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Clybucca Wetlands Management Options Study

WRL TR 2018/32 | October 2020

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Executive summary

ES.1 Background

The Collombatti-Clybuca floodplain, inclusive of the Clybuca Wetlands, is located on the Macleay River estuary floodplain. The floodplain is located approximately 15 kilometres from the ocean entrance at South West Rocks and has a contributing catchment area of approximately 26,000 hectares. Runoff from the catchment is channelled across the floodplain through a complex network of natural creeks and constructed drainage channels (Figure ES1.1). Downstream water levels within this network are controlled by a tidal floodgate barrage structure located at Menarcobrinni that drains the upstream waters and prohibits tidal inundation from the river.

Historically, the Clybuca Wetlands were a large freshwater wetland complex that extended across the floodplain and was disconnected from the estuary. Early explorers to the area described the Clybuca Wetlands as:

“Extensive swamps and lagoons of many thousand acres in extent, whose verdant sea, of high waving reeds and sedge, stretches away to the base of the distant forest ranges. Large flocks of aquatic birds, of wonderful variety, all busily engaged, and fish leaping out of the water in every direction.”

During the early 1960s, large drainage construction works were completed across the Macleay River estuary, including at Clybuca Wetlands, for flood mitigation purposes. These on-ground works modified the creek system and enhanced drainage. This resulted in improved connectivity with downstream tidal waters and a tidal barrage was subsequently required at Menarcobrinni to prevent tidal inundation. In addition to flood mitigation, this infrastructure enhanced the agricultural productivity of the low-lying land for pasture grazing.

The extensive drainage network has had unintended environmental impacts, including the production of acidic by-products from the drainage of acid sulfate soils (ASS) and exacerbation of ‘blackwater’ (i.e. low-oxygen water) runoff into the estuary which has been extensively documented in previous studies (Walker, 1961, 1963 1972; Naylor *et al.*, 1998; Webb McKeown, 1997; Tulau and Naylor, 1999; Cheeseman *et al.*, 2004; KSC, 2004; Andrews *et al.*, 2005; Chartres *et al.*, 2005; McLennan *et al.*, 2005; Telfer, 2005; Bush *et al.*, 2006; Birch, 2010; GeoLINK, 2010; GeoLINK, 2012). As such, the Collombatti-Clybuca floodplain was identified as an acid sulfate soil hotspot priority area in NSW (Tulau and Naylor, 1999). On-ground remediation efforts during the 1990s

resulted in the construction of low sills/weirs in the trunk drain network. These works aimed to raise groundwater levels and reduce acid export without impacting agricultural productivity. The remediation of large acid scalds was also undertaken. Despite these efforts, poor water quality, including low pH and low dissolved oxygen, continues to discharge from the low-lying floodplain areas at Clybucca.

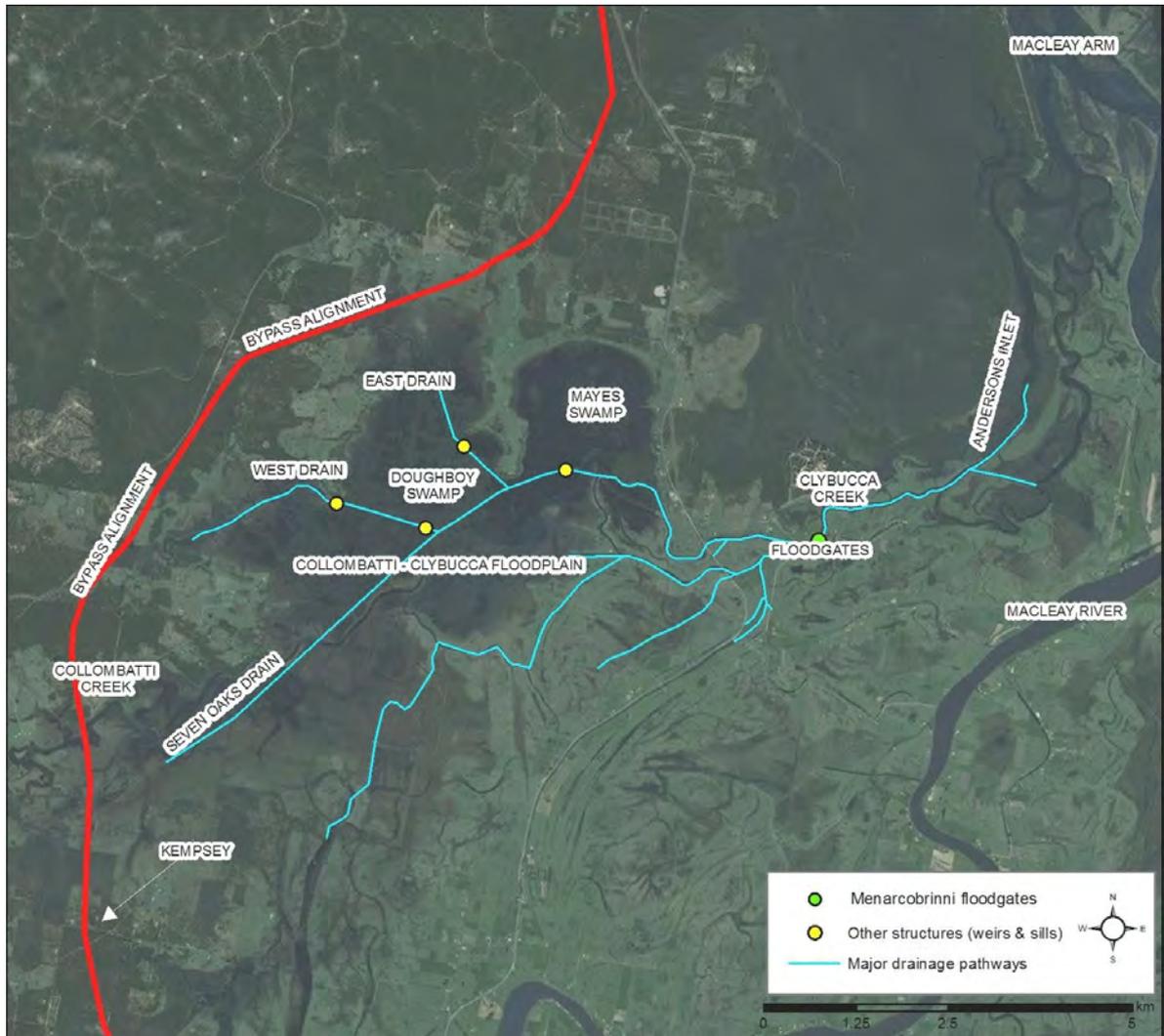


Figure ES1.1: Key features of the Collombatti-Clybucca floodplain

During the Oxley Highway to Kempsey Pacific Highway upgrade project, Transport for NSW (previously NSW Roads and Maritime Services (RMS)) purchased a proportion of the Clybucca wetland complex as part of the biodiversity offset requirements of the project. Elevated land (above the floodplain) was originally purchased as biodiversity offsets for the habitat offset requirement including, wet sclerophyll forest. However, in several instances the property boundaries extended to the low-lying Clybucca Wetland areas of Mayes Swamp and Doughboy Swamp. This provided a

unique opportunity where one entity owned the majority of the worst affected acid sulfate soil land across the Collombatti-Clybucca floodplain. Further voluntary acquisitions of low-lying land have occurred over the proceeding years to extend the area owned by TfNSW. The NSW Environment Protection Authority have also approved a supplementary offset strategy whereby wetland habitats acquired/restored can be used as biodiversity offsets in place of other habitat types. This opportunity has led to the development of large-scale remediation strategies for the ASS affected wetland areas.

The aim of this study is to investigate the feasibility and potential impact of each management option, not only in terms of water quality and wetland extent, but also any potential impact on floodplain inundation, drainage and saltwater intrusion. The options detailed in this investigation provide a range of strategies aimed at improving existing or potential future wetland habitats via the restoration of a natural wetting and drying regime. Any suggested on-ground works are tested to ensure that they improve surface water quality, by reducing acid drainage from the Clybucca floodplain, while not impacting adjacent landholders. Additional outcomes from the study include a detailed literature review, extensive field surveys and monitoring, and validated catchment and hydrodynamic numerical models.

The management options investigated in this study were developed based on extensive field surveys and site understanding with input from the Clybucca Government Working Group. The working group consists of representatives from Local Land Services, Kempsey Shire Council, National Parks and Wildlife Services, Department of Planning, Industry and Environment (formerly OEH), Department of Primary Industry – Fisheries, TfNSW, NSW EPA and Crown Lands. Community feedback and discussions were an integral contribution to the outcomes of this study. Local landholders, the Seven Oaks Drainage Union, local community groups, and relevant government agencies were consulted on their views regarding a sustainable management solution for the study area. Information gathered from the feedback sessions was included in the development of the management options and integrated with model outputs to establish viable remediation strategies for the study area. Funding for this study has been provided by the Saltwater Recreational Fishing Trust's Flagship Fish Habitat Action Program.

ES.2 Management Options Summary

The management options were developed to mitigate the effects of poor water quality and provide improved hydrological conditions that are more representative of natural wetting and drying conditions common in estuarine backswamp environments. The overall approach of the development of management options was to enable adaptable management onsite, considering

factors such as climate change and land ownership, and allow strategic floodplain management to ensure that wetland habitat thrives, resulting in the safekeeping of the estuary health into the future. Management options range from land only options (with no modifications to the drainage infrastructure), to freshwater only management options, to a full tidal remediation scenario. The management options that were assessed as part of this study are summarised in Table ES2.1.

Management options were investigated to understand, not only the potential environmental benefits, but also the impact on surrounding properties, relating to:

- Floodplain inundation;
- Drainage times; and,
- Saltwater intrusion.

Comprehensive field investigations were completed across the Collombatti-Clybucca floodplain to develop a detailed hydrodynamic model. This model was constructed to represent the floodplain as it exists today and collected data was input into the model to verify its ability to replicate the present day conditions (often referred to as the “Base Case”). Once developed, modifications were made to the base case to test “what if” scenarios of different management options. The use of a numerical model allowed for a range of management options to be tested to understand potential impacts under different hydrological conditions.

Results from the hydrodynamic modelling were used to assess the feasibility of each management option in terms of whether environmental remediation will be effective and whether drainage of private land will be affected. Findings from the numerical modelling for the remediation benefits of each of the management options are summarised in Table ES2.2. ‘Kilometres of drain remediated’ (Table ES2.2) has been assessed for freshwater, as length of drain with an increase in water level, and for tidal water, as length of drain from the floodgates to the tidal extent. ‘Hectares of wetland created’ (Table ES2.2) was assessed as the area upstream below a weir invert for freshwater options, or as the maximum tidal extent for tidal options.

Indicative costings are provided in Table ES2.3. Note that these costs only consider detailed design and on-ground works and are intended to guide further discussion relating to management option feasibility. Other costs not included relate to additional factors that may (or may not) be required such as; environmental assessments, consultation, landholder compensation, approvals, additional technical investigation (geotechnical, ASS) etc.

Note that flood modelling is currently being undertaken using the adopted Lower Macleay River flood model (Jacobs, 2019). This model will assess the impact of proposed management options on large, major river flood events (i.e. design 1% AEP).

Table ES2.1: Summary of management options

	Management option	Freshwater/tidal	Description
1	Land management only	Freshwater	Only land management actions such as fencing, weed control, native bush regeneration and acid scald remediation. No modifications to be made to the drainage network.
2	Shallow freshwater on low-lying wetland areas	Freshwater	Modification of weirs and levees to allow for freshwater inundation across low-lying wetland areas.
3	Shallow freshwater on low-lying wetland areas with extension of McAndrews Drain	Freshwater	The same as Management Option 2 with a new swale drain constructed connecting McAndrews Drain to Seven Oaks Drain.
4a	Modified floodgates to allow controlled in-drain tidal flushing	Tidal*	Modification of eight (8) floodgates to allow tidal water into the drainage network up to an elevation of -0.4 m AHD.
4b	Modified floodgates to allow controlled overland tidal flushing	Tidal*	Modification of eight (8) floodgates to allow tidal water into the drainage network and onto the floodplain up to an elevation of 0.0 m AHD.
5a	Decentralise floodgates to multiple locations – overland inundation	Tidal*	Decommission the Menarcobrinni floodgates after installing four (4) smaller floodgate structures upstream to allow overland inundation within Mayes and Doughboy Swamps.
5b	Decentralise floodgates to multiple locations – in-drain only	Tidal*	Decommission the Menarcobrinni floodgates after installing two (2) smaller floodgate structures upstream to allow in-drain tidal only flushing.
6	Fully open floodgates	Tidal	Hinge the floodgate flaps at Menarcobrinni open to allow unrestricted tidal flow.

Table ES2.2: Summary of remediation benefits for each management option

Option number	Management option	Kilometres of drain remediated	Drain remediation strategy	Wetland Area (ha)	Wetland type
1	Land management only	None	-	None	-
2	Freshwater on low-lying wetland areas	12.5	Fresh	285	Fresh
3	Freshwater on low-lying wetland areas with extension of McAndrews Drain	12.5	Fresh	285	Fresh
4a	Modified floodgates to allow controlled in-drain tidal flushing	13.0	Tidal	None	Tidal
4b	Modified floodgates to allow controlled overland tidal flushing	22.5	Tidal	240	Tidal
5a	Decentralise floodgates to multiple locations – overland inundation	16.0	Tidal	115	Tidal
5b	Decentralise floodgates to multiple locations – in-drain only	6.6	Tidal	None	Tidal
6	Fully open floodgates	51.5	Tidal	725	Tidal

Table ES2.3: Summary of indicative implementation costs (on-ground works only*)

Option number	Management option	Design	On-ground Works	Ongoing [#]
1	Land management only [^]	\$40,000	\$80,000	\$50,000
2	Freshwater on low-lying wetland areas	\$20,000	\$160,000	\$5,000
3	Freshwater on low-lying wetland areas with extension of McAndrews Drain	\$40,000	\$280,000	\$10,000
4a	Modified floodgates to allow controlled in-drain tidal flushing	\$15,000	\$160,000	\$5,000 – \$10,000
4b	Modified floodgates to allow controlled overland tidal flushing	\$15,000	\$160,000	\$5,000 – \$10,000
5a	Decentralise floodgates to multiple locations – overland inundation	\$70,000	\$350,000 - \$500,000	\$10,000 – \$15,000
5b	Decentralise floodgates to multiple locations – in-drain only	\$60,000	\$600,000 - \$1M	\$10,000 – \$15,000
6	Fully open floodgates	\$10,000	\$60,000	\$5,000 – \$10,000

*Does not include other factors such as environmental assessment, consultation, landholder compensation, approvals, additional technical investigation (geotechnical, ASS) etc. See Section 6 for list of sources of costs and benefits.

[^]Develop plan of management, initial fencing, and weed control.

[#]Ongoing cost relates to individual management option only. Ongoing general land management cost are additional. Monitoring costs are additional.

ES.3 Management areas

The Clybucca wetland complex was divided into three important management areas based on their individual hydrological characteristics. The three areas and their position in relation to TfNSW property boundaries (as of December 2019) are shown in Figure ES3.1 and include:

1. Mayes Swamp;
2. Yerbury's Scald (including land to the south of Seven Oaks Drain); and
3. Doughboy Swamp.

The management areas span the lowest lying sections of floodplain with the majority of Mayes Swamp and Yerbury's Scald below 0.0 m AHD (i.e. mean sea level), and Doughboy Swamp below +0.3 m AHD (Figure ES3.2). With the exception of three properties on the east of Mayes Swamp, the management areas are within the TfNSW property boundaries.

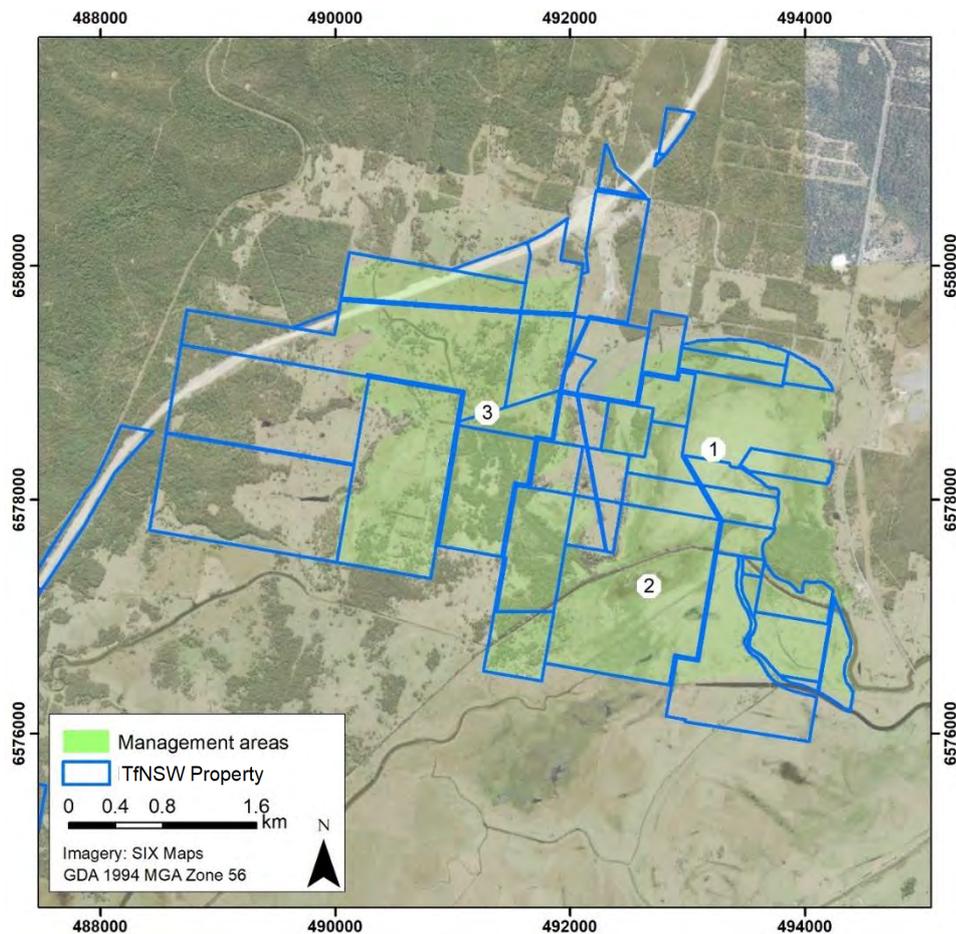


Figure ES3.1: Important wetland management areas on the Clybucca floodplain including; (1) Mayes Swamp, (2) Yerbury's Scald and (3) Doughboy Swamp

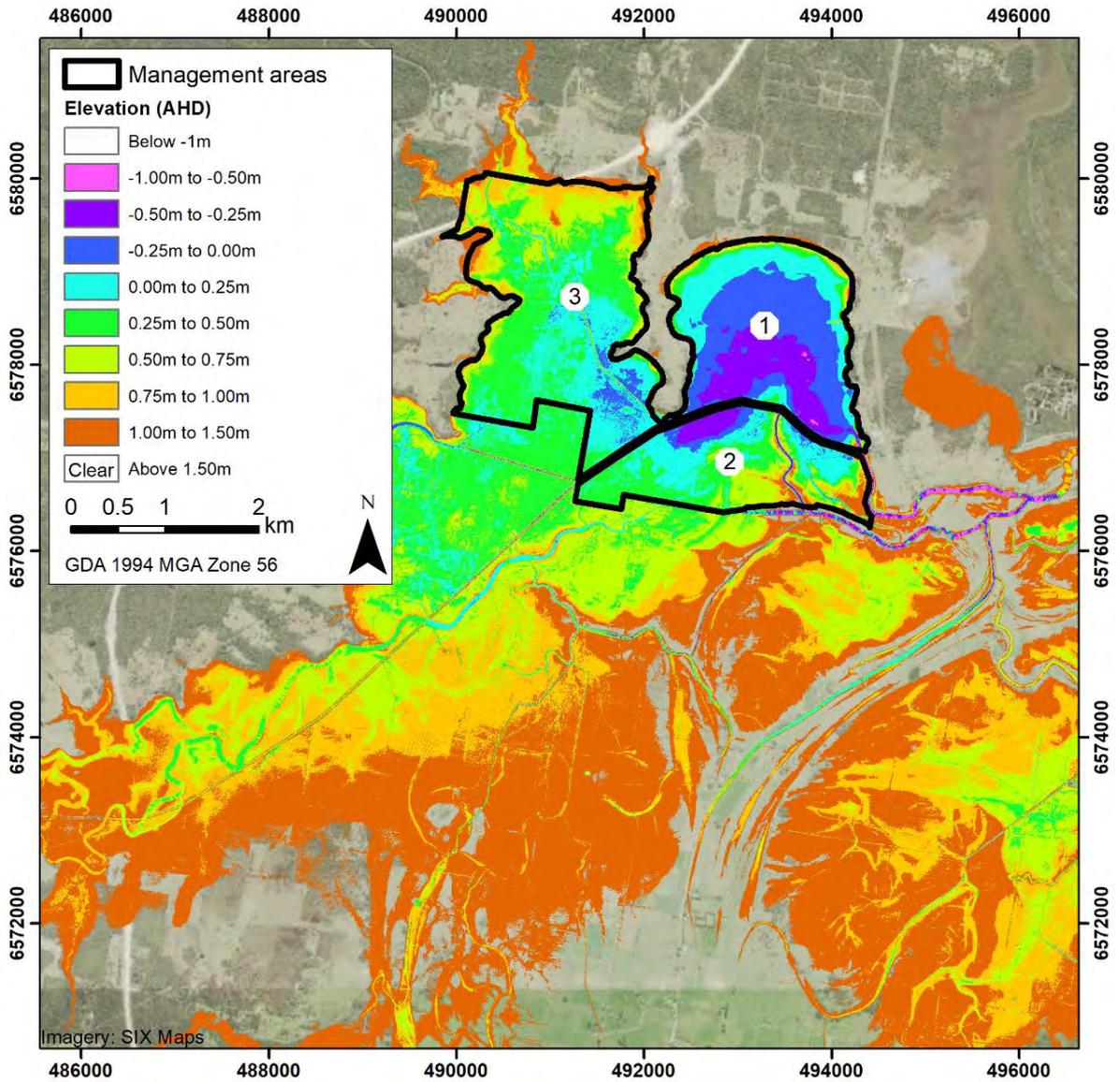


Figure ES3.2: Floodplain topography and key wetland management areas

ES.4 Management option modelling summary

ES4.1 Management Option 1: Land management only

Description

Management Option 1 does not include any modifications to the existing drainage network. Management recommendations for this option are land based as they will not impact water movements across the floodplain. This option comprises land management actions including:

- Fencing to exclude stock and pest species from rehabilitation areas;
- Pest and weed management;
- Wet pasture management;
- Fire risk management;
- Access control;
- Native bush regeneration; and
- Acid scald remediation.

These actions can be undertaken on TfNSW land with the aim of promoting native freshwater wetland on low-lying areas and more generally native vegetation rehabilitation across the management areas. This option can be implemented for all management options presented. However, water movements across the floodplain will govern where benefits can be fully realised.

Results

Land management options (such as fencing and revegetation) will not impact the floodplain hydrology. Changes in roughness across the floodplain may occur, however, this effect is negligible on floodplain hydrology. Subsequently, no numerical modelling analysis has been completed for this option.

Considerations

The approach to remediation outlined in Management Option 1 will require ongoing costs, including:

- Maintenance of fencing;
- Fire risk management;
- Drainage maintenance responsibilities; and
- Ongoing weed and pest management.

ES4.2 Management Option 2: Shallow freshwater on low-lying wetland areas

Description

Management Option 2 aims to improve the natural wetting and drying cycle of the low-lying ASS affected management areas as well as improve water quality (i.e. reduce acid and blackwater discharge) by raising the water table to provide shallow freshwater inundation on key management areas. This strategy would be implemented using the following remediation actions (Figure ES4.1):

- Construction of a new weir across Seven Oaks Drain at the downstream/eastern extent of Mayes Swamp with a crest level of 0.0 m AHD;
- Construction a new weir on the swale drain connecting Seven Oaks Drain and McAndrews Drain with a crest level of 0.0 m AHD;
- Removal/lowering of drainage levee banks along Seven Oaks Drain within TfNSW property boundary;
- Construction of a new weir across the East Drain near the Seven Oaks Drain confluence with a crest elevation of +0.1 m AHD.

Note that the present-day elevation of Yerbury's Sill is approximately -0.3m AHD.

Results

The numerical modelling results indicate (Figure ES4.2, Figure ES4.3 and Table ES4.1):

- Shallow freshwater inundation on Mayes Swamp increases by 20% during day-to-day conditions. The frequency of inundation increases, whereas there is minimal change in inundation depth;
- Yerbury's Scald remains inundated with freshwater (provided regular freshwater catchment inflows occur);
- Doughboy Swamp has a significant increase in inundation time from irregular inundation, to up to permanent inundation in areas below +0.1 m AHD;
- The average inundation depth across Yerbury's Scald and Doughboy Swamp increases by up to 30 cm during typical daily conditions;
- The water table is raised within 12.5 km of acid affected drainage channel;
- 285 hectares of freshwater wetland is created;
- There is a minor increase in drainage time across adjacent floodplain areas following a minor inundation event (approx. 1 year catchment event) with the greatest increase in drainage time occurring on the floodplain adjacent to Doughboy Drain. This was predicted to increase the surface water drainage time from 2 days (present day) to 2.5 days (for the modelled inundation level).

Considerations

In addition to the model results, the following implementation considerations have been identified:

- Access across Seven Oaks Drain at Yerbury's Sill will be inhibited. Additional works may be required to maintain access (e.g. rebuild existing dilapidated wooden bridges);
- Seven Oaks Drain levee banks would be lowered, which may impact access, particularly in the Mayes Swamp area;
- Sediments from the lowered levee banks will require disposal; and,
- Changes to the drainage network will need to be completed in consultation with the Seven Oaks Drainage Union and adjacent floodplain landholders.

Table ES4.1: Summary of standing water drainage time for floodplain areas following an approx. 1 year catchment event (+0.75m AHD inundation level)

Location	Time taken for floodplain to drain (days)	
	Base case	Management Option 2
Doughboy Drain floodplain	2.0	2.5
Shackles Drain floodplain	0.7	0.8
Southern floodplain	0.4	0.4
Upper Seven Oaks Drain floodplain	2.1	2.2
West Drain floodplain	5.3	5.6

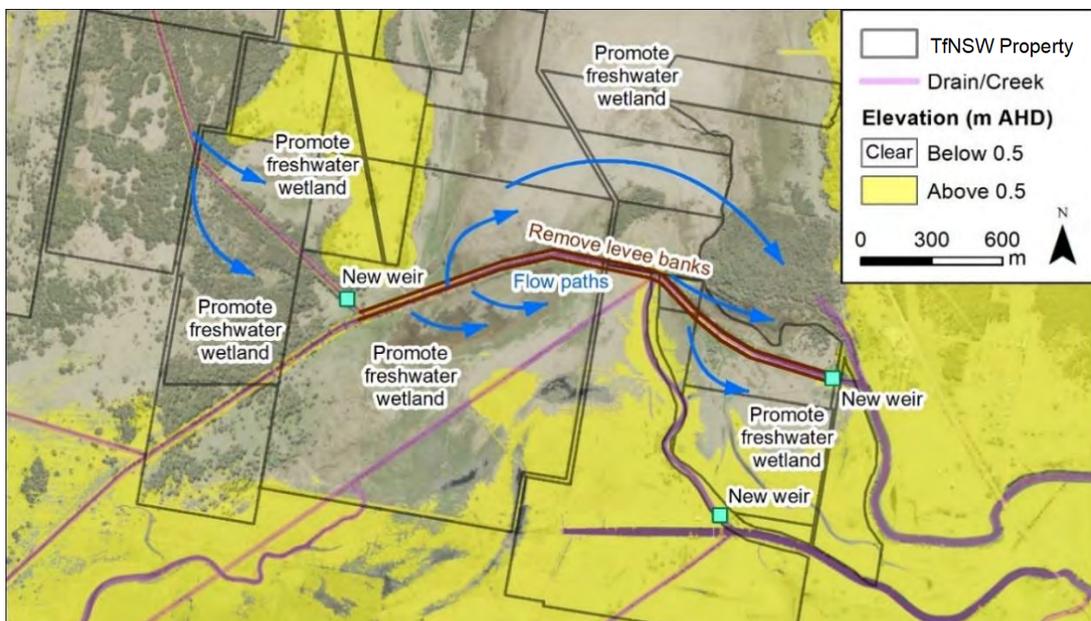


Figure ES4.1: Diagram outlining modifications to the drainage network and conceptual flow paths for Management Option 2

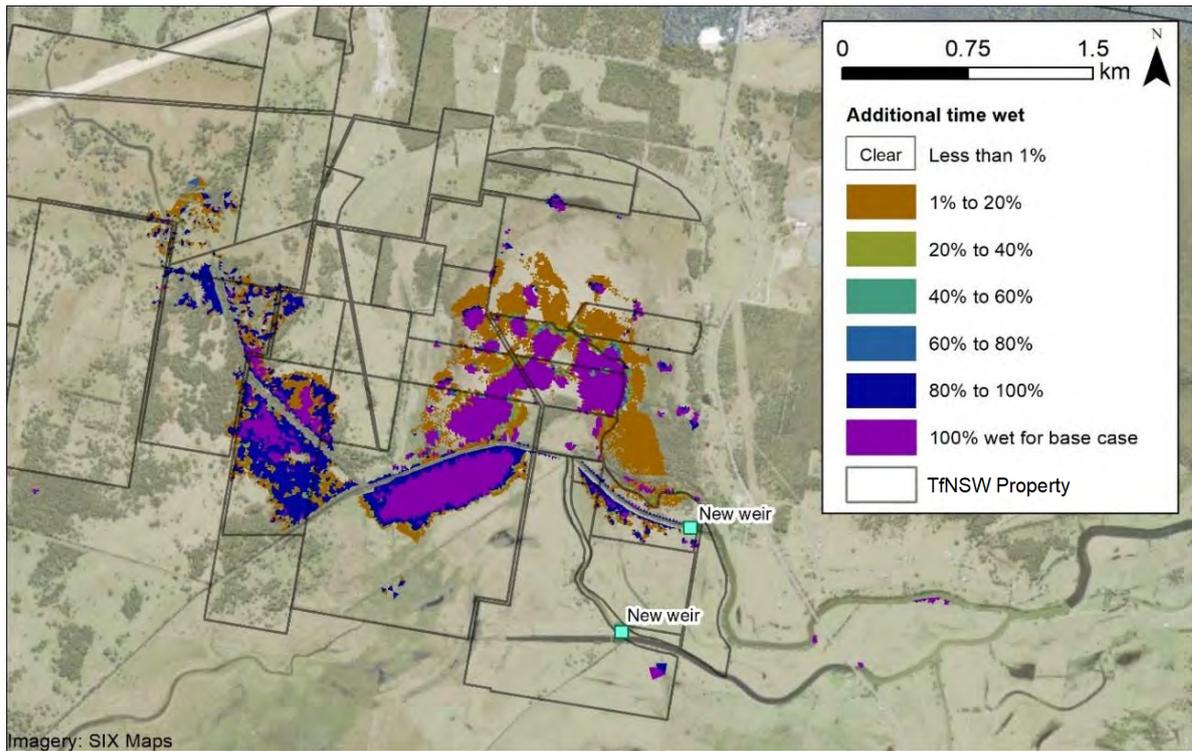


Figure ES4.2: Difference in inundation time between the base case and Management Option 2 during day-to-day conditions (includes a 6 month runoff event)

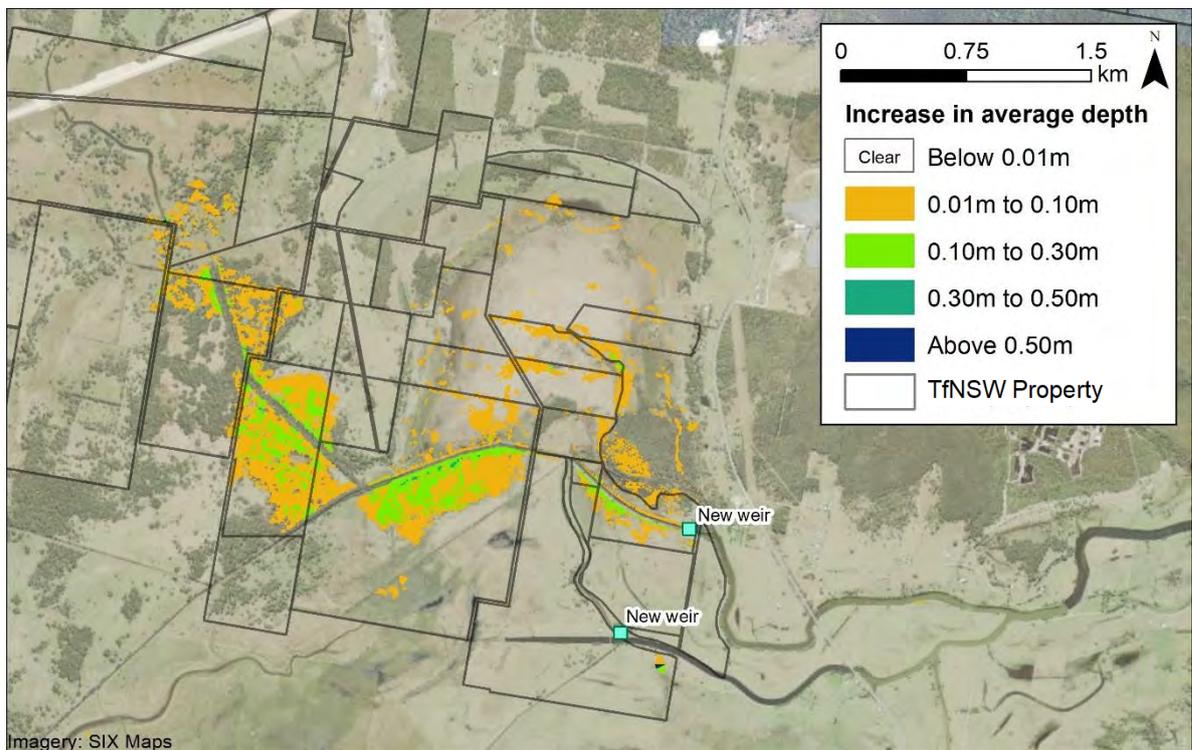


Figure ES4.3: Difference in inundation depth between the base case and Management Option 2 during day-to-day conditions (includes 6 month runoff event)

ES4.3 Management Option 3: Shallow freshwater on low-lying wetland areas with McAndrews Drain extension

Description

Management Option 3 involves extending McAndrews Drain along its existing alignment to connect to Seven Oaks Drain near West Drain. (Figure ES4.4). This strategy aims to provide improved (or maintained) drainage for upstream floodplain areas whilst enabling the potential for more significant changes to be made on the drainage network within TfNSW property boundaries. The design and implementation of this strategy requires careful consideration to ensure the remediation objectives within TfNSW areas are not compromised, whilst providing drainage benefit for upstream landholders. Implementation of the new drain has been assessed as well as the remediation actions proposed in Management Option 2 (e.g. to allow a comparison between a modified network with and without the new drain).

Results

The hydrodynamic modelling results indicate (Figure ES4.5, Figure ES4.6 and Table ES4.2):

- The majority of the floodplain has a change in inundation equal or less than ± 0.10 m, which results in a change in inundation time of less than $\pm 20\%$ when compared to Management Option 2 for day-to-day conditions;
- The water table is influenced within 12.5 km of the drainage network, thereby reducing acid export (as per Management Option 2);
- 285 hectares of freshwater wetland is created when it becomes inundated due to drainage modifications (as per Management Option 2);
- Extension of McAndrews Drain with a drain invert elevation of 0.0 m AHD and a shallow and wide channel geometry, results in a small reduction in drainage time (0 to 6 hours, depending on location) in comparison to Management Option 2 following inundation to approximately 1 year event levels;
- Floodplain drainage times for Doughboy Drain floodplain and West Drain floodplain areas remain slower than present day conditions, even with the drain extension in place;
- Drainage of the floodplain upstream of TfNSW properties (upper Seven Oaks Drain floodplain) occurs slightly quicker than present day conditions (2 days with drain extension compared to 2.1 days during present day); and
- As the proposed drain extension is shallow and wide, the drain is unlikely to impact/lower the local groundwater table below 0 m AHD.

Table ES4.2: Summary of drainage time for standing water on floodplain areas following an approx. 1 year catchment event (+0.75m AHD inundation level)

Location	Time taken for floodplain to drain (days)		
	Base case	Management Option 2	Management Option 3
Doughboy Drain floodplain	2.0	2.5	2.3
Shackles Drain floodplain	0.7	0.8	0.7
Southern floodplain	0.4	0.4	0.4
Upper Seven Oaks Drain floodplain	2.1	2.2	2.0
West Drain floodplain	5.3	5.6	5.5

Considerations

In addition to the model results, the following implementation considerations have been identified:

- Construction of the new drain would need to consider direct environmental impacts, such as clearing trees and disturbing habitat along the proposed drain alignment;
- Excavation of the new drain may result in excavation of acid sulfate soils that will likely require treatment and/or disposal;
- Weed management within the new drain would need to ensure that efficiency is maintained; and
- Responsibility for maintenance and overall ownership of the proposed drain extension would need to be considered.

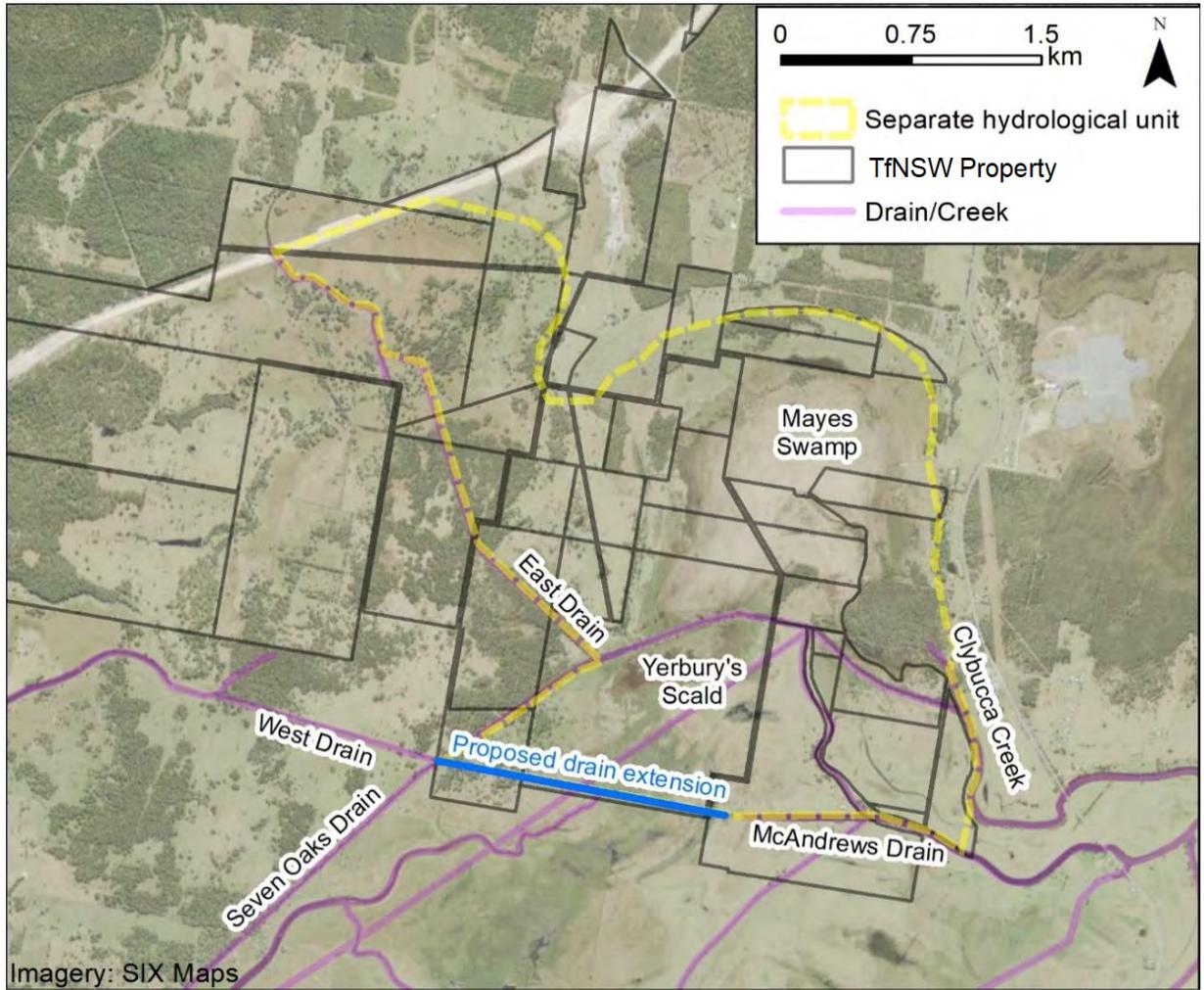


Figure ES4.4: Schematic of proposed drain extension from McAndrews Drain to Seven Oaks Drain within TfNSW land, including separate hydrological units

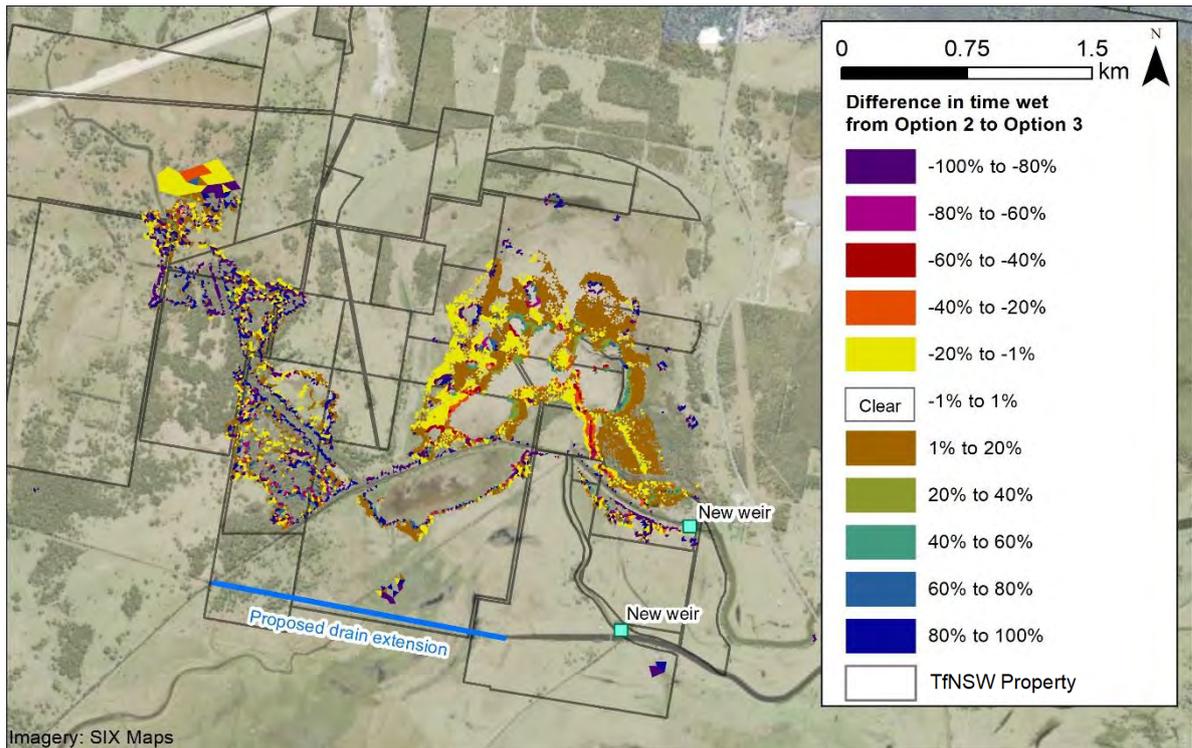


Figure ES4.5: Difference in inundation duration between Management Options 2 and 3 during day-to-day conditions (includes 6 month runoff event)

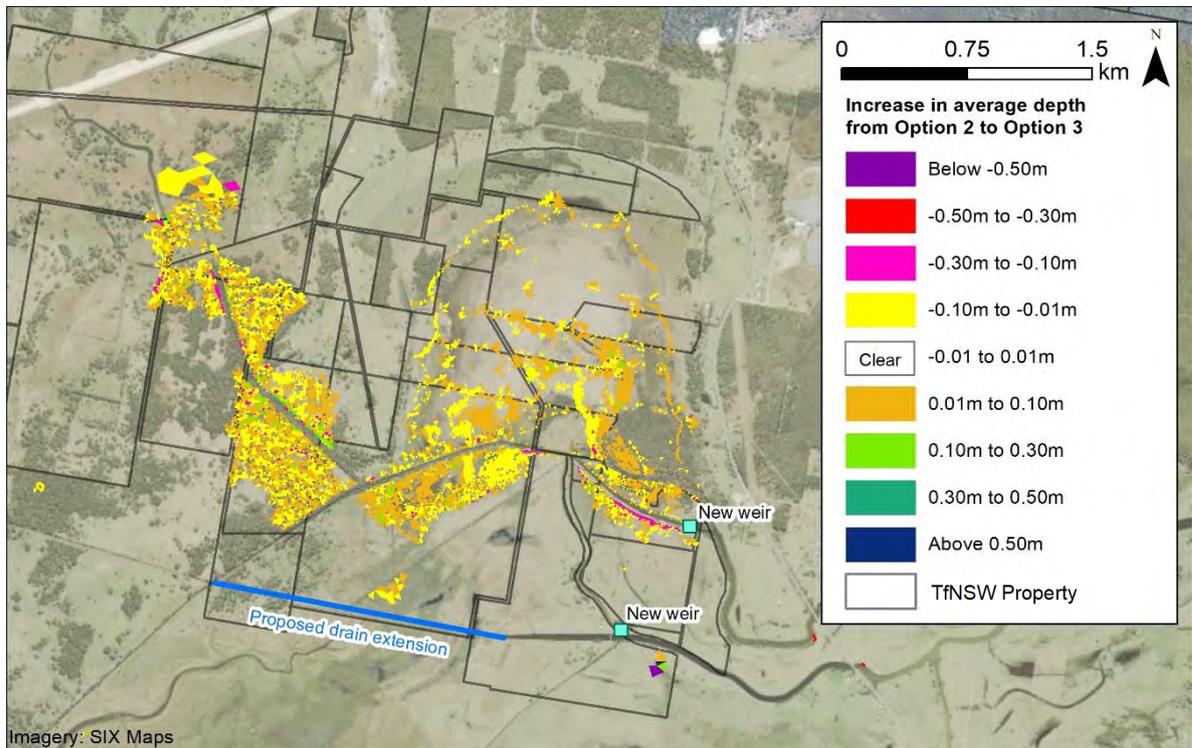


Figure ES4.6: Difference in inundation depths between Management Options 2 and 3 during day-to-day conditions (includes 6 month runoff event)

ES4.4 Management Option 4a: Modify floodgate to allow controlled tidal flushing in-drain

Description

Management Option 4a involves the implementation of eight (8) auto-tidal floodgates at the Menarcobrinni barrage to allow controlled in-drain only tidal flushing upstream of the floodgates. This is achieved by establishing a tidal cut-off trigger level of -0.4 m AHD at the auto-tidal floodgates. This approach aims to improve in-drain water quality and allow increased and improved aquatic connectivity. Controlled tidal flushing was previously trialled at Menarcobrinni (KSC, 2004).

Results

The results of the numerical modelling indicate (Figure ES4.7):

- Very low-lying (-0.3 m AHD) private land in Mayes Swamp, adjacent to Clybucca Creek is inundated at low tide flushing levels;
- Approximately 10% of estuarine salinity levels occur at the downstream boundary of Mayes Swamp (Figure ES4.8);
- During a tidal cycle, limited tidal flushing (~70 m³) is permitted upstream of the floodgates;
- Tidal flushing will occur infrequently during spring tides with a trigger level of -0.4 m AHD;
- In-drain tidal flushing influences 12.5 km of the drainage network, including to Yerbury's Sill within Seven Oaks Drain and throughout McAndrews Drain;
- Monitoring of drain salinity levels and active management of auto-tidal gate operational regime may enable more significant flushing outcomes to be achieved; and
- Benefits associated with weed management and buffering of acid will occur at downstream sections of the drainage network near Menarcobrinni floodgates.

Considerations

In addition to the model results, the following implementation considerations have been identified:

- Saltwater vegetation intrusion upstream of the floodgates (such as mangroves) may occur and potentially require management;
- Monitoring and adaptive management measures to maximise environmental outcomes and limit impacts to private land;
- The potential influence of tidal water on groundwater salinity;
- The potential influence of tidal water on extractions (groundwater and surface water) for irrigation or stock; and,
- The type of floodgate modification chosen and its management (including maintenance).

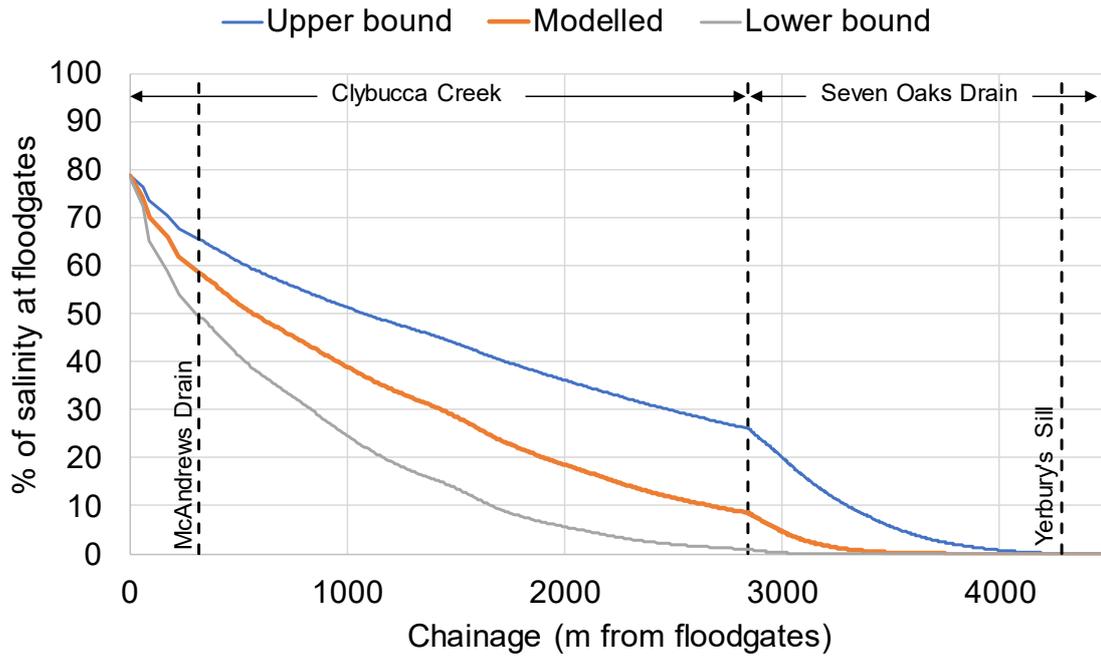


Figure ES4.7: Maximum level of salinity within Clybucca Creek for auto-tidal floodgates with a cut off level of -0.4 m AHD during dry conditions (no freshwater inflows)

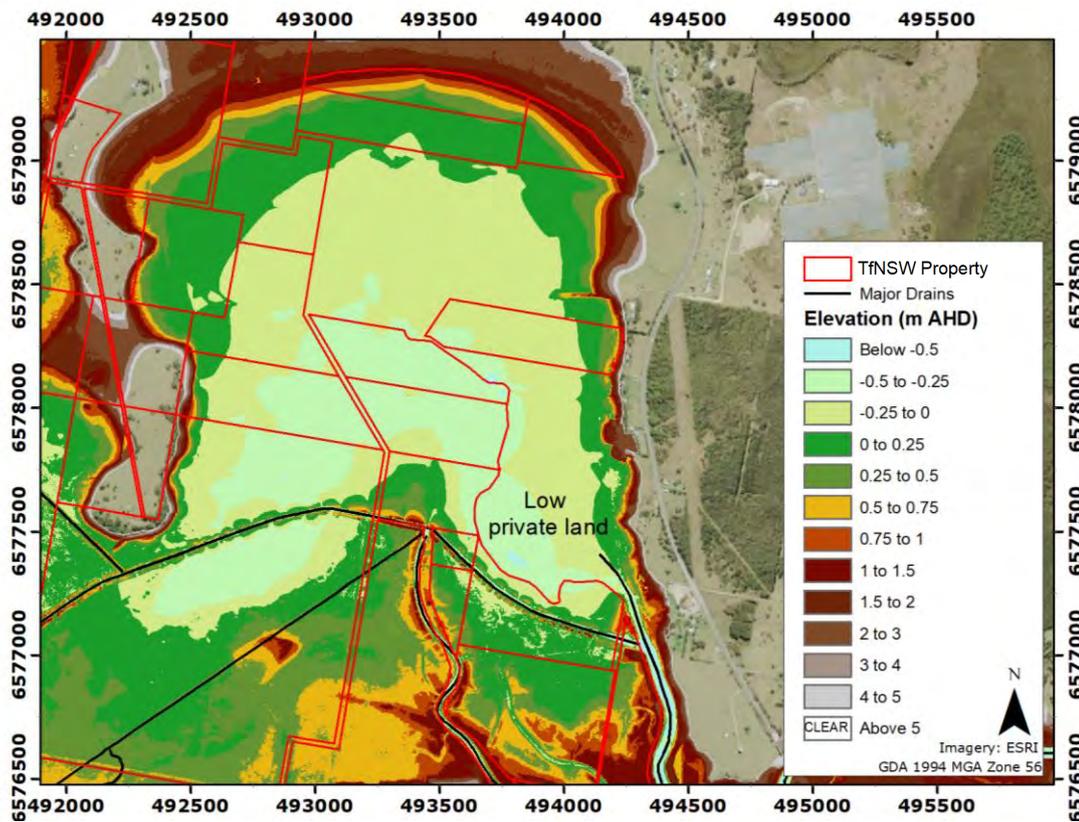


Figure ES4.8: Low-lying (-0.3 m AHD) private land within Meyes Swamp

ES4.2 Management Option 4b: Modify floodgate to allow controlled overland tidal flushing

Description

Management Option 4b involves the modification of eight auto-tidal floodgates at Menarcobrinni to allow controlled tidal flushing upstream of the floodgates to a level that will inundate low-lying floodplain within the management area below mean sea level. This is achieved with a tidal trigger level of 0.0 m AHD, hence enabling tidal exchange on every tide. This approach aims to create extensive aquatic habitat in-drain, intertidal wetlands and improved water quality.

