0.031
Total Nitrogen (mg/L N)	In house method W4	0.48
Total Kjeldahl Nitrogen (mg/L N)	** Calculation: TN – NOx	0.47
Nitrate (mg/L N)	APHA 4500 NO_3^--F	<0.005
Nitrite (mg/L N)	APHA 4500 NO_2^--I	0.014
Ammonia (mg/L N)	APHA 4500 NH_3-H	0.031
Chloride (mg/L)	APHA 3125 ICPMS *note 1&2	40
Sulfate (mg/L SO_4^{2-})	APHA 3125 ICPMS *note 1&2	11
Chloride/Sulfate Ratio	** Calculation	3.8
Total Coliforms (cfu/100 ml)	** APHA 9222-B	9,500
E.Coli (cfu/100 ml)	** ColiBlue Membrane Filtration	880
Enterococci (cfu/100 ml)	** Inhouse	760
Silver (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Aluminium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.472
Arsenic (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Cadmium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Chromium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Copper (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Iron (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	1.59
Manganese (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.022
Nickel (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.004
Lead (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Selenium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.002
Zinc (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.004
Mercury (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.0005
Lithium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.003
Beryllium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Boron (mg/L)	** Dissolved - APHA 3125 ICPMS *note 1&2	0.06
Silicon (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	4.50
Vanadium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.001
Cobalt (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.002
Strontium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.033
Molybdenum (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Antimony (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Barium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.003
Thallium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Bismuth (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Thorium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Uranium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Calcium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	3.7
Magnesium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	4.5
Potassium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	2.9
Sodium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	30.6

Notes:

1. Total metals - samples digested with nitric acid; Total available (acid soluble/ extractable) metals - samples acidified with nitric acid to pH <2;
   Dissolved metals - samples filtered through 0.45μm cellulose acetate and then acidified with nitric acid prior to analysis
2. Metals and salts analysed by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
3. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 μg/L (micrograms per litre) = 1000 ppb (part per billion).
4. For conductivity 1 dS/m = 1 mS/cm = 1000 μS/cm.
5. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
6. Analysis conducted between sample arrival date and reporting date.
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12. This report was issued on 21/04/2021.

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Graham Lancaster
Laboratory Manager

RESULTS OF WATER ANALYSIS

1 sample supplied by Rous County Council on 13/04/2021. Lab Job No. K5624.
Samples submitted by Chrisy Clay. Your Job: RCC PO 14458
PO Box 230 LISMORE NSW 2480

Parameter	Methods reference	Sample 1 Keith Hall Drain 12/4/21
	Job No.	*K5624/1*
pH	APHA 4500-H^+-B	5.83
Conductivity (EC) (dS/m)	APHA 2510-B	0.747
Total Dissolved Salts (mg/L)	** Calculation using EC x 680	508
Total Suspended Solids (mg/L)	GFC equiv. filter - APHA 2540-D	20
Bicarbonate (Alkalinity) (mg/L $CaCO_3$ equivalent)	** Total Alkalinity - APHA 2320	15
Acidity (mg/L CaCO3)	** -to pH 5.5 - APHA 2320	<1
Acidity (mg/L CaCO3)	** -to pH 7.0 - APHA 2320	22
Acidity (mg/L CaCO3)	** -to pH 8.3 - APHA 2320	42
Tannin and Lignin (mg/L)	** Inhouse	6.6
Biochemical Oxygen Demand$_5$ (mg/L O_2)	APHA 5210-B	2.5
Chemical Oxygen Demand (mg/L O_2)	** APHA 5220-D	98
Total Oils and Grease (mg/L)	APHA 5520-D (hexane extractable)	<2
Total Phosphorus (mg/L P)	In house method W4	0.12
Phosphate (mg/L P)	APHA 4500 P-G	0.020
Total Nitrogen (mg/L N)	In house method W4	1.32
Total Kjeldahl Nitrogen (mg/L N)	** Calculation: TN – NOx	1.30
Nitrate (mg/L N)	APHA 4500 NO_3^--F	<0.005
Nitrite (mg/L N)	APHA 4500 NO_2^--I	0.030
Ammonia (mg/L N)	APHA 4500 NH_3-H	0.139
Chloride (mg/L)	APHA 3125 ICPMS [*note 1&2]	182
Sulfate (mg/L SO_4^{2-})	APHA 3125 ICPMS [*note 1&2]	38
Chloride/Sulfate Ratio	** Calculation	4.7
Total Coliforms (cfu/100 ml)	** APHA 9222-B	3,040
E.Coli (cfu/100 ml)	** ColiBlue Membrane Filtration	80
Enterococci (cfu/100 ml)	inhouse	58
Silver (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Aluminium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.703
Arsenic (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.001
Cadmium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Chromium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.001
Copper (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Iron (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	5.16
Manganese (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.076
Nickel (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.005
Lead (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Selenium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.002
Zinc (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.014
Mercury (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.0005
Lithium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.007
Beryllium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Boron (mg/L)	** Dissolved - APHA 3125 ICPMS [*note 1&2]	0.05
Silicon (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	6.12
Vanadium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.001
Cobalt (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.006
Strontium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.123
Molybdenum (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Antimony (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Barium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	0.005
Thallium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Bismuth (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Thorium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Uranium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	<0.001
Calcium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	9.79
Magnesium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	16.4
Potassium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	5.79
Sodium (mg/L)	Dissolved - APHA 3125 ICPMS [*note 1&2]	113