Results

The hydrodynamic modelling results indicate (Figures ES4.9 to ES4.12):

- Significant areas of low-lying floodplain within the management areas are permanently inundated by up to 0.30 m of tidal water, including private land to the east of Mayes Swamp;
- Inundation of low-lying floodplain has a salinity up to 80% of the salinity level at the Menarcobrinni floodgates (which can range from fresh to ocean salinity levels);
- 240 hectares of intertidal wetland is created;
- Average catchment runoff events (< 1 year event) do not result in saline waters spilling onto private land; and
- 13 km of drain will be flushed with tidal water improving water quality and providing additional aquatic habitat.

Considerations

In addition to the model results, the following implementation considerations have been identified:

- Saltwater vegetation intrusion upstream of the floodgates (such as mangroves) may occur and need management;
- The potential influence of tidal water on groundwater salinity;
- The potential influence of tidal water on extractions (groundwater and surface water) for irrigation or stock;
- The type of floodgate modification and its management (including maintenance);
- Consideration will need to be taken to assess the impact of existing freshwater ecology; and
- Prior consultation will need to be conducted with floodplain landholders where tidal water would potentially inundate private landholdings on the east of Mayes Swamp.

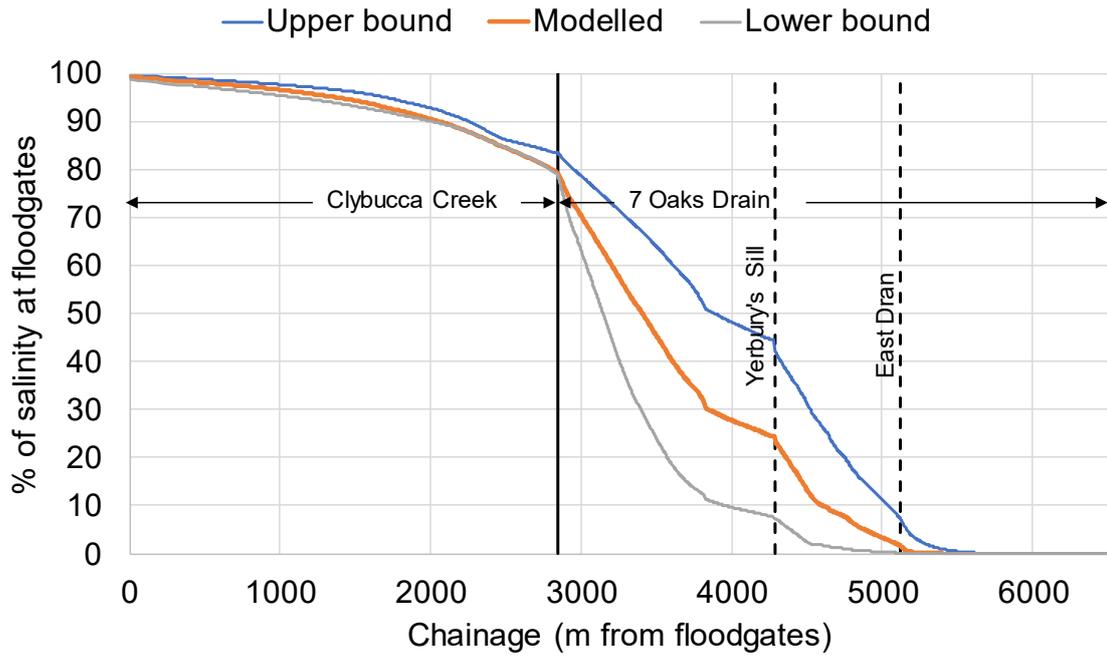


Figure ES4.9: Maximum salinity level and extent over a three-month period between Seven Oaks Drain and the Menarcobrinni floodgates with an auto-tidal cut off level of 0.0m AHD

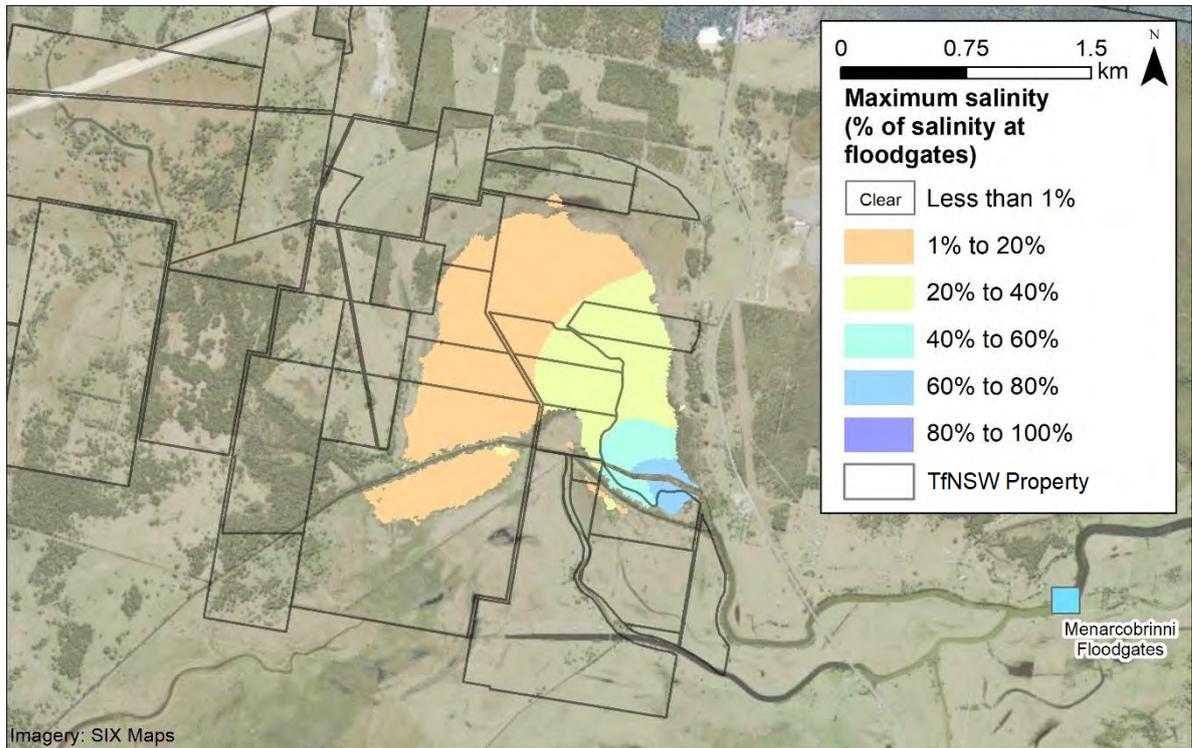


Figure ES4.10: Maximum salinity reached over a three-month period with an auto-tidal floodgate cut off level of 0.0 m AHD

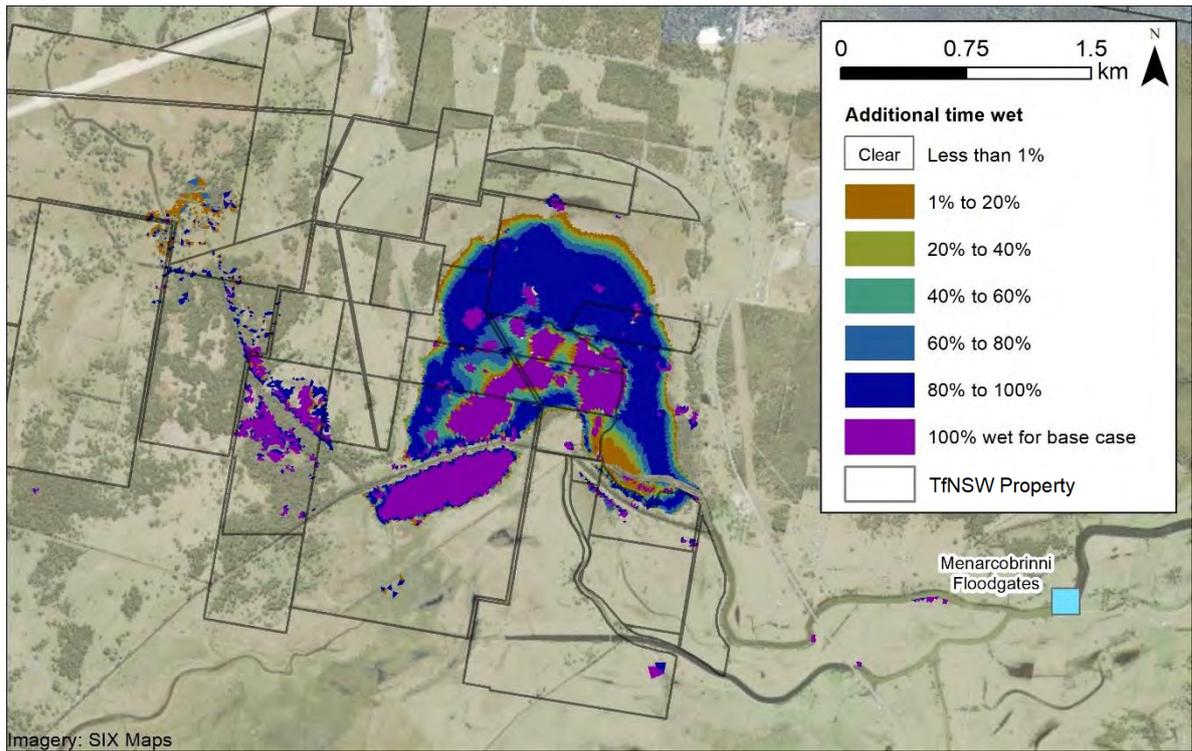


Figure ES4.11: Difference in inundation duration between the base case and Management Option 4b during day-to-day conditions (includes 6 month runoff event)

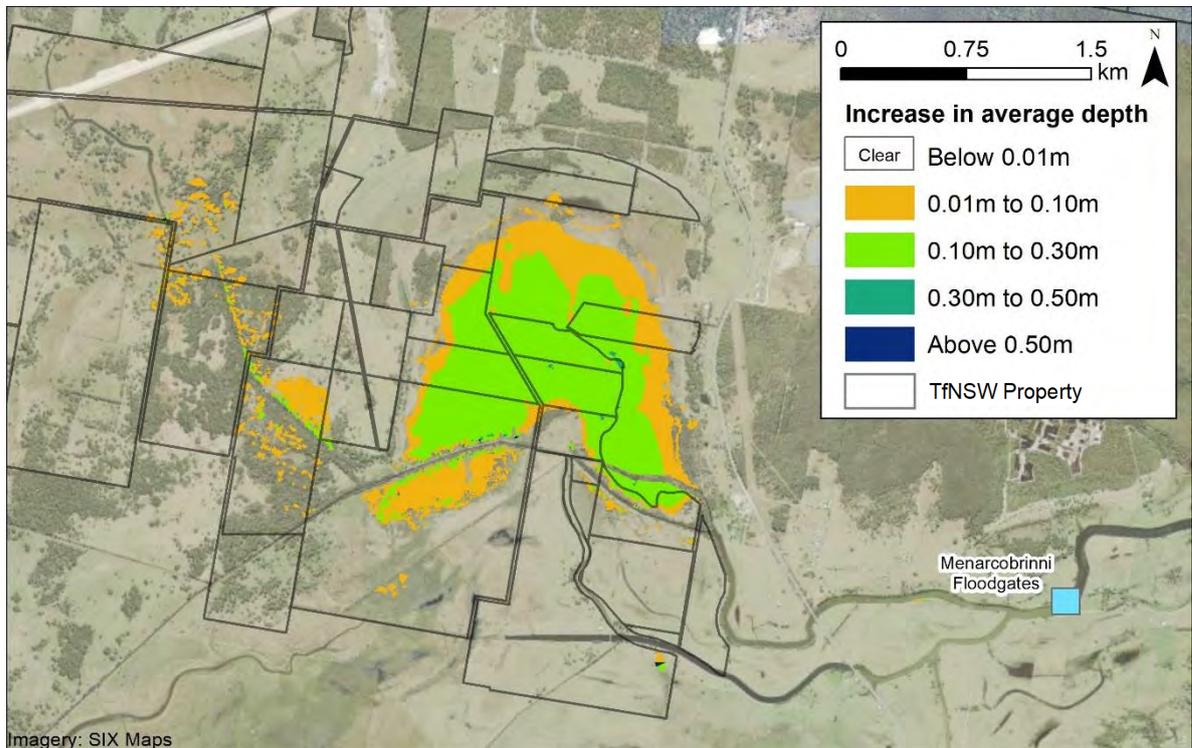


Figure ES4.12: Difference in inundation depths between the base case and Management Option 4b during day-to-day conditions (includes 6 month runoff event)

ES4.6 Management Option 5a: Decentralise Menarcobrinni floodgates and replace with multiple upstream structures – with tidal wetland inundation

Description

Management Option 5a involves decentralising the Menarcobrinni floodgates to locations upstream of the low-lying floodplain Doughboy Swamp and Mayes Swamp management areas (Figure ES4.13). This approach encourages overland inundation of the low-lying floodplain areas, creating significant areas of intertidal wetland habitat and improving poor water quality resulting from acid sulfate soils and blackwater runoff. Floodgate locations considered for Management Option 5b are located at narrow sections in the drainage network where multi-culvert structures have been assumed.

Results

The results of the numerical modelling indicate (Figure ES4.14):

- Significant tidal inundation across low-lying areas of TfNSW property;
- Significant tidal inundation of private land would occur without extensive additional on-ground mitigation measures;
- Approximately 1 km of additional levee banks required, with additional small floodgates structures at key locations would need to be constructed to prevent inundation across private land within Doughboy Swamp and the floodplain surrounding Doughboy Drain (Figure ES4.15);
- Approximately 1.2 km of additional levee banks would need to be constructed on the north bank of Seven Oaks Drain and a floodgate structure would need to be constructed on Clybucca Creek upstream of its intersection with Seven Oaks Drain to prevent inundation of low-lying land within Mayes Swamp (Figure ES4.16);
- Increased vulnerability to river backwater flooding (Menarcobrinni headworks crest elevation = +1.1 m AHD);
- 115 hectares of additional intertidal wetland created to the south of Seven Oaks Drain; and
- Up to 16 km of drain exposed to full tidal flushing.

Considerations

In addition to the model results, the following implementation considerations have been identified:

- Continued maintenance options for the Menarcobrinni floodgates (unless they are removed);
- Additional mitigation structures will be needed to prevent inundation of private land;
- Additional modelling would be needed to validate floodplain hydrodynamics with mitigation structures to prevent inundation of private property in place;
- The impact of turning freshwater habitat to saltwater habitat would need to be assessed; and

- Ownership of new floodgate structures would need to be addressed including responsibility for maintenance.

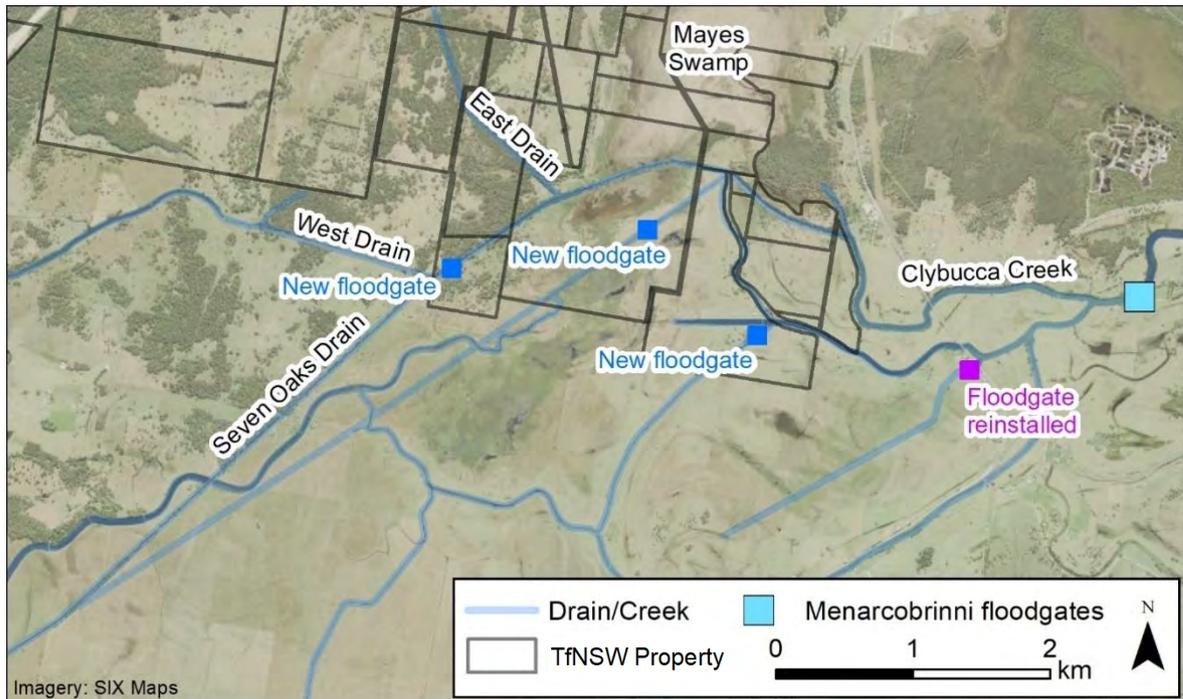


Figure ES4.13: Management Option 5a for location of upstream decentralised floodgates

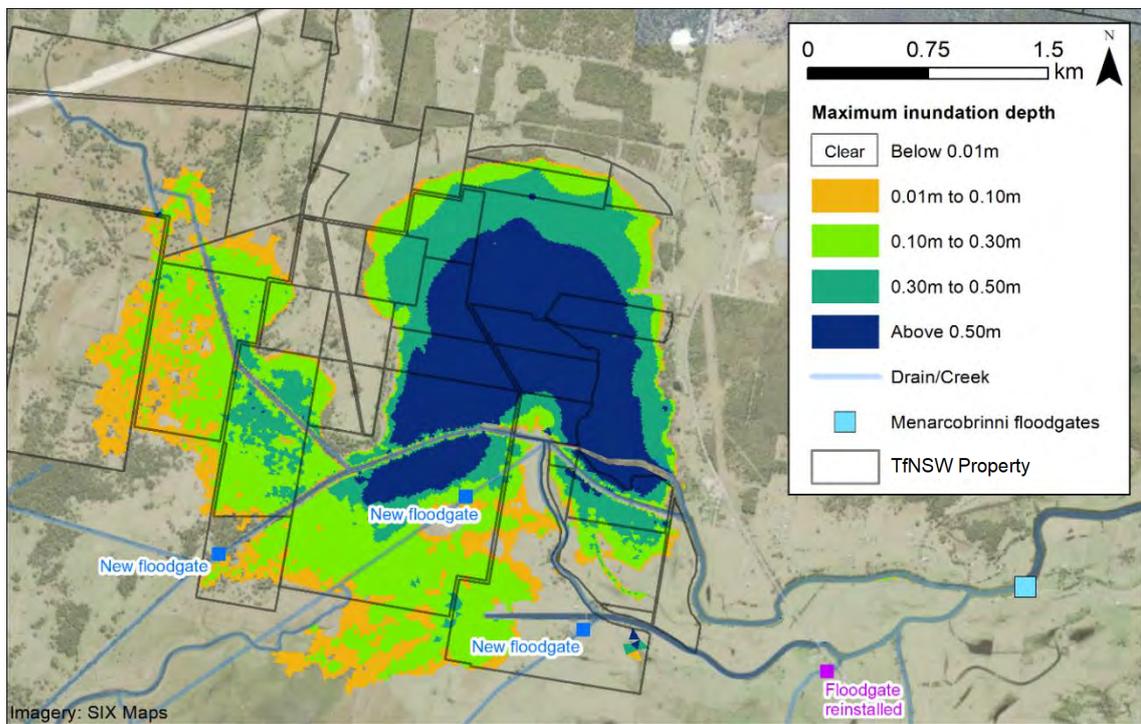


Figure ES4.14: Maximum tidal inundation depth and extent for Management Option 5a over a three-month dry period

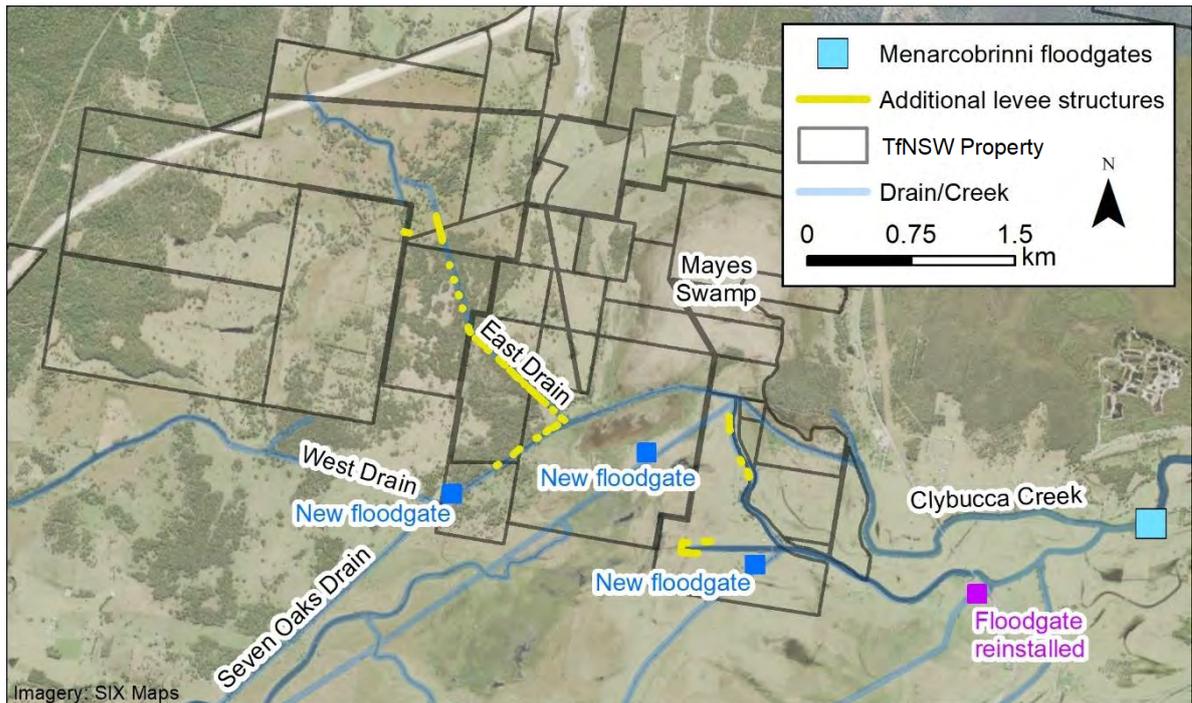


Figure ES4.15: Indicative location of structures to protect private land south of Seven Oaks Drain and within Doughboy Swamp from inundation for Management Option 5a

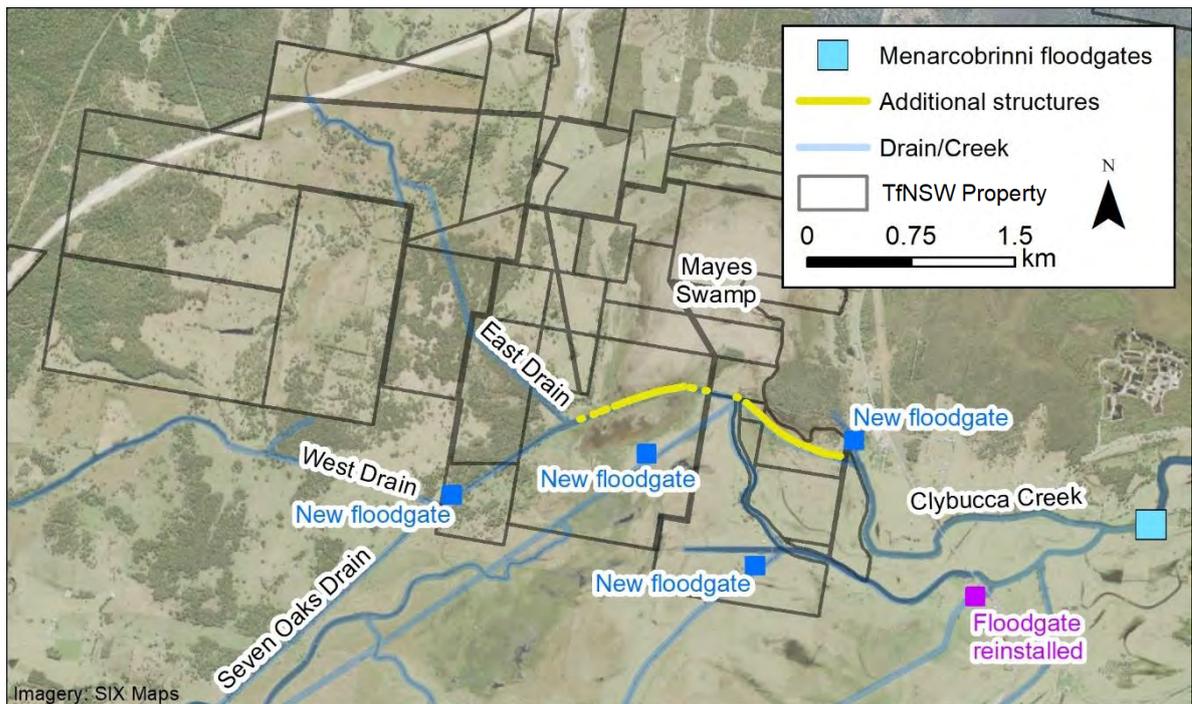


Figure ES4.16: Indicative location of structures to protect private land within Mayes Swamp from inundation for Management Option 5a

ES4.7 Management Option 5b: Decentralise Menarcobrinni floodgates and replace with two upstream structures – with no tidal inundation

Description

Management Option 5b involves decentralising the Menarcobrinni floodgates to locations downstream of the low-lying floodplain management areas (Figure ES4.17). These locations limit overland inundation of the low-lying floodplain areas and maintain the existing level of protection from river backwater flooding, while obtaining benefits associated with tidal flushing and aquatic connectivity. The individual management of sub-catchment areas upstream of the structures is also possible under this scenario. Floodgates constructed for this configuration need to be sufficiently large to provide drainage conveyance to drain the floodplain following flood events.

Results

The results of the numerical modelling indicate (Figure ES4.18 and Figure ES4.19):

- Minor tidal inundation of private land is predicted. This can be mitigated by the construction of small floodgate structures on side channels (Figure ES4.20);
 - Re-installing floodgate flaps on an existing structure on a drain to the south of McAndrews Drain; and
 - Adding an additional 20 m of levee with a floodgate on the end of a drain on the west bank of Humpty-back Creek;
- Humpty-back Creek (parallel to Macleay Valley Way) experiences in-channel tidal inundation;
- There is a small change to (present day) day-to-day inundation across the floodplain (increase in average depth of less than 0.10 m and average inundation time of less than 20% was caused by a slight change in where the tidal boundary is located) for a 6 month catchment rainfall event;
- Changes to drainage efficiency is negligible; and
- Up to 6.6 km of drain will be flushed with tidal water improving water quality and providing additional aquatic habitat.

Considerations

In addition to the model results, the following implementation considerations have been identified:

- Continued maintenance options for the Menarcobrinni floodgates (unless they are removed);
- Additional mitigation structures will be needed to prevent inundation of private land;
- Additional investigation of new floodgate headworks may be required to optimise detailed design and validate floodplain hydrodynamics;
- Consultation with landholder upstream of Menarcobrinni floodgates; and

- Ownership of new floodgate structures, including responsibility for management/maintenance.

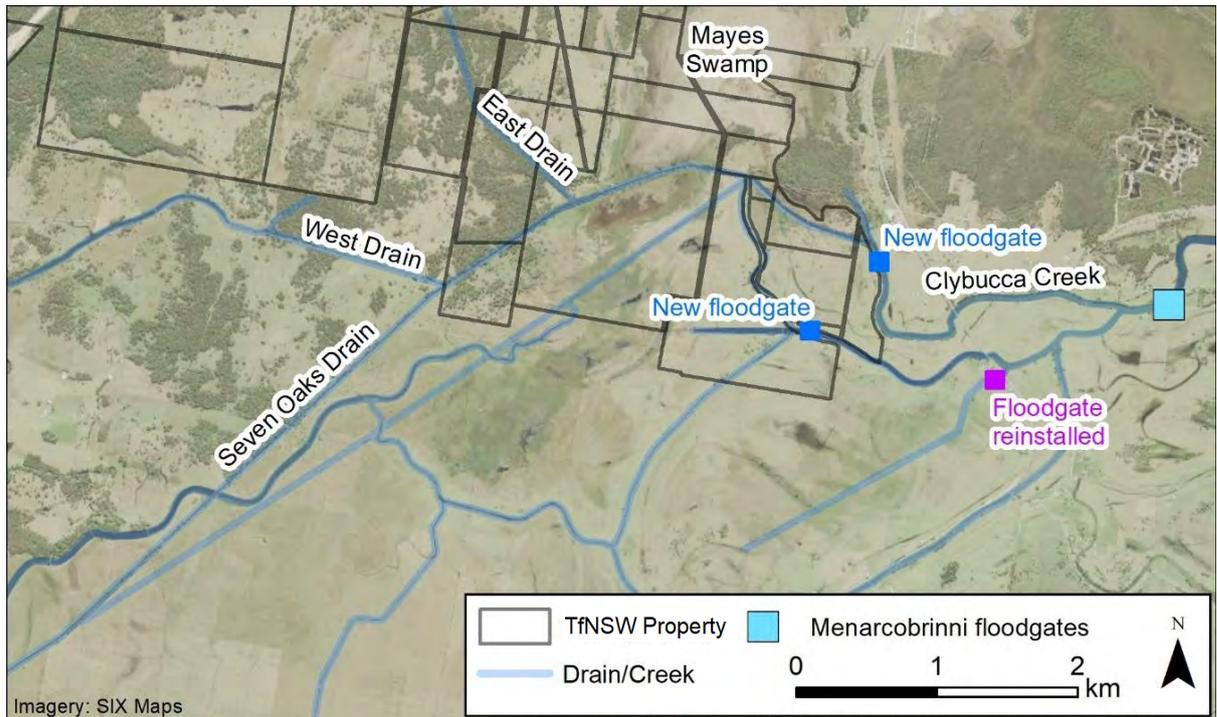


Figure ES4.17: Management Option 5b for location of upstream decentralised floodgates

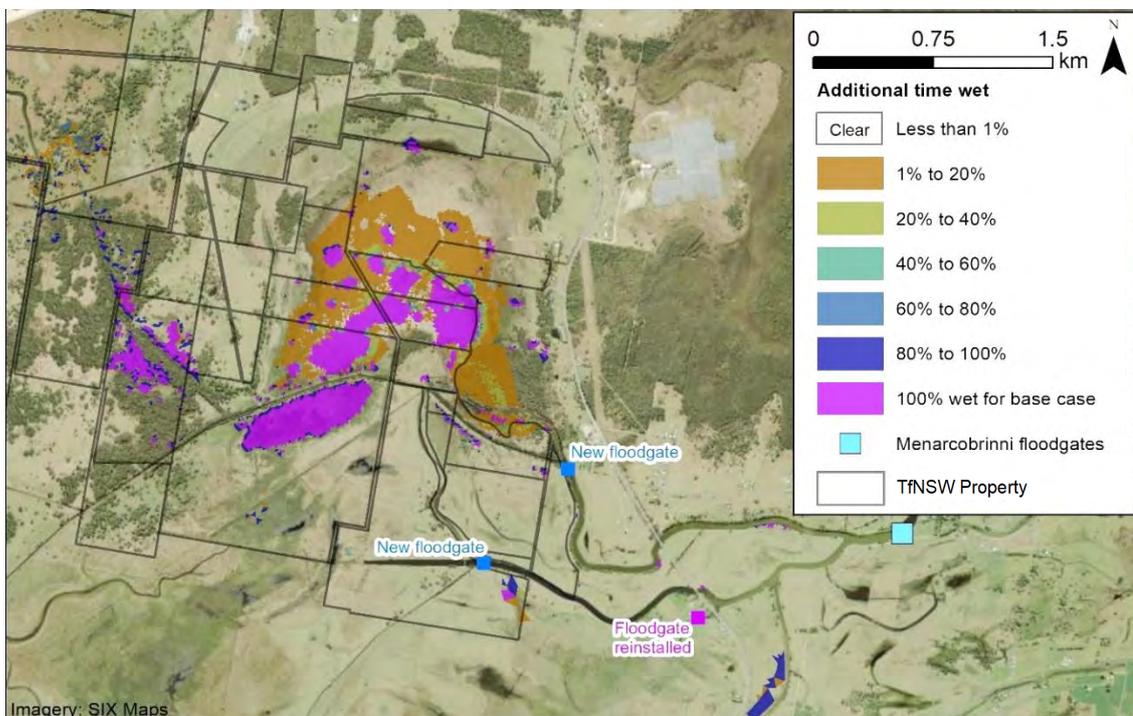


Figure ES4.18: Difference inundation duration between the base case and Management Option 5b during day-to-day conditions (includes 6 month runoff event)

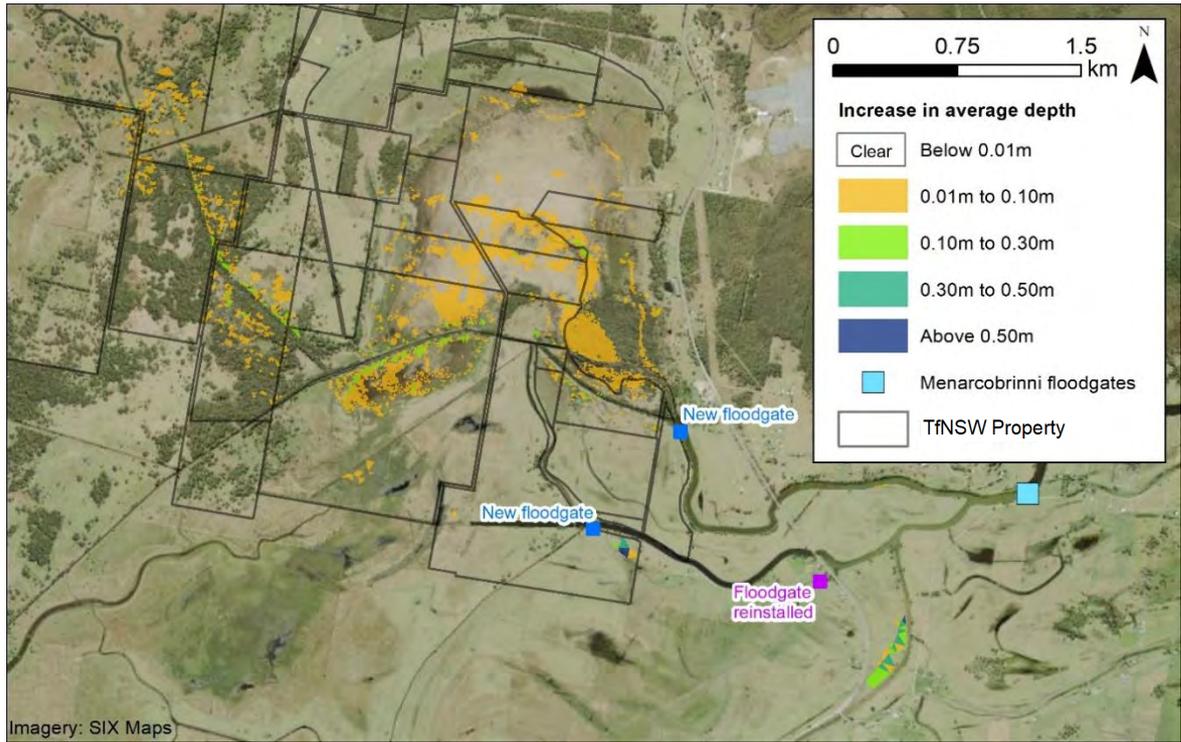


Figure ES4.19: Difference in inundation depths between the base case and Management Option 5b during day-to-day conditions (includes 6 month runoff event)

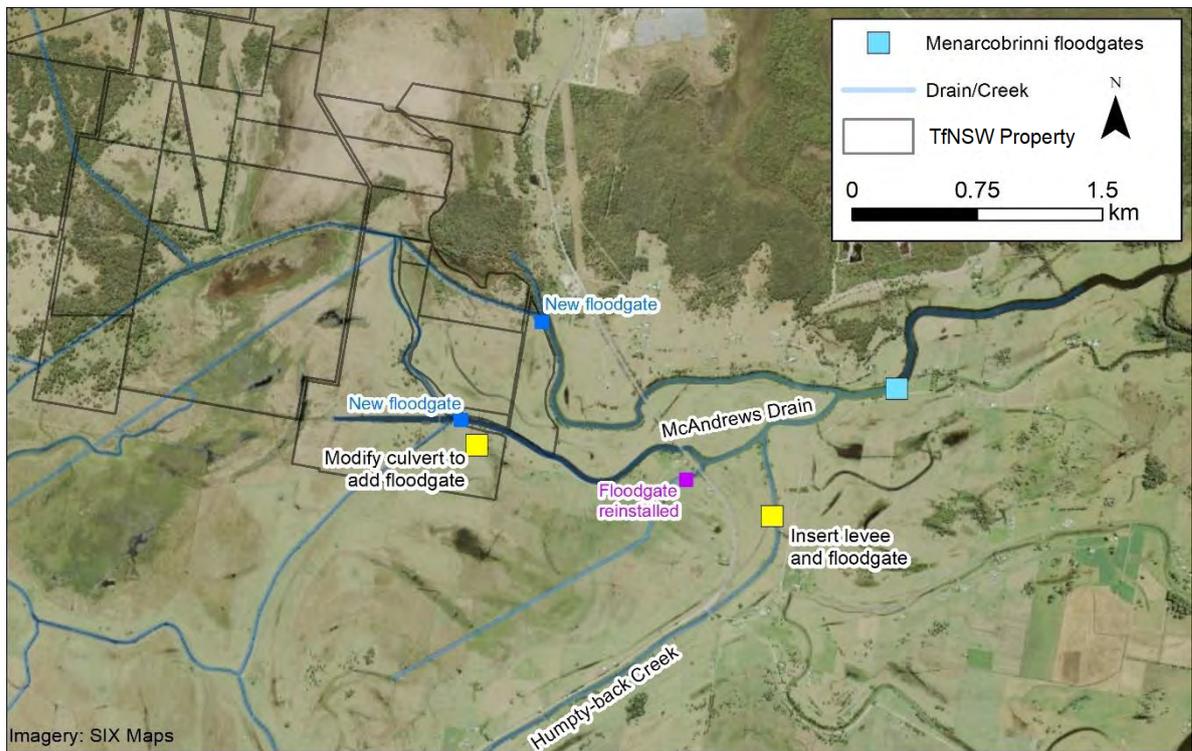


Figure ES4.20: Location of new infrastructure to prevent inundation of private land for Management Option 5b

ES4.8 Management Option 6: Floodgates fully open

Description

Management Option 6 investigates fully hinging open the 21 floodgates at the Menarcobrinni barrage to allow water flow in both directions. This management option aims to quantify the impacts of no floodgate restrictions during normal tidal conditions. This strategy would result in the greatest change (hydrologically and ecologically) to the floodplain and in the extensive creation of intertidal habitat. Impacts to existing floodplain drainage, water quality and private floodplain landholders is significant. By hinging open the gates, but leaving the structure and gates intact, the gates can be closed prior to flood events and prevent backwater flooding from the Macleay River.

Results

The results of the numerical modelling indicate (Figure ES4.21 to ES4.23):

- Mayes Swamp would be permanently inundated with depths from 0.10 m to above 0.50 m;
- Inundation of private property on the south west of Doughboy Swamp would occur at depths between 0.01 m and 0.10 m up to 100% of the time;
- Inundation of private property to the south of Seven Oaks Drain and south of McAndrews Drain would occur up to depths of 0.30 m up to 100% of the time;
- Concentrations of salinity on the floodplain would reach a maximum of 60% - 100% of the salinity at the Menarcobrinni floodgates;
- Up to 725 hectares of saltwater wetland is created when the floodplain is inundated with tidal water; and,
- Up to 51.5 km of drain will be flushed with tidal water improving water quality and providing additional aquatic habitat.

Considerations

The following implementation considerations have been identified in this Scenario:

- Other management options implemented;
- Extensive change of floodplain ecology;
- Value and extent of habitat creation;
- Impact of climate change on drainage;
- Change in land use;
- Land ownership;
- Changes to flood risk; and
- Overall change in floodplain hydrology.

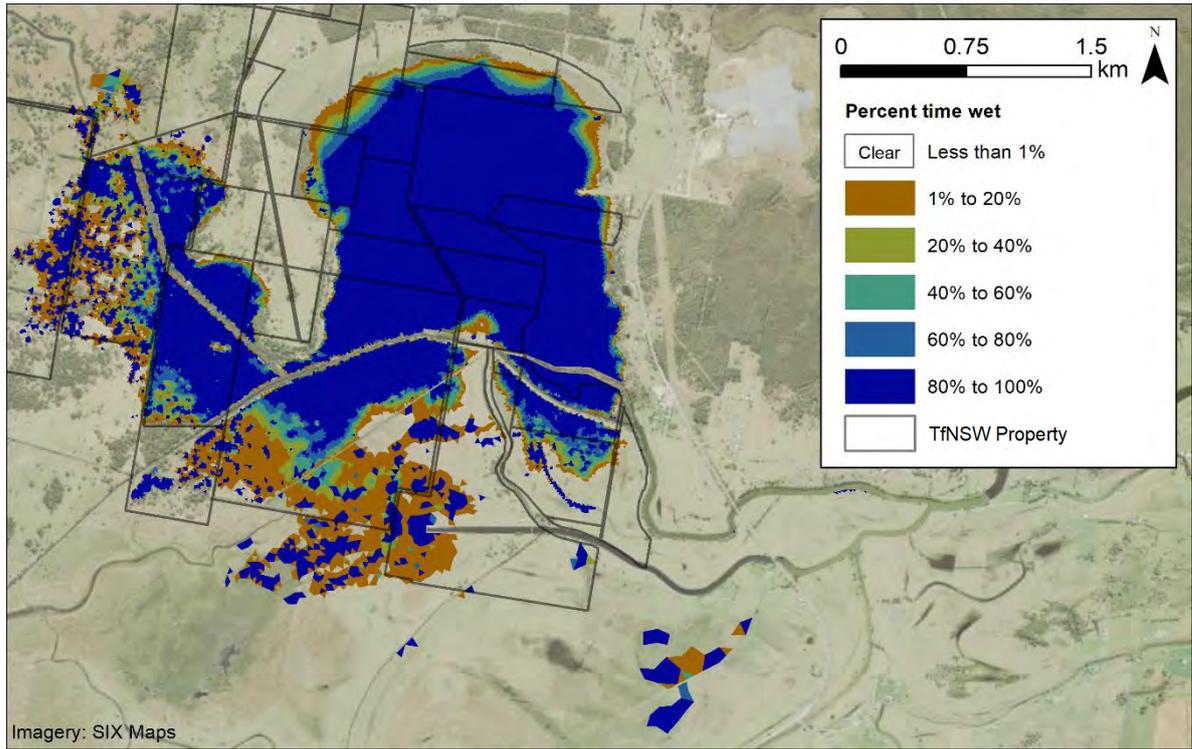


Figure ES4.21: Percent tidal inundation duration with Menarcobrinni floodgates hinged open

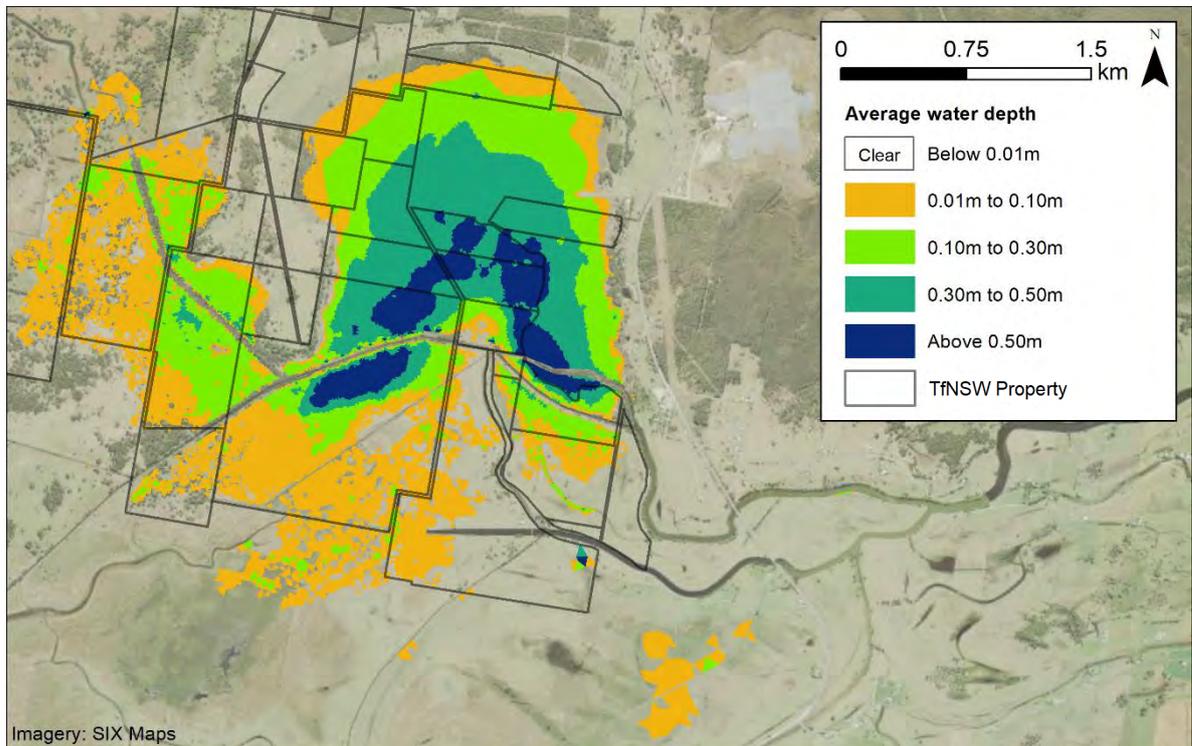


Figure ES4.22: Average tidal inundation depth (over a dry three-month period) with Menarcobrinni floodgates hinged open

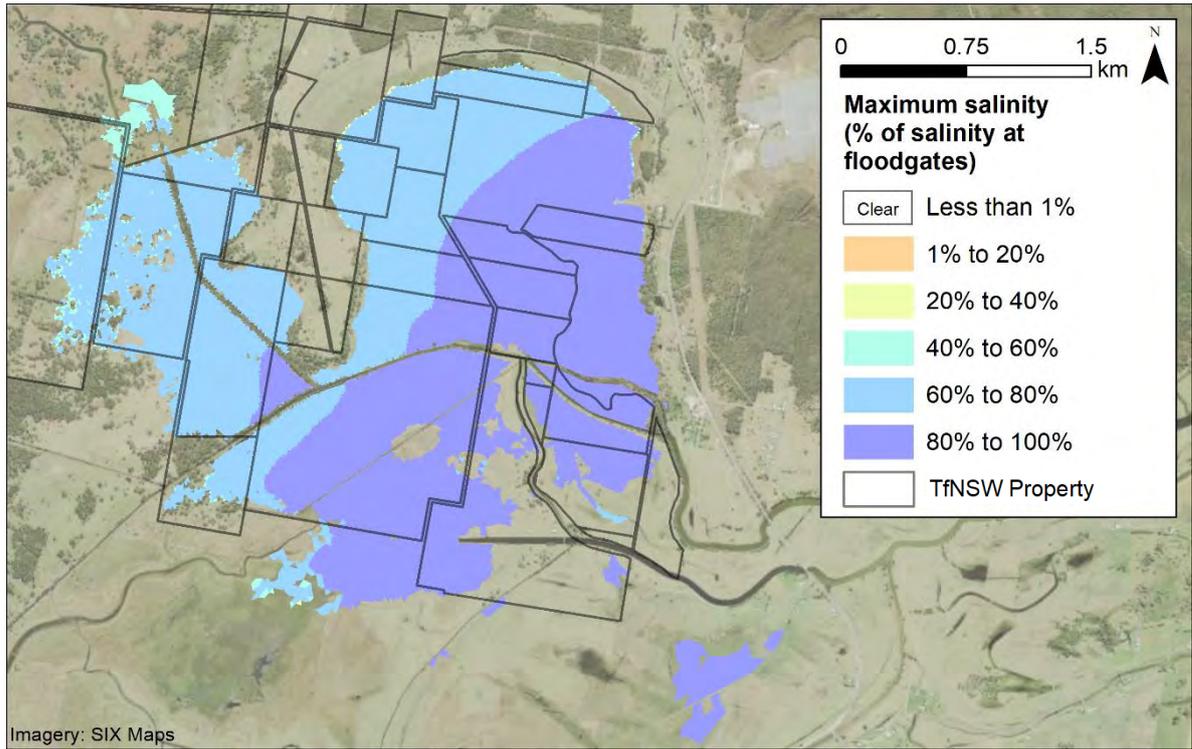


Figure ES4.23: Maximum saline intrusion (over a dry three-month period) with Menarcobrinni floodgates hinged open

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1 Introduction

1.1 Study description

The Collombatti-Clybucca floodplain, inclusive of the Clybucca Wetlands, is located on the Macleay River estuary floodplain. The floodplain is located approximately 15 kilometres from the ocean entrance at South West Rocks and has a contributing catchment area of approximately 26,000 hectares. The study area is presented in Figure 1.1 along with a list of local place names. Major flood mitigation drainage lines are provided in Figure 1.2 and summarised Table 1.1.

The Collombatti-Clybucca floodplain (hereafter referred to as the Clybucca floodplain) consists of two (2) named wetland backswamp complexes called Mayes Swamp and Doughboys Swamp. Over the past century, extensive drainage and flood mitigation works have been constructed across the Macleay River floodplain. These works have resulted in drainage of large backswamp areas. The impact of these drainage works has been twofold. Firstly, there has been an agricultural benefit due to the improvement of day-to-day drainage due to the efficient removal of surface water following rainfall events. Secondly, environmental degradation has occurred due to the presence of acid sulfate soils (ASS) and resulting acidic discharge to the wider Macleay River estuary, as well as increased frequency and magnitude of low dissolved oxygen (DO) 'blackwater' runoff events. In 1998, the Clybucca wetlands were declared an ASS 'hotspot' by the New South Wales government due to the environmental degradation caused by ASS at Clybucca. Investigation and remediation efforts were undertaken during the 1990s and early-2000s which remediated key ASS scald sites and installed a series of elevated sills in major drainage channels to reduce acid discharge while maintaining agricultural productivity. Despite these efforts, poor water quality including low pH and low DO continues to discharge from the low-lying floodplain areas at Clybucca.

During the Frederickton to Eungai Pacific Highway upgrade project (2013 to 2016), Transport for NSW (TfNSW) (previously NSW Roads and Maritime Services (RMS)) acquired a large proportion of the Clybucca wetland complex as part of the biodiversity offset requirements of the highway upgrade project. Higher land was acquired to offset several key habitat types impacted by the highway project, including wet sclerophyll forest. However, in many instances the properties purchased extended to the low-lying Clybucca wetlands, resulting in an excess of wetland habitat surplus to that required under the TfNSW biobanking program. Through discussions with the NSW Environment Protection Authority (EPA) a supplementary offset strategy was approved and the wetland habitats at Clybucca can be used as biodiversity offsets in place of other habitat types. This provided a unique opportunity whereby one entity (TfNSW) owned the majority of the worst affected ASS land across the Clybucca floodplain.

Subsequently, further voluntary land acquisitions have occurred to extend the area owned by TfNSW to include adjacent low-lying land in the Mayes Swamp area.

A change of land use for the Clybucca wetlands requires a management strategy that rehabilitates wetland habitats and improves water quality, whilst considering potential impacts to the surrounding floodplain and landholders. The primary aim of this study is to provide a comprehensive scientific investigation of the hydrologic impacts of various on-ground options for future management of the Clybucca wetlands. While previous studies have generally focused on localised ASS remediation, this study provides the opportunity to focus on water movement across the Clybucca floodplain under a range of different conditions. This study also provides the relative impacts of each management option on properties adjacent to the TfNSW owned land and across the broader Clybucca floodplain. Funding for this study has been provided by the Saltwater Recreational Fishing Trust's Flagship Fish Habitat Action Program.

The options investigated in this study were developed in consultation with the Clybucca Government Working Group, consisting of representation from Local Land Services, Kempsey Shire Council, National Parks and Wildlife Services, Department of Planning, Industry and Environment (DPIE) (formerly OEH), Department of Primary Industry – Fisheries, TfNSW, NSW EPA and Crown Lands. While not all potential management options have been considered, the drainage options detailed in this investigation provide a range of strategies that aim to rehabilitate wetland habitats by working towards restoration of the natural wetting and drying of the wetland areas and improve surface water quality by reducing acid drainage from the Clybucca floodplain, with minimal impacts to adjacent landholders.

Community feedback and discussions were an integral part of the outcomes of this study. Local landholders, the Seven Oaks Drainage Union, local community groups, and relevant government agencies, were consulted on their views of working towards a sustainable management solution for the study area. Information gathered from the feedback sessions was integrated with detailed scientific investigation to establish viable management options for the study area. Additional outcomes from the study include a detailed literature review, regional flood impact assessment, site-specific field measurements, and validated catchment and hydrodynamic numerical models.

1.2 About this report

The terms hydrology, hydraulics, hydrodynamics and remediation are used regularly throughout this report. The plain English definitions of these terms is provided as follows for reference:

- 'Hydrology' is used in the broader sense relating to the interaction of rainfall, surface water, groundwater and the contributing climate, as well as catchment characteristics which drive the water cycle. Hydrologic modelling is used to quantify the volume and timing of rainfall runoff that flows from the upland catchment to the wetlands;
- 'Hydraulics' defines the flow of water through and over structures (e.g. culverts and weirs);
- 'Hydrodynamics' is used to define floodplain water movement in terms of water levels, flow speeds and flow distributions across the landscape. Hydrodynamic modelling is used to quantify water movement over the floodplain both before and after on-ground works;
- 'AHD', or Australian Height Datum is the vertical datum in Australia. 0 m AHD is approximately mean sea level; and
- The term 'remediation' means to remedy a symptom of damage, and in this report is used in the context of reducing pollution from degraded ASS areas. Whereas, the terms 'rehabilitation' or 'restoration' are used to describe the process of returning degraded wetlands to their former state after some process (e.g. over-drainage) has resulted in damage.

The report is composed of the following sections:

- **Chapter 2** provides background information to this study, including an overview of the legacy management issues and progress towards remediation of the study area;
- **Chapter 3** provides a description of the wetland processes across the Clybucca floodplain;
- **Chapter 4** provides a discussion of general management approaches to remediation of acid sulfate soils and blackwater;
- **Chapter 5 to Chapter 12** present the management options for Clybucca and include the outcomes of the detailed assessment, including numerical modelling, completed for each option;
- **Chapter 13** summarises the flood impact assessment of selected management options;
- **Chapter 14** discusses how sea level rise is likely to impact the Clybucca floodplain;
- **Chapter 15** provides an indicative cost and benefit assessment for the different management options; and
- **Chapter 16** provides a summary of the study findings.

This report has been structured to highlight the key findings of the study. Following a list of references (Section 9), significant tasks that do not form the core outcomes of the study have been documented as appendices, including:

Appendix A provides background theory on acid sulfate soils;

Appendix B provides a summary of existing data;

Appendix C provides a summary of field data collection;

Appendix D provides a summary of hydrodynamic model development;

Appendix E provides a summary of hydrodynamic model validation;

Appendix F provides a summary of modelling data processing techniques;

Appendix G provides a summary of sensitivity tests completed for salinity; and

Appendix H provides the regional flood impact assessment of selected management options.

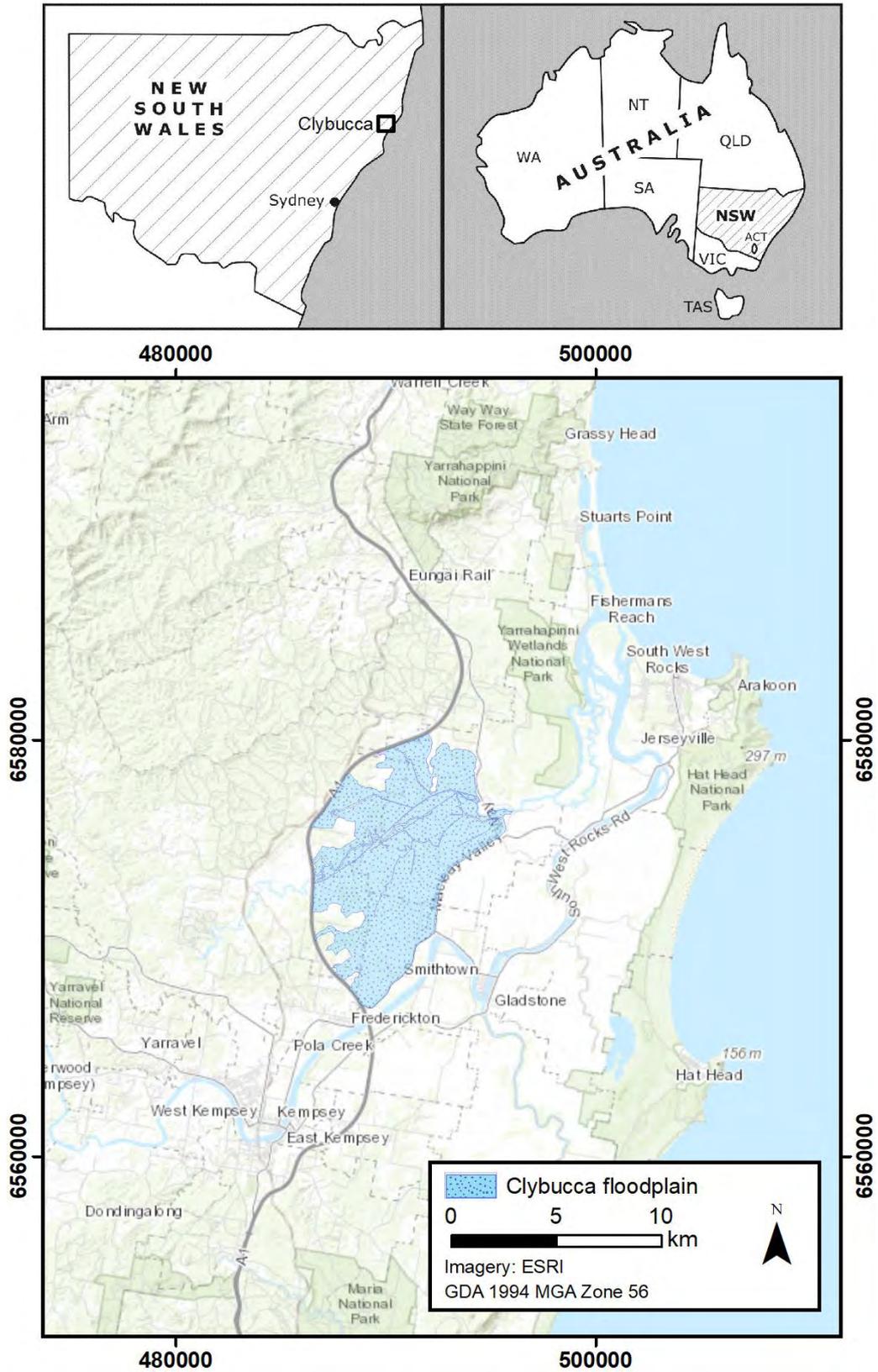


Figure 1.1: Location of the Clybucca floodplain (study area)

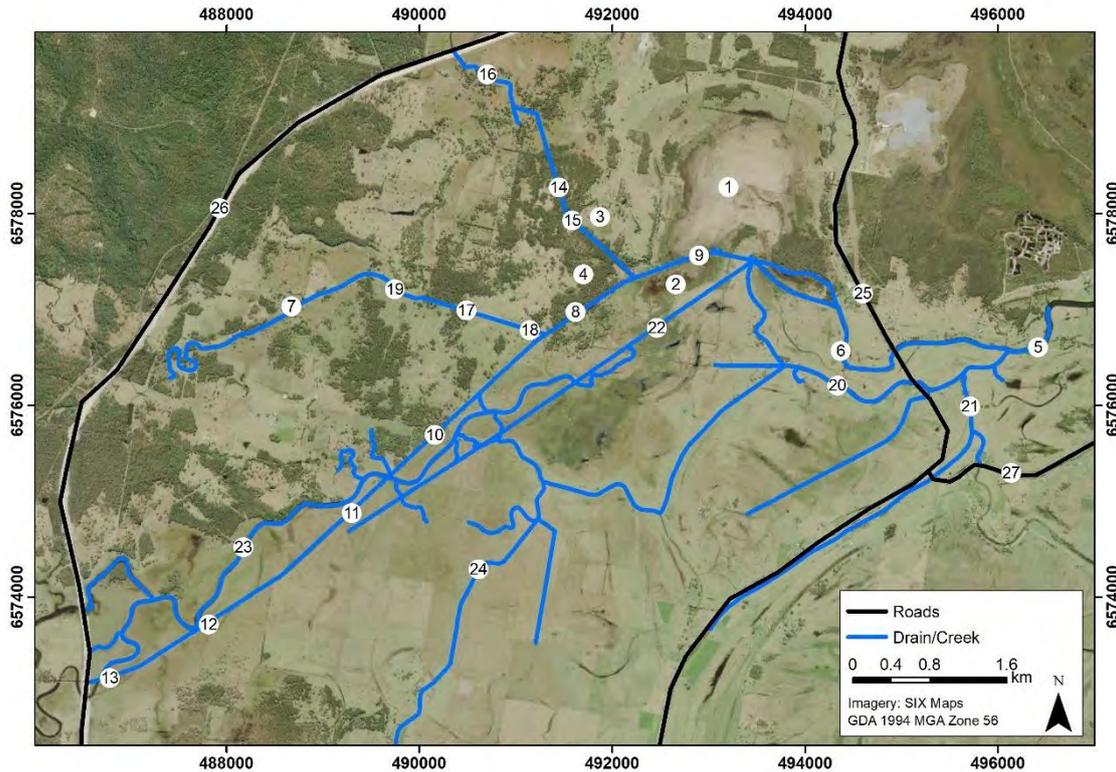


Figure 1.2: Common place names and key drainage lines at the study site

Table 1.1: Keys relating to common place names and drainage lines at the study site

Key	Name	Key	Name
1	Mayes Swamp	15	East Drain Weir
2	Yerbury's Scald	16	Johnsons Creek
3	Latham's Scald	17	West Drain
4	Doughboy Swamp	18	West Drain Weir #01
5	Menarcobrinni Floodgates	19	West Drain Weir #02
6	Clybucca Creek (downstream)	20	McAndrews Drain
7	Clybucca Creek (upstream)	21	Humpty-back Creek
8	Seven Oaks Drain	22	Doughboy Drain
9	Yerbury's Sill	23	Collombatti Creek
10	Seven Oaks Drain Weir #01	24	Shackles Drain
11	Seven Oaks Drain Weir #02	25	Macleay Valley Way
12	Seven Oaks Drain Weir #03	26	Pacific Highway
13	Seven Oaks Drain Weir #04	27	Plummers Lane
14	East Drain		

2 Clybucca wetlands background

Summary:

- The Clybucca wetlands were full of “*Large flocks of aquatic birds, of wonderful variety, all busily engaged, and fish leaping out of the water in every direction*” prior to European development.
- Extensive drainage networks were constructed throughout the Macleay River floodplain. Doughboy Drain was the first drain constructed on the Clybucca floodplain in 1884.
- The Macleay Valley Flood Mitigation Scheme began in the 1960’s and resulted in extensive drainage of the Clybucca floodplain including the completion of Andersons Inlet, Seven Oaks Drain and the Menarcobrinni floodgates.
- By 1990, issues associated with the drainage of acid sulfate soils were evident across the Macleay River Estuary and investigations into remediation began.
- In 1998 Clybucca was mapped as an acid sulfate soil hotspot.
- Between 1998 and 2004 numerous remediation works including installation of sills across the drainage network were completed.
- In recent years numerous studies were conducted highlighting the important issues associated with acid sulfate soils and blackwater discharge.
- Poor water quality draining from the Clybucca floodplain still impacts the wider estuary today despite ‘paddock’ scale remediation efforts.

2.1 Preamble

The following section outlines the drainage history of the Clybucca floodplain and the modifications which drained one of the largest coastal wetland complexes in New South Wales. This section focuses on what the Clybucca wetlands may have looked like before any drainage occurred, how drainage affected the Clybucca floodplain (as well as the broader Macleay River Estuary where relevant), and the subsequent investigations focused on addressing water quality issues. The environmental impacts of acid sulfate soil and blackwater runoff are also discussed within the context of the broader Macleay River estuary.

2.2 The historic Clybucca wetlands

The Macleay River was historically connected to the ocean between South West Rocks and Grassy Head. The sand barrier between these two (2) headlands created a natural boundary between the estuary and the ocean, causing low energy conditions within the estuary. This resulted in the deposition of estuarine muds, which gradually infilled the Macleay basin over the last 3,000 years. The estuary is now dominated by river processes (Telfer, 2005). Within the estuary, Collombatti Creek flowed from highland catchment areas to the Clybucca floodplain where it spilled out across the low-lying floodplain connecting with Mayes and Doughboy Swamps before proceeding to flow down Clybucca Creek which connects with the Macleay Arm in the Macleay Estuary.

Prior to European exploration in 1817, the Macleay River estuary was an important area described as being “full of natural bounty” (Telfer, 2005). Numerous archaeological records show the area’s importance to indigenous Australians, known as the Dunghutti people, who lived throughout the region (WMA Water, 2009). The area around Clybucca included extensive freshwater meadows, seasonal freshwater swamps and reed swamps. Clybucca itself had approximately 285 hectares of seasonal freshwater swamp in what is now known as Mayes and Doughboy swamps (Goodrick, 1970). This was the largest freshwater swamp on the north coast of New South Wales (Tulau, 2011).

The wetlands would have been occupied by a large variety of freshwater vegetation and numerous kinds of water birds (PWD, 1978). Early explorers to the area described the Clybucca wetlands as (WetlandCare Australia, 2010):

“Extensive swamps and lagoons of many thousand acres in extent, whose verdant sea, of high waving reeds and sedge, stretches away to the base of the distant forest ranges. Large flocks of aquatic birds, of wonderful variety, all busily engaged, and fish leaping out of the water in every direction.”

2.3 Drainage of the Clybucca floodplain

European settlement on the Macleay River estuary occurred in 1827 when timber cutters settled to the area. Shortly thereafter, the ship building industry developed within the estuary (Telfer, 2005). During this time the mouth of the Macleay River was located at Grassy Head. It was not until a large flood in 1893 broke through the sand dune barrier at South West Rocks that the first alterations to the estuary occurred (Webb, McKeown, 1997; Eddie, 2000). The new entrance at South West Rocks was fixed with

the construction of rock training walls and the old entrance at Grassy Head was closed. It was reported that this change resulted in an increase of saltwater egress up Clybucca Creek (Telfer, 2005).

In the early 1900's the prospect of draining land in the Macleay floodplain started to gain momentum. While focus was on the value of flood mitigation drainage, the reclamation of land was also floated as a benefit (Telfer, 2005). By the 1920's, construction of drainage channels throughout the Macleay River floodplain had begun (Tulau and Naylor, 1999). August of 1924 saw the formation of the Seven Oaks Drainage Union amidst uncertainty of whether drainage would improve the value of land (Tulau, 2011). In 1951, after two (2) years of large floods, the Macleay Valley Flood Mitigation Scheme was initiated (Telfer, 2005). This resulted in the development of 210 one-way floodgates, 116 kilometres of drains and 180 kilometres of levees across the floodplain between 1963 and 1976 (Tulau and Naylor, 1999, Telfer, 2005). Installing one-way floodgate structures at the end of drainage networks ensured that backwater flooding from the river and tidal flows were limited. With respect to floodplain drainage, the floodgates acted to maintain upstream surface water levels at the low-tide elevation. This drainage allowed areas that were historically inundated to be used more extensively for agriculture. Using floodgates in this manner also has other impacts, including:

- Increasing the available freeboard in drains;
- Decreasing the groundwater elevation in land surrounding drains; and
- Oxidation of acid sulfate soils (ASS) (See Appendix A for additional information).

The first drain to be established on the Clybucca floodplain was Doughboy Drain, a shallow drain developed using the horse and scoop method (Tulau and Naylor, 1999). Construction of this drain was completed by 1884 and a concrete dam structure was built in 1895 to prevent saltwater intrusion up Clybucca Creek (Tulau, 2011). As part of the Flood Mitigation Scheme, in the 1960's numerous works were completed across, including (PWD, 1978):

- Seven Oaks Drain;
- West Drain;
- East Drain;
- McAndrews Drain;
- Shackles Drain (between McAndrews Drain and Frederickton); and
- Installation of a 21 culvert floodgate structure at Menarcobrinni (Figure 2.1).



Figure 2.1: Menarcobrinni floodgates

In addition to these works, Andersons Inlet was excavated downstream of the floodgates by excavation through elevated coffee rock which significantly increased the conveyance of the system by bypassing Clybucca Creek and removing previously elevated flow restrictions (Figure 2.2) (Tulau, 2011). This new connection to the estuary enabled floodwaters to drain more efficiently during wet times, however, it also allowed tidal waters to flow upstream and extend to the Clybucca floodplain due to the improved conveyance within the system (Glamore and Rayner, 2017).

Further modifications were made to the drainage network across the Clybucca floodplain over the following years. Between 1975 and 1979 Seven Oaks Drain, East Drain and West Drain were modified to further increase their capacity (KSC, 2004; Glamore and Rayner, 2017). Additionally, regular maintenance was conducted in the drainage network, including spraying of weeds and clearing out of weeds, to ensure efficiency of the drainage network (PWD, 1978). Inspections of the drains in July 2018 indicated that this maintenance is no longer continued within East Drain (pers. comms T. Saul, 2019).

Presently, the drains across the Clybucca floodplain are owned and managed by multiple entities. Figure 2.3 provides an overview of drainage ownership including a large number of small privately owned drains.



Figure 2.2: Clybucca Creek to Andersons Inlet cutting, 1966 (KSC via Tulau, 2011)

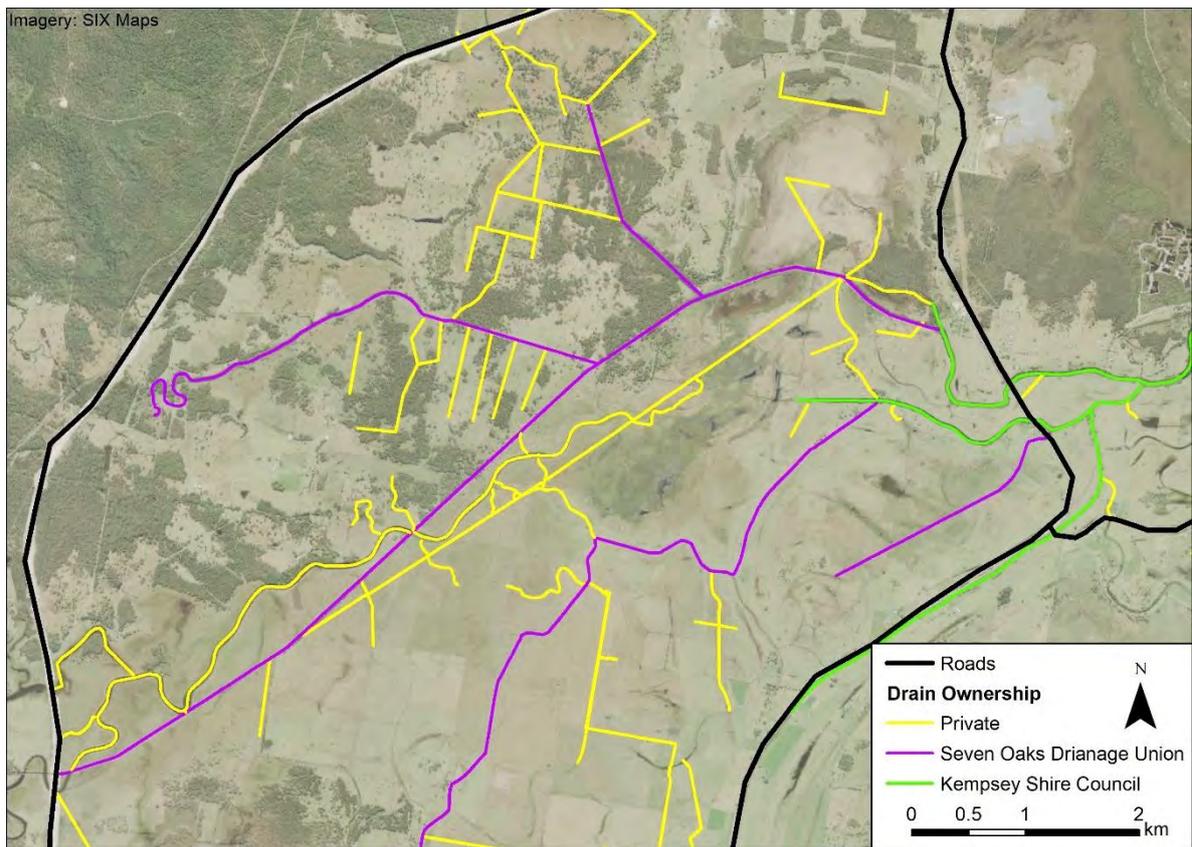


Figure 2.3: Ownership of drains on the Clybucca floodplain

2.4 Acid sulfate soils on the Clybucca floodplain

Acid sulfate soils (ASS), historically referred to as ‘catclays,’ have been found in the Macleay Valley from Kempsey to South West Rocks (Tulau and Naylor, 1999). ASS are generally classified as potential ASS (PASS) or actual ASS (AASS). PASS refers to ASS that remains undisturbed and unoxidized within the ground below the water table and has a near-neutral pH. When drainage occurs, the water level within the ground drops exposing soils to oxygen. When PASS becomes exposed to the oxygen in air it turns into AASS as a chemical reaction occurs. This chemical reaction produces acid which can then be transported into drains. It has been estimated that the equivalent of approximately 220 Olympic swimming pools of acid (550 ML) with a pH of 3 is discharged into the Macleay River estuary during the initial flush of a rainfall event due to ASS (Glamore and Rayner, 2017). A detailed description of ASS including the environmental impacts is provided in Appendix A.

ASS was first discovered in the 1700’s when large areas of marsh and fenland were drained in the Netherlands (Tulau, 2011). The existence of ASS in Australia was known as early as the late 1800’s and the first records of ASS in the Macleay region were recorded by Patrick Walker in 1960 (Tulau, 2011 and Tulau and Naylor, 1999). The effects of draining ASS were observed in the Macleay as early as 1968 with Allen Strom of National Parks saying, “Any further drainage of the Macleay wetlands could be disastrous” (Tulau, 2011). Of significant issue within the Lower Macleay was the poor water quality due to the drainage of ASS. Table 2.1 summarises the impacts ASS can have on waterways and floodplains.

Table 2.1: Summary of impacts associated with ASS (Tulau, 2007)

Impact type	Description of ASS 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 built structures (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, sugar cane, tea-tree, grazing and dairy. Reduction in arable land through creation of acid scalds.

Historically, poor water quality due to ASS and low dissolved oxygen ‘blackwater’ resulted in massive fish kills, detrimental economic impacts on the local fishing industry, reduction of oyster yields, and

degradation of agricultural land (Glamore and Rayner, 2017). In the 1990's, the culmination of these events resulted in investigations to remediate waterways degraded due to over drainage of ASS.

Investigations into ASS remediation options across the Clybucca floodplain began in the 1990s. These investigations included (Enginuity Designs, 2003; Glamore and Rayner, 2017):

- Construction of Yerbury's Sill (at -0.3 m AHD);
- Construction of four (4) other low-level earthen sills upstream on Seven Oaks Drain;
- Construction of small levees or bunds to retain surface water on floodplains;
- Construction of drop board structures across levee cut out points;
- Management stock by employing wet pasturing and grazing techniques;
- Remediation of surface acid scalds;
- Enhancing wetland habitat values; and
- Reducing the potential for acid discharge to the estuary.

In 1999, the Macleay acid sulfate soil local action group installed two (2) small sluice gates within the existing floodgate structure at Menarcobrinni (KSC, 2004). Due to concerns about saltwater impacting low-lying areas upstream of the sluice gates their use was abandoned after a brief trial (Glamore and Rayner, 2017).

In 1998, the NSW Department of Land and Water Conservation (DLWC, now the NSW Department of Planning, Industry and Environment) mapped areas within the Clybucca floodplain as an ASS hotspot. This resulted in the Collombatti-Clybucca ASS hotspot project beginning in September 2001 led by Kempsey Shire Council (KSC) (Enginuity Design, 2003). Further mitigation works were implemented as part of this project including (KSC, 2004):

- Fencing off the southern acid scald (known as Yerbury's scald);
- Scald revegetation trials on the southern scald;
- Installation of a weir at -0.2 m AHD on East Drain;
- Fencing of acid scald area adjacent to East Drain (known as Latham's Scald);
- Acid scald revegetation in the fenced off area adjacent to East drain;
- Installation of a weir at +0.1 m AHD on West Drain;
- Installation of a weir at +0.2 m AHD on West Drain (further upstream); and
- Introduction of surface salts on acid scalds.

Since construction of these mitigation works there have been numerous studies completed that look at the issues associated with ASS on the Clybucca floodplain and more generally the Macleay River Estuary. These include:

- Cheeseman et al. (2004) – A case study testing the effectiveness of the NSW Environmental Services Scheme in combatting environmental degradation due to ASS;
- Edeson et al. (2004) – A study into the effects of freshwater ponding on ASS;
- Andrews et al. (2005) – A study of surface vegetation impacts on ASS;
- Chartres et al. (2005) – A study investigating how sub-surface shell material effects ASS;
- McLennan et al. (2005) – A study assessing the variability of surface water chemistry in relation to vegetation across Mayes Swamp;
- Telfer (2005) – A study conducted to determine and analyse the extent of data collected across the Macleay River estuary;
- Bush et al. (2006) – A study of the historical datasets to determine the effectiveness of monitoring at ASS hotspots;
- Birch (2010) – A study into the ecology of the Macleay River estuary;
- WetlandCare (2010) – A concept plan for promoting the best management of the Clybucca wetlands;
- GeoLINK (2012) – A study investigating the management of the Macleay River Estuary;
- Glamore and Rayner (2017) – A feasibility study looking at multiple options for the remediation of the Clybucca wetlands; and
- Rayner and Glamore (2017) – A preliminary draft lot-by-lot management plan developed for low-lying property on the Clybucca floodplain.

2.5 Blackwater and the Clybucca floodplain

In addition to ASS, poor water quality across Macleay River estuary has been linked to low dissolved oxygen (DO) 'blackwater' runoff events. Blackwater events occur when prolonged ponding of water on a floodplain, usually following significant rainfall events, result in the breakdown of organics that are intolerant to water (OEH, 2017). This breakdown uses dissolved oxygen creating what is known as 'hypoxic' conditions where oxygen is taken out of water faster than it can be replenished. The resultant water, devoid of oxygen with a high organic content, is black in colour, hence its name, 'blackwater.'

Runoff of low DO waters from coastal floodplains can occur naturally, however the drainage and development of backswamp areas for agriculture exacerbates the frequency and magnitude of blackwater runoff events.

This occurs primarily due to two (2) key processes:

1. Replacement of water tolerant vegetation with pasture species that die off when inundated with water and decompose causing hypoxic conditions; and
2. Increased connectivity of water across the floodplain meaning blackwater previously isolated and retained in the poorly connected backswamp areas drains efficiently into receiving waters following the receding of floodwaters.

Drainage of the Clybucca wetlands has resulted in the establishment of non-water tolerant pasture grass species that die when prolonged inundation occurs and can quickly decompose. This process is intensified in summer months when warmer temperatures accelerate the biodegradation process. The occurrence ASS further exacerbates blackwater events at Clybucca. Iron and sulphur minerals (pyrite) within ASS create mono-sulfidic black ooze (MBO) deposits in drainage channels which, when mobilised, can remove oxygen from the water (Johnston et al., 2003b). Blackwater events have resulted in broad economic impacts to the wider Macleay River estuary often resulting in pasture die off, fish kills and impacts to downstream users (Rayner and Glamore, 2017).

2.6 Impacts of poor water quality within the Macleay River estuary

Poor water quality associated with ASS and blackwater from Clybucca impacts the immediate waterways upstream of the Menarcobrinni floodgates as well as the receiving waters of Clybucca Creek, Andersons Inlet and the Macleay Arm. Previous investigations of the fate and transport of flows from the Clybucca floodplain indicate that discharges have the potential to impact 50 km of estuarine waterways. ASS and blackwater events have historically had the following effects on water quality:

- Low water pH due to acid discharge;
- High iron and aluminium concentrations due to oxidation of ASS; and
- Deoxygenated water due to breakdown of organic matter and MBO mobilisation.

Figure 2.4 outlines the process and timeline by which ASS and blackwater are generated and discharged after a flood event. This process is further discussed in Appendix A within the context of ASS. Generally, impacts associated with blackwater occur between 6 to 30 days after a flood event, once organic matter has decomposed. The effect of acidic groundwater is highest once surface waters have drained, with an elevated groundwater table promoting a strong gradient from the acidic soil matrix to surface drainage channels (Figure 2.5).

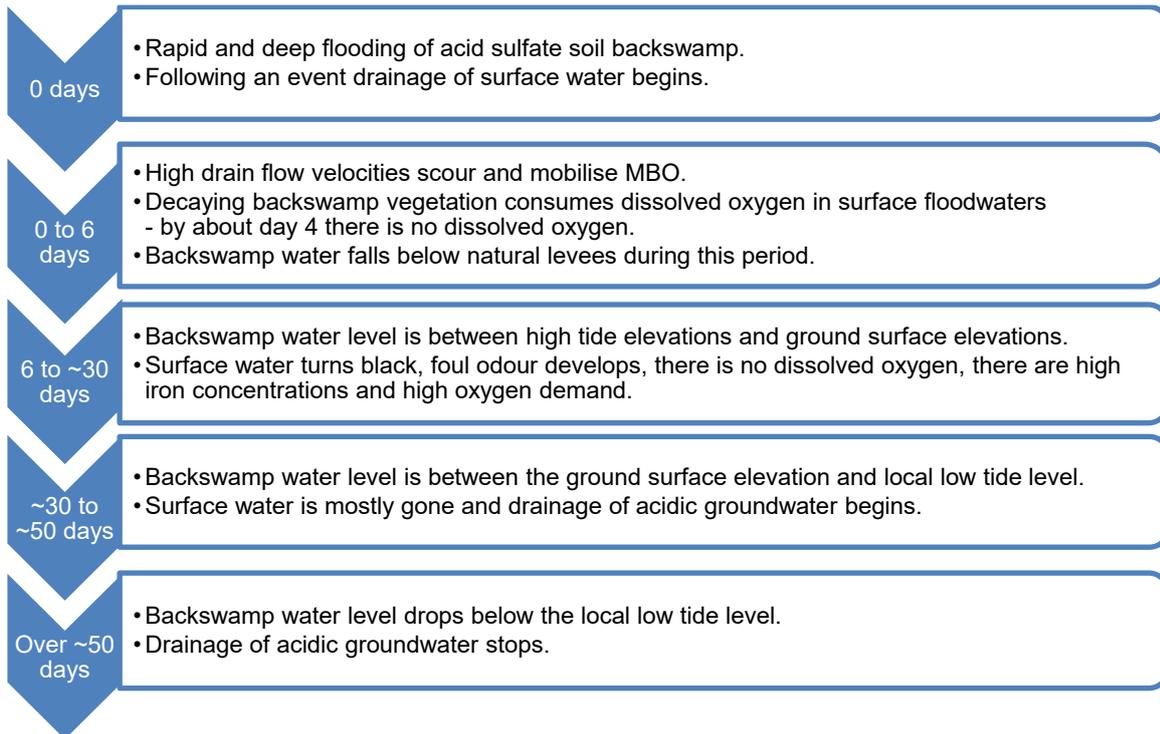


Figure 2.4: Summary of water quality changes following major flooding of a backswamp (adapted from Johnston, 2003b)

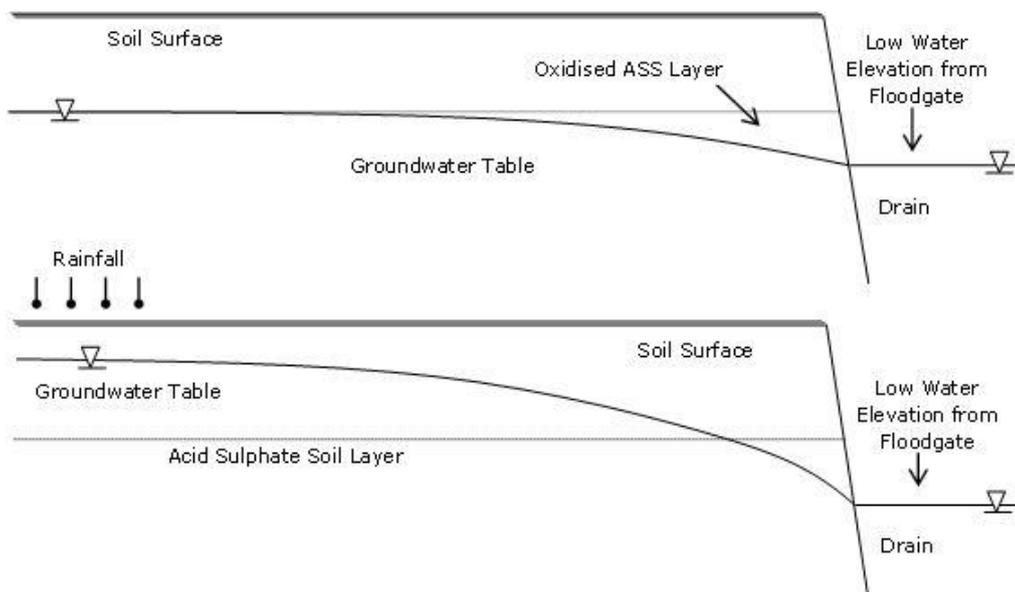


Figure 2.5: Discharge of acidic groundwater under dry (top) and post-flood (bottom) conditions (Glamore, 2003)

Within the Macleay River estuary, the impacts of ASS and blackwater events have been detrimental to local industry. Aquaculture within the estuary has suffered from events which resulted in the massive killing of oyster stock and fish (Tulau, 2011). An example of a newspaper article expressing this issue is shown in Figure 2.6. Examples of aquatic fauna die off as a result of a 2015 blackwater are shown in Figure 2.7 and Figure 2.8. In addition to fish kills, there is often an increase in disease within aquatic organisms associated with poor water quality. An example of this is 'redspot' which is a disease within fish which occurs due to acidic water damaging the skin of fish (Johnston, 2003b).

During investigations on the Clybucca wetlands (outlined in Appendix C) high levels of iron flocculant were observed in the drainage network (Figure 2.9). Large quantities of iron and aluminium like this result from ASS oxidation and can be toxic to aquatic organisms (Johnston, 2003b). When ASS oxidises, iron and aluminium stored within the soil substrate are released alongside sulfuric acid. Presence of iron flocculant can be an indicator of MBO deposits. It has been shown that 10 milligrams of MBO can deplete one litre of water of oxygen in a matter of minutes (Johnston, 2003b). Figure 2.10 shows MBO which has been disturbed from its resting place at the bed of Seven Oaks Drain.

The environmental effects of ASS and blackwater runoff have both immediate and long-term impacts. In the short-term aquatic life dies off or becomes diseased and habitats are destroyed. These impacts continue and compound in the long-term. In areas where acid is prolonged native vegetation dies off and is replaced with acid tolerant vegetation. Aquatic life that has died off or become diseased takes a long time to re-establish, provided there are improvements in water quality allowing the habitat to recover. A single runoff event can leave a lasting impact on the estuary that might take years to recover (Johnston, 2003b; Tulau, 2007).

Oysters, fish die in rivers

POLLUTION BLAMED FOR MASSIVE KILL

Oyster farmers on the lower Macleay have lost stock valued at thousands of dollars and many of the river's fish breeding grounds have been seriously affected in the past couple of days by the discharge of floodwaters into creeks and streams.

In the latest incidence of water pollution, oyster growers in the Clybucca Creek area are putting their losses in excess of \$80,000. They blame them on flood mitigation works carried out in Clybucca Creek, Yarrahappinni and Andersons Inlet.

The discharge from Lower Macleay swamps is also blamed for the huge fish kill which appears to have wiped out breeding grounds in Belmore River, Kinchela Creek, Spencers Creek and the Stuarts Point arm of the Macleay River.

Thousands upon thousands of dead fish, killed apparently by lack of oxygen, are floating in creeks and streams, creating a health hazard as they begin to decay.

The Kempsey Shire Council, told of the situation yesterday, had no answers to it when contacted mid-afternoon. The health surveyor (Mr. J. H. Bow) assessed and was done the p

test under flood conditions last week.

Mr. Beattie said his inspection of the lower Macleay River system yesterday had revealed huge numbers of dead fish in the river between Jerseyville and Smithtown and as far up the Belmore River as the Seale bridge.

Fishermen who have lived on the Macleay all their lives claim most of the troubles began in 1967 when certain drainage schemes were constructed by the flood mitigation committee.

Since then, they say, flood and stormwater drainage from the Clybucca and Yarrahappinni catchments has been forced down the old bed of the river.

There have been repeated claims that flood mitigation works in Clybucca Creek have changed tidal patterns.

Andersons Inlet, opened to make a new bed for the Clybucca Creek, is being blamed for losses by many oystermen.

Mr. Bill Barber, manager of Mr. Oyster Company, said yesterday he had already lost 33 per cent of his maturing oysters in Anderson's inlet.

Mr. Barber put the value of each tray at \$30. He still had to move

27,000 sticks of oysters valued at between \$1.20 and \$1.50 a stick.

Of these, he expected to lose between 60 and 70 per cent.

Other oyster farmers forced to move their stock were Messrs Rex Nunn and James Byrnes, and George Cameron and Ron Biddell.

About 1,000 trays of oysters are believed to have been moved from the Golden Hole - Andersons Inlet area.

Oysters are only able to survive for about three days in the polluted water.

Oyster farmers with stock below the "barrel" are not so seriously affected by the flood discharge.

Mr. Barber said black water from the Kinchela area was killing fish in Spencers Creek, something he had never seen in his 48 years on the Macleay.

He believed the pollution problem was as bad as last year's and reiterated that floodwater was being "ponded" by the flow from Broadwater and the head of Clybucca Creek.

He said that until the flood channel was cut through Andersons, the problem now existing was unheard of. It had also been aggravated by the construction of headworks and levees on the Broadwater.



Figure 2.6: Article from the Macleay Argus, 15 March 1977, p.1 (via Tulau, 2011)



Figure 2.7: Example of blackwater runoff impacting aquatic fauna, February 2015 (Photo: M. Osborne)



**Figure 2.8: Example of low DO blackwater flowing into estuarine receiving waters
(Photo: M. Osborne)**



**Figure 2.9: Example of iron flocculant and iron staining upstream of the East Drain weir resulting
from ASS oxidation**



Figure 2.10: MBO deposits in Seven Oaks Drain

3 Clybucca wetlands processes

3.1 Preamble

Historically, agricultural land use practices have limited the scale of remediation possible in the Mayes and Doughboy Swamp areas, primarily due to the very low elevation of the topography and the shallow depth of ASS. Previous remediation efforts (Enginuity Designs, 2003; KSC, 2004) have resulted in some improvement in reducing ASS impacts, however poor water quality persists. In low-lying backswamp landscapes such as Mayes and Doughboy Swamps, large scale remediation is difficult without a change of land use management from agriculture to conservation. Further, large scale remediation is often difficult unless undertaken across an entire 'hydrological unit'. Following the acquisition by TfNSW of the lowest lying, worst ASS affected land on the Clybucca floodplain, the potential for catchment scale remediation of the floodplain is possible.

For effective remediation strategies to be implemented, it is necessary to understand the hydrological processes of the Clybucca floodplain. A detailed field investigation and data collection program was completed (Appendix C) to build on existing knowledge of the floodplain processes (Appendix B). As part of the investigation, three (3) important management areas have been determined which comprise the Clybucca wetland complex. These areas have been defined based upon their individual hydrological characteristics. The three (3) areas and their position in relation to TfNSW property boundaries (as of December 2019) are shown in Figure 3.1 and include:

1. Mayes Swamp;
2. Yerbury's Scald (including land to the south of Seven Oaks Drain); and
3. Doughboy Swamp.

It is important that the future management of the Clybucca floodplain should consider the hydrological influence of each area on the broader floodplain landscape. Tidal influence and backwater flooding effects also have a significant influence on the floodplain hydrology processes. In the following sections, in addition to describing the unique attributes of each management area, an overview of hydrological influences of the tide across the Clybucca floodplain has been presented.

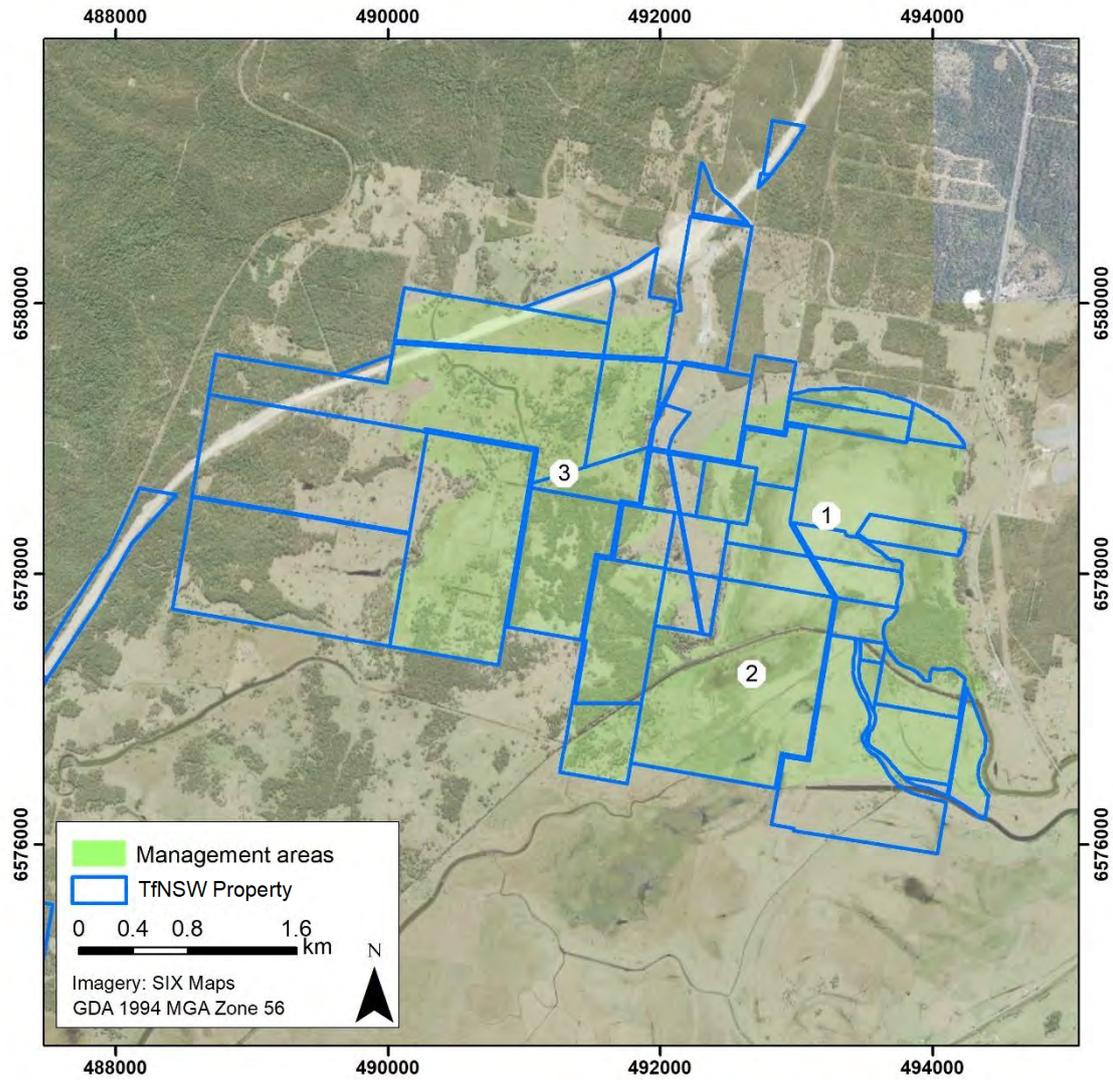


Figure 3.1: Key wetland management areas on the Clybucca floodplain including (1) Mayes Swamp, (2) Yerbury's Scald, and (3) Doughboy Swamp

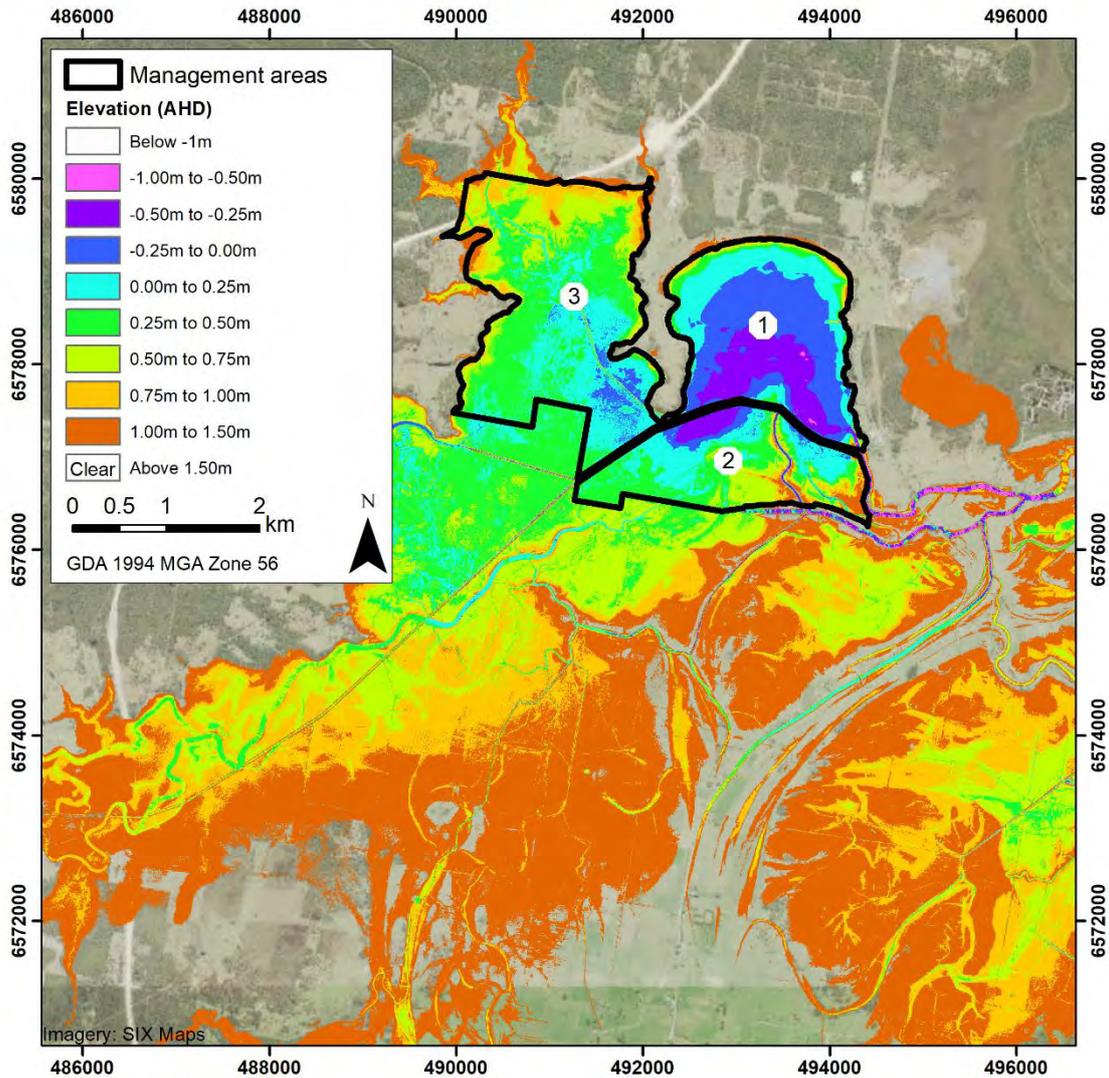


Figure 3.2: Elevation of the Clybucca floodplain including (1) Mayes Swamp, (2) Yerbury's Scald, and (3) Doughboy Swamp

3.2 Mayes Swamp

Mayes Swamp, located to the north east of the Clybucca floodplain, is approximately 350 ha in size and can be characterised as a large backwater basin. Historically, water flowing from upstream locations (including Collombatti Creek, Clybucca Creek and Johnsons Creek) would have discharged across the floodplain near Yerbury's Scald before filling up Mayes Swamp and continuing down Clybucca Creek. The majority of Mayes Swamp is below 0.0 m AHD in elevation (Figure 3.3).

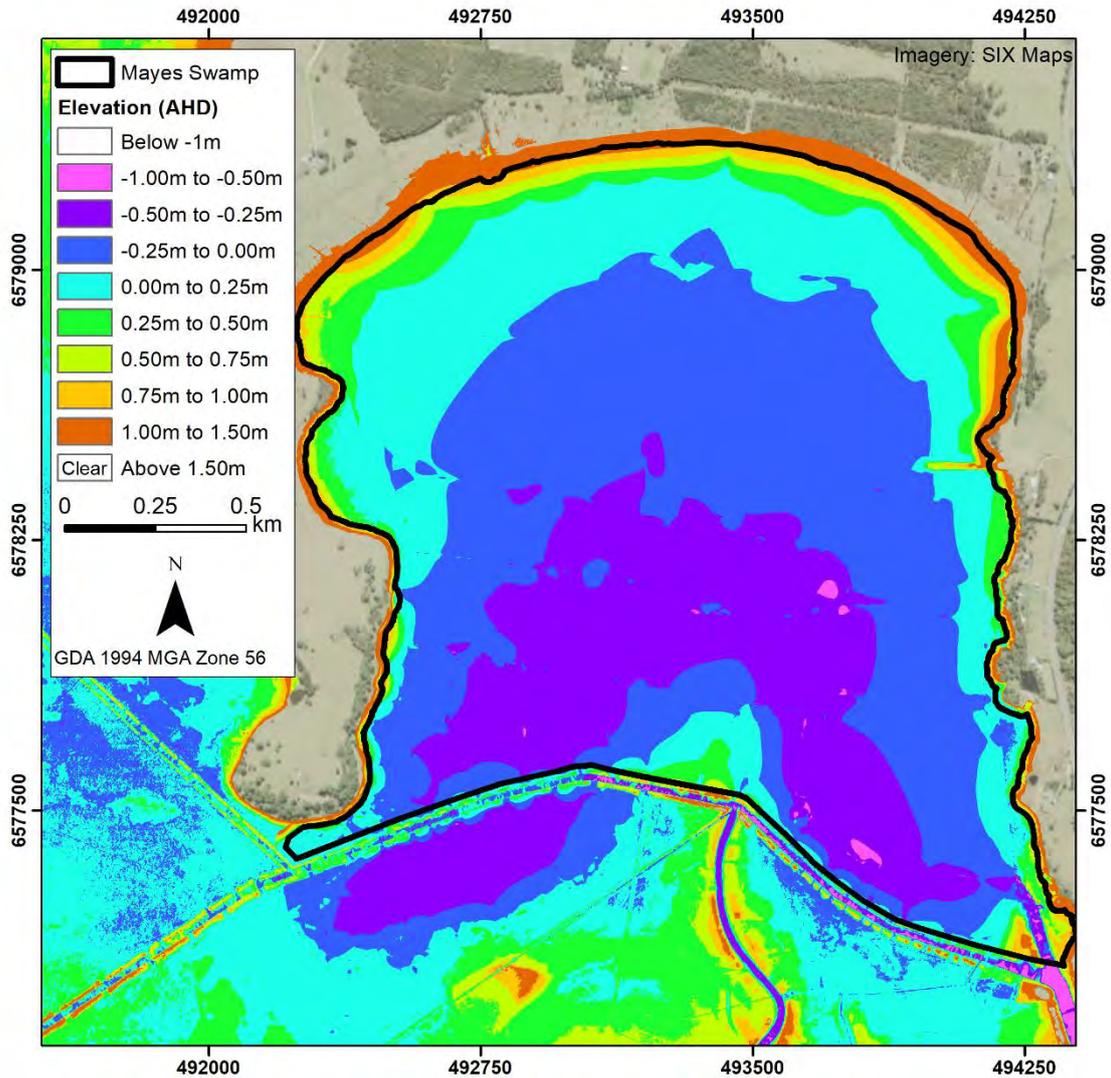


Figure 3.3: Elevation of the Mayes Swamp management area

Mayes Swamp is the most downstream section of the wetland complex at Clybucca. Ponding of water across the floodplain and freshwater wetland ecosystems would have been common prior to the construction of drainage infrastructure, which now provides efficient drainage of surface water from the floodplain. There are several drop board structures located on the levee bank of Seven Oaks Drain that are designed to maintain an elevated groundwater table within Mayes Swamp during dry conditions. During recent site inspections the condition of these structures was observed to be poor and water could easily flow from the floodplain to Seven Oaks Drain. Ponding of water across Mayes Swamp is now only common during wet periods.