Notes:

1. Total metals - samples digested with nitric acid; Total available (acid soluble/ extractable) metals - samples acidified with nitric acid to pH <2;
   Dissolved metals - samples filtered through 0.45μm cellulose acetate and then acidified with nitric acid prior to analysis
2. Metals and salts analysed by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
3. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 μg/L (micrograms per litre) = 1000 ppb (part per billion).
4. For conductivity 1 dS/m = 1 mS/cm = 1000 μS/cm.
5. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
6. Analysis conducted between sample arrival date and reporting date.
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Laboratory Manager

RESULTS OF WATER ANALYSIS

1 sample supplied by Rous County Council on 21/04/2021. Lab Job No. K5965.
Samples submitted by Chrisy Clay. Your Job: RCC PO 14458
PO Box 230 LISMORE NSW 2480

Parameter	Methods reference	Sample 1 Keith Hall Drain 21/04/21
	Job No.	*K5965/1*
pH	APHA 4500-H^+-B	5.90
Conductivity (EC) (dS/m)	APHA 2510-B	2.58
Total Dissolved Salts (mg/L)	** Calculation using EC x 680	1,754
Total Suspended Solids (mg/L)	GFC equiv. filter - APHA 2540-D	16
Bicarbonate (Alkalinity) (mg/L $CaCO_3$ equivalent)	** Total Alkalinity - APHA 2320	17
Acidity (mg/L CaCO3)	** -to pH 5.5 - APHA 2320	<1
Acidity (mg/L CaCO3)	** -to pH 7.0 - APHA 2320	19
Acidity (mg/L CaCO3)	** -to pH 8.3 - APHA 2320	40
Tannin and Lignin (mg/L)	** Inhouse	0.40
Biochemical Oxygen Demand$_5$ (mg/L O_2)	APHA 5210-B	1.4
Chemical Oxygen Demand (mg/L O_2)	** APHA 5220-D	84
Total Oils and Grease (mg/L)	APHA 5520-D (hexane extractable)	<2
Total Phosphorus (mg/L P)	In house method W4	0.08
Phosphate (mg/L P)	APHA 4500 P-G	0.078
Total Nitrogen (mg/L N)	In house method W4	0.81
Total Kjeldahl Nitrogen (mg/L N)	** Calculation: TN – NOx	0.81
Nitrate (mg/L N)	APHA 4500 NO_3^--F	<0.05
Nitrite (mg/L N)	APHA 4500 NO_2^--I	<0.05
Ammonia (mg/L N)	APHA 4500 NH_3-H	0.267
Chloride (mg/L)	APHA 3125 ICPMS *note 1&2	681
Sulfate (mg/L SO_4^{2-})	APHA 3125 ICPMS *note 1&2	115
Chloride/Sulfate Ratio	** Calculation	5.9
Total Coliforms (cfu/100 ml)	** APHA 9222-B	760
E.Coli (cfu/100 ml)	** ColiBlue Membrane Filtration	90
Enterococci (cfu/100 ml)	inhouse	124
Silver (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Aluminium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.635
Arsenic (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Cadmium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Chromium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.001
Copper (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Iron (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	4.48
Manganese (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.050
Nickel (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.004
Lead (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Selenium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.002
Zinc (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.011
Mercury (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.0005
Lithium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.011
Beryllium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Boron (mg/L)	** Dissolved - APHA 3125 ICPMS *note 1&2	0.17
Silicon (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	6.67
Vanadium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.001
Cobalt (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.005
Strontium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.361
Molybdenum (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Antimony (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Barium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	0.006
Thallium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Bismuth (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Thorium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Uranium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	<0.001
Calcium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	22.7
Magnesium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	48.3
Potassium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	14.2
Sodium (mg/L)	Dissolved - APHA 3125 ICPMS *note 1&2	404

Notes:

1. Total metals - samples digested with nitric acid; Total available (acid soluble/ extractable) metals - samples acidified with nitric acid to pH <2;
   Dissolved metals - samples filtered through 0.45μm cellulose acetate and then acidified with nitric acid prior to analysis
2. Metals and salts analysed by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
3. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 μg/L (micrograms per litre) = 1000 ppb (part per billion).
4. For conductivity 1 dS/m = 1 mS/cm = 1000 μS/cm.
5. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
6. Analysis conducted between sample arrival date and reporting date.
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11. Results relate only to the samples tested.
12. This report was issued on 27/04/2021.