At the south eastern corner of Mayes Swamp, the floodplain is connected directly to the lower section of Clybucca Creek. The remnant of this creek extends into the centre of Mayes Swamp with no visible structures or bund observed to prevent surface water drainage.

Vegetation across Mayes Swamp was observed to be predominantly freshwater wetland meadows dominated by vegetation such as grasses, herbs, rushes and sedges less than 1 m tall (Staines, 2019). There were also sparse areas of swamp oak forest and on the south east corner of the floodplain a significant paperbark swamp forest was observed (Staines, 2019). There were no areas within Mayes Swamp where the vegetation was classified as “good condition” (Staines, 2019).

The elevation of Mayes Swamp would have been historically higher prior to European development. The over drainage of the wetland areas has led to irreversible shrinkage of the clay soils, as well as the drying out of surface peat which was subsequently burnt during the 1900s (per comms. T. Saul 2019). Mayes Swamp is now situated below mean sea level (0 m AHD) and therefore poorly drained, often relying on evapotranspiration to remove standing surface water.

3.3 Yerbury’s Scald and surrounding land to the south of Seven Oaks Drain

The management area south of Seven Oaks Drain, including Yerbury’s Scald, is completely owned by TfNSW. Its size is approximately 250 ha. It is bounded to the north by Seven Oaks Drain and includes the largest acid scald present on the Clybucca floodplain, Yerbury’s Scald (Figure 3.4), which has an area of approximately 20 hectares. The lowest point of the scald has been surveyed to be -0.65 m AHD, however the surface elevation is generally situated at between -0.3 and -0.2 m AHD. Levee banks on Seven Oaks Drain are discontinuous, allowing connectivity between the floodplain Seven Oaks Drain at elevations above -0.1m AHD.

Downstream (to the east) of Yerbury’s Scald, a swale drain (i.e. shallow and wide) with an invert at approximately -0.4 m AHD runs north to south, connecting Seven Oaks Drain with McAndrews Drain. The banks of this swale drain are approximately +0.6 m AHD.

Doughboy Drain is a narrow constructed channel that bisects the floodplain to the south of Yerbury’s Scald. It connects the remnants of Collombatti Creek in the west, to Seven Oaks Drain in the east.



Figure 3.4: Yerbury's Scald (March 2018) showing Yerbury's Sill located in Seven Oaks Drain

This area is predominantly a freshwater wetland meadow dominated by vegetation such as grasses, herbs, rushes and sedges less than 1 m tall (Staines, 2019). To the west of the management area there are sections of swamp oak and paperbark forests (Staines, 2019). There were no areas in this section of floodplain where the vegetation was classified as “good condition” (Staines, 2019). The majority of this section of floodplain is below an elevation of +0.5 m AHD (Figure 3.5).

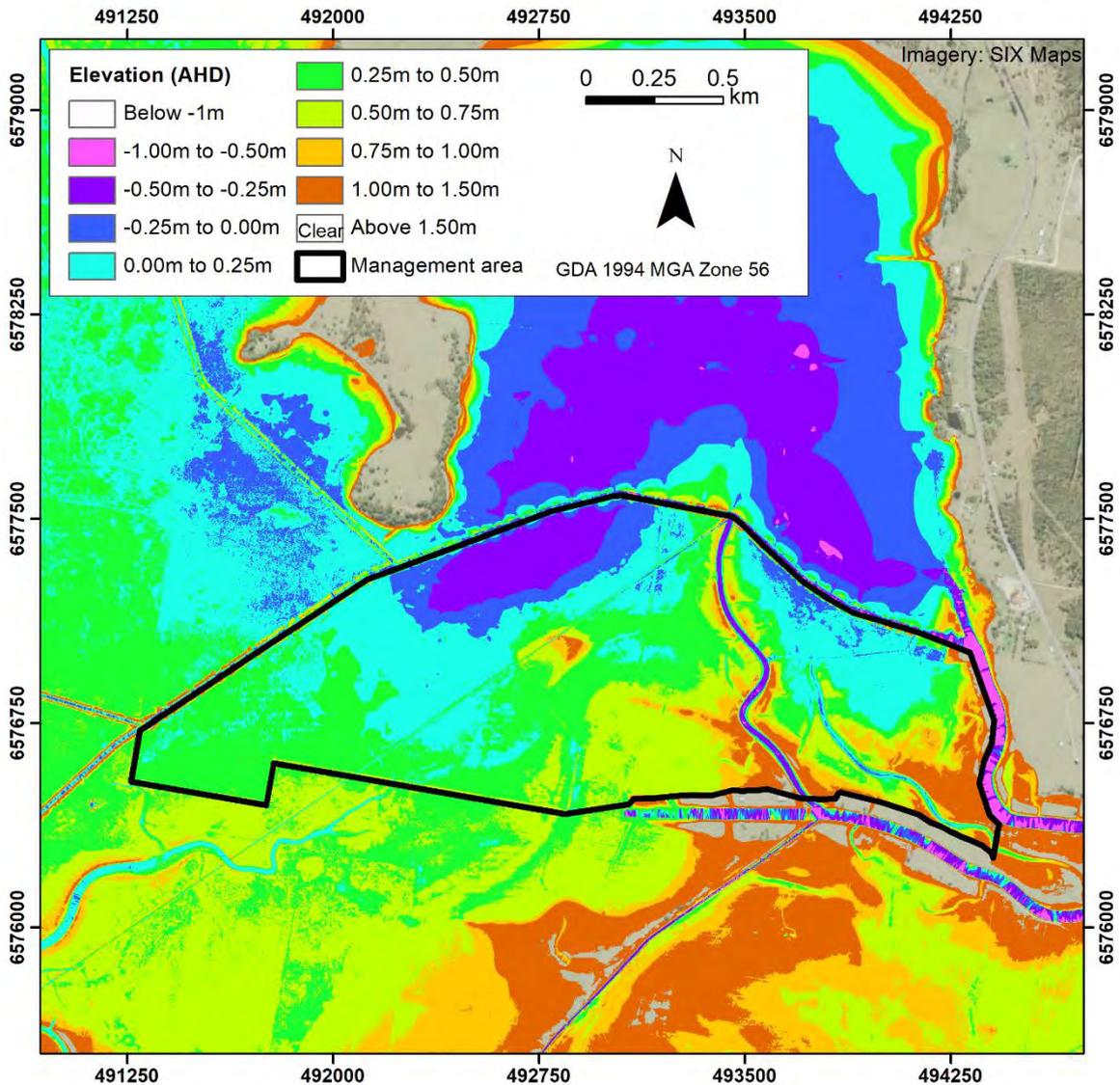


Figure 3.5: Elevation and location of the management area to the south of Seven Oaks Drain under TfNSW ownership

3.4 Doughboy Swamp

Doughboy Swamp receives catchment inflow from the Johnsons Creek sub-catchment. Clybucca Creek (the upper section) also indirectly flows into the south west section of the floodplain. Doughboy Swamp encompasses an area of approximately 490 ha. The area features highly acidic soils, with acid discharge, surface scalds and iron deposits occurring in the Doughboy Swamp area. A key feature of the swamp is known as Latham’s Scald, an acid scald on the east bank of East Drain adjacent to the East Drain weir. The management area for Doughboy Swamp is contained within TfNSW owned properties.

The lowest area of this floodplain is located adjacent to the downstream section of East Drain (Figure 3.6). The majority of Doughboy Swamp sits below +0.5 m AHD with the lowest areas below 0.0 m AHD. Doughboy Swamp is covered with an approximate 50/50 mix between freshwater wetland meadows (note this includes areas of pasture grasses) and swamp oak/paperbark forests (Staines, 2019). The northern section of the floodplain has scattered paperbark swamp forests (Staines, 2019). Across the Clybucca wetland complex, Doughboy Swamp contained the only section of flora classified as “good condition”, which was swamp oak/paper bark forest located on the west side of East Drain near the weir (Staines, 2019). It was in this location that a threatened species of fauna (rose-crowned fruit dove) was observed during vegetation mapping (Staines, 2019).

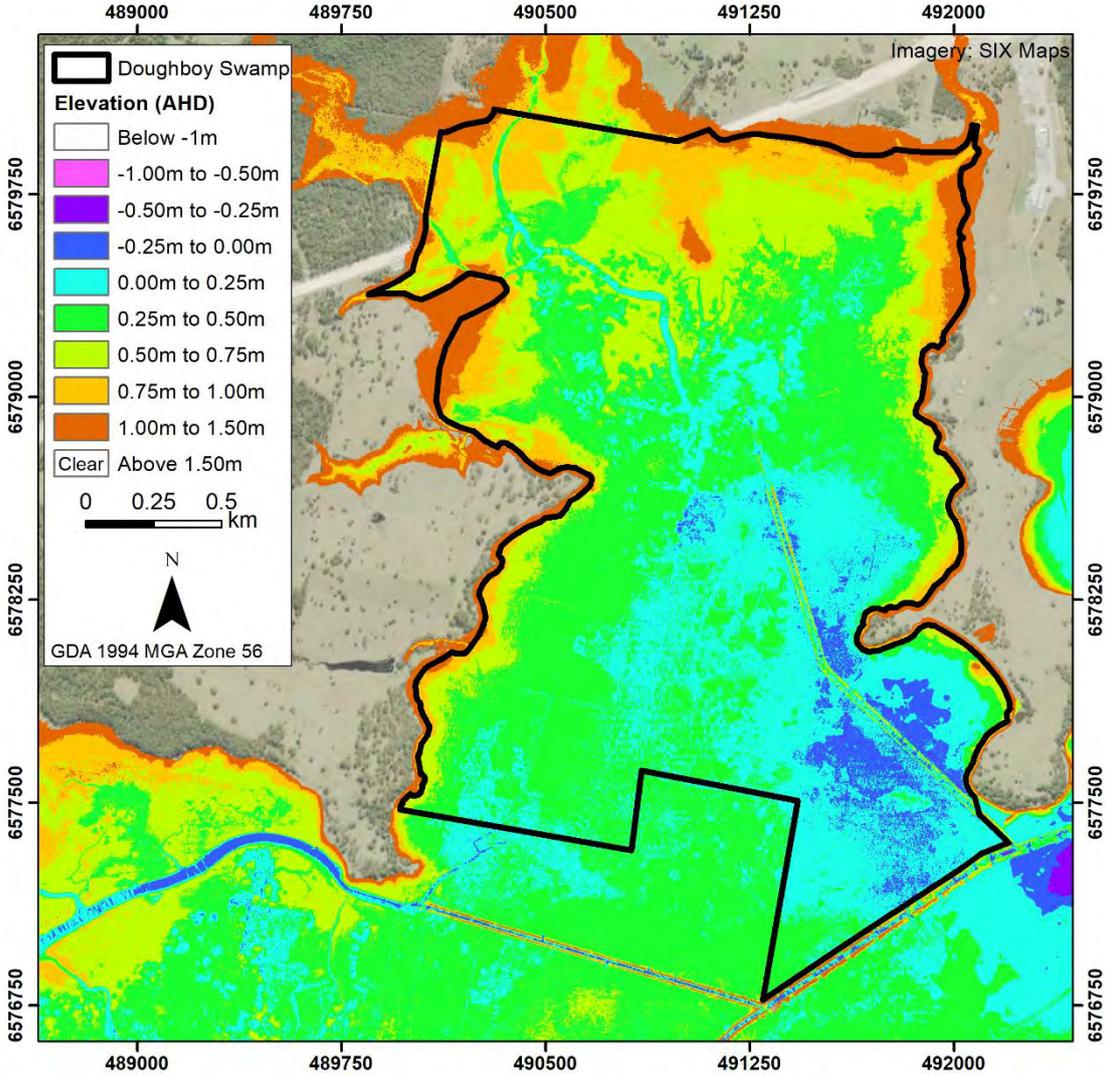


Figure 3.6: Elevation and location of the Doughboy Swamp management area under TfNSW ownership

Connection of drainage pathways between Johnsons Creek and East Drain is limited and overland flow across the swamp is common. Levee banks on the side of East Drain act to disconnect the floodplain from the drain. It was found that this generally means inundation of the floodplain is prolonged. Field observations observed that no works had been completed in recent years to maintain the drainage efficiency of East Drain. The result is that trees and bridges that had fallen in the channel are causing blockages. This could result in increased frequency and level of inundation across the adjacent floodplain. This was in stark contrast to West Drain, which has been maintained and efficiently drains to Seven Oaks Drain.

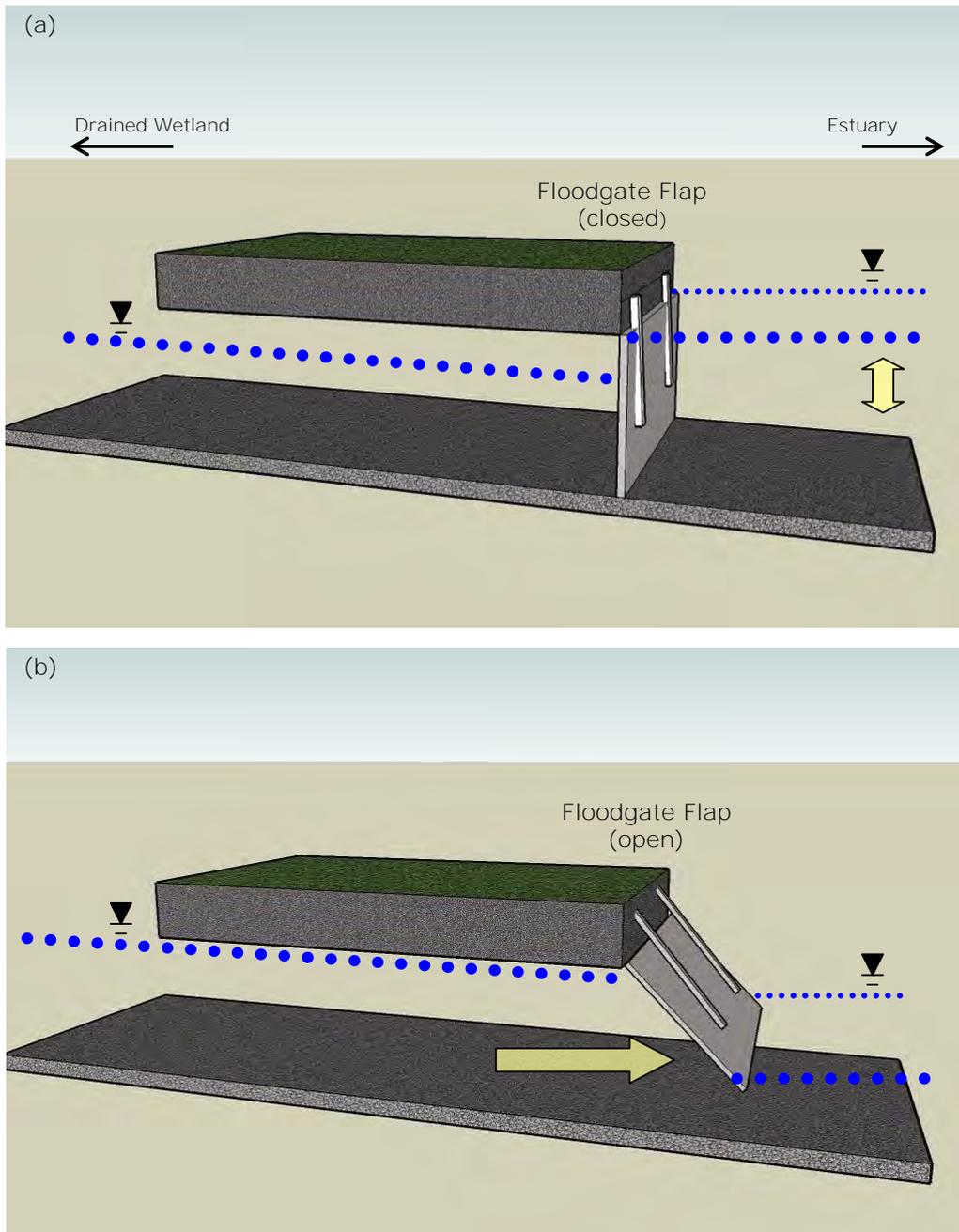
3.5 Effect of floodgates and backwater flooding on catchment hydrology

3.5.1 Floodgates and tidal influence

Floodgates, such as at Menarcobrinni, can be used to control water levels within a drainage network and prohibit flows upstream by only allowing flow in one direction as shown in Figure 3.7. When the water level in the estuary downstream of the floodgates is higher than the water level in the drainage network upstream, the floodgates close under hydrostatic pressure and prevent upstream flow. Once the downstream water level falls to below the upstream water level, discharge from the drainage network to downstream is possible.

During normal operating conditions (i.e. low catchment inflows), the water level within a drainage network upstream of floodgates is maintained at the low tide level. An example of this can be seen in Figure 3.8 at the Menarcobrinni floodgates where the water level within McAndrews Drain falls to the low tide level each tidal cycle as the water within the drain is able to flow through the floodgates. The water level behind the floodgates (i.e. in McAndrews Drain) rises during each high tidal cycle as inflows from upstream backup behind the closed floodgate. This also means that if the low-tide water level increases on the downstream side of the floodgates, like during a flood event, water in the drainage network and connected floodplain will be unable to drain.

Floodgates are an effective mechanism to lower the water level within a drainage network as well as lowering the surrounding groundwater table. This increases acid transport from ASS as discussed in Section 2 and Appendix A.



**Figure 3.7: 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**

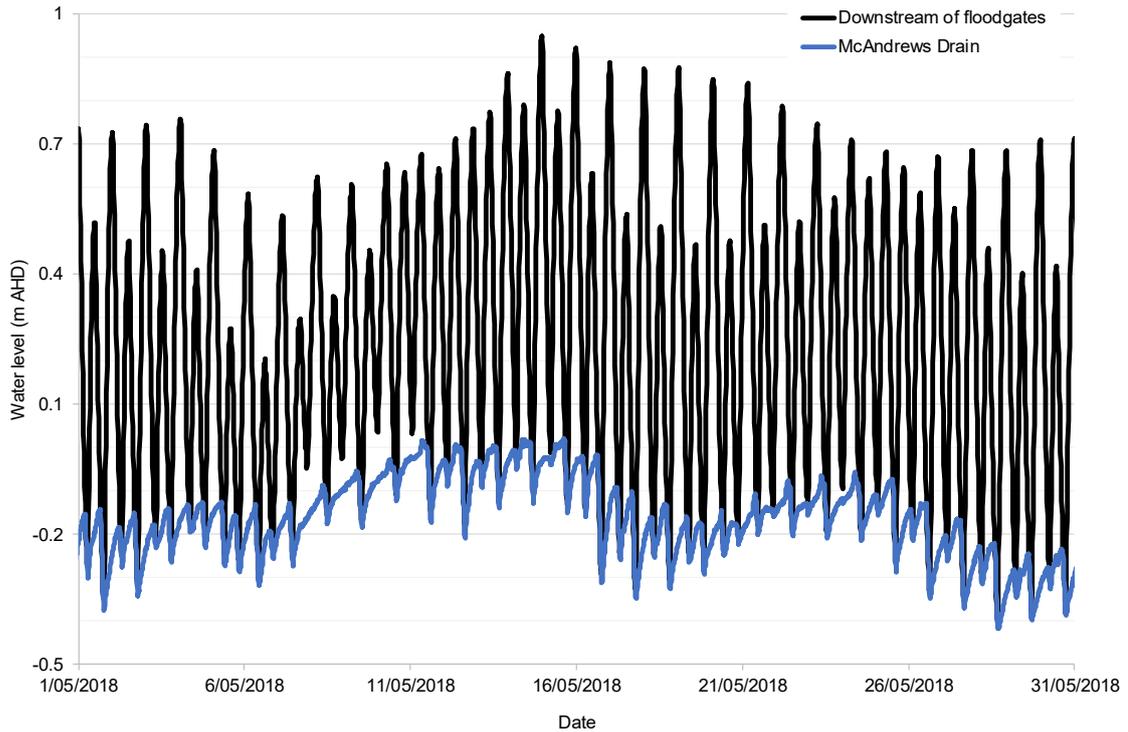


Figure 3.8: Comparison of the water levels measured downstream of the Menarcobrinni floodgates and upstream of the floodgates on McAndrews Drain during May 2018

3.5.2 Backwater flooding

‘Backwater flooding’ is a term used to describe inundation of land caused by downstream controls such as tidal levels or river levels. It is dependent on both the water level downstream of the floodgates and upstream catchment inflows. When the water level downstream of the floodgates remains high for extended durations (such as during a large river based flood event) water cannot be discharged from the drainage network and as a result, catchment runoff flows back up behind the closed floodgate resulting in floodplain inundation.

An example of backwater flooding of the Clybucca floodplain can be seen in Figure 3.9. During March 2018, a large rainfall event raised water levels within the Macleay River estuary. This resulted in raised water levels for a period of time (22 March to 30 March 2018). During this period, water flowing from the catchment upstream of the Menarcobrinni floodgates could not flow downstream due to elevated water levels within the estuary. As a result, water backed up behind the floodgates and peak flood levels reached 1.4 m AHD within McAndrews Drain causing widespread floodplain inundation. While during day-to-day conditions water levels within the drainage network will be kept at the low tide level, during

flood conditions, water levels within the drainage network are controlled by the flood level in the Macleay River.

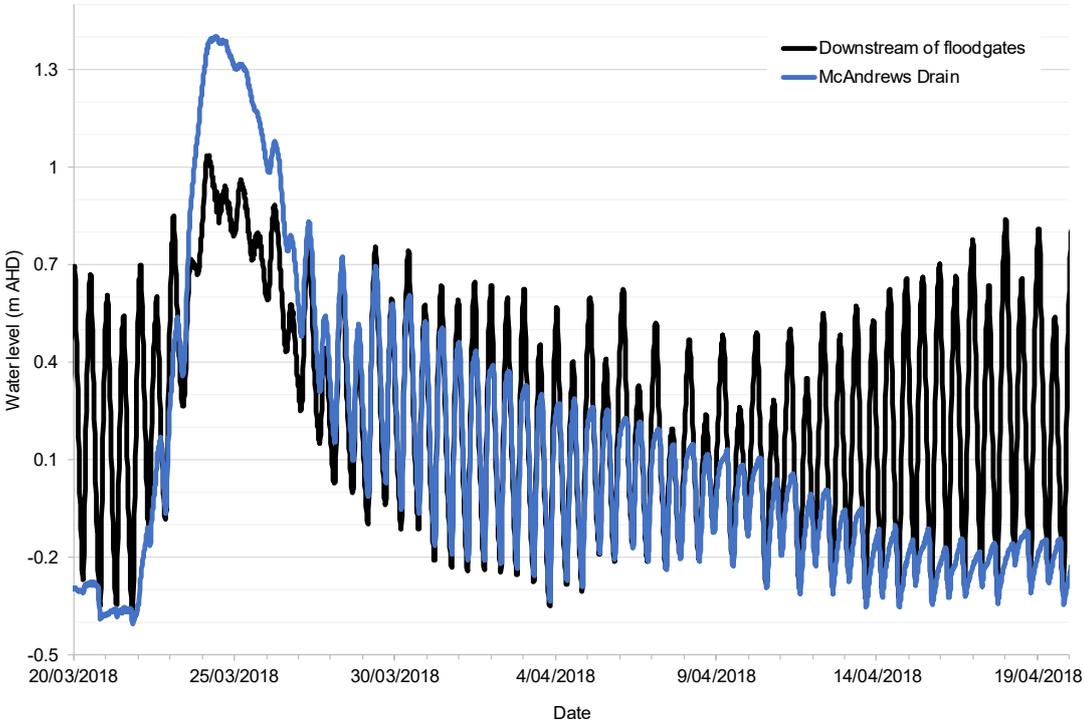


Figure 3.9: Comparison of the water levels measured downstream and upstream of Menarcobrinni floodgates in McAndrews Drain during a runoff event in May and April 2018

3.5.3 Floodgate effects on floodplain hydrology

Floodplain surface and groundwater levels are predominantly controlled by downstream water levels and catchment inflows (including direct rainfalls). Table 3.1 explains this effect on the floodplain hydrology during different environmental conditions.

Table 3.1: Effect of the floodgates on floodplain hydrology on the Clybucca floodplain during different environmental conditions

Dry/flood event	Location	Floodplain hydrology
Dry	Entire estuary	Water is drained from low-lying floodplain land. The groundwater table is lowered based on low drain water levels.
Flood	Entire estuary	Drainage of the Clybucca floodplain is controlled by the water levels in the wider estuary. Backwater flooding will occur until water levels in the wider estuary recede. The groundwater is recharged.
Flood	Clybucca catchment only	Drainage of the Clybucca floodplain is controlled by the water level in the estuary. Backwater flooding will occur until the floodplain can drain through consecutive low-tide cycles. Groundwater on the Clybucca floodplain is recharged and its level is raised.
Flood	Downstream estuary only	Floodgates prevent raised water levels in the estuary entering the Clybucca drainage network. Any catchment inflows will back up within the Clybucca drainage network until the estuary water levels recede. Groundwater on the Clybucca floodplain is dependent on the level of local catchment inflows.

4 Approach to remediation

4.1 Preamble

Historical land management of the Clybucca floodplain has resulted in degradation of the floodplain environmental values (see Section 2). Remediation during the 1990s and 2000s was previously undertaken on a “paddock” scale and aimed at reducing ASS impacts while maintaining agricultural land uses and productivity. However, at this scale there is often only the limited ability to effectively remediate the environment and the current best practise is for a catchment wide approach which is most effective in reducing water quality impacts, improving estuarine productivity, and rehabilitating degraded habitats and ecosystems (Glamore and Rayner, 2017). Due to TfNSW owning a significant portion of the worst ASS affected low-lying land (Section 1), the opportunity for large-scale changes to floodplain management is possible.

This section of the report outlines potential remediation strategies that can be implemented on the Clybucca floodplain. In order to address ASS pollution, this section focuses on restoring natural wetting and drying cycles in historic wetland areas and improving floodplain water quality and biodiversity. Changes to the floodplain drainage regime have been considered to ensure minimal impacts to the private landholder’s productivity. This means:

- No salt water inundates private land; and
- Changes to the floodplain either reduce or have no impact on flood drainage times.

Remediation strategies are presented for the mitigation of ASS (Section 4.2), which focuses on floodplain drainage management and blackwater reduction (Section 4.3). Note that issues associated with MBOs are linked to ASS runoff. Indicative costings for remediation options are also provided.

4.2 Drainage management strategies

4.2.1 Overview of drainage management strategies

As described in Section 2, impacts due to ASS are largely the result of drainage and floodgate construction. Issues such as over-drainage encourage the increased export of ASS runoff into the waterways. Further, high density drainage enables the export of blackwater that would have previously been isolated from the estuary. By modifying drains and drainage infrastructure, impacts of ASS can be significantly reduced. Potential remediation strategies that reduce ASS and blackwater impacts include:

- Construction of weirs to elevate groundwater levels and limit acid discharge;
- Introduction of tidal flushing through floodgate manipulation/modification to neutralise acid water in-drain;
- Drain infilling and/or reshaping to reduce acid export; and
- Relocation of floodgates further upstream and decentralisation of floodgate infrastructure to improve water quality and enable improved management on a sub-catchment basis.

4.2.2 Weir construction

Installation of weirs in drainage channels has been shown to reduce the production of acid across ASS affected floodplains (Blunden and Indraratna, 2000). Weirs promote higher drain and groundwater elevations that reduce groundwater drawdown, thereby minimising the hydraulic gradient between groundwater and drainage channels. The optimal weir crest elevation is dependent on the elevation of the acidic soil layer. Ideally, the weir crest elevation is situated at, or above, the elevation of the actual acid sulfate soil (AASS) layer. This minimises the lateral flow of acidic water from the ground into the adjacent drain (Figure 4.1).

Weirs are often designed to reduce acid export whilst maintaining effective drainage during wet periods. Adjustable weirs (i.e. drop boards) are desirable to maintain agricultural productivity following flood periods, while raising the weir crest during dry periods reduces the groundwater hydraulic gradient and minimises acid export. Figure 4.1 depicts how a weir reduces acid generation and export.

Tulau (2007) listed several criteria that need to be considered for design and installation of weirs to be successful, including:

- Suitable to local conditions;
- Maintains the efficiency of the flood mitigation system;
- Controls different water levels;
- Uses low maintenance and durable materials;
- Complies with workplace health and safety (WHS);
- Vandal resistant;
- Cost effective;
- Landholder willingness and approval; and
- Complies with current legislation.

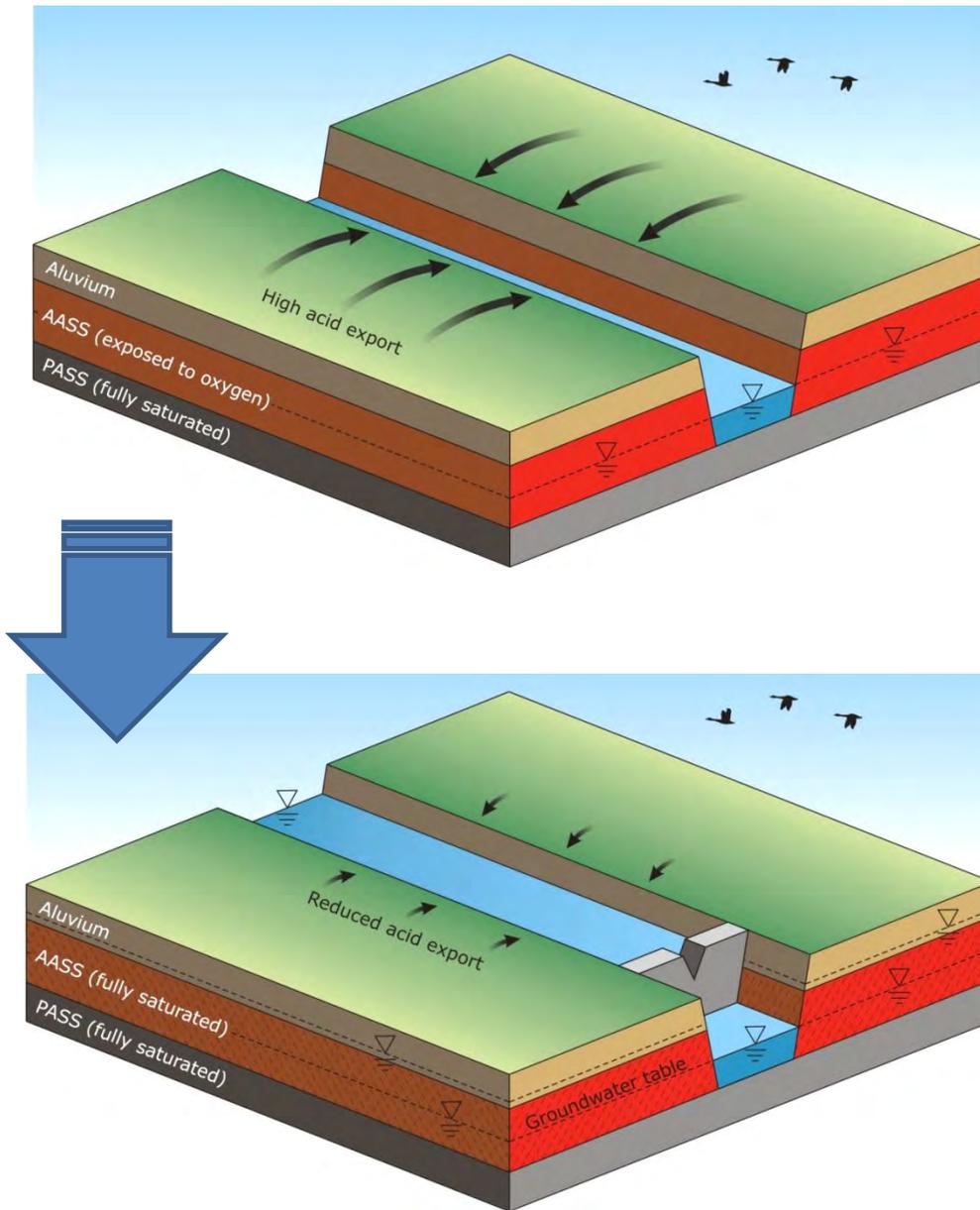


Figure 4.1: Weir implementation before (top) and after (bottom)

4.2.3 Introduction of saline water through floodgate manipulation

One-way floodgates prohibit tidal inundation, maximise pasture drainage, and maintain drain water levels at low tide elevations. When ASS is present, tidal floodgates increase acid discharge and restrict in-drain tidal buffering of acidic waters. Floodgate management and/or modification is widely practiced in NSW as a method of improving water quality and reducing ASS impacts. Glamore (2003) showed that modified floodgates that permit two-way tidal flows significantly improved water quality, and generally reduced the downstream impacts of ASS discharges. Similar findings have been shown

following floodplain remediation by Ruprecht et al. (2017). Furthermore, specific benefits of floodgate modification include:

- Improved drain water quality through flushing and acid buffering;
- Reduced exotic drain vegetation; and
- Increased fish passage (NSW DPI, 2007).

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 utilise controlled in-drain tidal flushing for weed management, while not impacting adjacent floodplain areas of agricultural production. Uninhibited tidal restoration is rarely implemented, except when tidal amplitude is low, where the floodplain topography is above tidal levels, or where agricultural land use practices are abandoned. The installation of auto-tidal gates permits tidal flushing up to a pre-determined elevation based on the topography of the floodplain. Figure 4.2 depicts how a modified floodgate can allow tidal flushing to an ASS affected drainage channel.

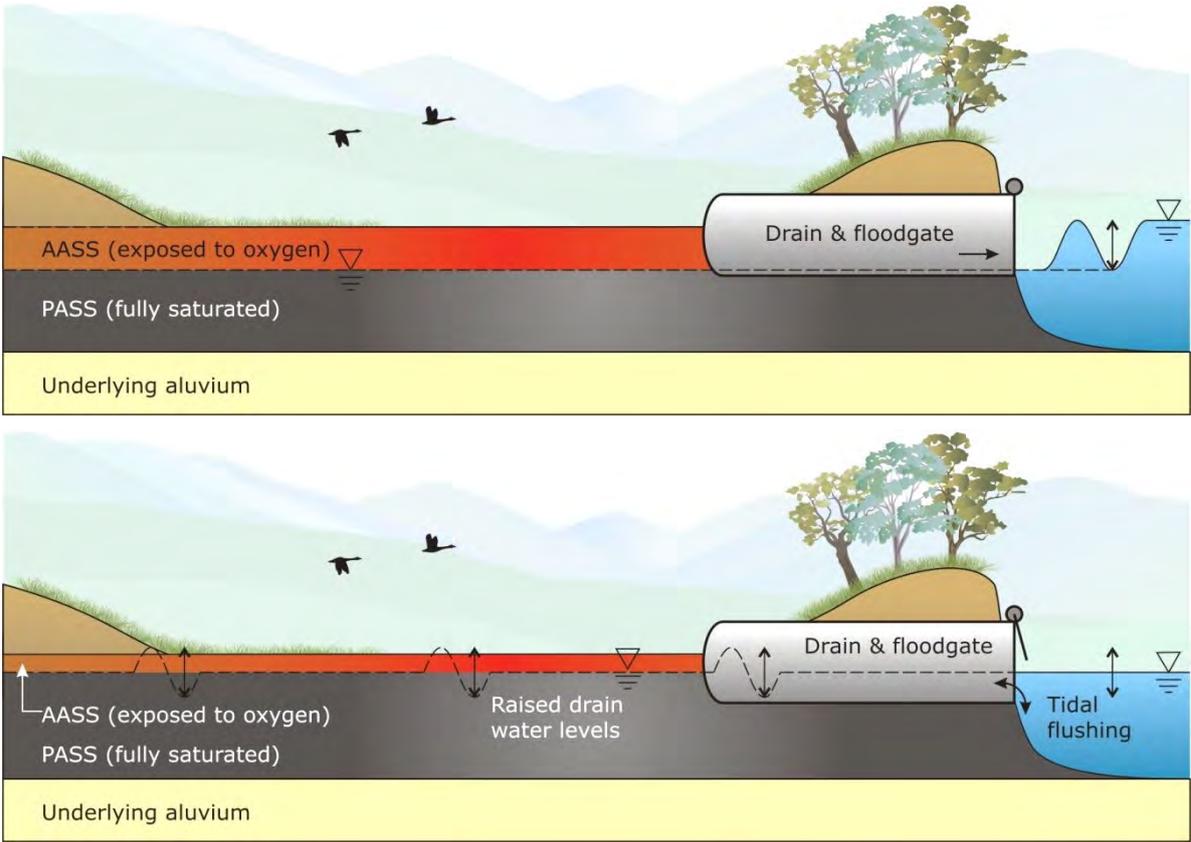


Figure 4.2: Tidal flushing of an ASS affected drainage channel

Note that historically Clybucca was a freshwater wetland. Due to works undertaken during the flood mitigation scheme, such as the creation of Andersons Inlet and the lowering of Mayes Swamp due to over drainage and historical fires, it is now possible for tidal water to reach Clybucca wetland areas. Introduction of saline water will convert the ecosystem from freshwater to tidal. Impact assessments of this on local flora and fauna will need to be considered.

4.2.4 Drain infilling, shallowing and reshaping

Infilling, shallowing and reshaping drains can be an effective means of reducing acid discharge and other negative impacts of over drainage, particularly in ASS affected backswamps (Johnston et al., 2003a). Raising drain invert levels, while maintaining the effective drain cross-sectional area, acts to reduce acid seepage into surface water and maintains the drainage capacity of the existing system. These drains are commonly referred to as 'swale drains' and are depicted in Figure 4.3.

Narrow, deep drains are ideal candidates for drain reshaping, as the drain cross-sectional area required to provide efficient drainage can be maintained by conversion to a shallow, wide swale drain. Conversely, a wide, deep drain will require a significantly wider swale drain to be constructed to maintain the effective cross-sectional flow area. This strategy is applicable where the acid soil layer is sufficiently deep enough to enable an efficient drainage slope from the back swamp to the estuary without the drain invert disturbing the acid layer.

Infilling of drains within the extents of backswamp areas can return the natural wetting and drying cycles within the floodplain (Johnston et al., 2003b). This strategy is particularly relevant when adopted alongside floodplain remediation options such as wet pasture management and native bush regeneration (Section 4.3). Infilling of drains also slows the export of deoxygenated blackwater to the estuary. Restricting the export of blackwater once the water level falls within the natural levee banks after the peak of the flood, particularly following flood events, means the estuary can more effectively dilute the poor quality water draining from the backswamp.

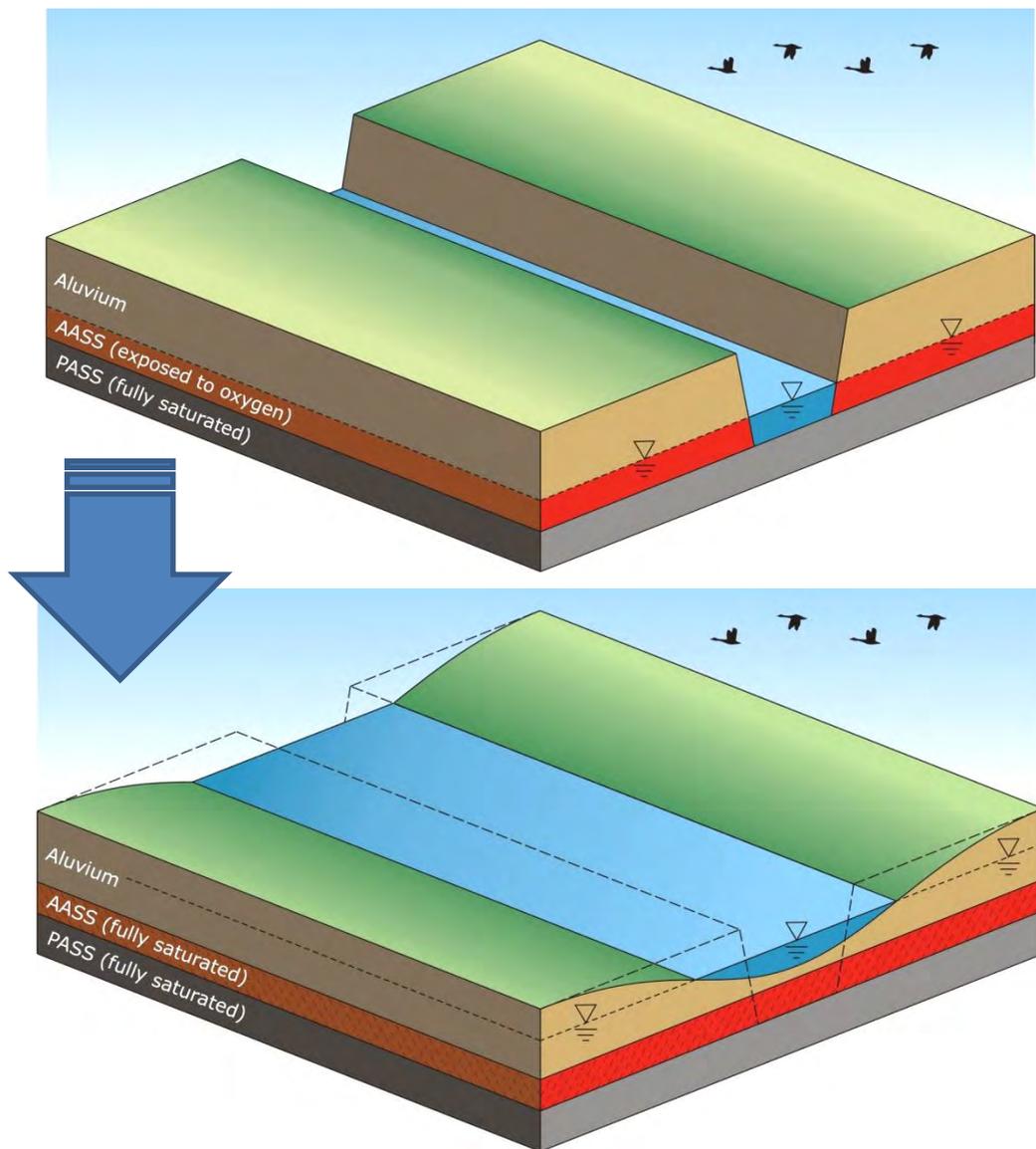


Figure 4.3: Before and after swale drain construction

4.2.5 Relocation of floodgates further upstream

Replacement of large headworks such as the Menarcobrinni floodgates with a number of smaller structures at strategic locations upstream can open up large stretches of creek and drain channels to tidal flushing (Figure 4.4). For example, historically at Clybucca there were two (2) sets of floodgates located further upstream on Clybucca Creek and McAndrews Drain prior to the construction of the Menarcobrinni floodgates (personal communication with G. Duffy, June 2019). The extent to which this decentralisation of floodgates can take place is dependent on floodplain and levee elevations. Where there is a low-lying floodplain with levees located below the high tide water mark, this option may not be

feasible unless further works are completed to raise levee banks. Environmental benefits for stretches of creek and drain channels located downstream of floodgates that have been moved upstream include:

- Limited drainage of acidic groundwater;
- Increased fish passage;
- Improved water quality; and
- Buffering of acid.

Floodgates prevent fish passage along drainage and creek channels. By decentralising floodgates to strategic locations upstream, large extents of fish habitat can be created. Additionally, drainage of acidic groundwater is limited to during low-tides and can be buffered by the natural bicarbonate found in tidal water.

Management benefits associated with decentralising floodgates include:

- Drainage of different sections of the floodplain can be controlled independently;
- Control of weeds that are exposed to tidal water; and
- Smaller floodgates are easier to service and maintain.

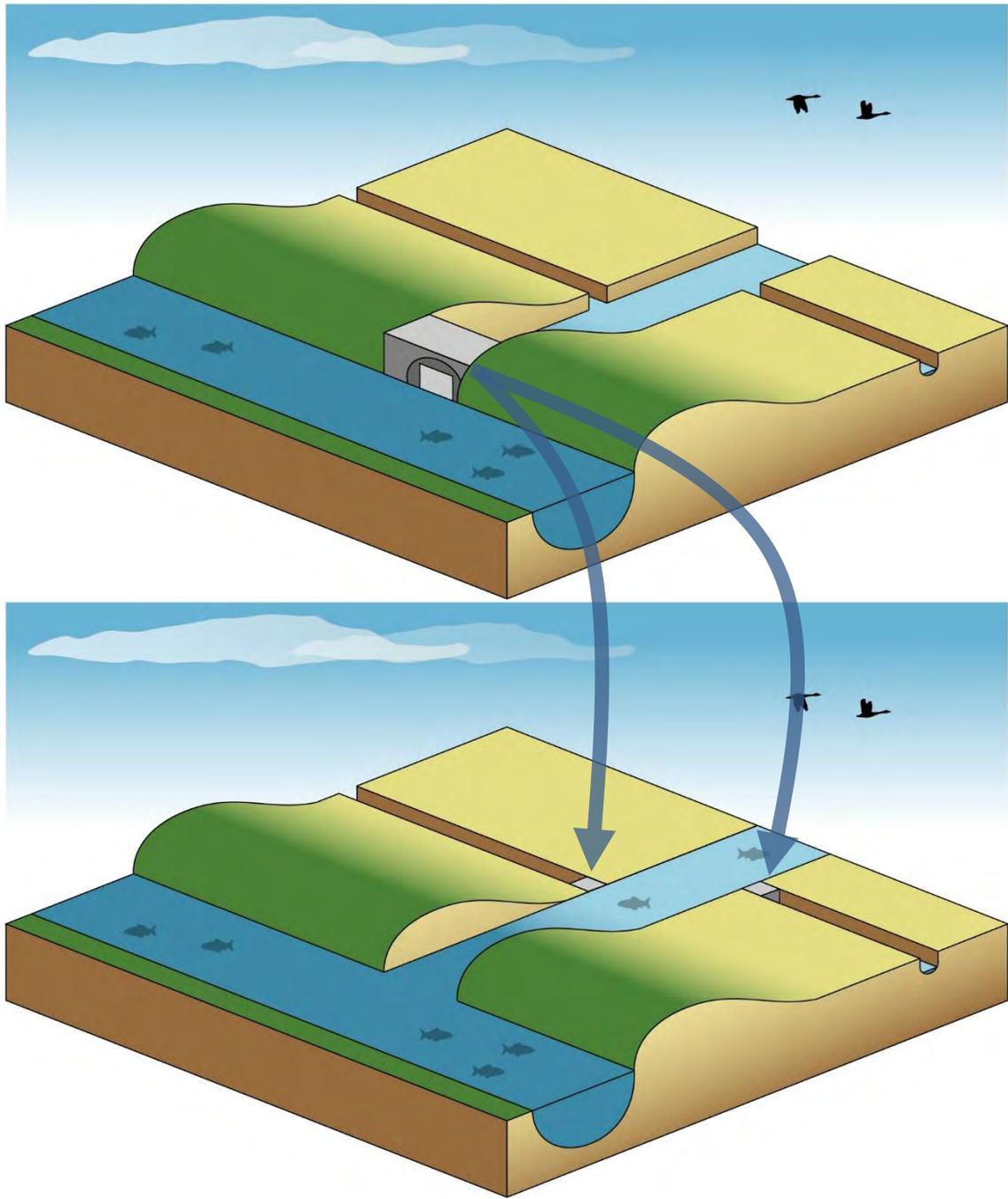


Figure 4.4: Diagram showing creation of habitat through relocation of floodgates upstream

4.3 Floodplain management strategies

4.3.1 Overview of floodplain management strategies

In addition to modification of drainage assets, land based remediation strategies can be undertaken to mitigate the risks of ASS and blackwater runoff while encouraging biodiversity and native habitat restoration. Generally, land based strategies can be implemented to varying degrees without modifying the flow paths (i.e. changing the drainage network) across the floodplain. Nevertheless, by re-introducing natural wetting and drying cycles across the floodplain, land based strategies can be more effective. Examples of land based management strategies include:

- Fencing to isolate rehabilitation areas;
- Pest and weed management;
- Wet pasture management;
- Native bush regeneration; and
- Acid scald remediation.

4.3.2 Fencing to isolate rehabilitation areas

Removing stock from floodplain rehabilitation areas allows native bush regeneration to occur. Surveys of young native regenerative growth at Clybucca showed vegetation is experiencing ongoing disturbance due to grazing (Staines, 2019). Fencing of areas, including where acid scalds are present, such as Latham's Scald or Yerbury's Scald, has previously shown to assist the growth of native vegetation (Figure 4.5) (KSC, 2004). This strategy should be used alongside other drain and floodplain strategies. For example, restoring natural wetting and drying cycles to scalded areas, reducing the number and frequency of dry events, will assist in native vegetation growth.

4.3.3 Pest and weed management

The strategy of pest and weed management helps facilitate remediation of natural habitat across the floodplain. Pests, such as foxes, can disrupt biodiversity across the floodplain (OEH, 2011). Similarly, weeds can choke out native vegetation. Surveys of young native regenerative growth at Clybucca showed vegetation is experiencing ongoing disturbance due to weed growth (Staines, 2019). By managing both pests and weeds the redevelopment of native ecological communities can be encouraged.



Figure 4.5: Example of fencing constructed to exclude stock from Yerbury’s Scald (KSC, 2004)

4.3.4 Wet pasture management

Wet pasture, or reflooding, involves retaining fresh surface water on pastures during dry periods by limiting drainage. It is often used as a method for maintaining agricultural land use practices during drought conditions. Tulau (2007) asserted that this option aims to contain acid and other oxidation products within the soil and surface water by raising water levels in the drain (Figure 4.6). This is usually achieved by installation of structures in the drainage channel such as weirs, removal of levee banks, and/or modification of pasture drainage pathways by drain infilling or reshaping (see Section 4.2). Encouraging freshwater retention on the floodplain will also help promote the growth of native water tolerant vegetation. For this reason, wet pasture management can be effective in managing both ASS and blackwater. Note that wet pasture management is dependent on regular catchment inflows.

Johnston et al. (2003b) showed that the acid discharge rate from a wet pasture managed system significantly reduces acid export where groundwater seepage is the main export pathway. This is mainly achieved by reducing the frequency and volume of groundwater flow through modifications to the surrounding drainage network. Subsequently, this option is particularly suitable to sites like Clybucca with high to extreme hydraulic conductivity (i.e. a fast groundwater flow rate).

When areas of wet pasture are created this helps to encourage water tolerant vegetation growth. Replacement of pasture species with water tolerant vegetation reduces the severity of blackwater events. This is because there is less vegetation that will decompose and trigger hypoxic conditions within the runoff water after a flood event.

Wet pasture areas can also help to mitigate the risk of fire and acid scalding. When fires occur in drained backswamps they can result in large acidic scald areas becoming exposed as vegetation and organic material previously covering ASS are burnt. When acid scalds occur, evaporation of acidic water can cause acidic salts to be deposited on the surface of the scald. These salts can cause highly concentrated acidic runoff. Further, there has been evidence that expansion of Yerbury's Scald has occurred due to windblown acidic salts killing native vegetation (KSC, 2004). Wet pasture reduces the risk of fires by retaining water on the floodplain making a wetter backswamp (Johnston et al., 2003b).

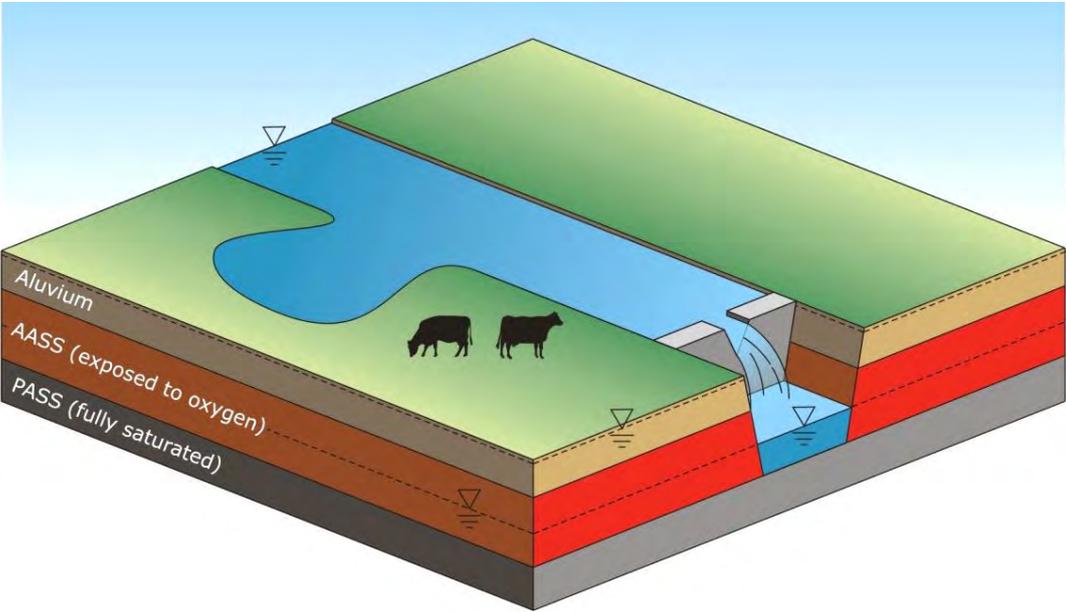


Figure 4.6: Wet pasture management

4.3.5 Native bush regeneration

Regenerating native bushland aims to encourage increased biodiversity across the floodplain and boost ecosystem services. New habitat can be created for a range of different ecosystems including aquatic and bird life. This strategy should be implemented in conjunction with fencing and weed/pest management strategies.

Native bush regeneration is possible across the existing floodplain without any modifications to flow paths or drainage infrastructure. Nevertheless, native bush regeneration is optimised when performed alongside drainage management strategies. For example, by returning the natural wetting and drying cycles to backswamp areas through actions such as creating weirs, levee removal and/or drainage reshaping works, native water tolerant vegetation is promoted which reduces the severity of blackwater events. Furthermore, having water in natural backswamp areas and promoting native water tolerant vegetation growth will limit the risk of peat fires and reduce the subsequent accumulation of acidic surface salts which can be detrimental to the environment.

4.3.6 Acid scald remediation

Acid scalds have detrimental effects on the environment. During wet events large stores of acidic salts on the surface of scalds can easily be transported to the estuary. There has also been evidence of acid scalds expanding due to vegetation dying from exposure to windblown acidic salts from adjacent scalded areas (KSC, 2004; Rosicky, 2006). It is therefore important that remediation of acidic scalds occurs to prevent the exacerbation of these issues.

Two (2) methods for rehabilitation of acid scalds have been proposed by Tulau (2007):

1. Promoting inundation of scalds with water; and
2. Adding organic matter/vegetation to the scald surface.

Prolonged inundation of water across scalded areas, which can be promoted through modifications of the drainage network such as installing weirs or construction of levees, can contain acid to a designated area and prevent further oxidisation of ASS. This will subsequently reduce the discharge rate of acid into the drainage network particularly where groundwater seepage is the main export pathway (Tulau, 2007).

Rosicky (2006) found that acid scalds were missing a layer of between 0.2 m and 0.4 m of vegetation and mulch across their surface. Tulau (2007) recommends remediation of the acid scald by re-introducing this layer of vegetation for the following benefits:

- Improve soil texture;
- Prevent evaporation; and
- Bind aluminium.

To assist in revegetation of the scald, strategies such as stock exclusion and liming of the scalded surface should also be considered. Figure 4.7 shows an example revegetation completed for a section of Yerbury's Scald in 2004.



Figure 4.7: Revegetation of Yerbury's Scald with water tolerant pasture (KSC, 2004)

4.4 Summary of indicative costs for remediation options

Table 4.1 provides a summary of the approximate costs (based on standard commercial rates) for the design, construction, implementation, and annual maintenance of various remediation options proposed. Note that these costs relate directly to design, implementation and annual maintenance and do not include costs associated with any additional investigation that may be required such as:

- Environmental impact assessment;
- Flood studies;
- Stakeholder consultation;
- Licensing, approvals and administration costs; and
- Monitoring.

Table 4.1: Indicative costs for various land management options

Management Option	Design Cost*	Implementation	Maintenance (per annum)
Weir	\$15,000	\$12,000 to \$36,000	\$6,000 to \$17,000
Floodgate modification	\$15,000	\$10,000 to \$30,000 per gate	\$6,000 to \$12,000
Culvert/floodgate relocation	\$40,000	\$70,000 to \$120,000 per culvert	\$10,000
Drain infilling	\$20,000	Equipment establishment (\$6,000) + unit rate (\$12,000/500 m)	None
Levee removal	\$20,000	Equipment establishment (\$6,000) + unit rate (\$12,000/500 m)	None
Drain reshaping	\$20,000	Equipment establishment (\$6,000) + unit rate (\$24,000/500 m) + spoil disposal	None
Wet pasture	\$20,000	Potential: Structure relocation + Land acquisition + Drain infilling	None
Pest control/weed management	-	\$1,000 per ha	
Fencing	-	\$5,000 per km + labour (\$100 per hour)	

*Engineering design only, does not consider additional studies (e.g. environmental impact assessments, flood studies etc.)

5 Management options

5.1 Preamble

Six (6) management options have been developed for the Clybucca wetlands (Table 5.1). These management options range from actions that have a minimal impact to the existing drainage of the wider floodplain (Option 1) to options that will significantly alter the floodplain hydrology (Option 6).

Management options have been developed to enable a staged implementation approach, if required, based on future changes such as floodplain ownership and climate change. The development of each management option has been completed within the bounds of a number of constraints that guide the scale of remediation strategies that can be implemented, including:

- Floodplain hydrology;
- Topography (i.e. floodplain elevation);
- TfNSW property boundaries and adjacent private land;
- Tidal levels;
- Extent of ASS; and
- Existing drainage infrastructure.

Additionally, the development of management options was completed alongside consultation with landholders, the Seven Oaks Drainage Union and other stakeholders who have provided feedback on the different options. Management options were selected by the Clybucca Government Working Group and have been designed to improve water quality, increase ecosystem services and satisfy biodiversity offset requirements.

Each option has been assessed and numerically modelled with model results presented and analysed. Two (2) criteria have been used to determine the feasibility of each management option, namely:

1. Changes to inundation depth, extent and frequency on TfNSW land; and
2. Changes to inundation depth, extent and frequency on private landholder properties.

Table 5.1: Description of management options investigated

Option number	Management option	Freshwater/tidal	Description
1	Land management only	Freshwater	Only land based actions such as fencing, weed management and native bush regeneration will occur. No modifications to the drainage network.
2	Freshwater on TfNSW land only	Freshwater	Modification of weirs and levees to allow for shallow inundation across wetland areas.
3	Freshwater on TfNSW land only with extension of McAndrews Drain	Freshwater	Same as Option 2 with a new swale drain constructed connecting McAndrews Drain to Seven Oaks Drain to allow large catchment flows to bypass TfNSW wetland areas.
4a	Modified floodgates to allow controlled in-drain tidal flushing	Tidal*	Modification of eight (8) floodgates to allow tidal water into the drainage network up to an elevation of -0.4 m AHD.
4b	Modified floodgates to allow controlled overland tidal flushing	Tidal*	Modification of eight (8) floodgates to allow tidal water into the drainage network and onto the floodplain up to an elevation of 0.0 m AHD.
5a	Decentralise floodgates to multiple locations – overland inundation	Tidal*	Decommission the Menarcobrinni floodgates after installing four (4) smaller floodgate structures upstream to allow overland inundation within TfNSW land.
5b	Decentralise floodgates to multiple locations – in-drain only	Tidal*	Decommission the Menarcobrinni floodgates after installing two (2) smaller floodgate structures upstream to allow in-drain tidal only flushing.
6	Fully open floodgates with uncontrolled tidal flushing	Tidal	Hinge the floodgate flaps at Menarcobrinni open to allow full tidal inundation across the floodplain.

*Freshwater management options 1, 2 or 3 can be concurrently implemented in upstream sections of the drainage network.

The first criterion assesses whether TfNSW land can be converted from pasture to wetland. This conversion to wetland would require an increase in the current inundation depth, extent and frequency on TfNSW land.

The second criterion assesses whether each management option will impact day-to-day drainage on private land (i.e. nuisance flooding). The aim of the management options is such that there would be no increase in inundation depth, extent or frequency on private land during day-to-day conditions.

In addition to these two (2) criteria, additional modelling has been completed for selected scenarios to determine the impact of changes to the drainage network on draining larger catchment flood events. This assessment has been completed for Management Options 2 and 3. These model results determine how drainage of runoff events, with an annual exceedance of probability (AEP) in the order of 20%-40% (i.e. an event that would recur every 2 to 5 years) will be affected by the proposed modifications to the drainage network. This is the scale of event that will most likely have the greatest impact on the floodplain. Events larger than this are likely to be driven by major flooding within the wider estuary with drainage being controlled by the water levels downstream of the Menarcobrinni floodgates. The impact of any proposed modifications to the drainage network to major flood levels has been assessed using the adopted Macleay River flood model (Jacobs, 2019).

6 Base case

6.1.1 Description

In numerical modelling, a 'base case' is commonly used to quantify change between proposed modifications (in this case different management options) and existing 'base case' floodplain hydrology. This allows different 'what if' scenarios to be tested and the potential benefits and impacts to be quantified. A base case for the Clybucca floodplain has been developed and validated against data measured across the floodplain (see Appendices D and E).

Two (2) simulations were run for the 'base case' model for comparison against different management options. These simulations have allowed for the quantification of:

1. Changes to inundation depth, extent and frequency for day-to-day conditions;
2. Changes to flood drainage times.

6.1.2 Day-to-day inundation depth, extent and frequency

Assessment of the inundation depth, extent and frequency was completed using a two (2) exceedance per year (2EY) catchment runoff event, which is a runoff event that has the likelihood of occurring two (2) times per year (or one event occurs every six months) (see Figure 6.1). A synthetic runoff event was created using a calibrated AWBM rainfall-runoff model based on a 2EY rainfall event (see Appendix D). Initial conditions were set so that flood storage within the low-lying floodplain management areas was full (see Section 3 for details on the management areas). This simulates the worst-case effects that a 2EY runoff event will have (i.e. a runoff event flowing into an already wet floodplain). A tidal signal was used as the downstream boundary condition to simulate drainage over multiple tidal cycles.

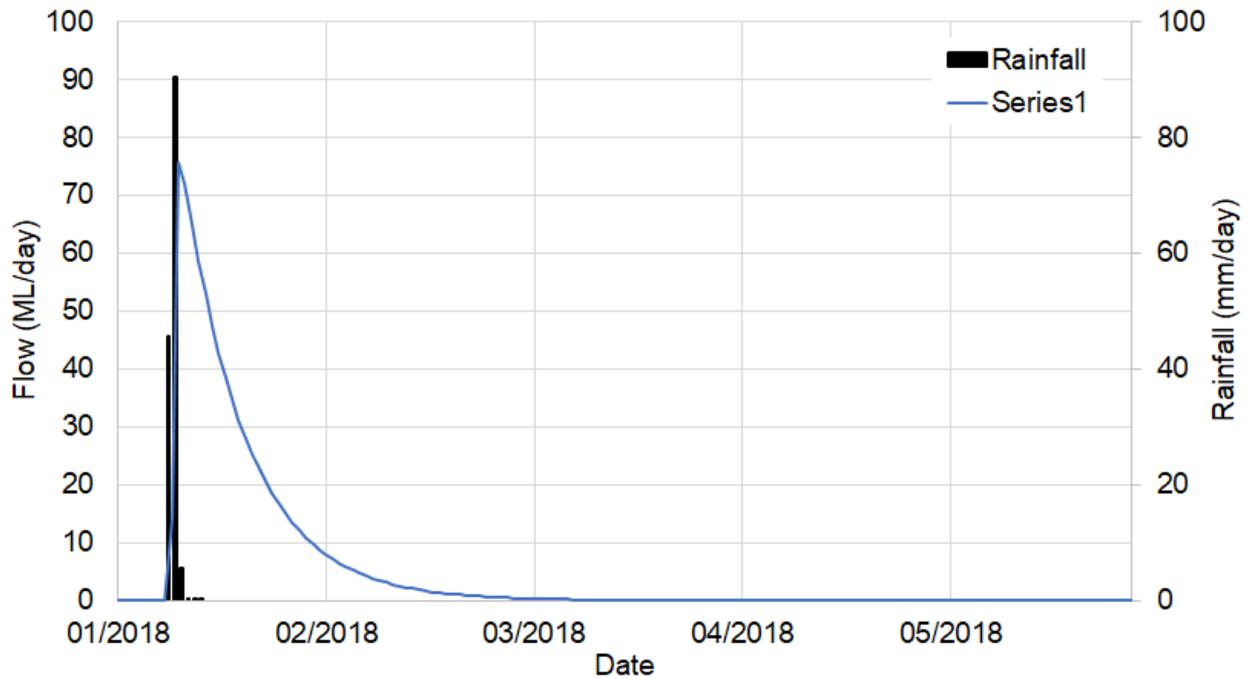


Figure 6.1: Example of a synthetic 2EY (every 6 months) catchment rainfall-runoff event to Seven Oaks Drain

Results for inundation depth, extent and frequency modelling of the base case with a 2EY catchment runoff event are shown in Figure 6.2 and Figure 6.3. These figures show the percent time wet and average inundation depth for a 2EY runoff event respectively for a three (3) month period following the rainfall event. Note these results are conservative as there was no infiltration applied across the model domain and evaporation was included as a component of the catchment inflow calculation (see Appendix D).

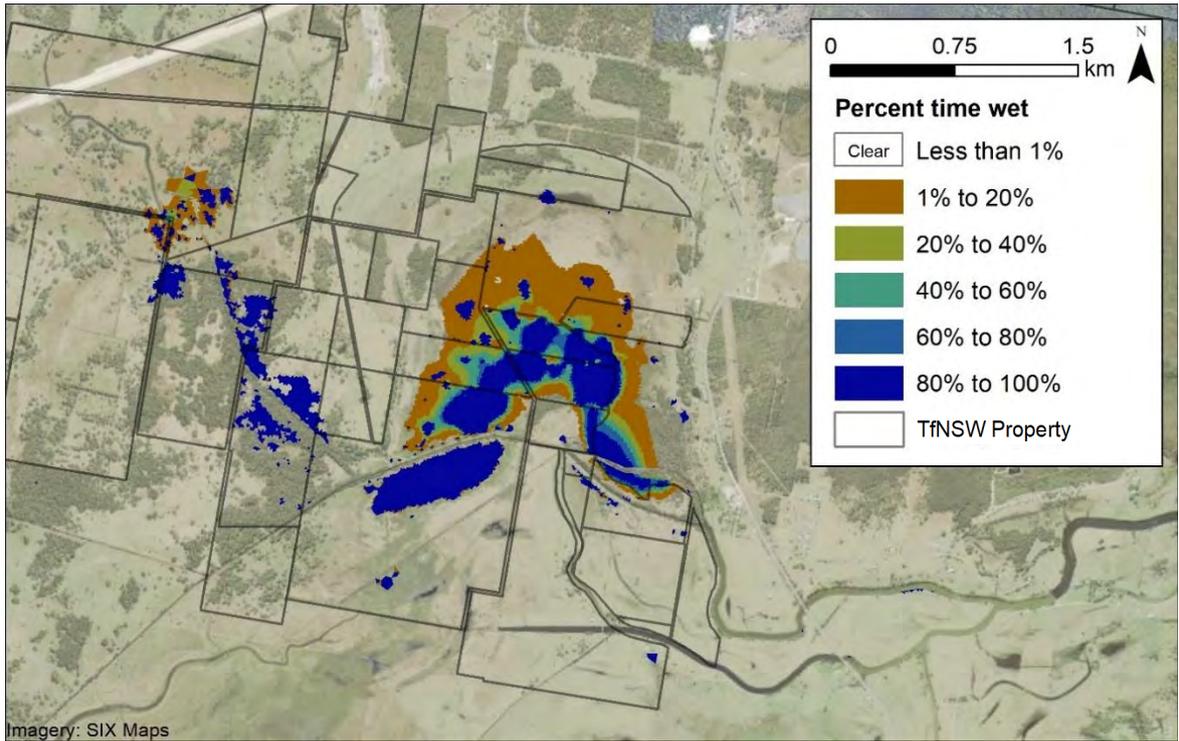


Figure 6.2: Percent time inundated for a 3 month period following a 2EY runoff event for the base case

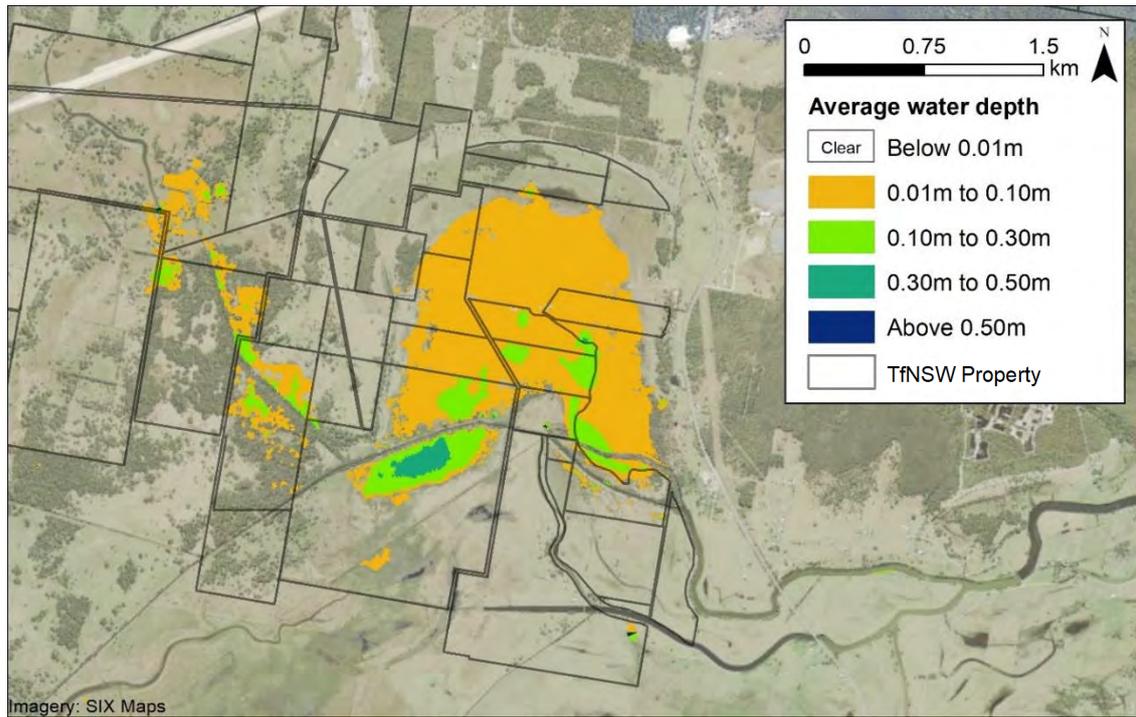


Figure 6.3: Average inundation depth over a 3 month period following a 2EY runoff event for the base case

Results show that a 2EY event causes inundation across the low-lying floodplain management areas. Yerbury’s Scald receives up to 0.5 m of inundation depth for periods extending the duration of the three (3) month simulation period. Sections of Doughboy Swamp also receive inundation for the duration of the simulation period, albeit to a lower depth of up to 0.3 m. Large sections of Mayes Swamp are inundated; however, this is generally for a shorter period (less than 80% of the time) and at a lower inundation depth (0.01 m to 0.10 m) when compared to Yerbury’s Scald.

6.1.3 Flood drainage time

To assess changes to the floodplain drainage following a flood event, the initial conditions across the model were set so that the water elevation was +0.75 m AHD with no additional catchment inflows during this simulation. This level is equivalent to the inundation level resulting from an approximate 1-in-1 year rainfall event. An average condition tidal signal (i.e. not influenced by flooding) was applied to the model boundary condition downstream of the Menarcobrinni floodgates. This simulation was designed to determine if modification of the drainage network/infrastructure will alter drainage times following a minor flood event. Note that changes to design flood levels (e.g. 1% AEP event) are to be tested using the adopted Lower Macleay Flood Model (Jacobs, 2019).

Table 6.1 outlines the elevations that sections of floodplain spanning private property at Clybucca would start to become inundated. Water levels on the floodplain at these locations have been assessed by extracting timeseries data from the numerical model simulations at the locations in the drainage network specified in Figure 6.4.

Table 6.1: Elevations at which sections of privately owned floodplain become inundated

Floodplain	Elevation where inundation begins (m AHD)
Doughboy Drain floodplain	+0.3
Shackles Drain floodplain	+0.5
Southern floodplain	+0.5
Upper Seven Oaks Drain floodplain	+0.4
West Drain floodplain	+0.1

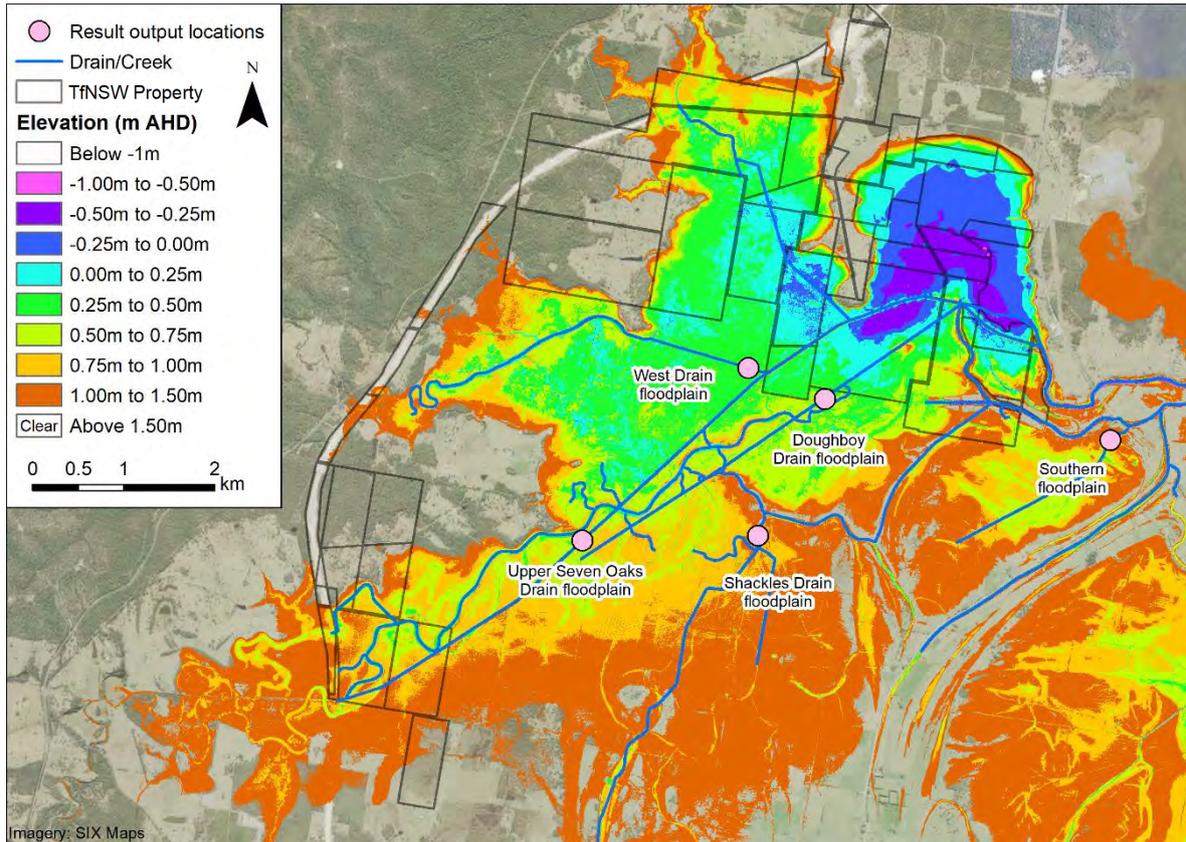


Figure 6.4: Location of timeseries measurements used for comparison of drainage times

Timeseries results for drainage times of each floodplain are presented in Figure 6.5 to Figure 6.9. Table 6.2 summarises the number of days it takes for the water levels to recede following inundation. These results show that drainage times increase for lower areas of the floodplain. The West Drain floodplain takes the longest time to drain (5.3 days).

Table 6.2: Present day modelled drainage times from a standing water level of +0.75 m AHD

Location	Time taken for floodplain to drain (days)
Doughboy Drain floodplain	2.0
Shackles Drain floodplain	0.7
Southern floodplain	0.4
Upper Seven Oaks Drain floodplain	2.1
West Drain floodplain	5.3

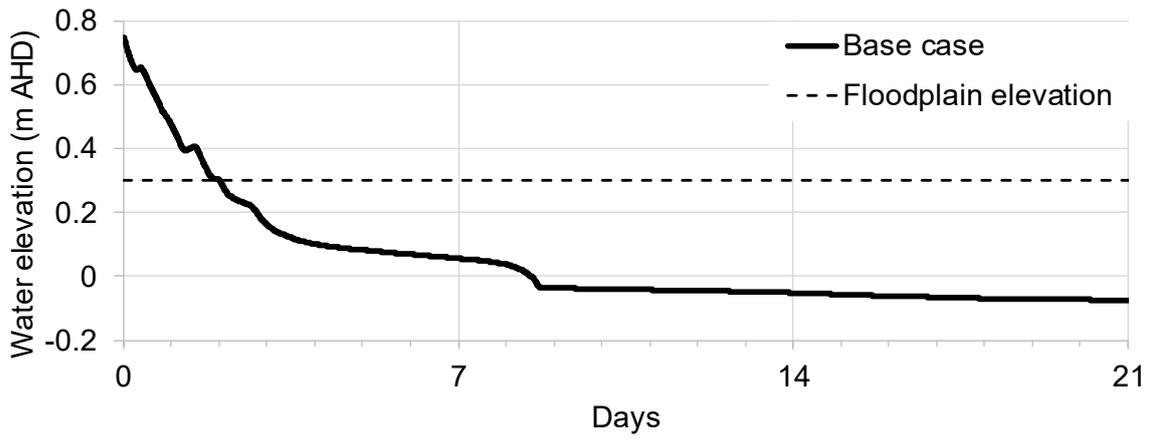


Figure 6.5: Drainage time for the Doughboy Drain floodplain

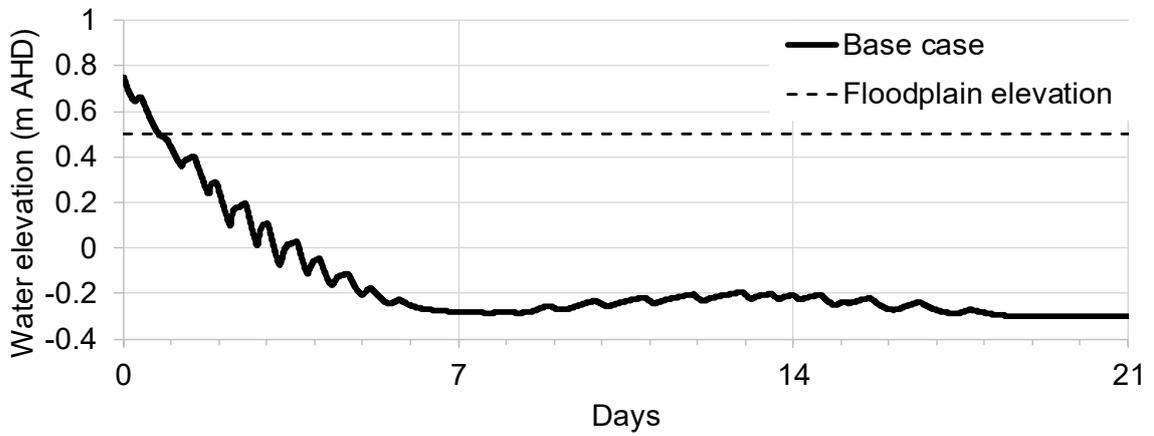


Figure 6.6: Drainage time for the Shackles Drain floodplain

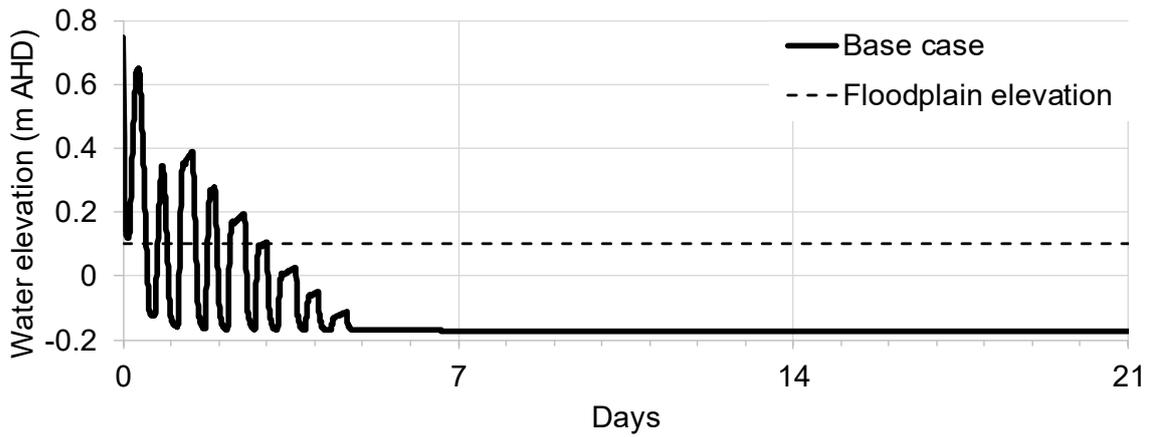


Figure 6.7: Drainage time for the Southern floodplain

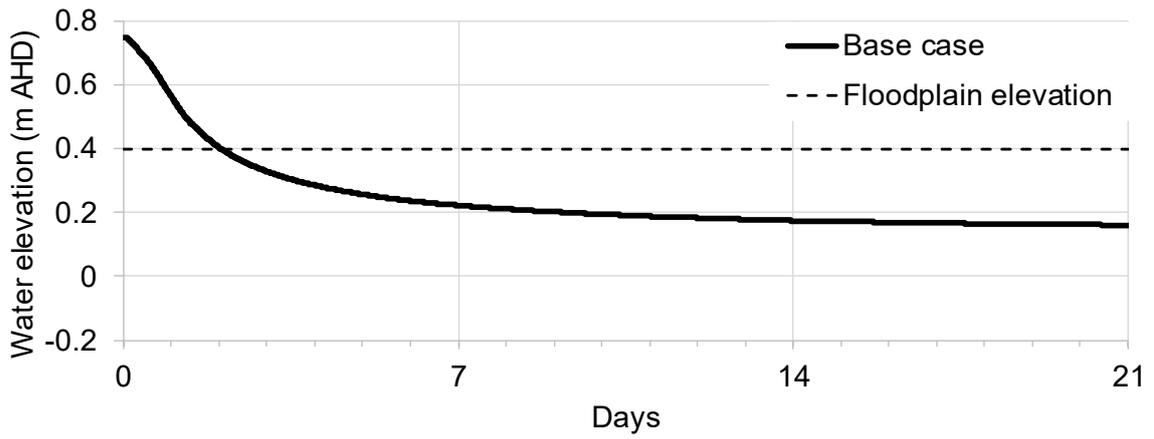


Figure 6.8: Drainage time for the upper Seven Oaks Drain floodplain

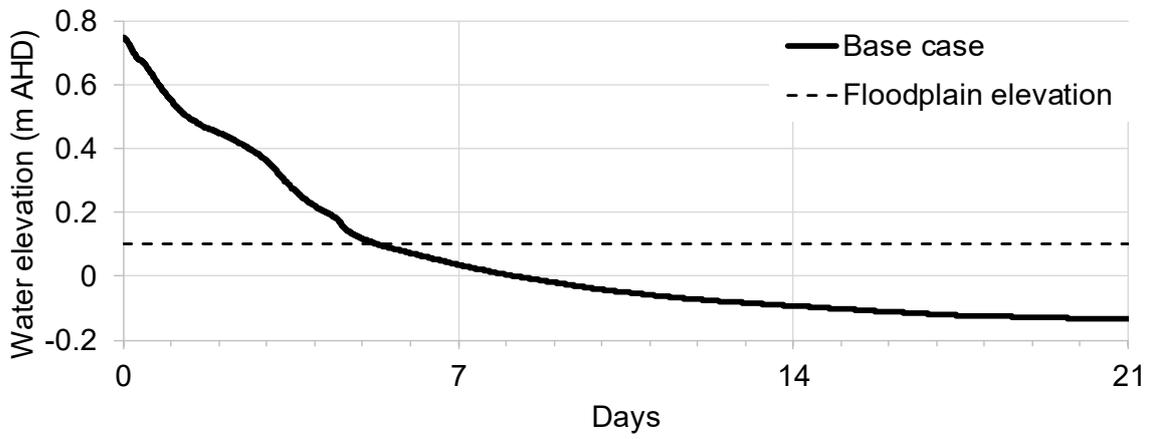


Figure 6.9: Drainage time for the West Drain floodplain

7 Management Option 1: Land management only

7.1 Description

The first management option for the rehabilitation of the Clybucca wetlands (Option 1) does not include any modifications to the existing drainage network. Management recommendations for this option are land-based, as they do not impact water movements across the floodplain. This option comprises typical conservation land management actions including:

- Fencing to exclude stock and pest species from rehabilitation areas;
- Pest and weed management;
- Wet pasture management;
- Fire risk management;
- Access control;
- Native bush regeneration; and
- Acid scald remediation.

These actions can be undertaken on TfNSW land with the aim of promoting native freshwater wetland on low-lying areas and, more generally, native vegetation rehabilitation across the management areas. This option can be implemented for all management options presented, however, movement of water across the floodplain will govern areas where benefits of land specific management options can be fully realised. Note, the approach to remediation outlined in Option 1 will require ongoing costs, including:

- Maintenance of fencing;
- Fire risk management;
- Drainage maintenance responsibilities, and
- Ongoing weed and pest management.

7.2 Impact on floodplain hydrology

Land management options (such as fencing and revegetation) will not have any significant impacts on the floodplain hydrology. Changes in roughness across the floodplain may occur, however, the effect of this is negligible on floodplain hydrology. Subsequently, no numerical modelling has been completed for this option.

8 Management Option 2: Shallow freshwater on low-lying wetland areas

8.1 Description

This management option aims to improve water quality and promote shallow freshwater on the Mayes Swamp and Doughboy Swamp wetland areas by raising the long-term water table on key sections of the low-lying floodplain (i.e. below +0.1 m AHD) land. This strategy will be implemented using the following remediation approaches:

- Modification and construction of weirs;
- Removal of levee banks to promote water connectivity between drainage channels and low-lying floodplain areas; and
- Encourage water tolerant vegetation growth.

Water quality benefits realised through the implementation of Management Option 2 include:

- Acidic water is contained and subsequent runoff during day-to-day drainage is reduced;
- Potential for further oxidisation of ASS is minimised;
- Aluminium, iron and other metals released through oxidisation of ASS can be contained; and
- The risk of blackwater is reduced through the establishment of water tolerant vegetation in place of pasture grasses.

In addition to reducing ASS and blackwater risk, this option will utilise TfNSW land as additional flood storage ensuring that surface water is quickly removed from higher floodplain areas during day-to-day conditions. This is achieved by removing flow barriers, such as levee banks adjacent to Mayes Swamp on Seven Oaks Drain, allowing water to flow directly onto the low-lying areas. Increases in inundation depth, extent and frequency on key management areas of Mayes Swamp, Doughboy Swamp and Yerbury's Scald will rehabilitate freshwater wetland habitat.

Implementation of Management Option 2 is achieved through the following modifications to the drainage network within TfNSW boundaries:

- Construction of a new weir across Seven Oaks Drain at the downstream/eastern extent of Mayes Swamp with a crest level of 0.0 m AHD;

- Construction a new weir on the swale drain connecting Seven Oaks Drain and McAndrews Drain with a crest level of 0.0 m AHD;
- Removal of levee banks on Seven Oaks Drain adjacent to Mayes Swamp and Yerbury's Scald;
- Construction of a new weir across East Drain at its downstream/southern extent with a crest level of +0.1 m AHD.

Figure 8.1 outlines the modifications to the drainage network alongside the conceptual processes.

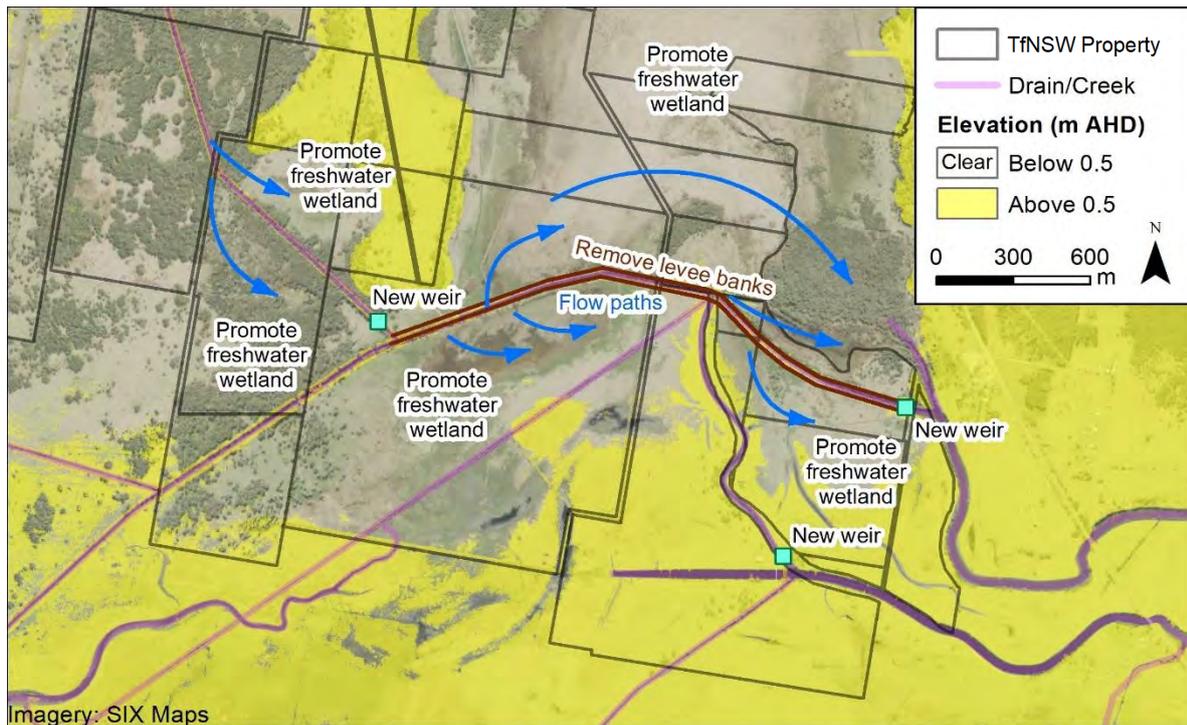


Figure 8.1: Diagram outlining modifications to the drainage network and conceptual processes for Management Option 2

Implementation of Management Option 2 involves modification to the floodplain drainage network that may have broader management consequences. There are several considerations that need to be addressed prior to implementation, such as:

- Access across Seven Oaks Drain via Yerbury's Sill will be inhibited so alternative access may need to be arranged (e.g. maintenance of existing dilapidated wooden bridges);
- Levees on the banks of Seven Oaks Drain, which have previously been used for access, will be removed and alternate access may need to be arranged; and

- Soil from levee banks being removed will need to be disposed of – one possible use could be to infill/reshape drains within TfNSW land.

Furthermore, it should be noted that East Drain and Seven Oaks Drain are managed and maintained by Seven Oaks Drainage Union. Any changes to these drainage channels should be undertaken in consultation with the Seven Oaks Drainage Union.

8.2 Design specification and optimisation

Model results for the base case show that Mayes Swamp and Yerbury's Scald act as flood storage retention basins during larger runoff events, however, currently floodwaters recede quickly from these low-lying areas. To promote freshwater wetland habitat and mitigate the impacts of ASS and blackwater runoff, an increase in the inundation depth, extent and frequency in these areas is required. This can be achieved through changing weir elevation, width and locations, and removal/lowering of drain levee banks. To determine the optimal design specifications for these modifications several optimisation calculations and model runs were completed and included investigations into:

- Management area inundation frequency;
- Management area inundation depth and extent;
- Location of weirs; and
- Levee bank assessment.

8.2.1 Management area inundation frequency

To assess how weir elevation influences inundation frequency on the floodplains, an analytical ten (10) year optimisation model was created for the existing Yerbury's Sill and the surrounding low-lying floodplains. Outputs from this analysis highlighted how different weir crest levels may influence inundation frequency of TfNSW land in the areas of Yerbury's Scald and Mayes Swamp (Table 8.1). Note that this calculation is a function of catchment inflows passing across the Yerbury's Sill and is independent of backwater effects (i.e. backing up of water behind elevated downstream water levels) and pooling of direct rainwater which can also influence inundation. Furthermore, this model is conservative as no infiltration was taken into account and evaporation was only included as a component of the catchment inflows.

Table 8.1 demonstrates that through the manipulation of weir crest levels at Yerbury's Sill, the inundation frequency of the low-lying management areas can be effectively managed. The analysis

confirms that tidal levels at Menarcobrinni significantly influence present day inundation and floodplain hydrology. Indeed, weirs can be utilised and optimised to ensure that, provided there is catchment runoff to the system, the wetland management areas will be inundated. Note that it is unrealistic to expect that there will be permanent inundation of the management area floodplains as this is a function of natural wetting and drying cycles. Situations, as observed during field investigations in 2018/2019, where there is no flow within the drainage network will always occur and in these situations, there will be no flow to divert onto low-lying wetland areas. Nevertheless, increased inundation across the management areas will occur by diverting water across the low-lying floodplain and this will increase retention times of water within the wetland complex. This will result in greater extents of TfNSW land that can be effectively re-established as freshwater wetland habitat.

Table 8.1: Wetland inundation frequency for varying Yerbury Sill crest levels

Crest level (m AHD)	Days per year Yerbury's Scald is inundated	Days per year Mayes Swamp is inundated
-0.35 (Existing level)	0	0
-0.30	11	0
-0.20	96	11
-0.10	365	96
-0.05	365	164
0.00	365	365

8.2.2 Management area inundation depth and extent

In addition to the long term inundation frequency modelling, detailed hydrodynamic modelling was completed for weir elevations of -0.1 m AHD and 0.0 m AHD for new weirs located downstream of Yerbury's Sill on Seven Oaks Drain (location shown in Figure 8.1) to assess the depth and extent of inundation. It was determined that an elevation of 0.0 m AHD provided maximised potential habitat creation without negatively impacting drainage from private properties. Similarly, an elevation of +0.1 m AHD was chosen for the new East Drain weir (location shown in Figure 8.1).

8.2.3 Location of weirs

The location of the new weirs (as shown in Figure 8.1) was determined based upon local topography, weir width, weir elevation and the subsequent depth, extent and frequency of inundation of TfNSW land. Present day drainage over Yerbury's Sill is determined based on the sill crest elevation and width. Currently, Yerbury's Sill is approximately 14 m wide (Figure 8.2). During peak flows of ~3 m³/s (as calculated during catchment modelling for a 2EY event) the depth of water across the weir is

approximately 0.25 m above the weir crest. By increasing the width of the weir to 50 m the equivalent depth above the weir crest becomes 0.1 m effectively resulting in greater flow conveyance of the weir. That is, a wider weir will convey more flow than a narrow weir of the same elevation. An increase in width can be achieved by constructing a new weir on Seven Oaks Drain downstream of Yerbury's Sill at a wider channel location and adding an additional weir on the swale drain that connects Seven Oaks Drain and McAndrews Drain (Figure 8.3). Benefits of relocating the weir location is that the weir crest can be raised without negatively impacting drainage of standing surface waters following wet weather events.



Figure 8.2: Existing Yerbury's Sill width

Optimisation of weir location and geometry indicated that when the new weir on Seven Oaks Drain is raised to 0.0 m AHD, water is not retained on Yerbury's Scald or Mayes Swamp unless a new weir was also built on the swale drain that connects Seven Oaks Drain and McAndrews Drain (Figure 8.4). This is due to a lower invert level of this swale drain at approximately -0.4 m AHD which provides an alternate drainage route. Therefore, to encourage increased inundation depth, extent and frequency on TfNSW land a new weir could be constructed on the swale drain that connects Seven Oaks Drain and McAndrews Drain at an elevation equivalent to the new weir on Seven Oaks Drain.

Further benefits of constructing new weirs downstream of Yerbury's sill include (Figure 8.5):

- Larger extents of low-lying floodplain management areas owned by TfNSW can become inundated for greater depths, extents and frequencies;

- Moving the weir downstream means that water must flow through Mayes Swamp and out the relic channel of Clybucca Creek, whereas previously it could flow into Seven Oaks Drain immediately downstream of Yerbury's Sill; and
- The depth, extent and frequency of inundation on TfNSW land to the south of Seven Oaks Drain will also increase, promoting wetland habitat in these locations.

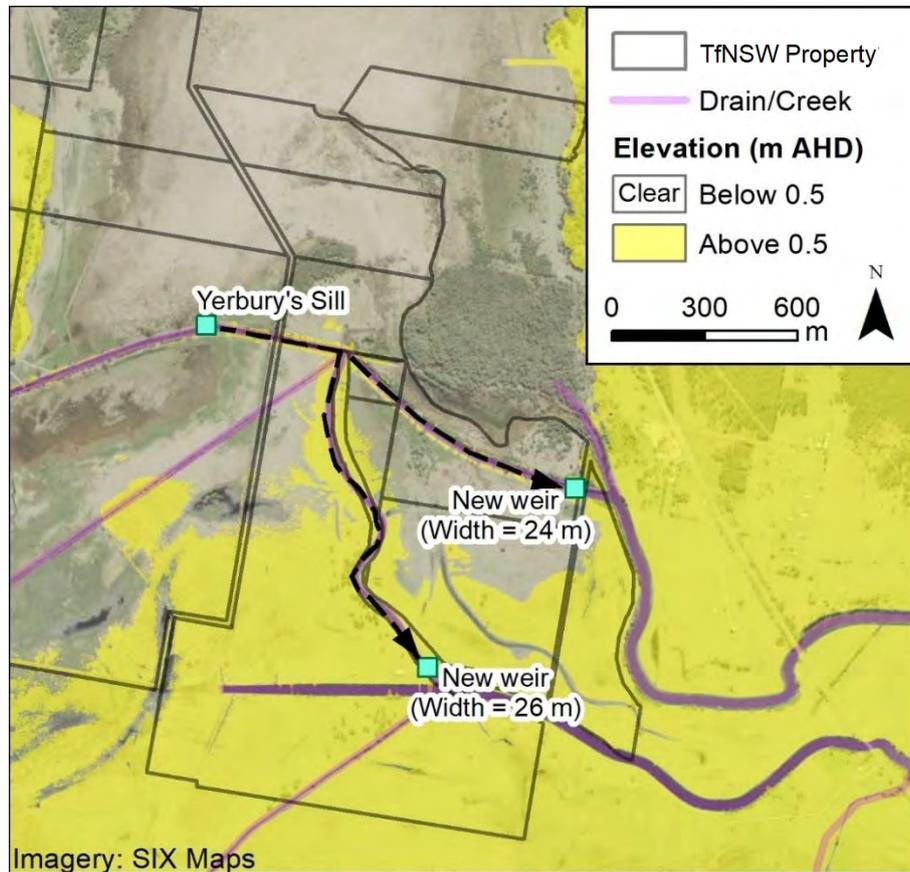


Figure 8.3: Diagram showing proposed location and widths of new weirs to replace Yerbury's Sill

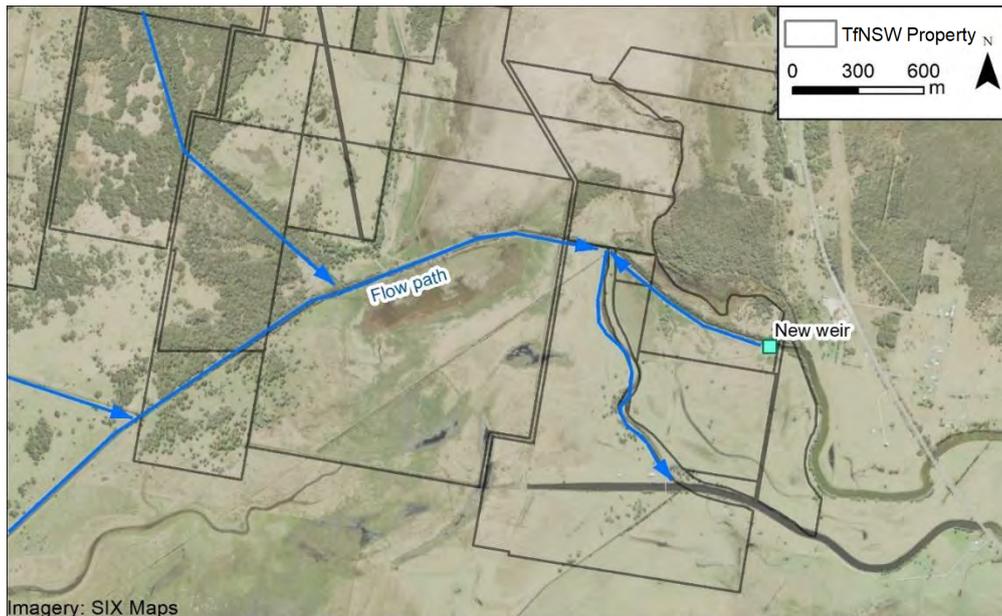


Figure 8.4: Diagram showing flow paths if there is no weir on the swale drain connecting Seven Oaks Drain and McAndrews Drain

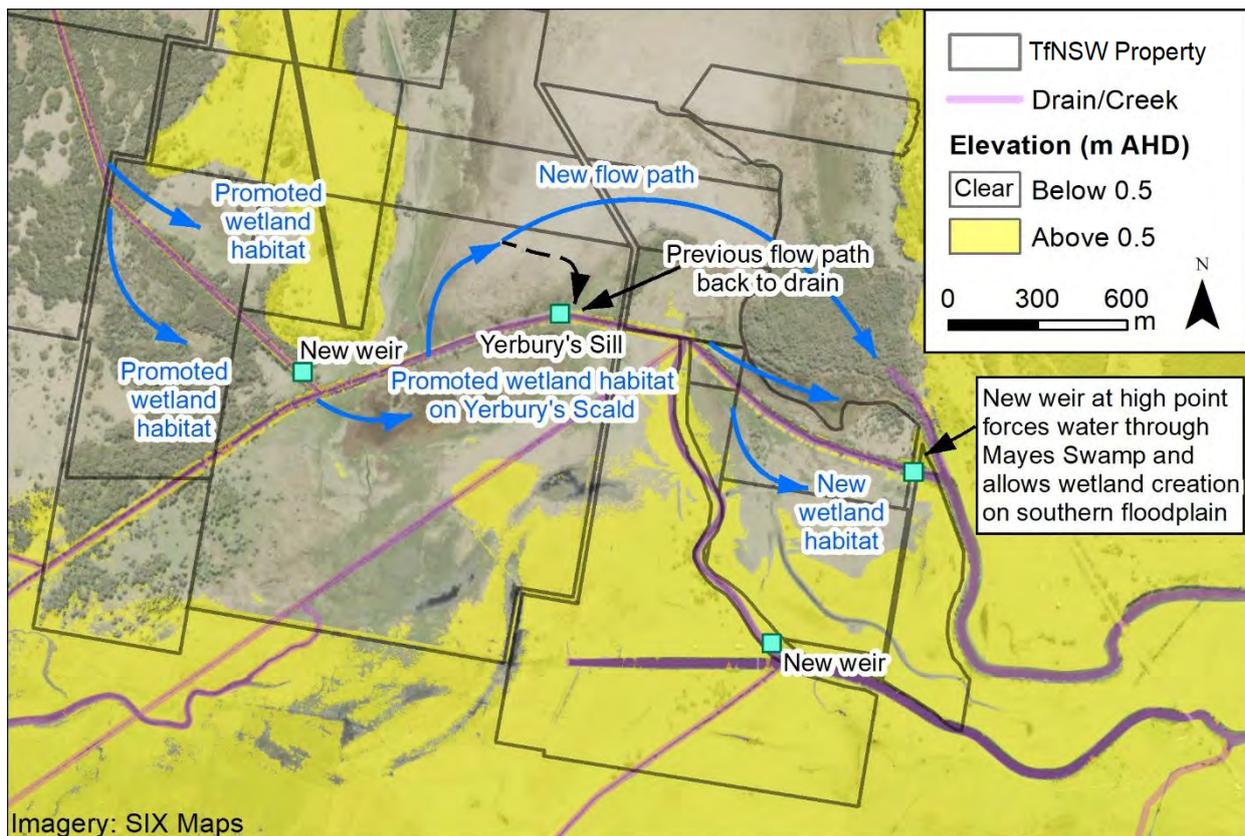


Figure 8.5: Diagram showing new flow paths created under Management Option 2

8.2.4 Levee bank assessment

Removal (or lowering) of drain levee banks can increase the floodplain drain connectivity resulting in a potential increase in inundation depth, extent and frequency of adjacent low-lying areas. Optimisation of test results were analysed to determine the effect of levee bank removal on Seven Oaks Drain and East Drain and to determine if they should be removed or lowered. It was found that removing the levee banks on East Drain resulted in reduced inundation of fresh water on nearby low-lying floodplain management areas such as Latham's Scald. This occurs as the connectivity between the low-lying floodplain and drain is increased by levee removal, which allows water to drain more efficiently from the floodplain to the drain. Conversely, removing levee banks on Seven Oaks Drain, from the new weir to the confluence of Seven Oaks Drain/East Drain, resulted in increased frequency of inundation of Mayes Swamp and Yerbury's Scald (Figure 8.6). This is due to the new weir on Seven Oaks Drain promoting flow onto wetland areas.