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Graham Lancaster
Laboratory Manager

RESULTS OF WATER ANALYSIS

1 sample supplied by Rous County Council on 27/04/2021. Lab Job No. K6222.
Samples submitted by Chrisy Clay. Your Job: RCC PO14458
PO Box 230 LISMORE NSW 2480

Parameter	Methods reference	Sample 1 Keith Hall Drain
	Job No.	*K6222/1*
pH	APHA 4500-H⁺-B	6.45
Conductivity (EC) (dS/m)	APHA 2510-B	15.0
Total Dissolved Salts (mg/L)	** Calculation using EC x 680	10,201
Total Suspended Solids (mg/L)	GFC equiv. filter - APHA 2540-D	20
Bicarbonate (Alkalinity) (mg/L $CaCO_3$ equivalent)	** Total Alkalinity - APHA 2320	42
Acidity (mg/L CaCO3)	** -to pH 5.5 - APHA 2320	<1
Acidity (mg/L CaCO3)	** -to pH 7.0 - APHA 2320	15
Acidity (mg/L CaCO3)	** -to pH 8.3 - APHA 2320	49
Tannin and Lignin (mg/L)	** Inhouse	6.0
Biochemical Oxygen Demand$_5$ (mg/L O_2)	APHA 5210-B	1.0
Chemical Oxygen Demand (mg/L O_2)	** APHA 5220-D	124
Total Oils and Grease (mg/L)	APHA 5520-D (hexane extractable)	6
Total Phosphorus (mg/L P)	In house method W4	0.05
Phosphate (mg/L P)	APHA 4500 P-G	0.011
Total Nitrogen (mg/L N)	In house method W4	0.73
Total Kjeldahl Nitrogen (mg/L N)	** Calculation: TN – NOx	0.73
Nitrate (mg/L N)	APHA 4500 NO_3-F	<0.005
Nitrite (mg/L N)	APHA 4500 NO_2-I	0.012
Ammonia (mg/L N)	APHA 4500 NH_3-H	0.290
Chloride (mg/L)	APHA 3125 ICPMS[note 1&2]	5,093
Sulfate (mg/L SO_4^{2-})	APHA 3125 ICPMS[note 1&2]	686
Chloride/Sulfate Ratio	** Calculation	7.4
Total Coliforms (cfu/100 ml)	** APHA 9222-B	404
E.Coli (cfu/100 ml)	** ColiBlue Membrane Filtration	144
Enterococci (cfu/100 ml)	**inhouse	312
Silver (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	<0.001
Aluminium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	0.251
Arsenic (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	<0.001
Cadmium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	<0.001
Chromium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	<0.001
Copper (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	<0.001
Iron (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	1.24
Manganese (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	0.041
Nickel (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	0.002
Lead (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	<0.001
Selenium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	<0.002
Zinc (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	0.006
Mercury (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	<0.0005
Lithium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	0.041
Beryllium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	<0.001
Boron (mg/L)	** Dissolved - APHA 3125 ICPMS[note 1&2]	1.02
Silicon (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	4.05
Vanadium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	0.001
Cobalt (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	0.002
Strontium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	2.46
Molybdenum (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	0.003
Antimony (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	<0.001
Barium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	0.010
Thallium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	<0.001
Bismuth (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	<0.001
Thorium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	<0.001
Uranium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	<0.001
Calcium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	115
Magnesium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	332
Potassium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	100
Sodium (mg/L)	Dissolved - APHA 3125 ICPMS[note 1&2]	2,832

Notes:

1. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 µg/L (micrograms per litre) = 1000 ppb (part per billion).
2. For conductivity 1 dS/m = 1 mS/cm = 1000 µS/cm.
3. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
4. Analysis conducted between sample arrival date and reporting date.
5. ** NATA accreditation does not cover the performance of this service.
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9. Results relate only to the samples tested.
10. This report was issued on 06/05/2021.

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checked: ....
Graham Lancaster
Laboratory Manager