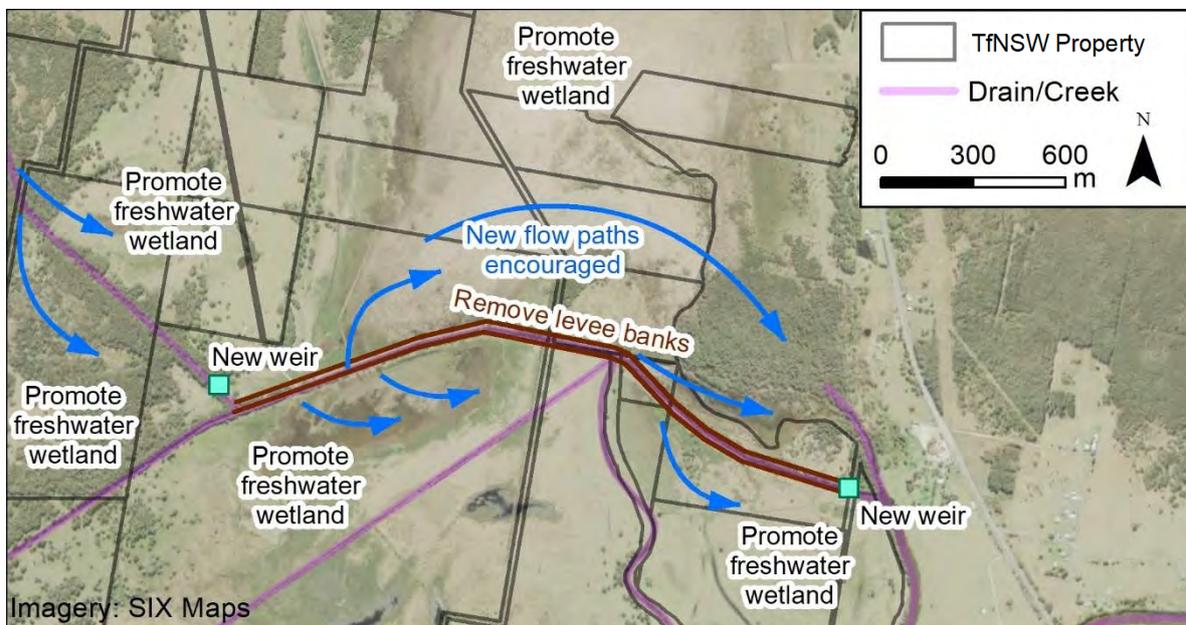


Figure 8.6: Locations where levee banks should be removed for Management Option 2

8.3 Results and assessment

Management Option 2 was assessed utilising a 2EY catchment runoff event (the same as for the base case) over a three (3) month period to quantify the effectiveness of the design in achieving inundation depth, extent and frequency outcomes. The impact to drainage was assessed by simulating drainage of a minor flood event whereby the floodplain is allowed to drain under idealised condition (i.e. normal tidal conditions and no additional inflows) from water level elevation of +0.75 m AHD. Results from these

simulations can be used to assess Management Option 2 against the present-day base case and other management options.

8.3.1 Day-to-day inundation depth, extent and frequency

Results showing the extent of change in drainage inundation depth, extent and frequency following a 2EY event for Option 2 when compared to the base case are presented in Figure 8.7 and Figure 8.8. Results indicate that there is an overall increase in time the low-lying management areas are inundated. Water inundates Mayes Swamp an additional 20% of the time under Management Option 2 when compared to the base case for the majority of the management area. Yerbury's Scald remains inundated throughout the modelled period with additional area on the outskirts of Yerbury's Scald becoming inundated. Doughboy Swamp has a significant increase in inundation time less than 1% to up to 100%. It is evident that the average inundation depth across Yerbury's Scald and Doughboy Swamp increases by up to 0.30 m (Figure 8.8). There is minimal change in inundation depth across Mayes Swamp, however the inundation duration is longer for the lowest lying areas (Figure 8.7).

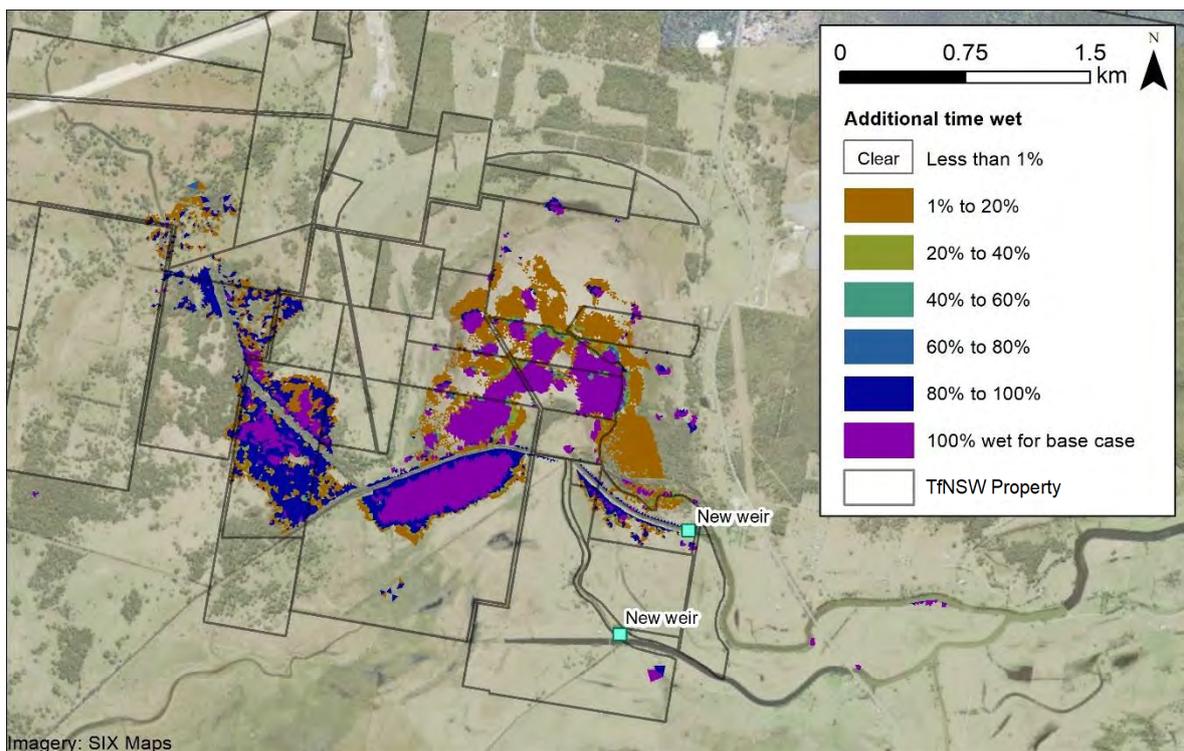


Figure 8.7: Difference in inundation time between the base case and Management Option 2 for a three (3) month period following a 2EY (6 month) runoff event

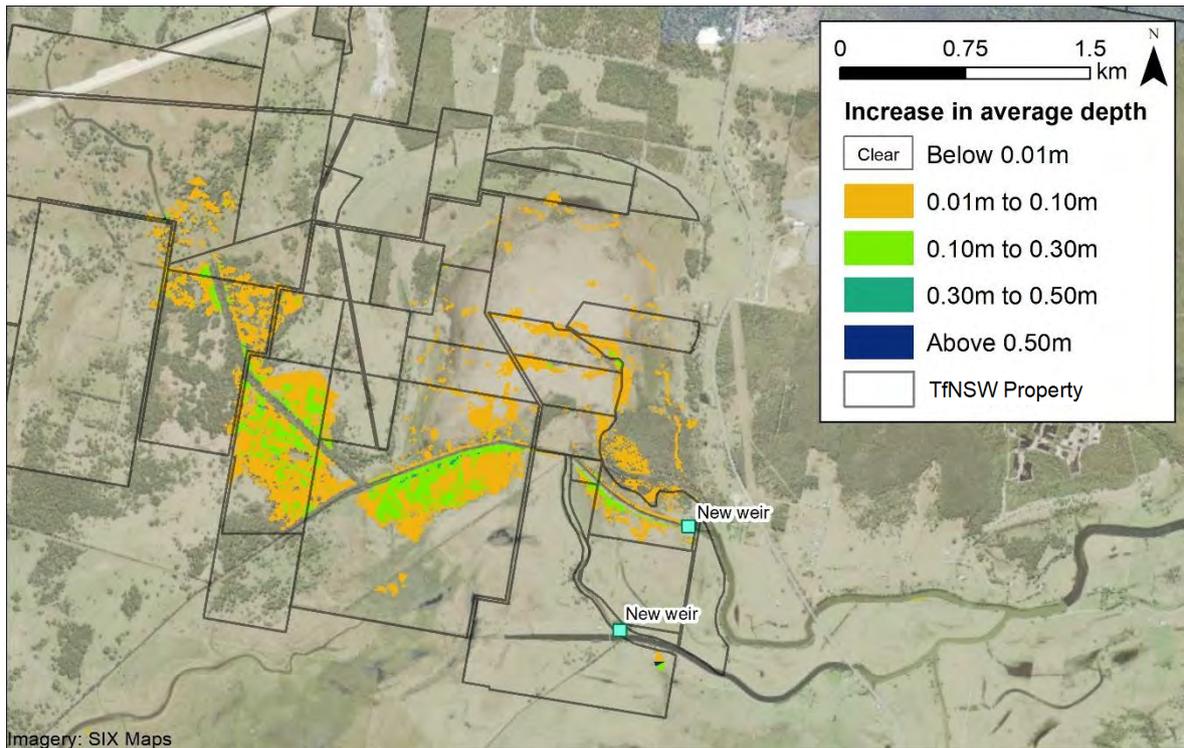


Figure 8.8: Difference in average inundation depth between the base case and Management Option 2 for a three (3) month period following a 2EY (6 month) runoff event

8.3.2 Flood drainage time

Numerical simulations were undertaken to determine how the floodplain drains after a flood event and following modifications outlined as part of Option 2. Timeseries results showing the fall in water level following a flood event as compared to the base case are presented in Figure 8.9 to Figure 8.13 for the floodplain locations as outlined in Figure 6.4 (see Section 6.1.3). Table 8.2 outlines the time it takes for flood waters to recede from sections of the floodplain spanning private property in comparison to the base case for the locations in Figure 6.4.

Results showing the difference in drainage for when the floodplain is inundated to 0.75 m AHD between Option 2 and the base case indicate that an increase in drainage time occurs across most of the floodplains. The greatest increase in drainage time is on the Doughboy Drain floodplain where water takes an additional 12 hours to drain.

Table 8.2: Summary of floodplain drainage after being inundated to +0.75 m AHD

Floodplain	Time taken for floodplain to drain (days)	
	Base case	Management Option 2
Doughboy Drain floodplain	2.0	2.5
Shackles Drain floodplain	0.7	0.8
Southern floodplain	0.4	0.4
Upper Seven Oaks Drain floodplain	2.1	2.2
West Drain floodplain	5.3	5.6

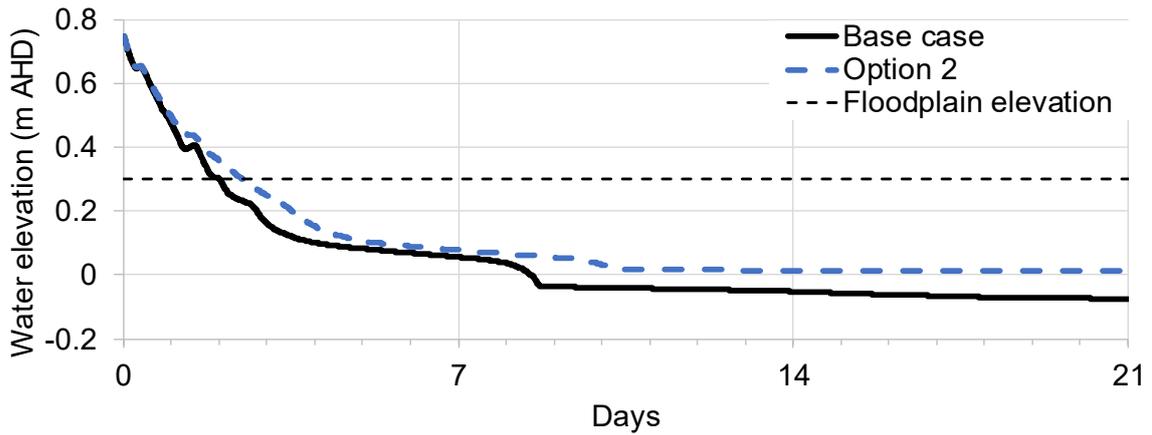


Figure 8.9: Drainage time for the Doughboy Drain floodplain

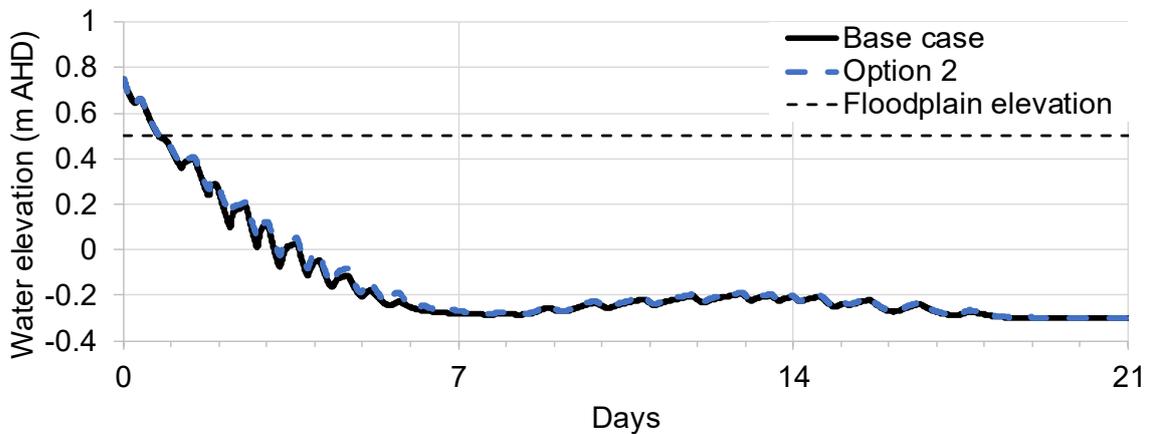


Figure 8.10: Drainage time for the Shackles Drain floodplain

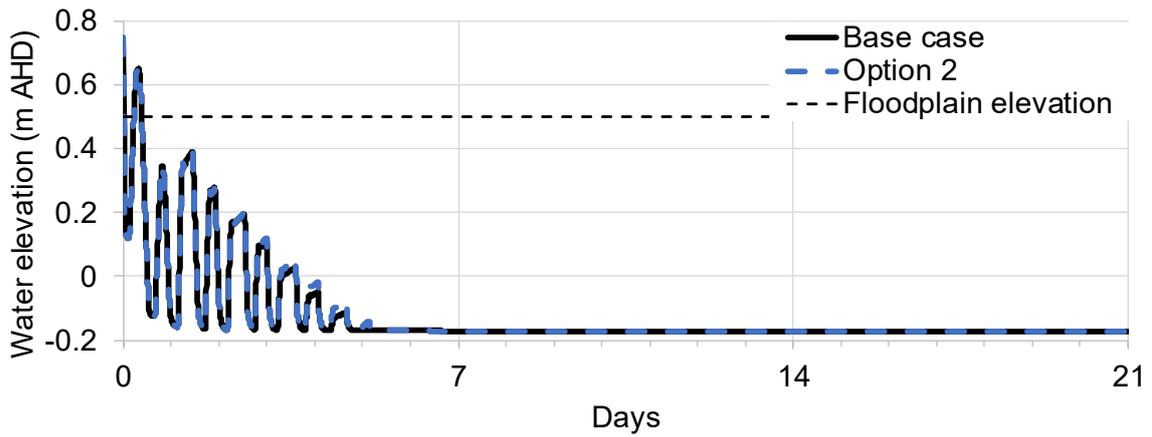


Figure 8.11: Drainage time for the Southern floodplain

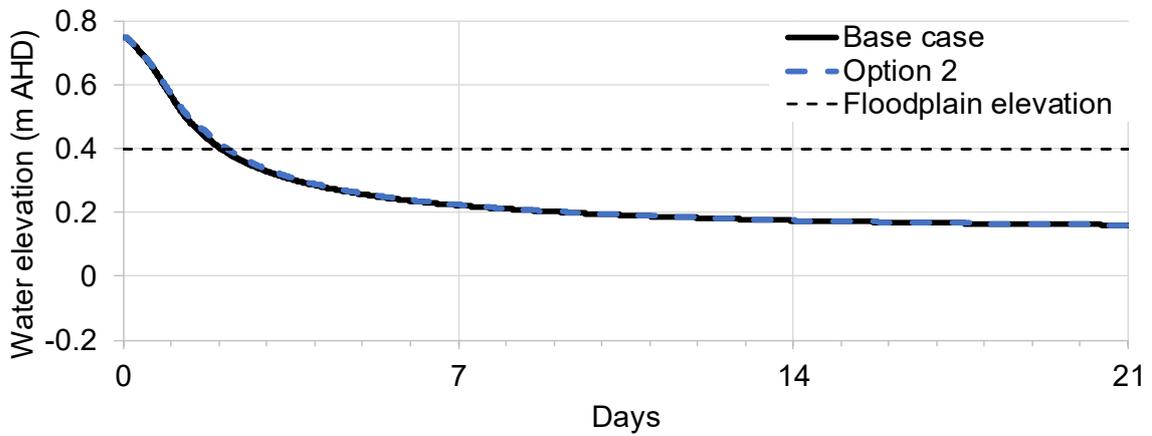


Figure 8.12: Drainage time for the upper Seven Oaks Drain floodplain

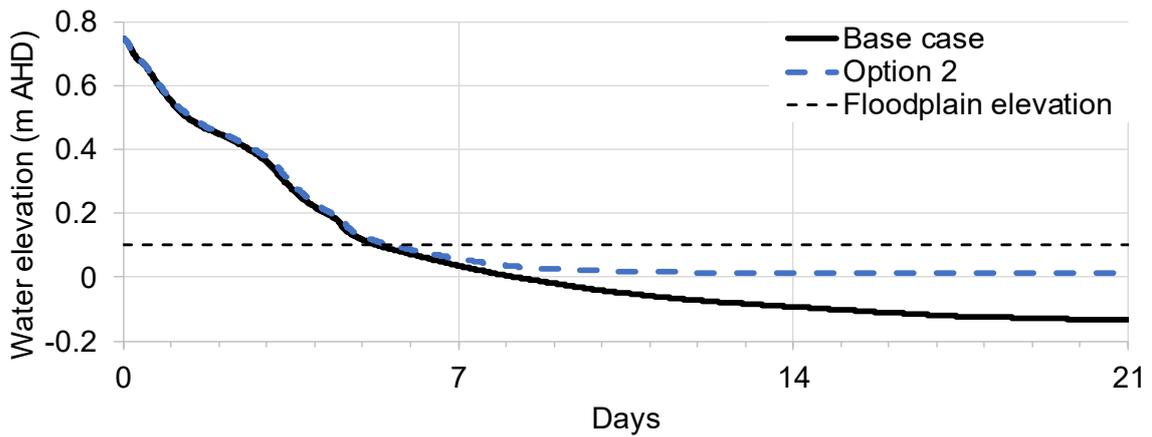


Figure 8.13: Drainage time for the West Drain floodplain

8.3.3 Summary of results

Overall, the optimised design for Management Option 2 successfully promotes an increase in inundation depth, extent and frequency on wetland management areas. Modelling indicated that there would be a minor increase in drainage times (i.e. hours) for floodplain wide inundations events. Changes to inundation depth, extent and frequency would only occur within TfNSW land with the exception of an increase on private property on the eastern side of Mayes Swamp at shallow depths (1 cm to 10 cm).

9 Management Option 3: Freshwater on low-lying wetland areas with McAndrews Drain extension

9.1 Description

Management Option 3 features the same on-ground works as Management Option 2 (i.e. weir construction and levee removal/lowering), combined with extending McAndrews Drain along its existing alignment to Seven Oaks Drain. The objective of this approach is to investigate the potential for improved drainage of upstream floodplain areas and improved management of wetland areas (Figure 9.1). This may allow greater changes to be made within TfNSW property boundaries without negatively impacting upstream floodplain users.

Conceptually, the optimum design of the new/extended drain is such that:

1. Day-to-day catchment runoff flows into the low-lying management areas of Mayes Swamp and Yerbury's Scald; and
2. During larger runoff events (greater than 2EY) standing water on the floodplain is channelled through the McAndrews Drain extension, allowing the upstream floodplain to drain faster.

The alignment of the drain would remain within TfNSW property boundaries. The drain would be constructed with a swale shape to ensure that it does not cut into underlying ASS layers. This will ensure that it does not exacerbate issues associated with acid export from the groundwater as occurs elsewhere on the floodplain. Furthermore, this drain adjustment will improve blackwater risk by ensuring that catchment scale flood events are drained efficiently.

Note that water levels in the Macleay River estuary are the dominate control of floodplain water levels and drainage potential.

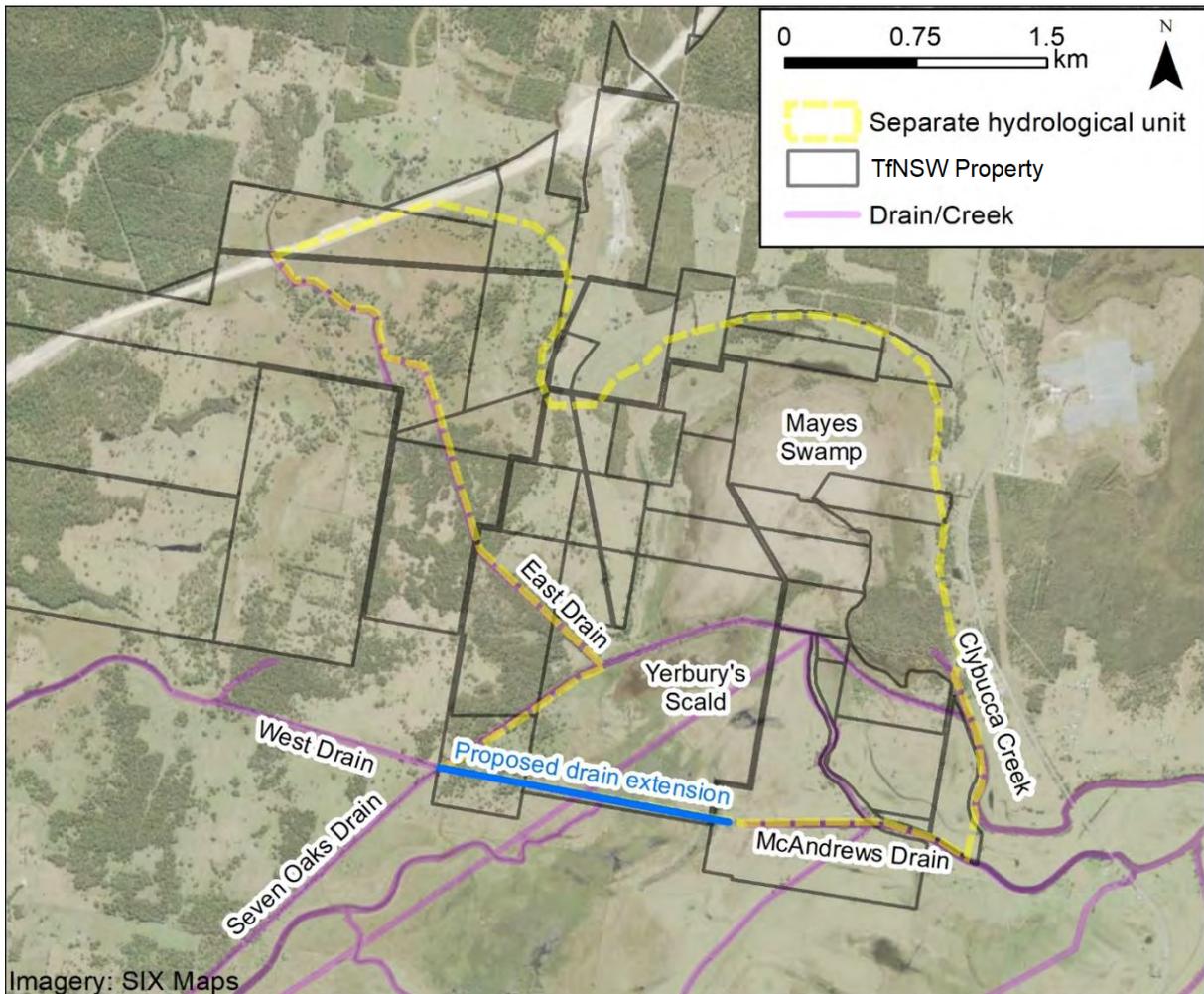


Figure 9.1: Diagram of new drain extending from McAndrews Drain to Seven Oaks Drain within TfNSW land with respect to the separate hydrological unit it would create

This option remediates the environmental impacts of acid runoff events by allowing major modifications within TfNSW land that will not impact the wider floodplain drainage. Modifications that can be implemented within TfNSW land include:

- Raising of weirs;
- Relocation of weirs;
- Removal of levee banks;
- Promotion of native water tolerant vegetation reestablishment;
- Removal of stock from land;
- Remediation of acid scalds;
- Reshaping and infilling drains; and

- Installation of new weirs.

Benefits of these remediation approaches are outlined in Section 4 and generally include:

- Reduced ASS and blackwater runoff by promoting natural wetting and drying cycles across the floodplain;
- Promotion of native water tolerant vegetation and subsequent freshwater wetland habitat with various associated ecosystem services; and
- Reduction of blackwater events and loss of pasture/crops by ensuring floods are drained efficiently.

Extension of McAndrews Drain to Seven Oaks Drain has the potential to impact the surrounding floodplain. The following management considerations should be assessed prior to implementation:

- Construction of the new drain will need to consider the environmental impacts of actions such as the felling of trees and disturbing habitat along the proposed drain alignment;
- Excavation of the new drain will result in spoil that will require liming and a location for disposal. This could potentially be used to infill/reshape drains within TfNSW property; and
- Responsibility for maintenance and overall ownership of the new drain being constructed will need to be considered.

Note, the benefits introduced by constructing a new drain extending from McAndrews Drain to Seven Oaks Drain will only be fully realised when implemented alongside other modifications to the drainage network. Therefore, implementation of the new drain has been assessed with the same modifications to the drainage network within TfNSW land as outlined in Management Option 2 (See Section 8.2 for details). This allows for the comparison between a modified drainage network with and without the new drain.

9.2 Design specification and optimisation

Management Option 3 has been designed to ensure that day-to-day drainage passes through low-lying TfNSW land while the peaks of larger flood events are directed from the western floodplain through the new drain. Currently, upstream areas of the Collombatti-Clybucca floodplain must flow through TfNSW land before discharging into the Macleay River estuary. Conceptually, construction of the drain extension with a shallow and wide cross-sectional profile may enable greater modifications to be made

to drainage infrastructure within TfNSW land, whilst not impacting the drainage of surface waters in upstream floodplain areas.

Design of the new drain extending McAndrews Drain to Seven Oaks Drain needs to consider the optimum drain dimensions to allow the required efficiency while remaining within environmental and management constraints. Subsequently, design of the drain has considered the following:

- Drain alignment;
- Underlying floodplain soil;
- Drain cross-sectional area;
- Drain invert level, including:
 - Inundation frequency modelling;
 - Hydrodynamic optimisation; and
- Drain gradient.

The following sections detail the optimisation investigation completed to determine the final design for the new swale drain extending from McAndrews Drain to Seven Oaks Drain.

9.2.1 Drain alignment

The new drain extending McAndrews Drain to Seven Oaks Drain will be aligned so that it is wholly within TfNSW property (Figure 9.2). Note, there is an easement owned by Crown Lands on the eastern side of the alignment which the drain will intersect and subsequently appropriate approvals will need to be sought for construction of the new drain. The drain will run parallel to the TfNSW boundary and connect to Seven Oaks Drain near West Drain.

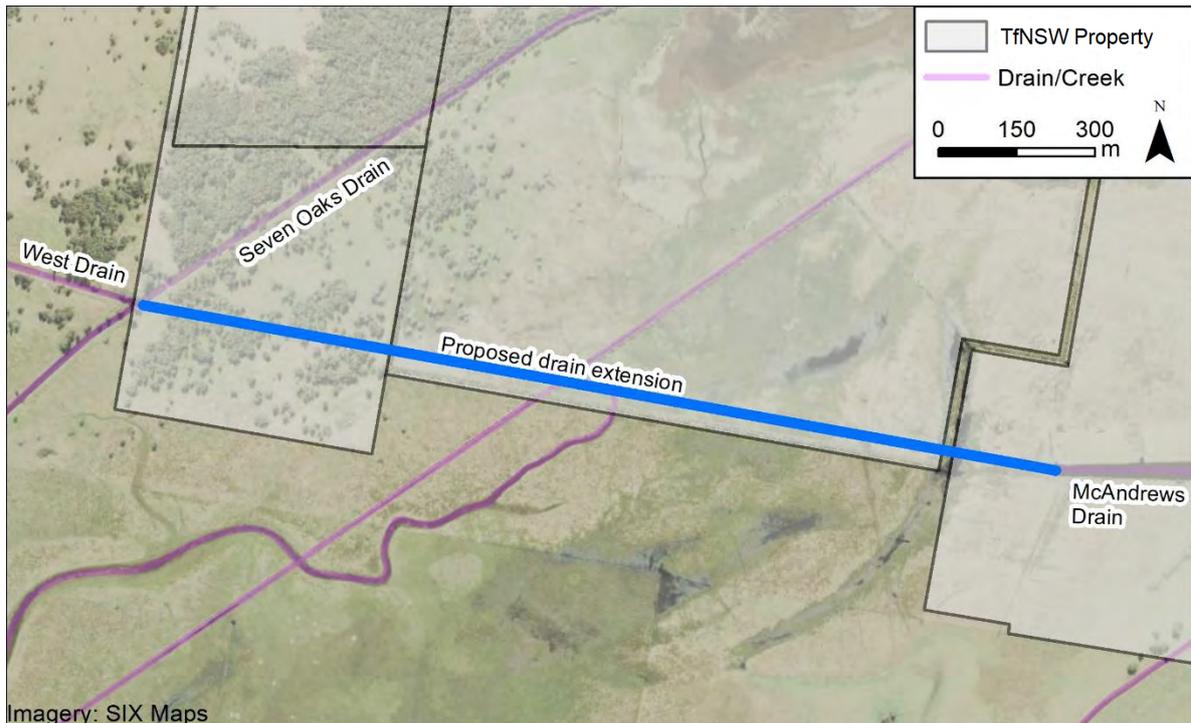


Figure 9.2: Alignment of new drain to be constructed from McAndrews Drain to Seven Oaks Drain within TfNSW property

9.2.2 Underlying floodplain soil

The aim of constructing the new drain extension is to improve both drainage outcomes for upstream floodplain users and environmental outcomes within TfNSW land. It is therefore important that construction of a new drain does not exacerbate, or create new, issues associated with ASS drainage. During field investigations (Appendix C), four (4) soil profiles were sampled along the proposed alignment of the new drain. At one of the sample locations it was discovered that ASS (either AASS or PASS) was located at the surface along the alignment (Figure 9.3). As such, it is preferential that excavation along this alignment is minimised as much as possible, as excavated material will require treatment and/or disposal.

Further investigation of acid sulfate soil depths and extent would be required as part of the development of an acid sulfate soil management plan that is likely required for approval on drain extension works.

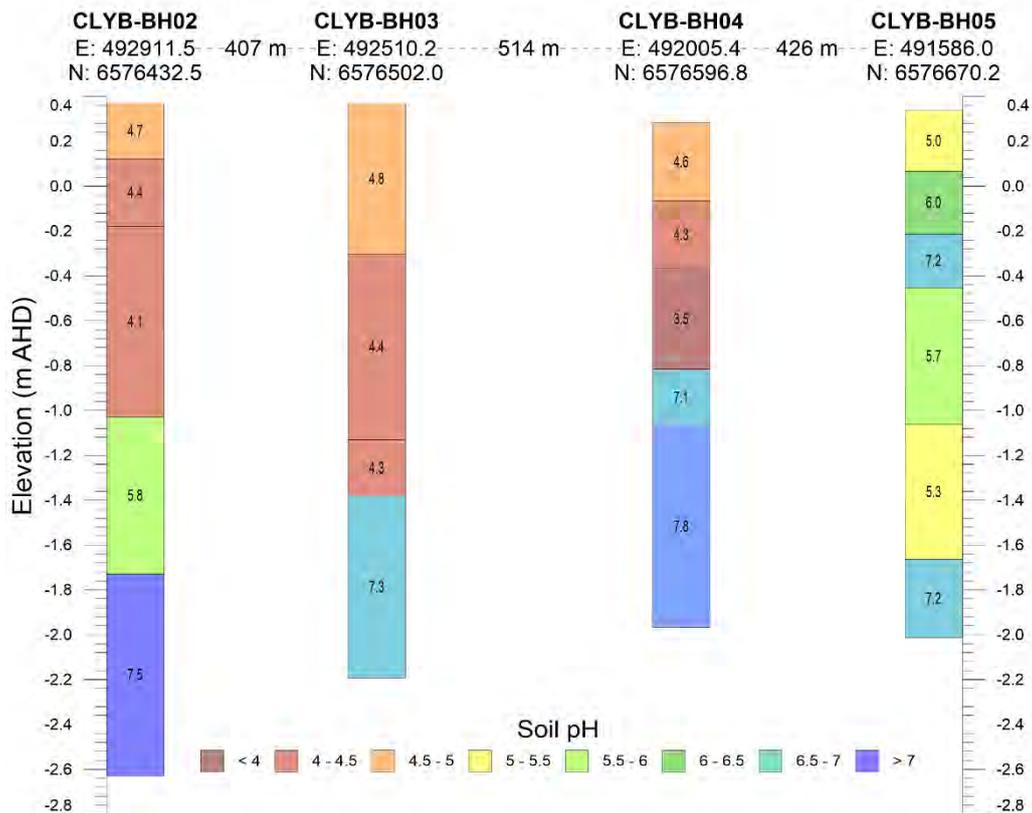


Figure 9.3: Location of ASS along the proposed drain extension of McAndrews Drain to Seven Oaks Drain with respect to different drain invert elevations

9.2.3 Drain cross-sectional area

The cross-sectional area of the drain is one of the main attributes that determines its flow capacity (in addition to the drain gradient and channel roughness). Therefore, the cross-section for the new drain needs to be large enough to provide enough flow capacity to convey peak flood waters. To achieve the required discharge capacity, a swale shaped cross-section (i.e. shallow and wide) has been selected. Swale drains allow equivalent flow capacity as deeper drains while reducing the impact cause by draining ASS layers (see Section 4.2.4).

9.2.4 Invert level

Designing the optimum invert level for the new drain needs to take into consideration the following:

- Impact on wetting and drying of the low-lying management area floodplain;
- Location of the ASS layer; and

- Remediation objectives within TfNSW land.

(A) Inundation Frequency Modelling

An analytical inundation frequency model (previously described in Section 8.2) was used to determine how the addition of the new drain affects the inundation frequency of low-lying wetland areas within TfNSW land. Table 9.1 shows how the invert level of the new drain changes the inundation frequency on Yerbury’s Scald and Mayes Swamp. Note, the remainder of the drainage network has been set as per Option 2 (see Section 8 for details). Results indicate that if the invert level of the new drain from McAndrews Drain to Seven Oaks Drain is above the crest level of the new weir on Seven Oaks Drain (0.0 m AHD) there is no change in inundation frequency within the low-lying management area floodplains.

Table 9.1: Effect of McAndrews Drain extension on wetland inundation frequency

Invert level new drain (m AHD)	Days per year Yerbury’s Scald is inundated	Days per year Mayes Swamp is inundated
No drain (existing for Option 2)	365	365
+0.2	365	365
0.0	365	365
-0.2	73	2
-0.4	11	2

This analysis highlights that if the invert level on the new drain is set at too low of an elevation, environmental outcomes resulting from separating TfNSW land as its own hydrological unit may not be fully realised as inflows may be diverted towards McAndrews Drain instead of the wetland areas.

(B) Hydrodynamic modelling

Hydrodynamic modelling was completed to further test the findings of the analytical model. Three (3) designs for the swale drain with different invert levels were taken into consideration (Figure 9.4):

Design 1: Invert level of -0.4 m AHD

Design 2: Invert level of 0.0 m AHD

Design 3: Invert level of +0.2 m AHD

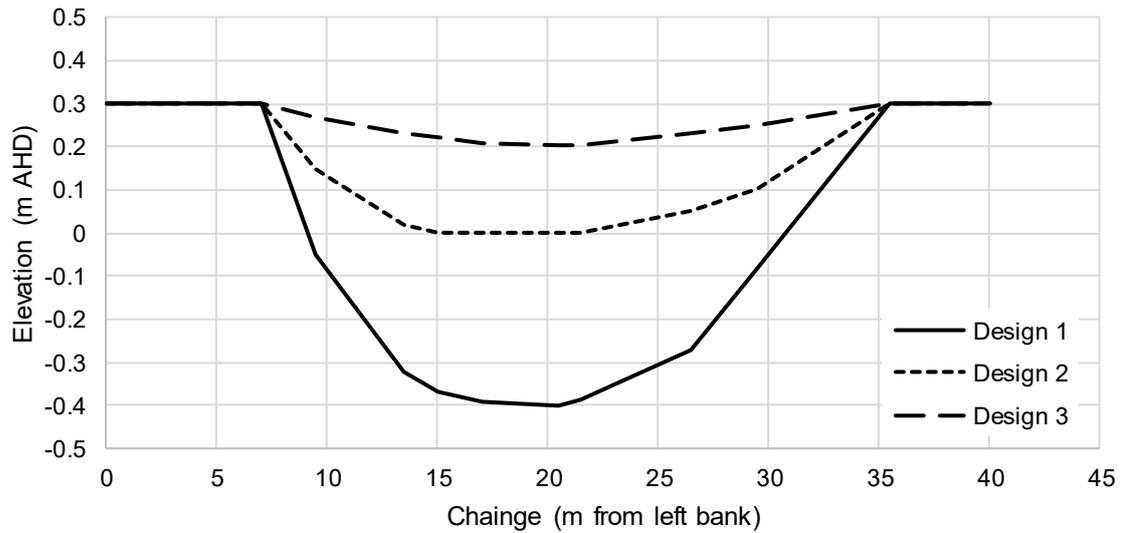


Figure 9.4: Alternative design options for the McAndrews Drain extension

Design 1 has the lowest invert level at -0.4 m AHD and is equivalent to the swale drain already connecting Seven Oaks Drain to McAndrews Drain on the east of Yerbury’s Scald. An invert of -0.4 m AHD results in any drainage remediation works within TfNSW property (e.g. shallow freshwater in wetland areas (Management Option 2)) becoming superfluous with modelling results indicating that catchment inflows are directed down the new swale drain instead of flowing to the wetland rehabilitation areas (Figure 9.5). While this indicates that the new drain has the ability to transport water from the floodplain, environmental benefits received by promoting regular inundation of low-lying areas do not occur. These results are in line with the analytical inundation frequency modelling completed (see Table 9.1). Subsequently, Design 1 is not recommended for this Management Option 3.

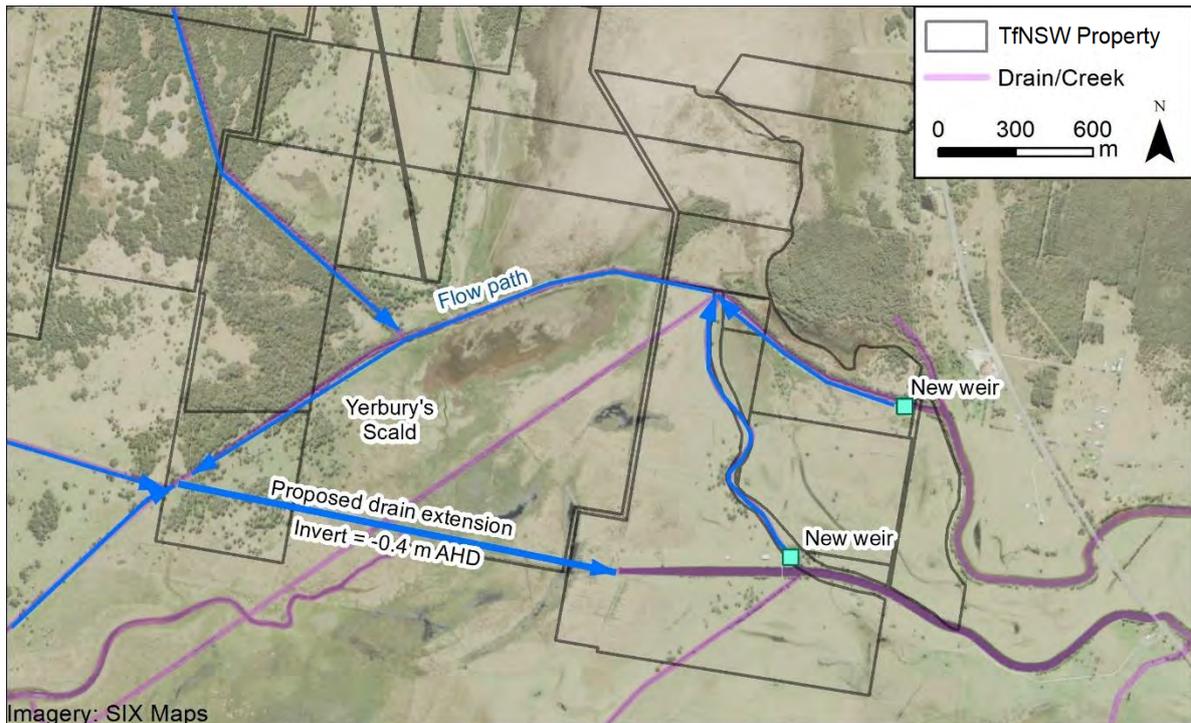


Figure 9.5: Flow paths when an invert level of -0.4 m AHD is adopted for the new swale drain

Figure 9.6 shows that by raising the invert of the new drain to 0.0 m AHD (Design 2), equivalent to the level of the weirs located downstream on Seven Oaks Drain (as specified in Management Option 2), the majority of catchment runoff flows to the Mayes Swamp and Doughboy Swamp areas, with the new drain conveying flow once wetland areas are fully inundated. This enables the promotion of wetland habitat in low-lying floodplain management areas during day-to-day conditions, while during higher flow conditions, inflows are channelled down the new drain. This process has the potential to reduce the risk of blackwater by reducing inundation time on agricultural areas of the floodplain. Note that overall floodplain drainage is predominantly determined by receiving water levels.

In comparison to Design 1 and Design 2, by constructing the new drain with an invert level of +0.2 m AHD (Design 3), greater flows will be encouraged to flow down Seven Oaks Drain more frequently, with greater catchment rainfall required for the new McAndrews Drain extension to convey flows. Hydrodynamic modelling of this option found that for drainage of a minor catchment flood event from an inundation level of +0.75m, Design 3 did not reduce floodplain drainage times (in comparison to the base case or Management Option 2) (Table 9.2).

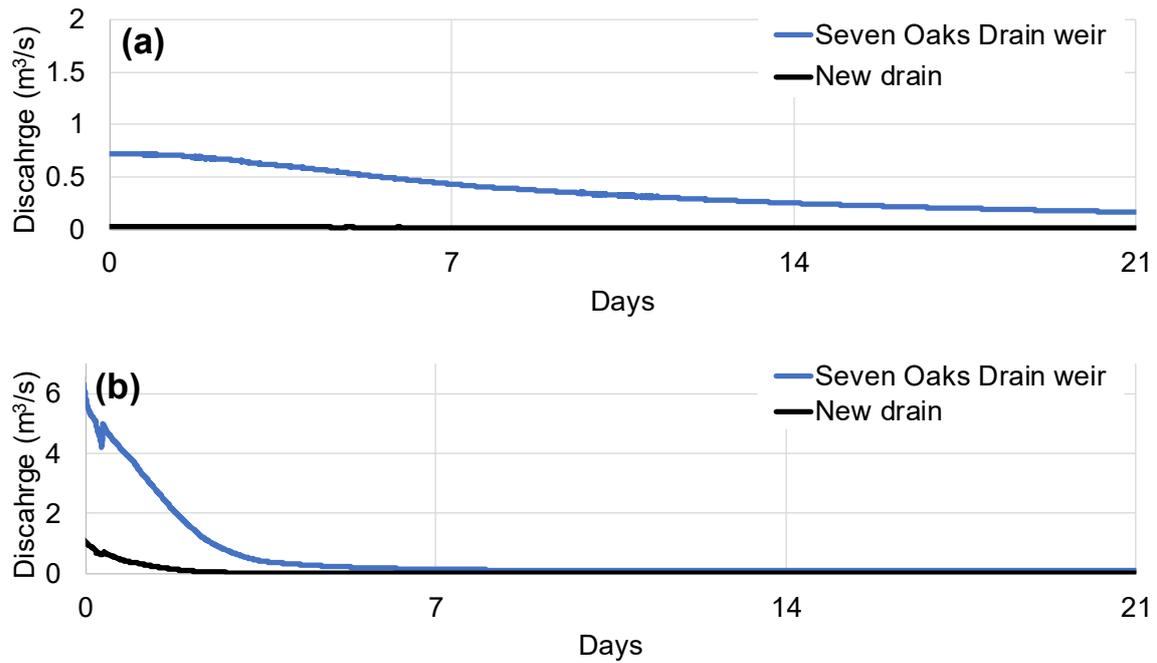


Figure 9.6: Flow comparison for Yerbury’s Sill and the new drain (Design 2) following (a) a day-to-day runoff event and (b) a flood event

Table 9.2: Summary of floodplain drainage times following a minor inundation event +0.75 m AHD when the new drain invert is +0.2 m AHD (see locations in Figure 6.4)

Location	Time taken for floodplain to drain (days)		
	Base case	Management Option 2	Management Option 3 Design 3
Doughboy Drain floodplain	2.0	2.5	2.5
Shackles Drain floodplain	0.7	0.8	0.8
Southern floodplain	0.4	0.4	0.4
Upper Seven Oaks Drain floodplain	2.1	2.2	2.1
West Drain floodplain	5.3	5.6	5.6

In summary, Design 2 with a drain invert level of 0.0 m AHD was chosen as the final design for Management Option 3 as:

- During day-to-day conditions water is directed onto the low-lying floodplain management areas within the TfNSW property resulting in wetland habitat creation and the ecological values associated; and

- During flood conditions water is removed from the floodplain quicker than if the drain was not constructed, resulting in less impact to private landholders.

9.2.5 Drain gradient

During modelling the new drain extending from McAndrews Drain to Seven Oaks Drain was implemented with zero gradient. This was adopted as there was no hydraulic requirement in this case to have a slope along the length of the drain.

9.3 Results and assessment

Two (2) numerical modelling simulations were completed for Management Option 3. First, a simulation was completed for Design 2 using a 2EY runoff event (the same as for the base case) over a three (3) month period to quantify the effectiveness of the design in achieving inundation depth, extent and frequency outcomes. Secondly, initial conditions were set so that the model began with a water level elevation of +0.75 m AHD across the floodplain. This was then used to test drainage efficiency and determine changes in floodplain drainage time. Results from both simulations can be used to assess Management Option 3 against the base case and Management Option 2 and determine the feasibility of constructing the McAndrews Drain extension.

9.3.1 Day-to-day inundation depth, extent and frequency

Results showing the change in drainage inundation depth, extent and frequency for Management Option 3 when compared to the base case are presented in Figure 9.7 and Figure 9.8. Results for Management Option 3 are similar to those of Management Option 2 and indicate that there is an overall increase in time the low-lying management areas are wet following a 2EY (6 month) runoff event. Mayes Swamp has an additional 20% inundation time when compared to the base case, with Yerbury's Scald remaining inundated for the majority of the modelled period. Doughboy Swamp has a significant increase in modelled inundation time from 0% to up to 100%. Average inundation depth across Yerbury's Scald and Doughboy Swamp increases by up to 0.30 m (Figure 8.8). There is minimal change in inundation depth across Mayes Swamp despite the floodplain remaining inundated for a longer period. These changes are primarily due to the weirs constructed at 0.0 m AHD at the eastern extent of the management area.

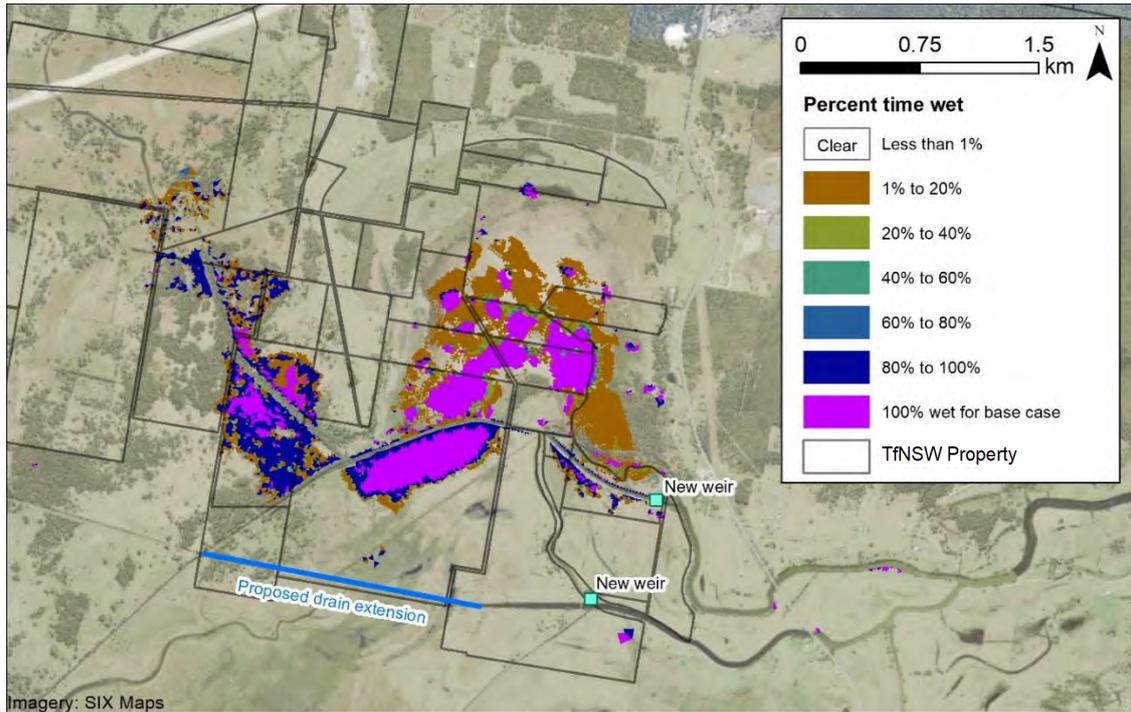


Figure 9.7: Difference in inundation time between the base case and Management Option 3 for a three (3) month period following a 2EY (6 month) runoff event

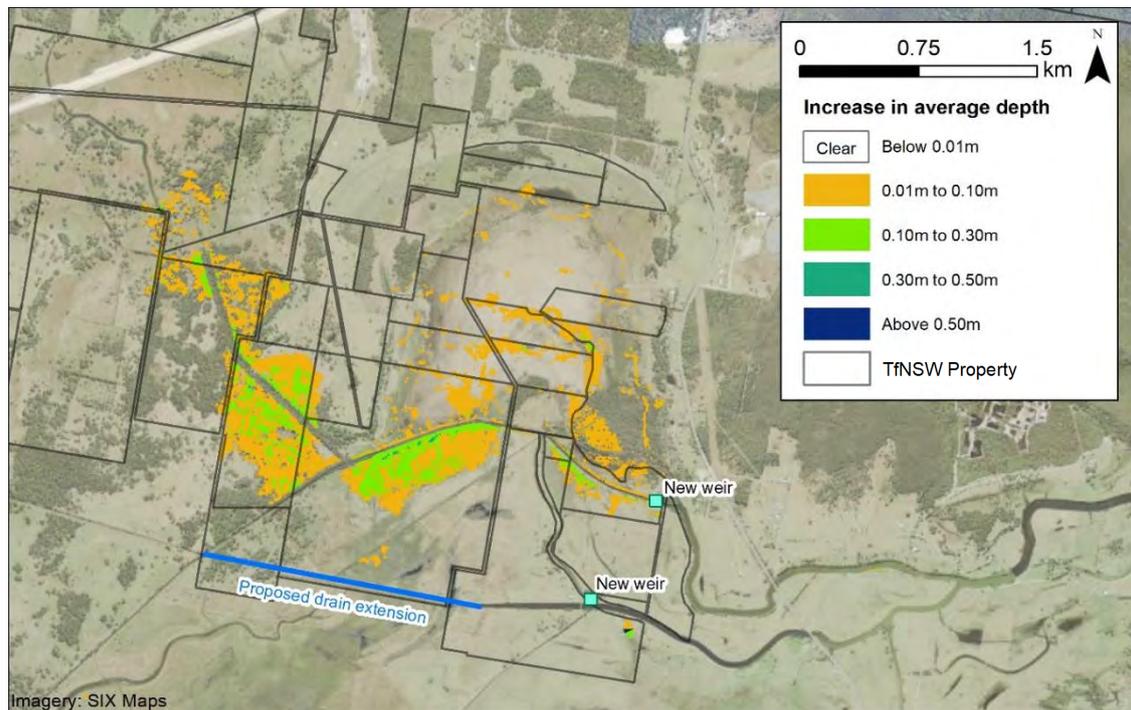


Figure 9.8: Difference in inundation depths between the base case and Management Option 3 for a three (3) month period following a 2EY (6 month) runoff event

Results showing a 2EY event for Management Option 3 have also been compared to Management Option 2 to determine the effect the new drain would have on wetland inundation. The extent of change in drainage inundation frequency and depth are presented in Figure 9.9 and Figure 9.10, respectively. Results show that the influence of the new drain extension has on wetland inundation is relatively small in comparison to Management Option 2. The majority of the floodplain has a change in inundation equal to ± 0.10 m resulting in a change in inundation time of less than 20%. Therefore, the remediation benefits of Management Option 2 remain unchanged, as intended with the conceptual approach of Management Option 3.

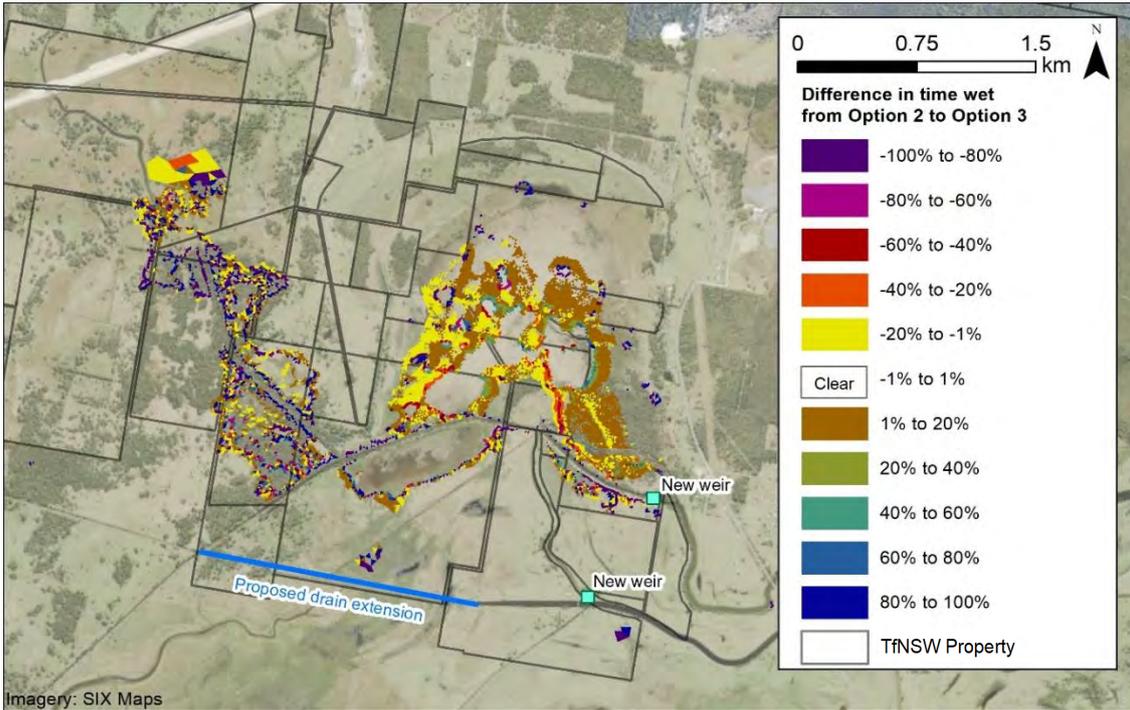


Figure 9.9: Difference in inundation time between Management Option 2 and Management Option 3 for a three (3) month period following a 2EY (6 month) runoff event

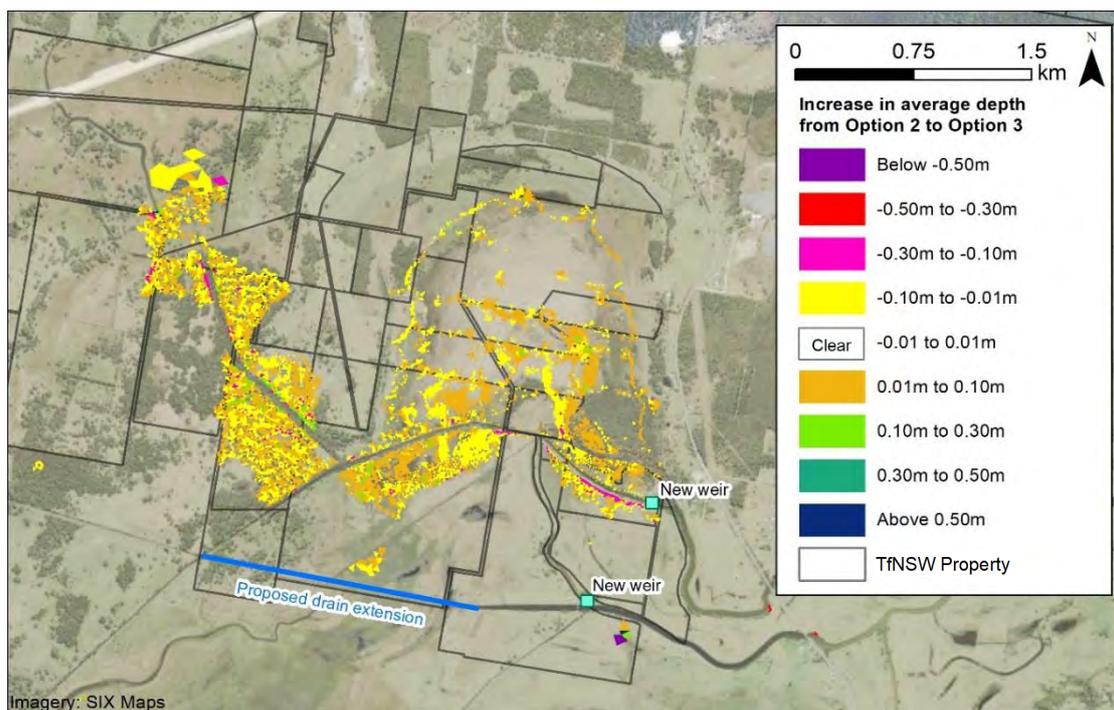


Figure 9.10: Difference in average water levels between Management Option 2 and Management Option 3 for a three (3) month period following a 2EY (6 month) runoff event

9.3.2 Flood drainage time

To assess how the introduction of a new drain from McAndrews Drain to Seven Oaks Drain influences drainage of floodwaters from the wider Clybucca floodplain, a simulation was completed whereby the time taken to drain floodwaters starting at an elevation of +0.75 m AHD from the floodplain was assessed. Timeseries results showing the fall in water level following a minor inundation event as compared to the base case and Management Option 2 are presented in Figure 9.11 to Figure 9.15 for the floodplain location (Figure 6.4, Section 6.1.3). Table 9.3 summarises the time it takes for the floodplain to drain in each case.

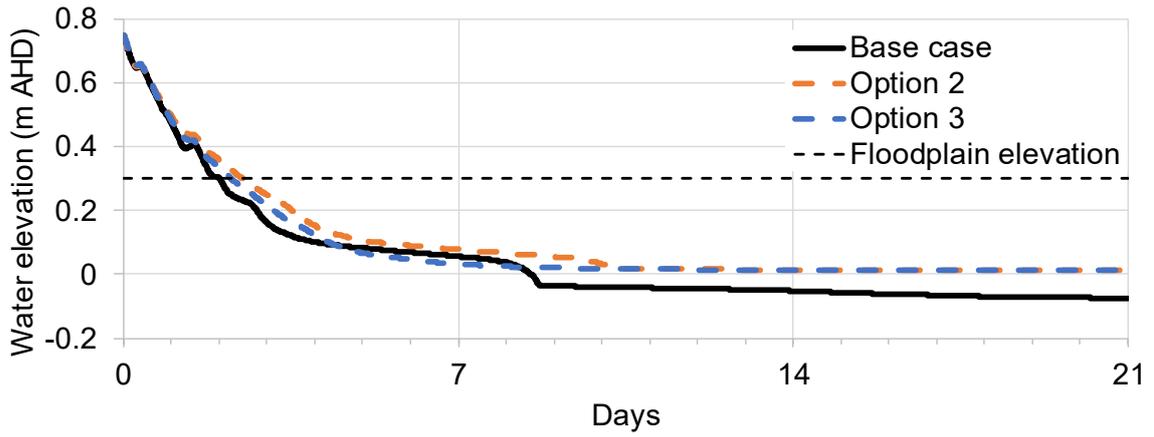


Figure 9.11: Drainage time for the Doughboy Drain floodplain

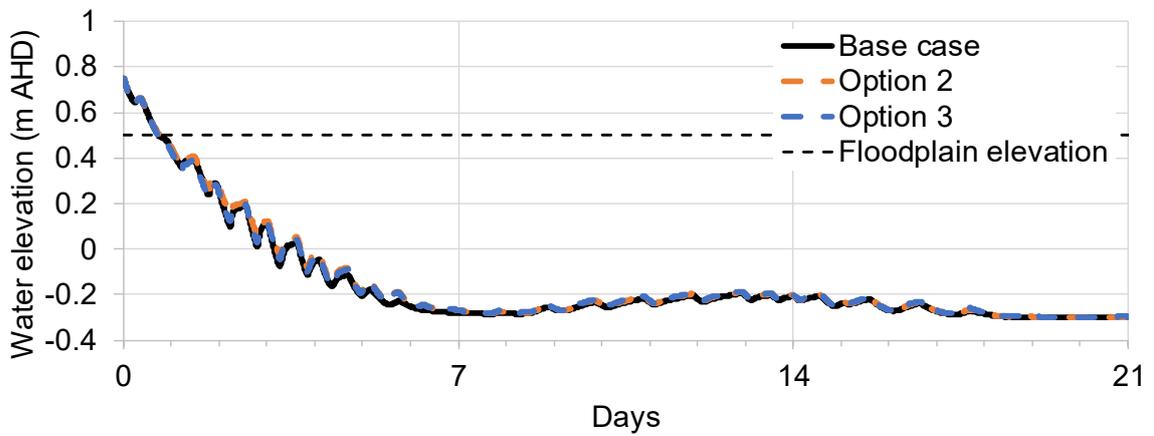


Figure 9.12: Drainage time for the Shackles Drain floodplain

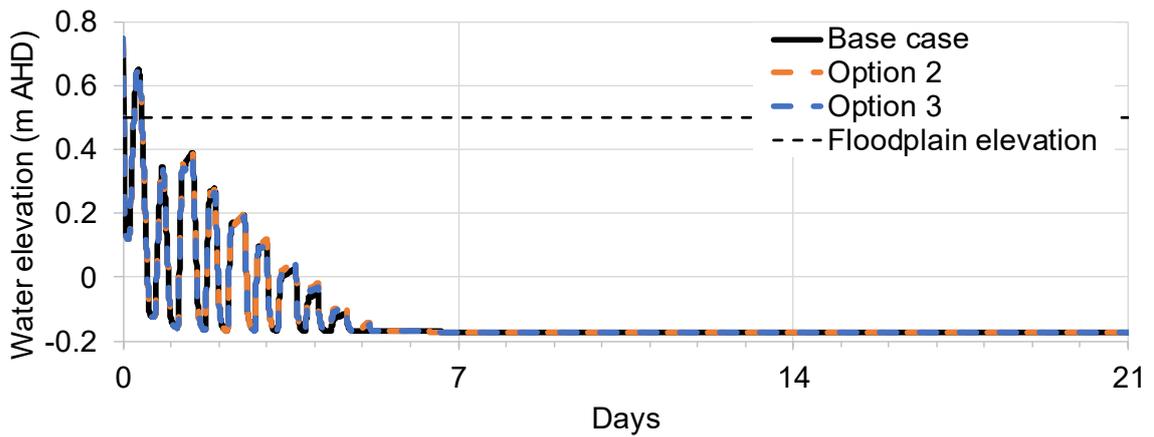


Figure 9.13: Drainage time for the Southern floodplain

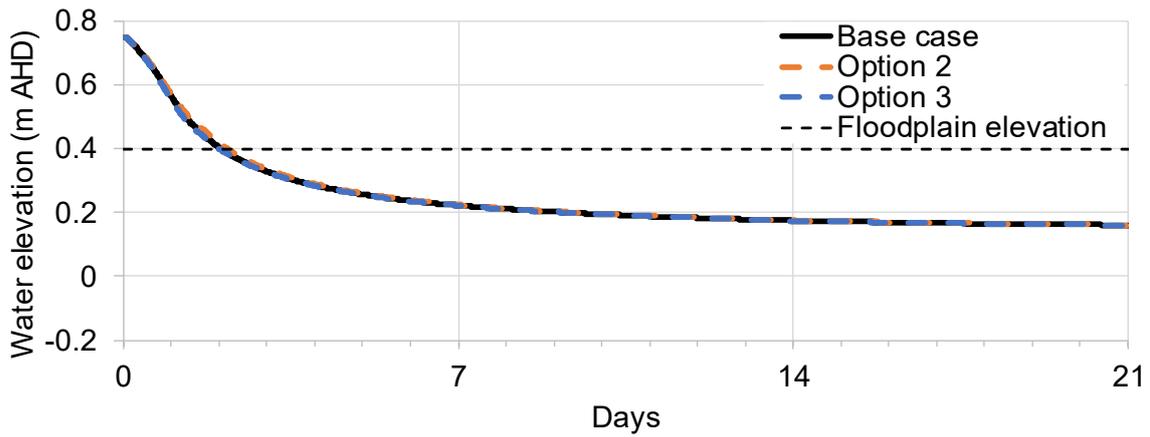


Figure 9.14: Drainage time for the upper Seven Oaks Drain floodplain

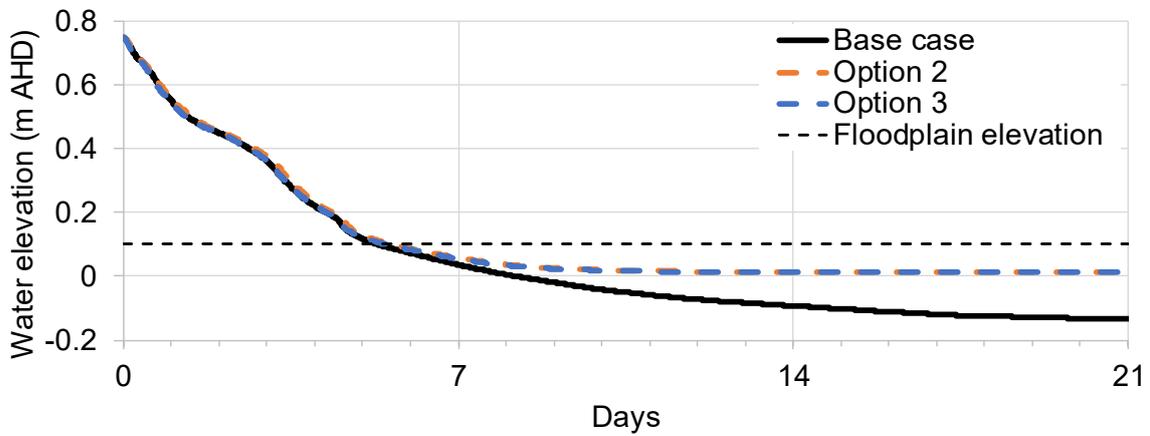


Figure 9.15: Drainage time for the West Drain floodplain

Table 9.3: Summary of floodplain drainage times following a minor inundation event +0.75 m AHD

Location	Time taken for floodplain to drain (days)		
	Base case	Management Option 2	Management Option 3
Doughboy Drain floodplain	2.0	2.5	2.3
Shackles Drain floodplain	0.7	0.8	0.7
Southern floodplain	0.4	0.4	0.4
Upper Seven Oaks Drain floodplain	2.1	2.2	2.0
West Drain floodplain	5.3	5.6	5.5

Management Option 3 is designed to mitigate against impacts caused by efforts to remediate ASS within the low-lying floodplain management areas. As such, the floodplain layout for Management Option 3 is the same as Management Option 2 with the exception of a new drain connecting McAndrews Drain to Seven Oaks Drain with a drain invert level of 0.0 m AHD (see Section 8). Results indicate that the introduction of a new drain at an elevation of 0.0 m AHD results in a small reduction in time that the floodplain is inundated in comparison to Management Option 2.

9.3.3 Summary of results

Numerical model results show that extending McAndrews Drains to Seven Oaks Drain is a feasible option to reduce the impact that modifications within TfNSW land may have on floodplain drainage. Furthermore, it was found that, by constructing the new swale drain with an invert elevation of 0.0 m AHD, there is negligible effect to the day-to-day wetting and drying outlined in Management Option 2, which aims to improve water quality and create wetland habitat within the low-lying floodplain management areas.

10 Management Option 4: Modify floodgates to allow controlled tidal flushing

10.1 Description

Previous studies have shown that modifying floodgates to allow two-way flow with tidal water upstream can have significant benefits for a drainage system by improving water quality, enabling fish passage and reducing in-drain vegetation (Glamore, 2003; NSW DPI, 2007). Option 4 is to install automatic tidal flushing floodgates (commonly referred to as auto-tidal floodgates) at Menarcobrinni floodgates to allow controlled tidal flushing upstream.

Auto-tidal floodgates function by allowing a controlled volume of water to flow upstream to a specified level whilst enabling normal floodgate drainage to occur. Figure 10.1 shows how during flood times the floodgates operate normally. During day-to-day conditions the auto-tidal gates mute the tidal signal allowing a controlled volume of water upstream of the floodgates.

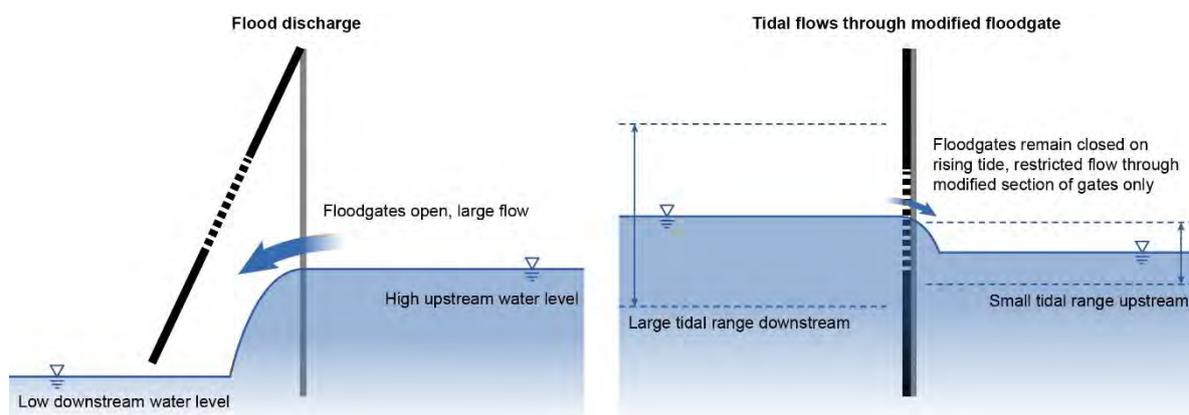


Figure 10.1: Diagram outlining how auto-tidal floodgates function

Tidal flushing can be implemented using two (2) approaches:

Management Option 4a: In-drain only tidal flushing (no overbank inundation); or

Management Option 4b: Overland tidal inundation.

The different tidal flushing assessed within Management Option 4 have different constraints, benefits and risk and are therefore assessed individually.

10.2 Management Option 4a: Controlled in-drain tidal flushing

Management Option 4a focuses on maintaining tidal flushing within drain levee banks. This approach has the following aims:

1. Improved in-drain water quality; and
2. Allow increased in-drain fish passage and aquatic habitat.

These are achieved by modifying the floodgates to allow controlled in-drain only tidal flushing to elevations below the floodplain level. This strategy does not result in any changes to the floodplain.

Benefits of Approach A for Option 4 include:

- A large section of in-drain channel is connected for fish passage and aquatic habitat;
- Increased flushing of water upstream of the floodgates;
- Increase in water level to reduce acid discharges;
- Higher salinity in drains which can limit freshwater weed growth, reducing maintenance costs and helping to ensure drain efficiency; and
- Buffer and neutralisation of acid in the drainage network.

Due to the low-lying elevation of connected wetland floodplain areas (i.e. Mayes Swamp), a low tidal cut off elevation is required to ensure tidal waters remain in channel. Subsequently, while benefits associated with tidal intrusion to the drainage network such as acid buffering or weed management may occur to some degree, this will generally only be in downstream sections of the drainage network where the salinity has a sufficiently high concentration to control weed growth.

10.3 Management Option 4b: Controlled overland tidal inundation

Management Option 4b involves increased tidal flushing resulting in overland tidal inundation across the low-lying floodplain areas. This approach has the following aims:

1. Create extensive tidal habitat in-drain and on the on the low-lying floodplain areas; and
2. Improved water quality.

This is achieved by modifying the floodgates to allow controlled tidal flushing to levels above that of the drainage channel levee banks. As a result of the increased flushing, there will be higher concentrations of salinity within the drainage network for Management Option 4b as compared to Management Option 4a which will maximise benefits associated with tidal intrusion such as acid buffering, weed management, and habitat creation. Benefits of Management Option 4b include:

- Creation of intertidal habitat (such as saltmarsh);
- Buffer and neutralisation of acid on the low-lying floodplain ASS areas and within drainage network;
- Increased inundation depth, extent and frequency on low-lying TfNSW floodplain;
- Fish passage and aquatic habitat;
- Increased flushing of surface water upstream of the floodgates;
- Increase in water level to reduce potential acid discharge; and
- Higher salinity in drains which can limit freshwater weed growth and associated maintenance costs and maintain drain efficiency.

Currently, the habitat across the low-lying management areas is a freshwater habitat. Management Option 4b would result in a habitat change from freshwater to tidal in some areas of the floodplain. Impacts of this change on the floodplain ecology should be considered. An assessment should be undertaken to determine if the introduction of a tidal system has a net negative or positive ecological outcome.

10.4 Other management considerations

There are several considerations that need to be addressed when implementing controlled tidal flushing strategies, including:

- Saltwater vegetation intrusion upstream of the floodgates (such as mangroves);
- Influence of tidal water on groundwater;
- Impact on water extraction (groundwater and surface water); and
- Type of floodgate modification (i.e. redundancy, functionality, adjustability, cost, maintenance and active management).

Modification of the floodgates to allow tidal flushing can be completed using several different designs including:

- Permanent slots cut into the floodgates;
- Hinging open of floodgates;
- Sluice gates (manual or automatic);
- Buoyancy driven auto-tidal gates; and
- SmartGates (Glamore, 2003) with automated controls.

Examples of different tidal gate designs are shown in Figure 10.2. The final design choice for installation at Menarcobrinni is dependent on:

- Cost of implementation;
- Risk willingness of the property;
- Cost of maintenance; and
- Ownership and operation (particularly for manually adjusted options).

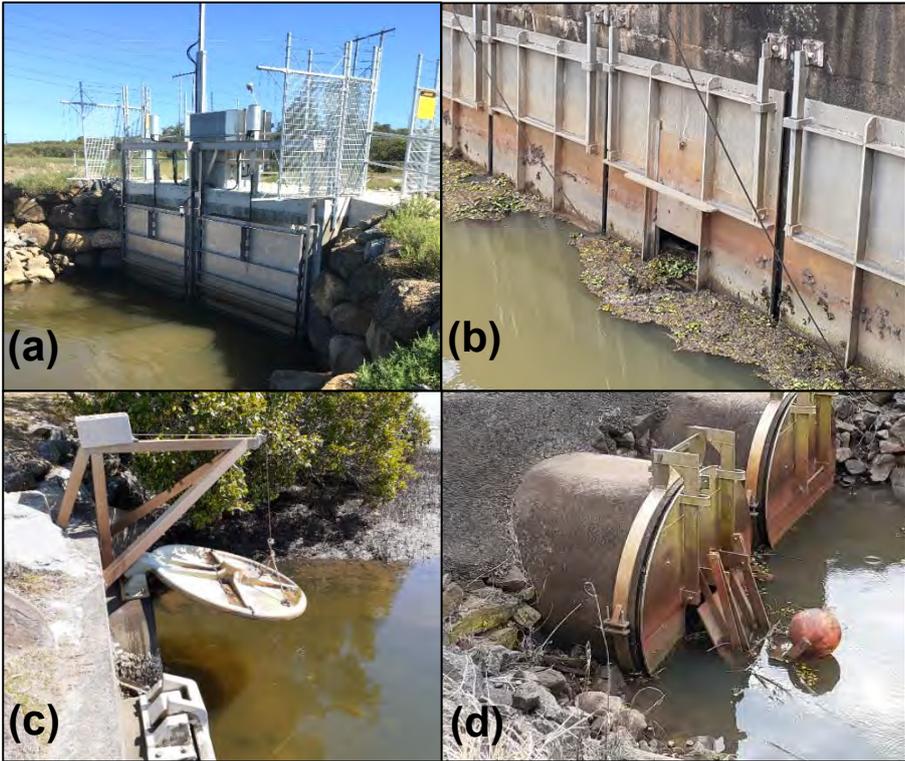


Figure 10.2: Example of floodgates with different modifications installed to control tidal flushing including (a) SmartGates, (b) manual sluice gate, (c) a floodgate hinged open and (d) a buoyancy controlled floodgate

There are a number of risks and benefits introduced when considering the use of auto-tidal floodgates to introduce in-drain or overland tidal flushing. It is worth noting that this option can be implemented alongside freshwater strategies for compounded benefit. Additionally, installation of smaller floodgates upstream (similar to Option 5, see Section 11) can be used to mitigate some of the potential risks posed by tidal flushing.

10.5 Design specification and optimisation

Numerical modelling of auto-tidal floodgates can be complex as there are multiple factors that need to be considered during floodgate design and interpretation of results. The effectiveness of auto-tidal floodgates in achieving management outcomes is dependent upon the following design considerations:

- Upstream topography and design cut off water level:
- Operational regime; and
- Floodgate dimensions.

To determine the optimal design specifications for modified floodgates a design specification and optimisation process has been completed. The following section details each of these design considerations for in-drain flushing (Management Option 4a) or controlled overbank flushing (Management Option 4b).

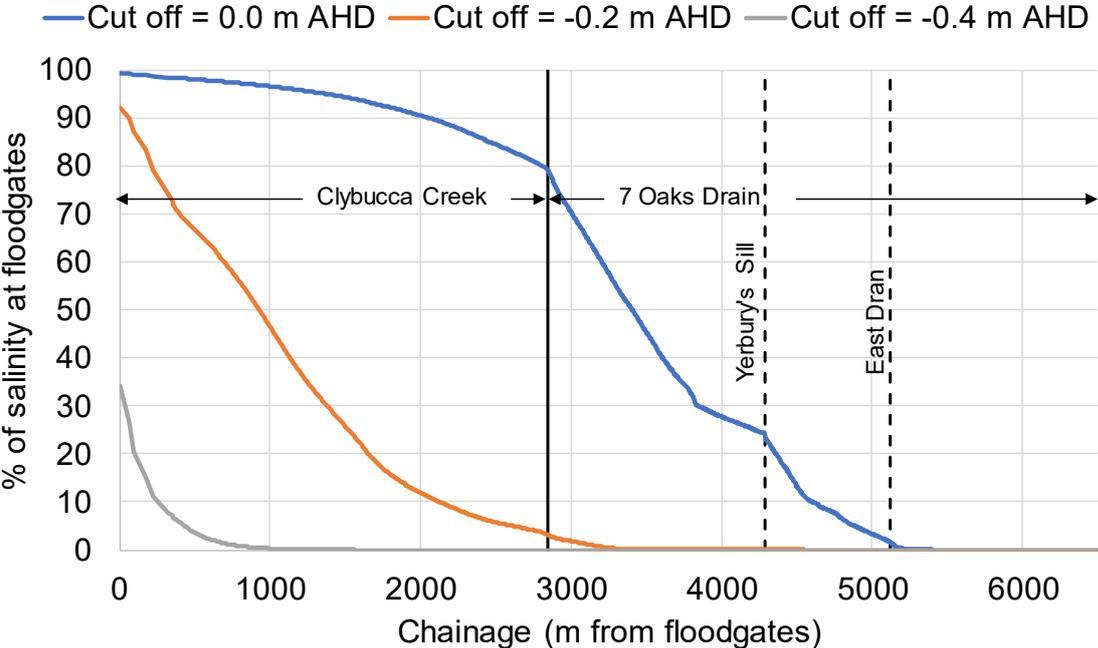
Since the level of salinity within the model domain is dependent on the salinity at the Menarcobrinni floodgates boundary, in the following sections, levels of salinity have been presented as a percentage of the salinity at the floodgates. For example, if there was a salinity of 20 PSU (Practical Salinity Units) at the floodgates, a location that has 50% of the salinity at the floodgates has a salinity of 10 PSU. Measurements of salinity (presented in Appendix C) showed that salinity at the floodgates can vary from 0 PSU (equivalent to freshwater) to 35 PSU (equivalent to the salinity in the ocean). Results of a salinity sensitivity analysis is presented in Appendix G.

10.5.1 Design cut off level

The primary design consideration for auto-tidal floodgates is the design cut off level. This is the water level at which, on a rising tide, the gates are triggered to close preventing further tidal water travelling upstream of the floodgates. This level can be set based upon elevation of land and drain levees behind the floodgate to ensure only desired areas become inundated (i.e. inundation of TfNSW land while ensuring private land remains dry) or that tidal waters remain within the drain levee banks. The cut off

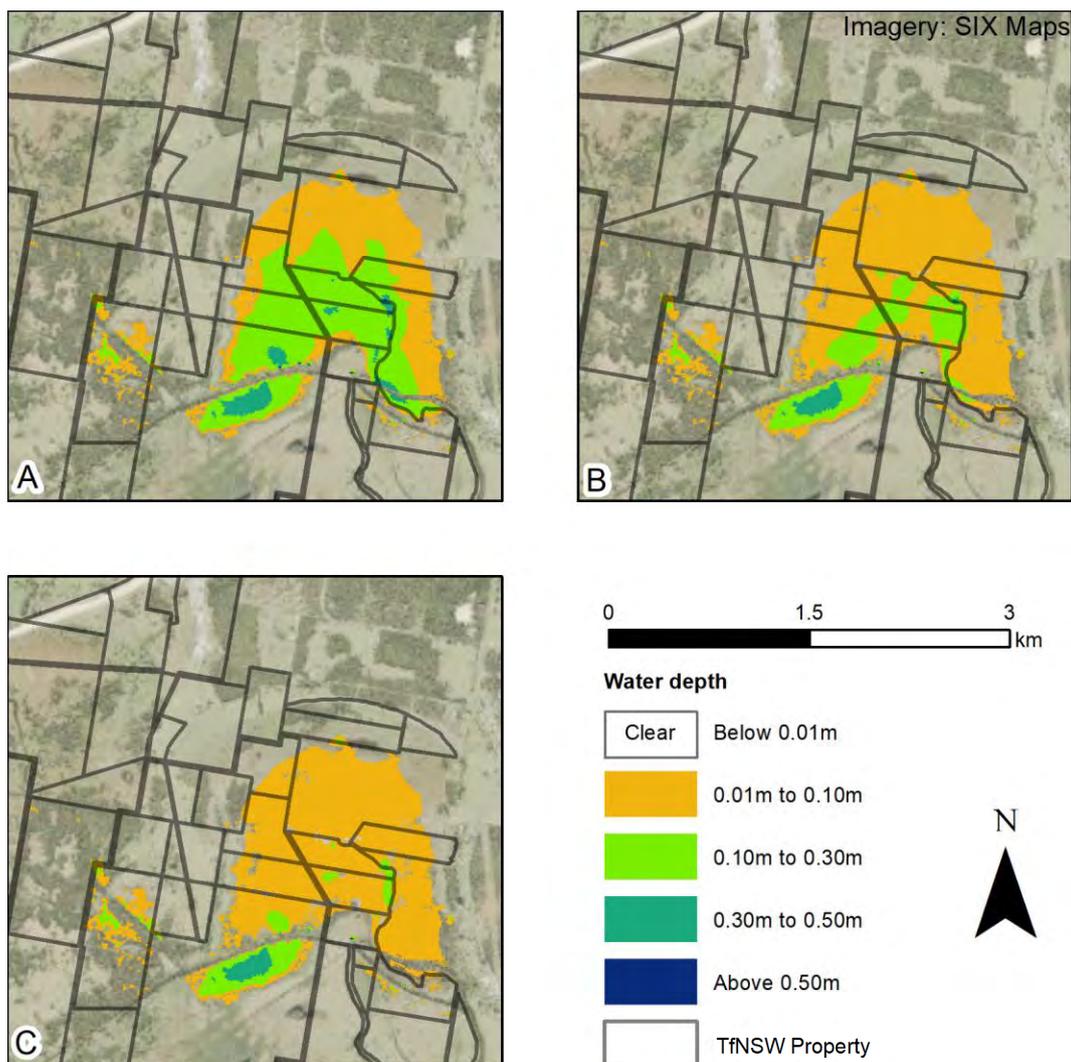
level determines whether in-bank or overbank flushing occurs and what (if any) additional on-ground works are required to mitigate undesired impacts or risks.

An optimisation process was undertaken to determine the ideal cut off level for the auto-tidal floodgates. Three (3) alternate cut off levels were tested (-0.4 m AHD, -0.2 m AHD and 0.0 m AHD). The main differences between each of the options is the extent to which tidal water penetrates into the drainage network and the time it takes for the floodplain to drain. Figure 10.3 shows how the cut off level affects the extent to which tidal water propagates up the drainage network. Figure 10.4 shows how the cut off level influences drainage from the floodplain following a 2EY (6 month) runoff event over a three (3) month period.



Note: Maximum salinity following a three (3) month simulation period. There were no catchment inflows and groundwater inflows were set as per the model validation.

Figure 10.3: Effect of floodgate trigger level on concentration of salinity within the drainage network



Note: Starting water level was 0.0 m AHD. No additional inputs from catchment inflows and groundwater.

Figure 10.4: Water depth at the end of a 3 month simulation period following a 2EY runoff event for floodgate cut off levels of (A) 0.0 m AHD, (B) -0.2 m AHD and (C) -0.4 m AHD

As a part of the optimisation process the cut off level which divides Management Option 4a and 4b was determined as the level at which inundation of the low-lying floodplain will occur. It was determined that cut off levels of -0.3 m AHD and below remain in-drain and do not spill onto the floodplain. For the cut of levels tested, only -0.4 m AHD was below this threshold.

Numerical modelling showed that the saline water reaching the low-lying floodplain (approximately 3 km upstream of the Menarcobrinni floodgates) for a cut off level of -0.2 m AHD is less than 3% of the salinity at the floodgates. It is unlikely this level of salinity would have a significant impact to the floodplain. Subsequently, if an increased level of freshwater inundation is acceptable then the cut off level could be

raised. Note this is dependent on factors such as groundwater and catchment inflows and would need to be specified as part of the technical design phase during the implementation of auto-tidal floodgates. For the purpose of this investigation a cut off level of -0.4 m AHD has been adopted for Management Option 4a as it is conservative and would not allow any inundation of the low-lying floodplain (neither fresh or tidal).

Between -0.3 m AHD and 0.0 m AHD varying extents of floodplain on TfNSW land become inundated (Figure 10.5). It was observed that the lowest section of floodplain is located to the south east of Mayes Swamp within private land. As a result, for any overland inundation to occur, private property on the east of Mayes Swamp will always be affected unless additional mitigation measures are implemented. For the purpose of modelling it has been assumed that inundation of private property on the east of Mayes Swamp has been permitted. Subsequently, a cut off level of 0.0 m AHD was chosen for Management Option 4b to maximise the level of flushing within the drainage network and increase the area available for wetland habitat creation.

Analysis of floodplain levels found that when inundation levels increase above +0.1 m AHD, additional private land would start to become inundated (specifically land adjacent to West Drain). Therefore, limiting the cut off elevation to 0.0 m AHD allows the maximum environmental benefit while preventing tidal water inundating private land (with the exception of land on the eastern side of Mayes Swamp). Additional on-ground works, such as floodgates and levee banks could also be constructed to prohibit overbank inundation on private land.

Design levels for Management Option 4a and 4b provide upper and lower bounds for modification of the Menarcobrinni floodgates to allow tidal flushing. Management Option 4a (-0.4 m AHD cut off level) has limited tidal flushing but ensures all tidal water remains in-bank while improving aquatic connectivity. Management Option 4b (0.0 m AHD cut off level) maximises overland inundation within TfNSW property without impacting private landholders on the wider floodplain (with the exception of private land to the east of Mayes Swamp). During detailed technical design of the auto-tidal floodgates, optimal cut off levels could be specified based upon the quantification of risk for each cut off elevation. An example of this would be if shallow freshwater inundation on wetland areas is found acceptable, a tidal cut off level of -0.2 m AHD may be feasible.

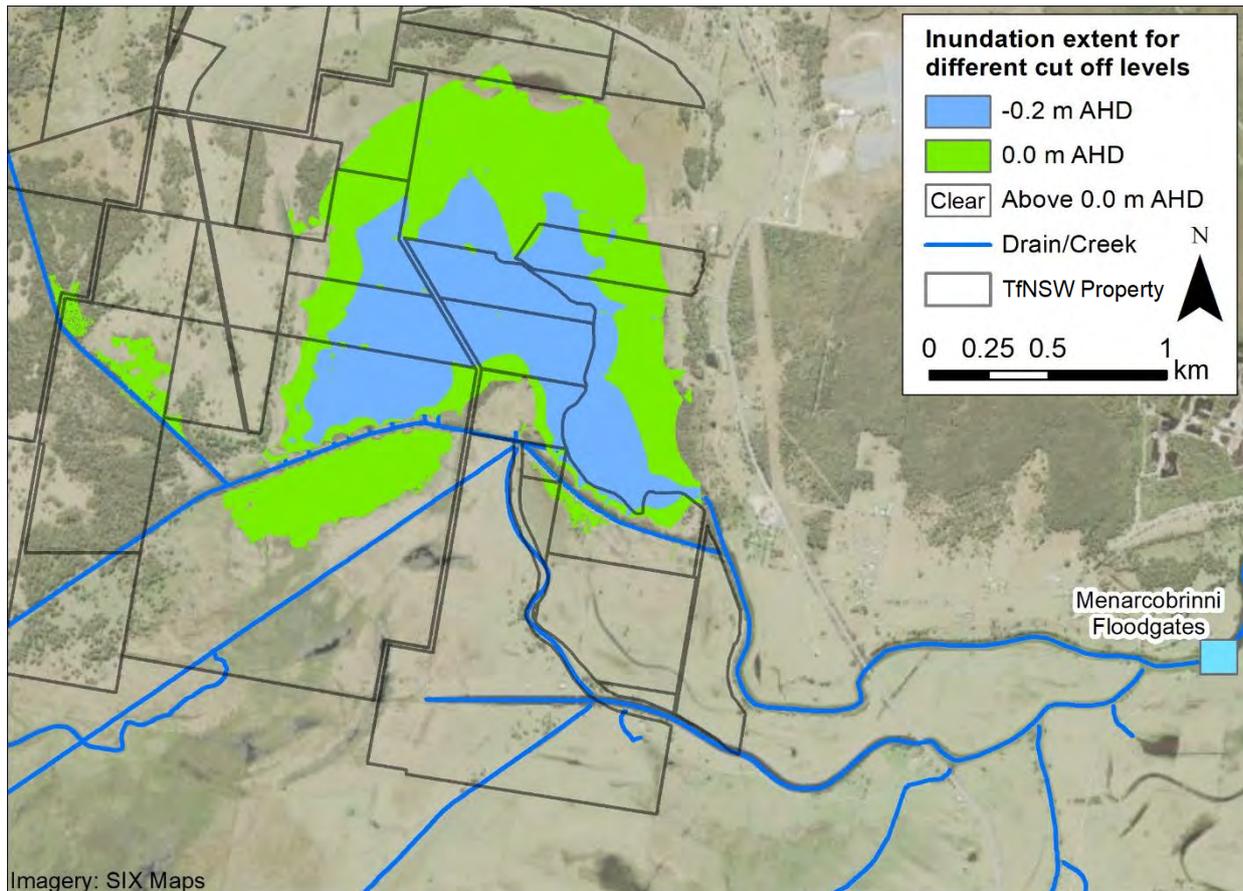


Figure 10.5: Extent of inundation for cut off levels of -0.2 m AHD and 0.0 m AHD

10.5.2 Operational rules

Factors such as climate (rainfall, antecedent conditions, etc.) or salinity in the estuary can be used to trigger the operational regime of the auto-tidal floodgates. An example of this is when a runoff event is predicted for the catchment, the floodgates can be shut beforehand allowing water to drain to the low-tide elevation. This ensures that the full capacity of the drain is used to capture the runoff event. Note that operational rules do not necessarily need to be automatically operated through mechanical means and can be performed through manual operations such as opening or closing sluice gates.

For the auto-tidal floodgates being installed at Menarcobrinni for Management Option 4 it was determined that their operation would be based upon the cut off water levels upstream of the floodgates only. This is the simplest design and can easily be implemented using buoyancy driven auto-tidal floodgates or mechanical auto-tidal floodgates such as SmartGates (Glamore, 2003).

10.5.3 Floodgate dimensions

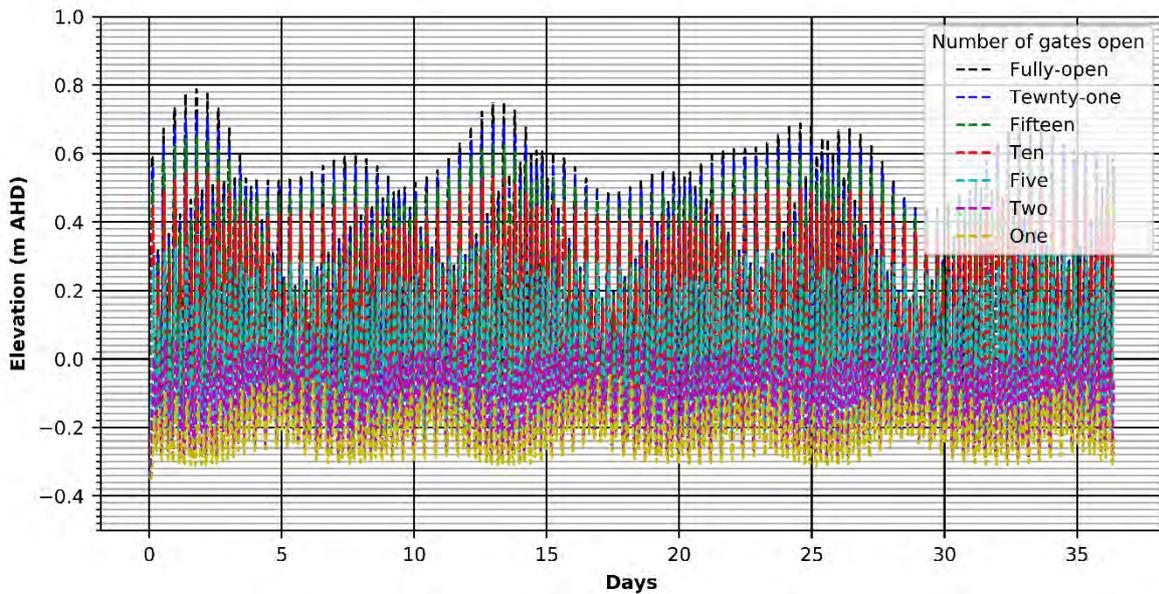
For a large floodgate system, such as at Menarcobrinni, not all floodgates need to be modified for the desired outcomes for Management Option 4. The dimensions and number of auto-tidal floodgates can be optimised to reduce maintenance costs while still achieving the desired benefits for drainage.

A sensitivity analysis was conducted using the 1D numerical model of the drainage network to test an array of floodgate configurations to determine the optimal number of floodgates that need to be opened to achieve tidal flushing objectives. Modified auto-tidal floodgates, which allow upstream flow through an orifice, with dimensions of 1 m by 1 m and invert of -1.8 m AHD were used. For this analysis the sluice gates were not closed, thereby effectively testing a manual sluice configuration. In each scenario, a different number of sluice gates was assessed to determine how many were needed to allow enough flow through the floodgates. For comparison, a scenario was also run with all 21 of the Menarcobrinni floodgates (1.8 m wide by 2.1 m high) permanently open allowing flow upstream. The following criteria was used to assess the number of floodgates needed:

- Water volumes at upstream sections of the low-lying floodplain on TfNSW land;
- Water levels at upstream sections of the drainage network; and
- Velocities through the floodgates.

For successful implementation of controlled tidal flushing, a significant volume of water needs to reach upstream sections of the drainage network to allow environmental objectives for remediation; particularly for Management Option 4b where inundation of low-lying wetland areas is occurring. The volume of water will also influence the salinity levels in the drainage network. The water levels upstream are important, particularly for distinguishing between Management Option 4a and 4b. Note that water levels will not necessarily be the same across the drainage network as the tidal signal will vary based on distance from the floodgates and channel geometry. High flows are also a consideration as high velocities can encourage scour of the creek channel and discourage fish passage (O'Connor et al., 2017).

Results of the sensitivity analysis showing the influence of different configurations on water levels is shown in Figure 10.6. Using this data and information on flow velocities and volumes, it was determined that between five (5) and ten (10) 1 m by 1 m sluice gates were needed depending on the management objectives. As a result, eight (8) floodgates were chosen for the final design of both approaches for Management Option 4.



Note: Number of floodgates open refers to the number of 1 m by 1 m sluice gates. For the “Fully-open” case, all existing 1.8 m wide by 2.1 m high culverts allowed flow upstream (i.e. the floodgate flaps were fully open allowing unrestricted flow).

Figure 10.6: Comparison of water levels on the downstream side of Yerbury’s Sill for different floodgate opening configurations

The sensitivity analysis found that with just one sluice gate (1 m x 1 m) open on a permanent basis, water levels at upstream locations in the network would reach elevations above -0.3 m AHD. This means that inundation of low-lying floodplain management areas would occur. Subsequently, for in-drain only tidal flushing (Approach A) the design of the modified floodgates would need to be either:

1. One sluice gate permanently open with dimensions smaller than the 1 m x 1 m gate modelled; or
2. Auto-tidal gates that close when water levels upstream of the floodgates reach a specified elevation (e.g. SmartGates or buoyancy driven floodgates).

It is recommended that auto-tidal floodgates be used as there would be high flow velocities with a single permanently open sluice gate scenario. Since one of the aims of Management Option 4a is to provide improved fish passage, a design with lower velocities (i.e. auto-tidal floodgates) is preferred.

10.6 Management Option 4a: results and assessment

Controlled, in-drain tidal flushing was modelled with an auto-tidal floodgate cut off level of -0.4 m AHD. Simulations were completed for a three (3) month period and included hydrodynamic and salinity

modelling. The model was simulated during a dry period with no catchment or groundwater inflows. Model results have been analysed to determine:

1. Volume of flushing achieved within the drainage network; and
2. Extent of salinity within the drainage network.

10.6.1 Volume of tidal flushing

Simulations using eight (8) auto-tidal floodgates with a cut off level of -0.4 m AHD showed that during a tidal cycle up to 70 m³ of tidal water can flush through the drainage network. Tidal flushing at elevations above -0.4 m AHD has the potential to inundate low-lying private land at the south-east area of Mayes Swamp. Note that flushing only occurred on seven (7) occasions over a three (3) month simulation period due to the low elevation of the cut off level. These flushing events coincided with spring tides downstream of the floodgates. Figure 10.7 shows how the water level downstream of the Menarcobrinni floodgates only falls below -0.4 m AHD during spring tides. Subsequently, during neap tides, no tidal flushing can occur.

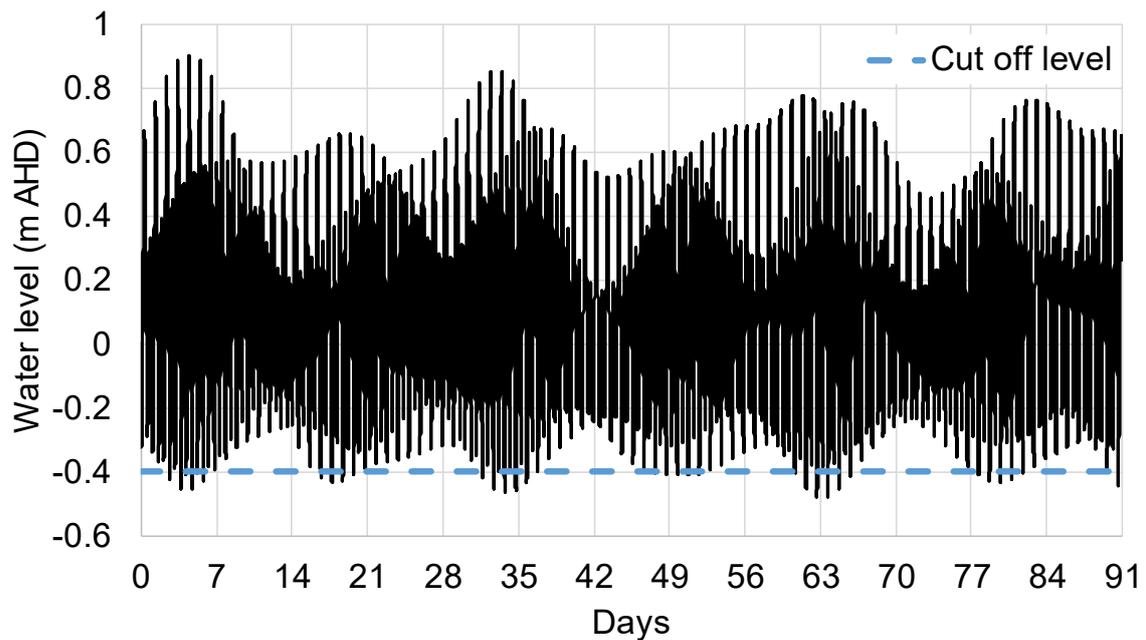


Figure 10.7: Water level downstream of the Menarcobrinni floodgates during the three (3) month simulation period

10.6.2 Extent of salinity

Model results showing the maximum level and extent of salinity within the drainage network for the three (3) month simulation period is shown in Figure 10.8. These results show that Yerbury's Sill is the limit of tidal water extending into the drainage network. This is expected as Yerbury's Sill has a crest elevation of -0.3 m AHD which is above the cut off level for the auto-tidal floodgates. Further analysis showed that a maximum salinity at the upstream end of McAndrews Drain was below 1% of the concentration at the Menarcobrinni floodgates (after the three month model period).

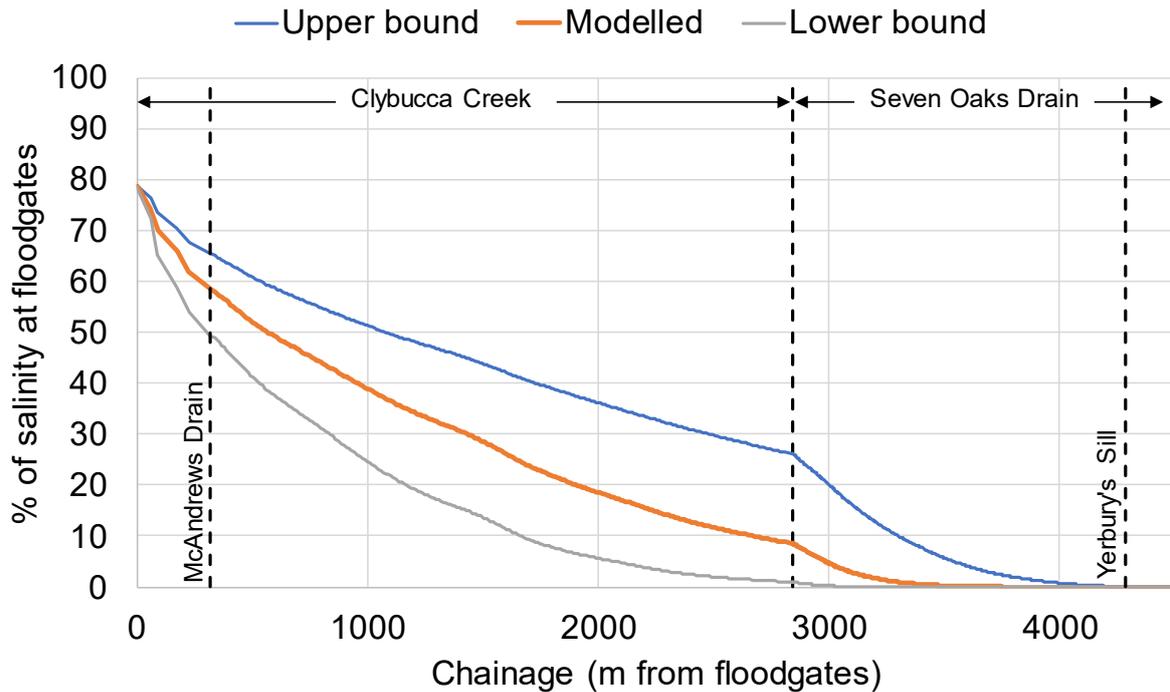


Figure 10.8: Maximum level (with uncertainty bounds) of salinity within Clybucca Creek when there are auto-tidal floodgates with a cut off level of -0.4 m AHD following 3 month period

Figure 10.9 shows the fluctuation in salinity levels at the confluence of McAndrews Drain and Clybucca Creek for the three (3) month simulation period. By comparing this with Figure 10.7, it can be seen that flushing events occur when the tide levels are below -0.4 m AHD on spring cycles. This limits the level of tidal flushing that occurs within the drainage network.

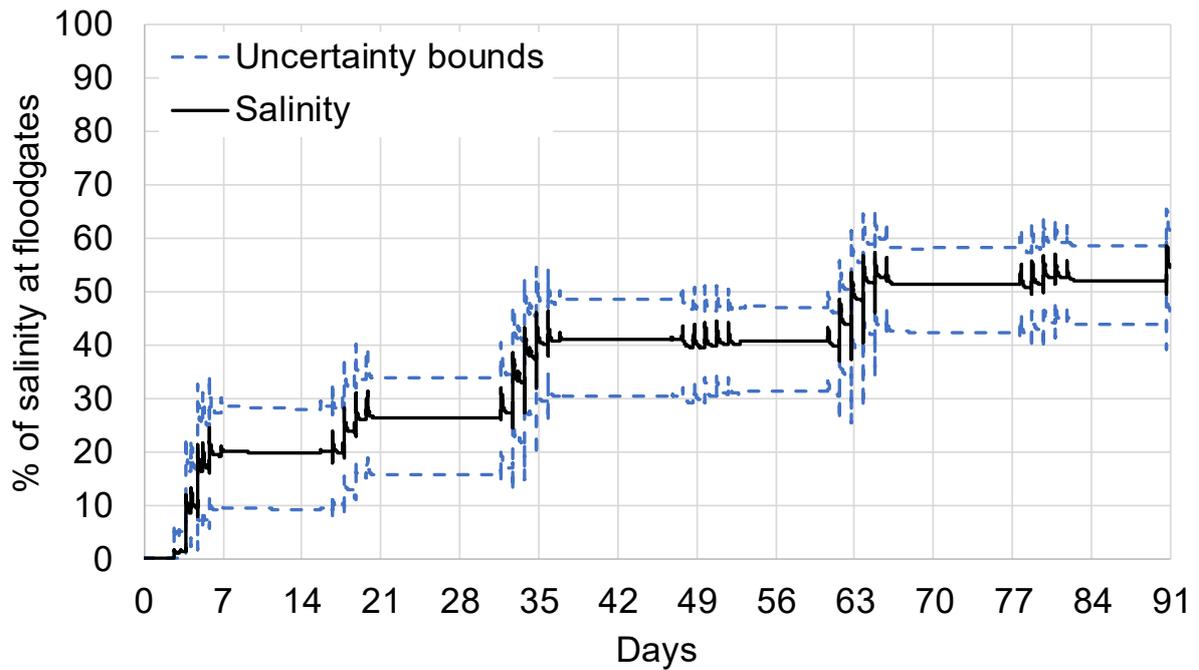


Figure 10.9: Timeseries of salinity levels at the confluence of McAndrews Drain and Clybucca Creek

10.6.3 Management Option 4a summary

Results for salinity levels within the drainage network show that benefits associated with weed management and buffering of acid will occur at downstream sections of the drainage network. Modification of the floodgates to have auto-tide floodgates with a cut off level of -0.4 m AHD will result in infrequent, limited flushing of up to 70 m³ per tidal cycle, during spring low tides only.

10.7 Management Option 4b: results and assessment

Controlled overland tidal inundation was modelled with an auto-tidal floodgate cut off level of 0.0 m AHD. Initial simulations of dry conditions were completed for a three (3) month period and included hydrodynamic and salinity modelling. Groundwater inflows were included as per the model validation (see Appendix D). A further three (3) month simulation was completed to determine the effects of a 2EY rainfall event on the system once it contains tidal water. Model results have been analysed to determine:

1. Maximum extent of overland tidal inundation during a dry period;
2. Impact of reduced channel storage for day-to-day drainage;

3. Assessment of whether saline water will spill out of the channel during a 2EY (6 month) rainfall event; and
4. Assessment of in-drain salinity levels.

10.7.1 Maximum extent of overland tidal inundation

The maximum extent of salinity across the Clybucca floodplain over a dry three (3) month period when auto-tidal floodgates are used with a cut off level of 0.0 m AHD is shown in Figure 10.10. Figure 10.11 shows how the salinity level increases once modified floodgates are installed alongside. Uncertainty bounds due to the selection of dispersion coefficient are also presented (see Appendix G for further details). The location of timeseries results presented in Figure 10.11 is displayed in Figure 10.10. Note, during these simulations no catchment inflows were simulated. These results show that by allowing a cut off level of 0.0 m AHD it is possible to restrict tidal inundation to within the low-lying floodplain within the management areas. These results also show that low-lying areas within private properties on the east of Mayes Swamp will become inundated with tidal water. Implementation of this management option will need to occur in consultation with floodplain landholders.

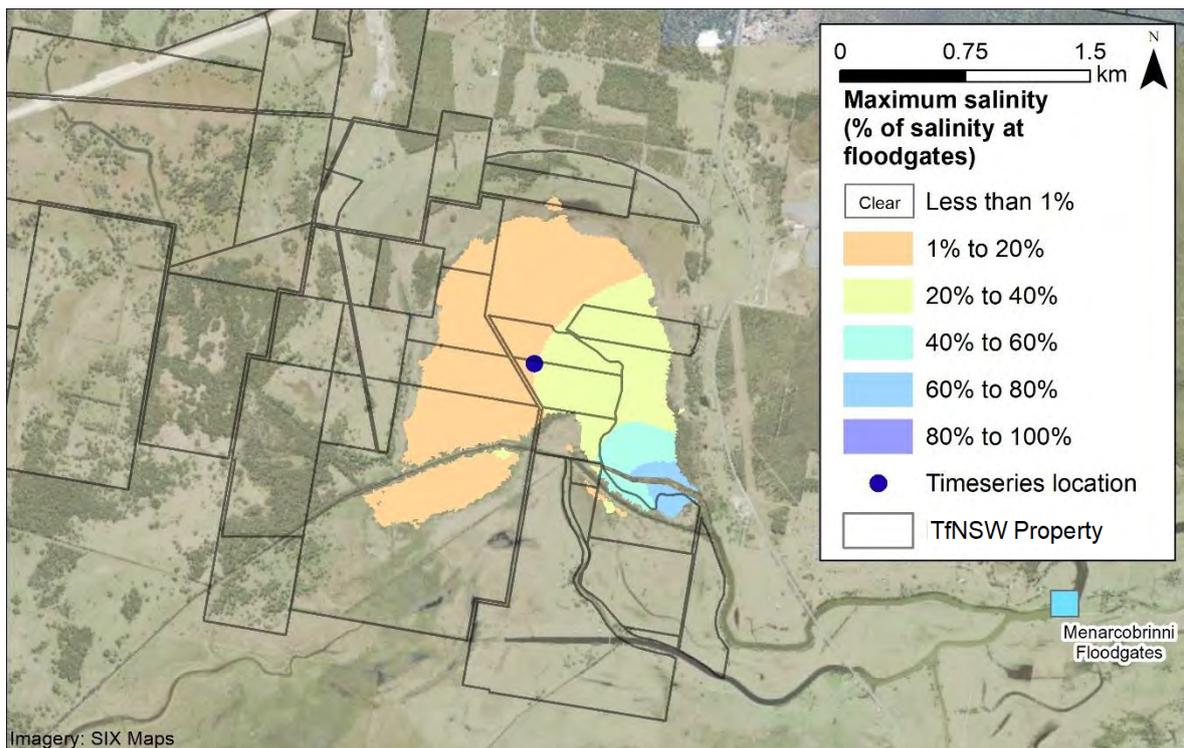


Figure 10.10 Maximum salinity reached after a three (3) month dry period with an auto-tidal floodgate cut off level of 0.0 m AHD

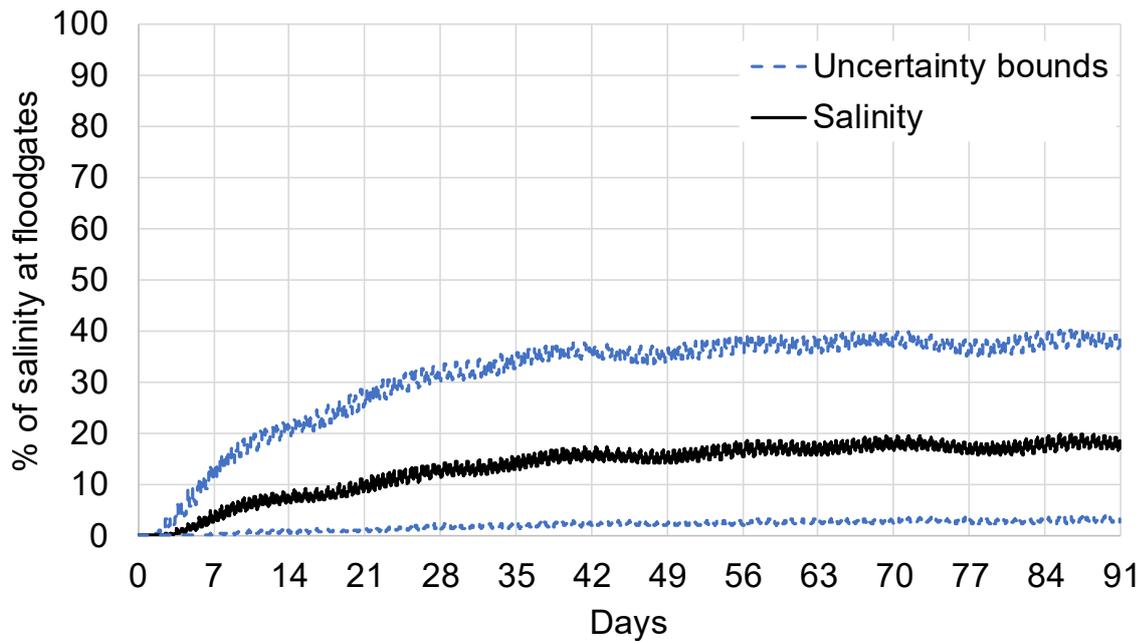


Figure 10.11: Salinity during a dry three (3) month period within Mayes Swamp with auto-tidal floodgates with a cut of level of 0.0 m AHD (see location in Figure 10.10)

10.7.2 Impact of tidal flushing on day-to-day drainage

Results showing the percent time wet and average inundation level were calculated for a three (3) month period following a 2EY (6 month) runoff event. The runoff event was simulated following an initial three (3) month dry period (i.e. total simulation period of six months) to allow tidal water to “pump up” the low-lying floodplain management areas with tidal water. This simulation was assessed to determine how allowing tidal flushing impacts on the overall wetting and drying across the management areas. The average inundation depth and percent time wet for Management Option 4b following a 2EY (6 month) runoff event has been compared to the base case. Figure 10.12 shows that there is a substantial increase in time that the floodplain is wet within Mayes Swamp. Similarly, Figure 10.13 shows an average increase in water level between 0.10 m and 0.30 m across Mayes Swamp.

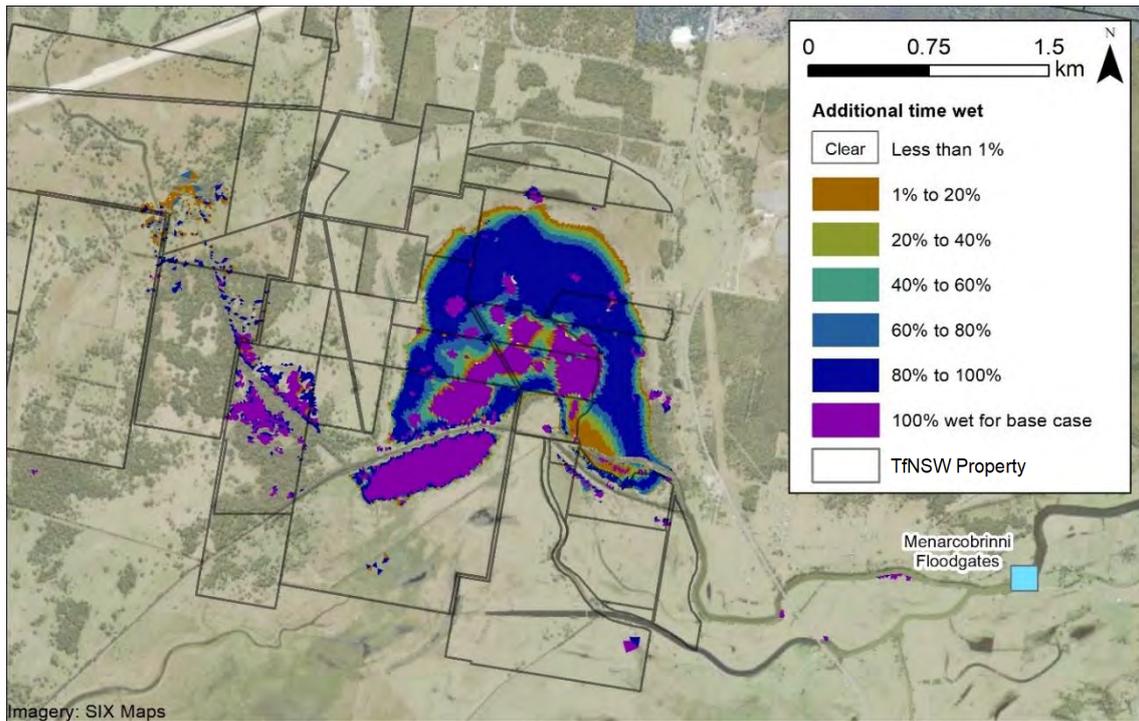


Figure 10.12: Difference in inundation duration between the base case and Management Option 4b for a three (3) month period following a 2EY (6 month) runoff event

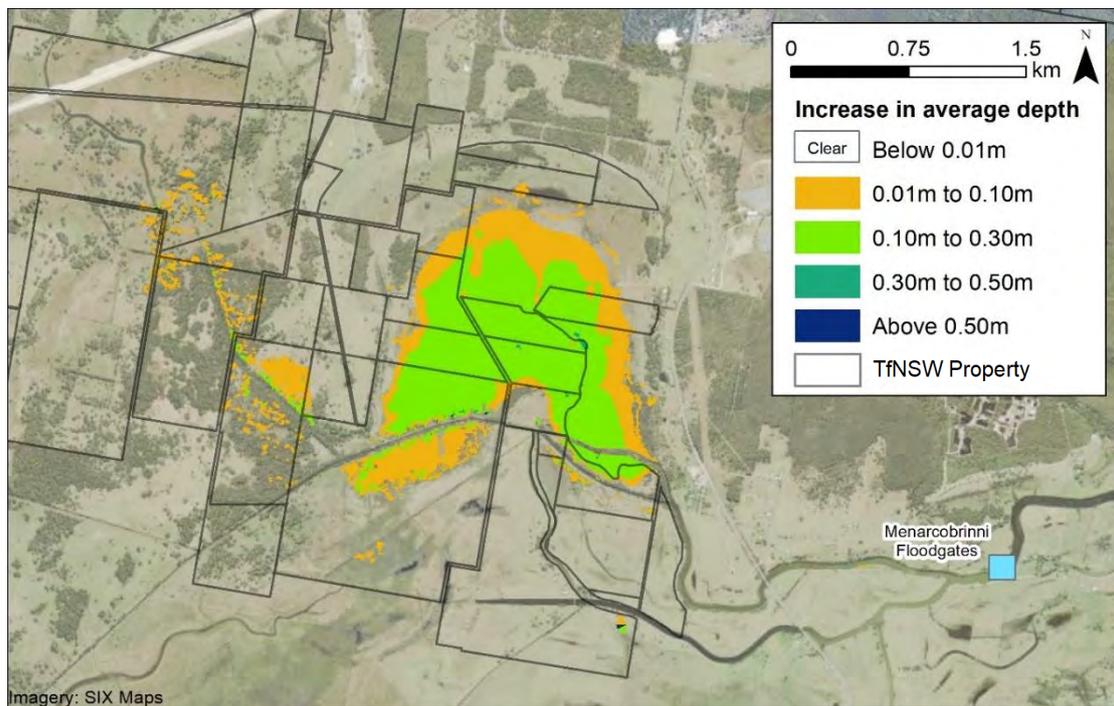


Figure 10.13: Difference in inundation depth between the base case and Management Option 4b for a three (3) month period following a 2EY (6 month) runoff event

10.7.3 Assessment of tidal inundation during day-to-day runoff conditions

Under a tidal flushing scenario, where the drainage system contains brackish to saline water and a minor rainfall event occurs, there is the risk for certain hydrological conditions to coincide (i.e. high tide, elevated salinity, low-moderate rainfall) whereby the drainage system overflows resulting in brackish inundation of adjacent floodplain land. This has the potential to result in impacts to non-salt tolerant vegetation (i.e. pasture grasses).

To assess this risk, the salinity component of the numerical model was run for a three (3) month period following a 2EY (6 month) runoff event with a tidal flushing cut off level of 0.0m AHD (Management Option 4b). Figure 10.14 shows the maximum extent of additional tidal water that will spill out of the drainage network onto the floodplain following the 2EY (6 month) runoff event. Additional overbank inundation was predicted to be contained within TfNSW land at the northern (upstream) end of East Drain at Johnsons Creek with a salinity less than 1% of that at the Menarcobrinni floodgates. These results also show that additional inundation will be restricted to TfNSW property and risks to wider floodplain users during these conditions is low.

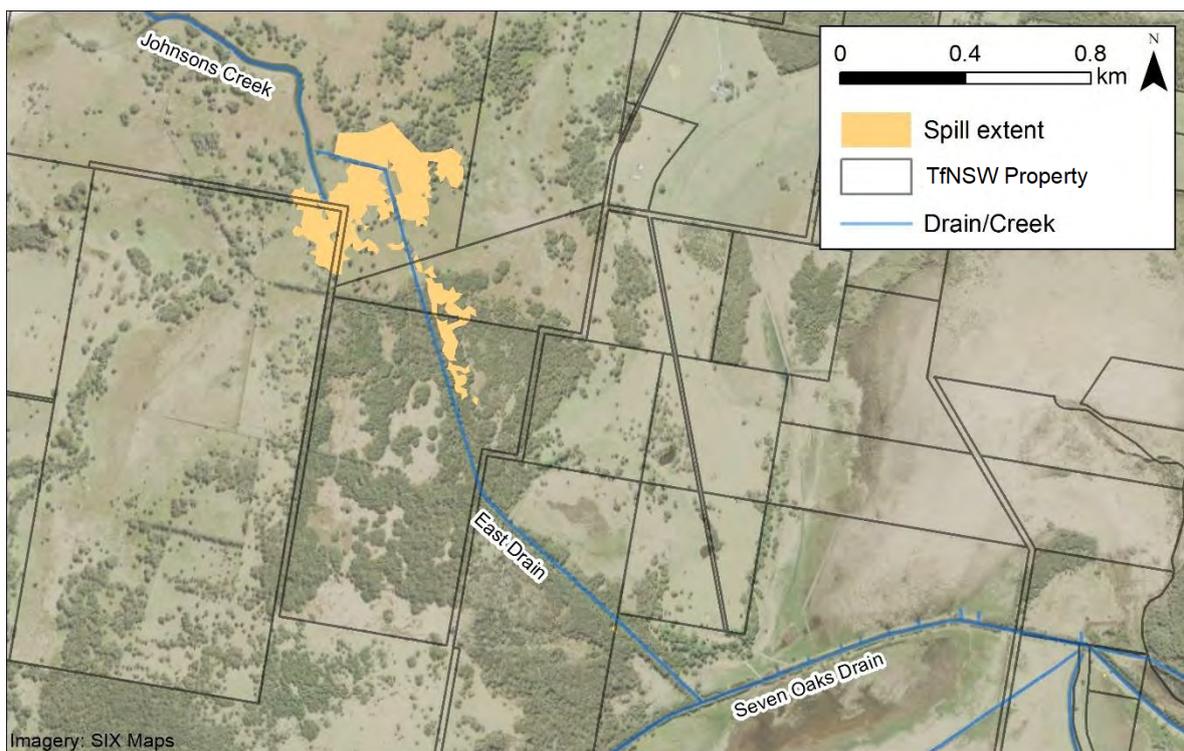
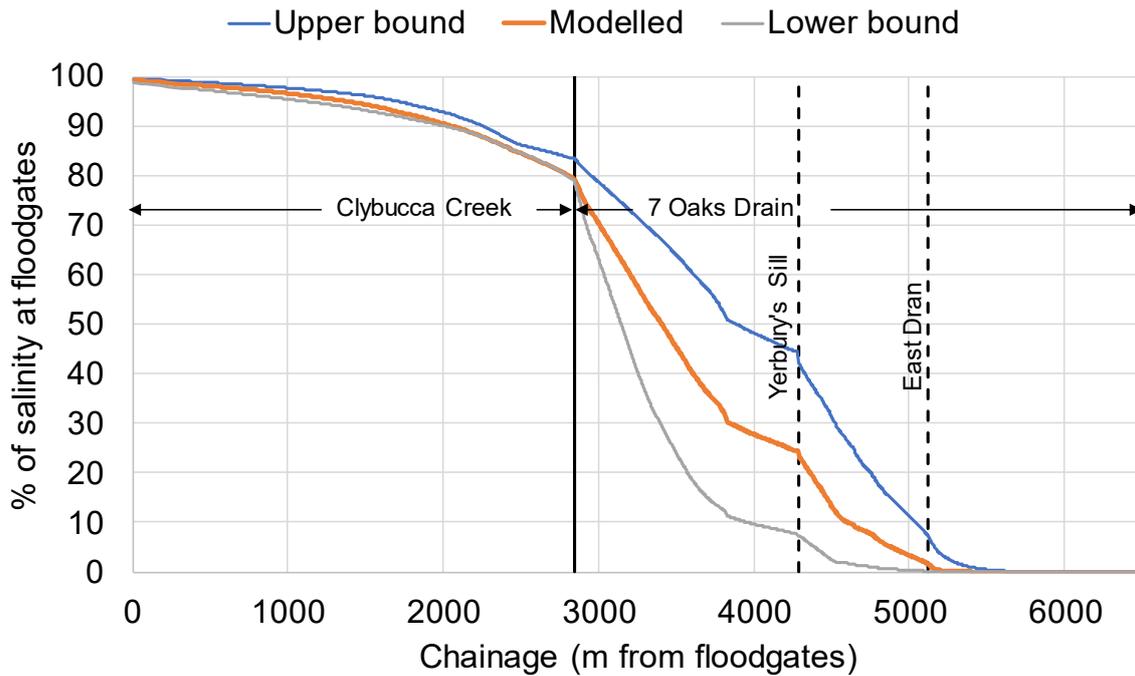


Figure 10.14: Areas where additional tidal water will spill onto the floodplain during a three (3) month period following a 2EY (6 month) runoff event with an auto-tidal floodgate cut off level of 0.0 m AHD (Management Option 4b)

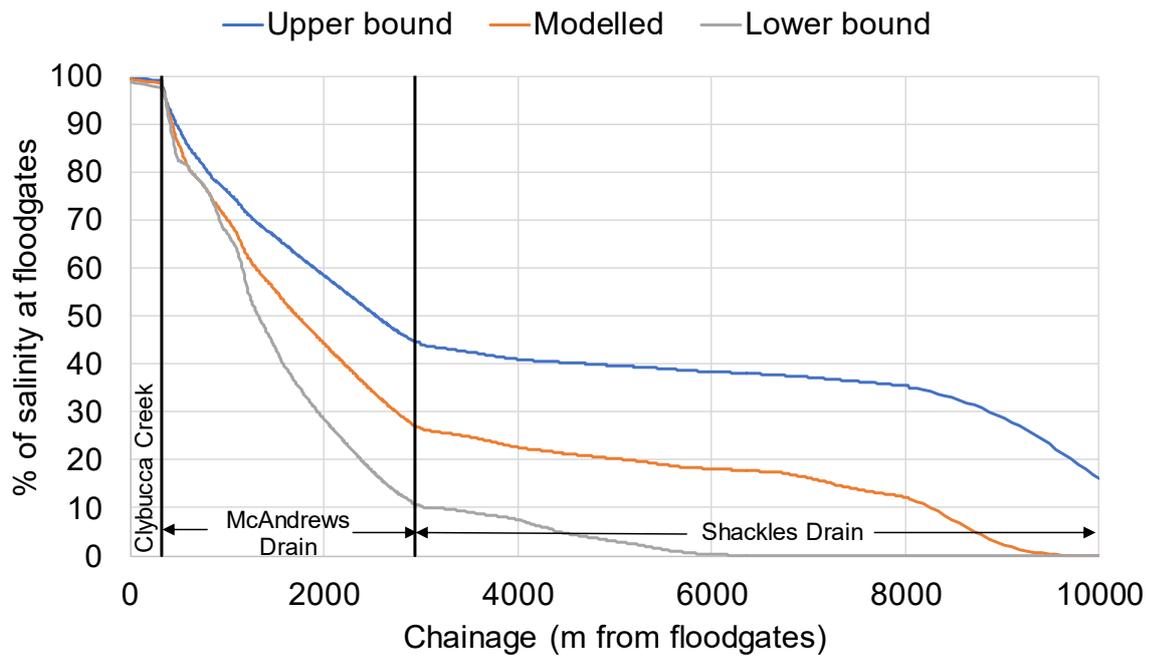
10.7.4 Assessment of in-drain salinity levels

Introduction of controlled tidal flushing to an upstream water level limit of 0.0m AHD will result in tidal inundation of low-lying wetland areas in Mayes and Doughboy Swamps, as well as the transport of saline waters throughout the downstream sections of the drainage network. Figure 10.15 and Figure 10.16 show the salinity levels and extent that will be reached within the drainage network. Results show that benefits associated with in-drain tidal water such as weed management and acid buffering will extend to East Drain, Seven Oaks Drain, Clybucca Creek, McAndrews Drain and Shackles Drain.



Note: The simulation period was three (3) months long. There were no catchment inflows and groundwater inflows were set as per the model validation.

Figure 10.15: Salinity level and extent between Seven Oaks Drain and the Menarcobrinni based on auto-tidal floodgates with a cut off level of 0.0 m AHD



Note: The simulation period was three (3) months long. There were no catchment inflows and groundwater inflows were set as per the model validation.

Figure 10.16: Salinity level and extent between Shackles Drain and the Menarcobrinni floodgates based on auto-tidal floodgates with a cut off level of 0.0 m AHD

10.7.5 Management Option 4b summary

Model results for Management Option 4b show that overland tidal inundation will occur across the low-lying floodplain management areas with the extent and depth of inundation dependent on the magnitude of tidal flushing. Salinity will vary from 1% to 80% within these areas. Private properties on the eastern side of Mayes Swamp will be inundated with tidal water. Inundation depth, extent and frequency modelling indicated that there would be a significant increase in water depth (up to 0.3 m) and duration (up to 100% of the time in certain areas) that will occur due to modification of the floodgates to allow tidal inundation to a level of 0.0 m AHD. Results also revealed that tidal water in upstream sections of East Drain and Johnsons Creek has the potential to spill onto the floodplain during minor rainfall events. This additional overbank inundation has a very low salinity (less than 1% of the salinity at the floodgates) and will be contained with TfNSW property boundaries. In-drain model results showed that saline water extends up the drainage network in Shackles Drain and in Seven Oaks Drain at the confluence with East Drain.

Modification of the Menarcobrinni floodgates to allow overland tidal inundation via modification of eight (8) auto-tidal floodgates, with a cut off level of 0.0 m AHD, will result in an increase of inundation depth,

extent and frequency across the low-lying floodplain management areas (Mayes and Doughboy Swamps). This will achieve environmental benefits by reducing oxidisation of ASS and restricting it to the floodplain. Salinity levels on the floodplain will result in the creation of significant intertidal habitat. Furthermore, there will be benefits such as weed control and acid buffering associated with saline water in the drainage network up to 1 km into the system. Flushing will occur continuously throughout the drainage network and across the low-lying floodplain improving water quality across the entire system.

Changes to the existing ecology will require further consideration. Consultation will be required with private landholders on Mayes Swamp, the Seven Oaks Drainage Union and other floodplain landholders upstream of the Menarcobrinni floodgates.

11 Management Option 5: Decentralise Menarcobrinni floodgates to multiple upstream structures

11.1 Description

Management Option 5 involves decommissioning the current floodgates at Menarcobrinni and installing multiple smaller floodgate structures upstream within the existing drainage network. The aim of this management option is to:

1. Improve water quality;
2. Increase fish and aquatic life habitat;
3. Increase wetland habitat; and
4. Enable individual management of different floodplain drainage areas on a sub-catchment basis.

As outlined in Section 4.2.5, by relocating the floodgates further upstream, larger extents of the drainage network are made available for fish and aquatic life habitat and tidal flushing of the drainage network will improve water quality. By strategically locating the floodgates upstream, wetland habitat can be created through strategic overland tidal inundation on low-lying ASS affected management areas (e.g. Management Option 4b). A summary of the benefits achieved by installing multiple floodgates upstream of the existing location includes (but are not limited to):

- Open a new section of the drainage network to the tide with improved water quality;
- Buffer capacity of tidal water reduces the impact of ASS;
- Increase habitat for fish and aquatic life;
- Increased inundation extent, depth and frequency on low-lying TfNSW land to reduce ASS export;
- Management of drainage areas on a sub-catchment basis;
- Smaller floodgate infrastructure required; and
- Reduced drain maintenance costs.

An example of floodgate decentralisation is the location of historical floodgates on the system prior to construction of the Menarcobrinni floodgates. Historically there were two (2) sets of smaller floodgates

installed upstream on Clybucca Creek and McAndrews Drain (per.comms G. Duffy, June 2019). The selected locations to install floodgates upstream will depend on:

- Locations of existing hydraulic structures (e.g. culverts);
- Locations of low and high points in levees;
- Additional on-ground works required to mitigate risks;
- Ecological value of saltwater versus freshwater wetland habitat;
- Floodplain connectivity; and
- Water extractions points (including groundwater and surface water).

In some instances, as well as moving floodgates upstream, construction of additional levees or drop board structures may allow a significant increase in environmental benefits by increasing the available area for habitat creation. Additional management considerations that will need to be addressed for Option 5 include:

- Continued maintenance options for the Menarcobrinni floodgates such as:
 - Full removal so no further maintenance;
 - Removing floodgate flaps and leaving the existing culvert structure; or
 - Hinging open the floodgate flaps.
- Ownership of new structures;
- Ongoing maintenance of new floodgates structures;
- Altered flood risk; and
- Access to structure locations for construction and maintenance.

11.2 Upstream floodgate configurations

For Option 5, two (2) different upstream floodgate location configurations were tested. The objective of the design process was to maximise the extent of drain that can be opened to tidal flushing, and therefore maximise water quality and environmental benefits, while ensuring that impacts to private property were mitigated. This resulted in the following two (2) configurations:

Management Option 5a: Allow inundation of low-lying wetland management areas; and
Management Option 5b: Maintain tide to within drain levee banks.

Management Option 5a is focussed on maximising environmental benefits, however, will require extensive mitigation works to protect private landholders. Management Option 5b is focussed on reducing private land inundation while achieving limited environmental benefits.

11.2.1 Management Option 5a

The configuration for Management Option 5a decentralised floodgates is shown in Figure 11.1. This design focuses on allowing overland tidal inundation on low-lying wetland management areas. Floodgates installed for Management Option 5a are located at narrow sections in the drainage network and would require relatively small structures (in comparison to the Menarcobrinni floodgate structure). Modelling of this design was completed with no catchment inflows to simulate dry conditions and understand the extent of tidal influence.

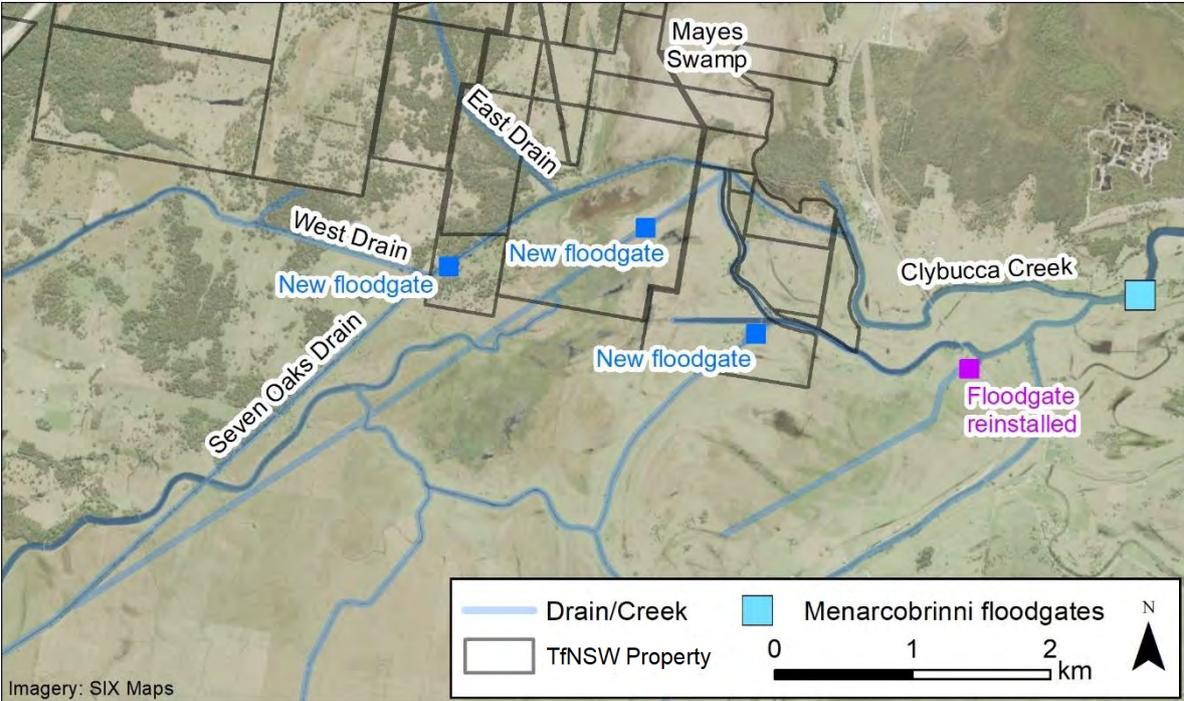


Figure 11.1: Management Option 5a for location of upstream decentralised floodgates

Note that for Management Option 5a, inundation of low-lying land will be with tidal water, resulting in a large scale change to ecology from freshwater to tidal. The altered floodplain ecology, from fresh to tidal, should be considered in further detail prior to implementation of Management Option 5a.

11.2.2 Management Option 5b

The configuration for Management Option 5b decentralised floodgates is shown in Figure 11.2. Floodgates for this configuration would be large structures with multiple floodgates, with a combined flow capacity similar to that of the existing Menarcobrinni floodgates. This design limits the tidal extent to within Clybucca Creek and McAndrews Drain. Limited additional on-ground works are required to mitigate risks to floodplain users due to the high drain levee bank elevations and limited floodplain connectivity. Because of this, the environmental benefits achieved through overland inundation of the floodplain are not realised with this configuration, however management of upstream floodplain areas can be undertaken on an individual sub-catchment basis.

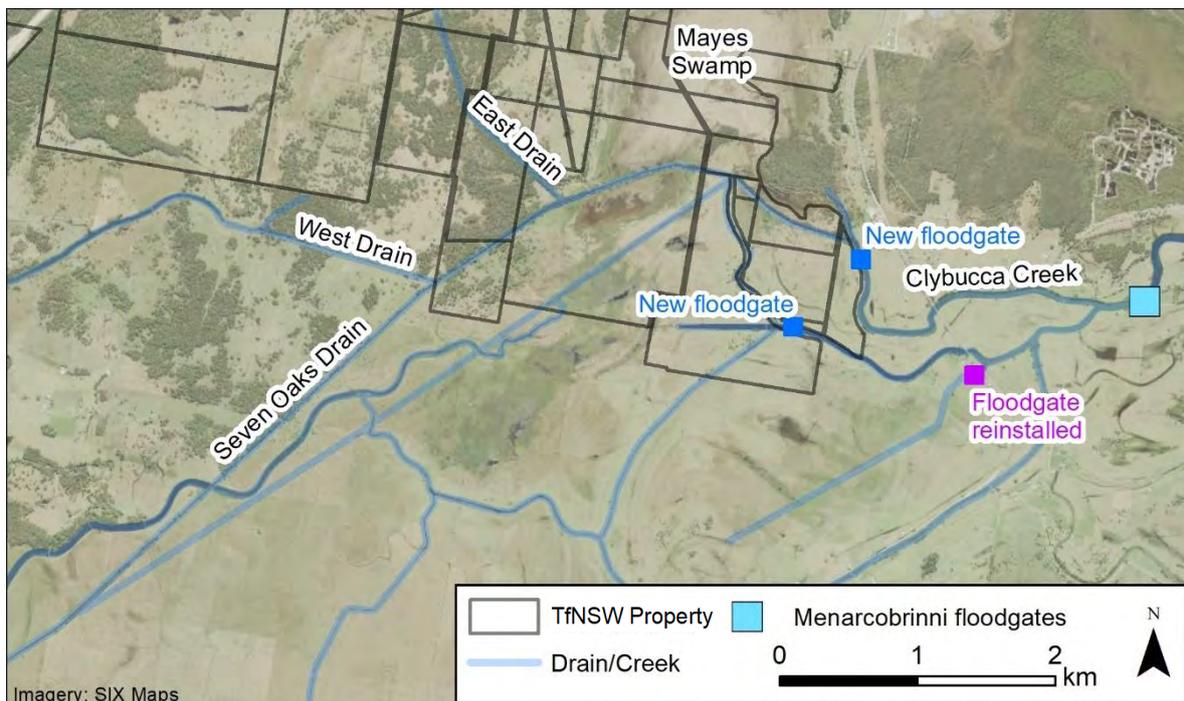


Figure 11.2: Management Option 5b configuration of upstream decentralised structures

11.3 Management Option 5a: results and mitigation measures

The Management Option 5a configuration involves decentralising the Menarcobrinni floodgates to multiple locations upstream of the low-lying floodplain management areas which promotes overland tidal inundation of the management areas. To determine the extent of potential inundation and quantify risks of tidal inundation of private property, a simulation during dry conditions was undertaken. Desktop analysis of results was completed to determine the additional on-ground works required to offset impacts to private property.

11.3.1 Maximum inundation extent

Simulations have been completed to determine the maximum tidal extent if the decentralisation of the Menarcobrinni Floodgates is completed as per Management Option 5a. Model results showed that significant tidal inundation of private land is likely. Inundation of private land was predicted to occur primarily in three (3) areas as shown in Figure 11.3:

- South of Seven Oaks Drain;
- On the south west of Doughboy Swamp; and
- On the east of Mayes Swamp.

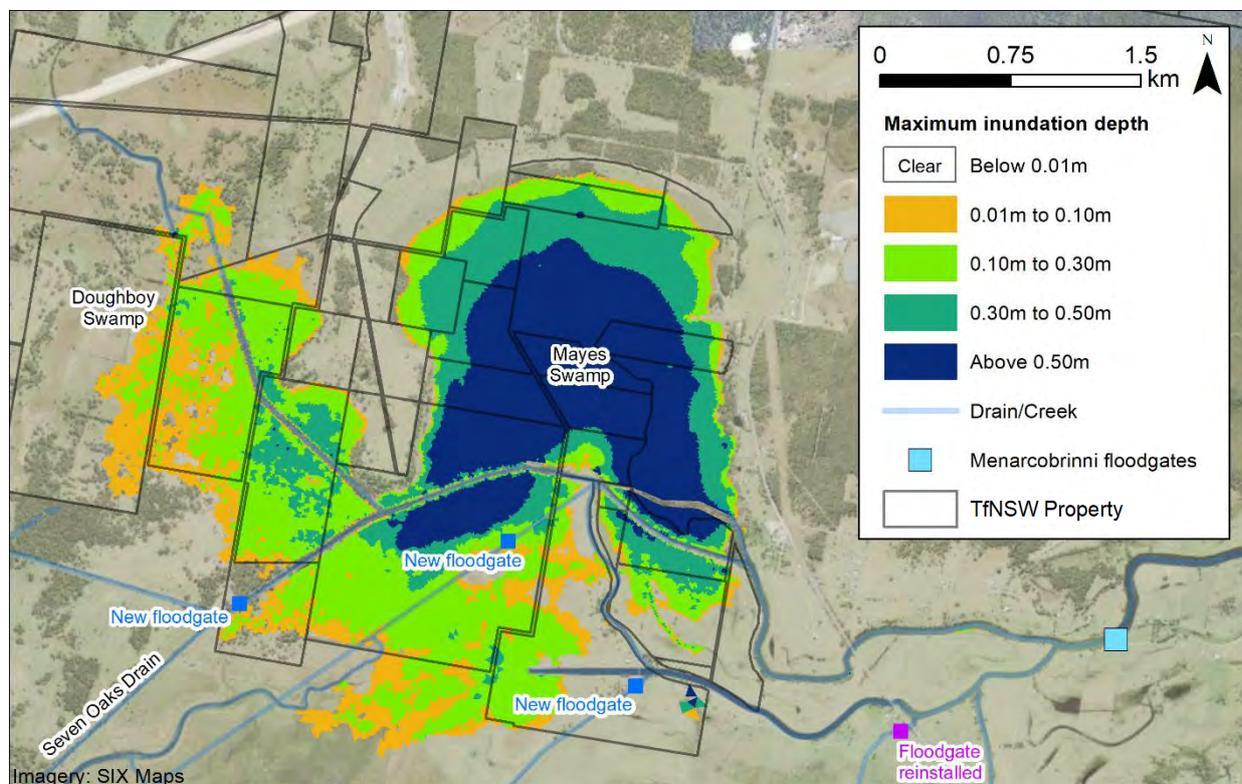


Figure 11.3: Maximum depth and extent of tidal inundation for Management Option 5a over a three (3) month period following a 6 month rainfall event

11.3.2 Mitigation measures

To mitigate against inundation of private land, extensive additional on-ground works such as levees and floodgate structures within small cut outs in the levee banks would be required. Figure 11.4 shows an

indicative guide to where additional levee banks will need to be placed to prevent inundation of private land to the south of Seven Oaks Drain and within Doughboy Swamp. In total, approximately 1 km of additional levee banks would be required. It is recommended that drop board or floodgate structures be installed at low points along these levees to ensure drainage of private land that the levees would disconnect from the drainage network. Any modifications like these will need further assessment to validate floodplain hydrodynamics and determine detailed design.

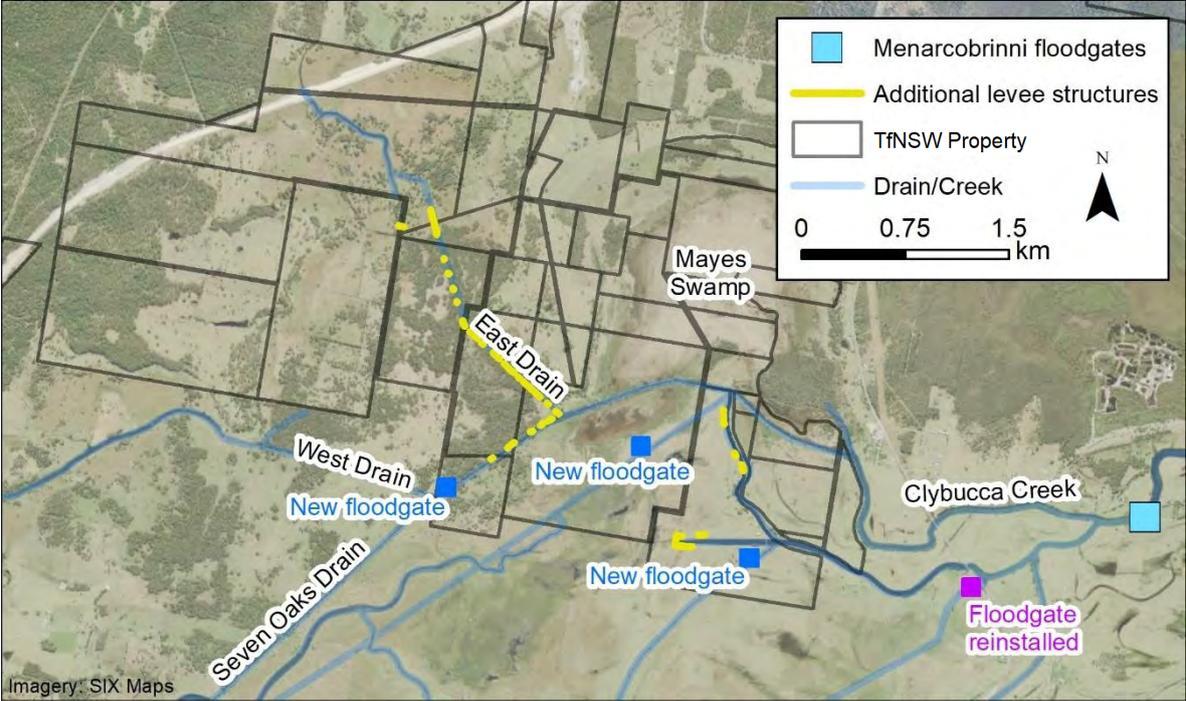


Figure 11.4: Indicative location of additional on-ground works required to limit inundation of private land south of Seven Oaks Drain and within Doughboy Swamp under Management Option 5a

The level of inundation within Mayes Swamp is extensive for Management Option 5a (see Figure 11.3). To prevent this inundation significant works need to be completed including raising 1.2 km of additional levee banks on Seven Oaks Drain and constructing a floodgate structure on Clybucca Creek upstream of its intersection with Seven Oaks Drain (Figure 11.5). These modifications also need validation through numerical modelling. As an alternative to construction of additional infrastructure to limit inundation at these locations, change in management or ownership of private low-lying land (below +0.5 m AHD) could be considered for portions of Mayes Swamp.

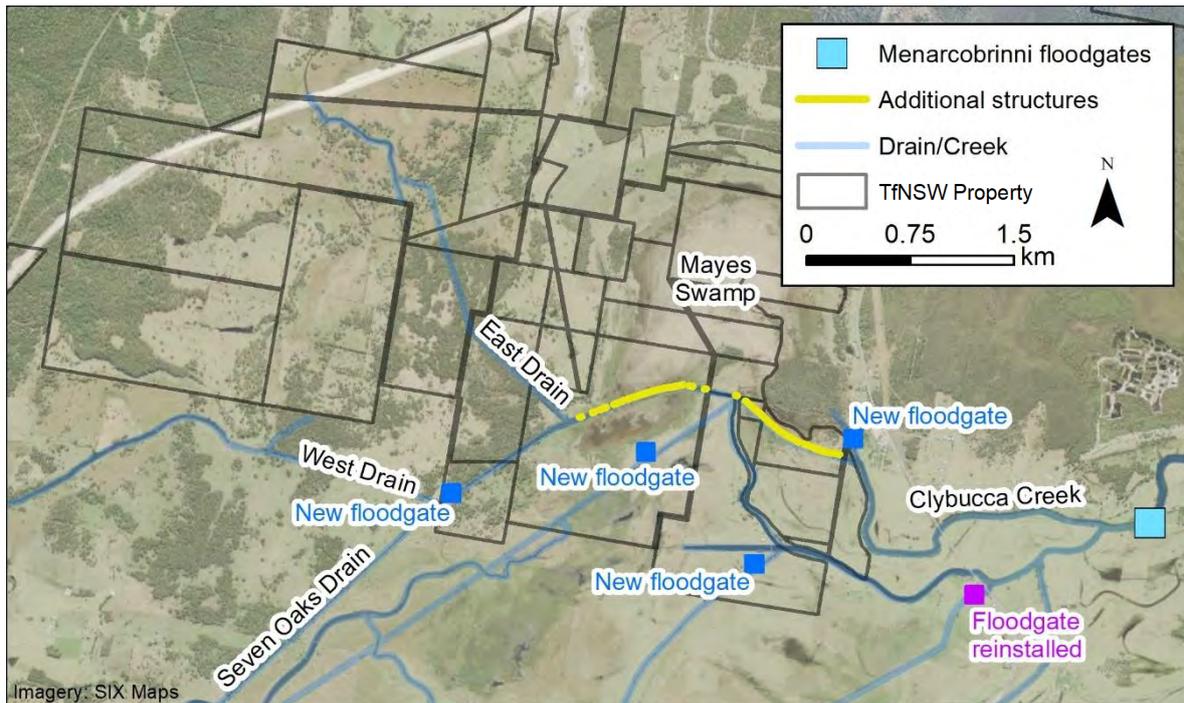


Figure 11.5: Indicative location of additional on-ground works required to limit inundation of private land within Mayes Swamp under Management Option 5a

11.3.3 Summary of findings

Decentralisation of the Menarcobrinni floodgates to locations upstream of the low-lying TfNSW floodplain will result in a significant level of tidal inundation across public and private properties. Mitigation works can be completed to limit overland tidal inundation to within TfNSW property. These works will include the construction of approximately 2.2 km of levee banks in addition to numerous floodgate structures. If completed, there will be significant environmental benefit from inundation of low-lying TfNSW land within the management area to the south of Seven Oaks Drain. There will be a significant level of flushing within the drainage network improving water quality within the system.

However, the additional on-ground works required to mitigate tidal inundation risks to private floodplain users will effectively mitigate much of the environmental aims of this management option. Furthermore, the Menarcobrinni headworks currently prohibit backwater flooding from the estuary to an elevation of +1.1 m AHD. For the smaller decentralised structures to provide the same backwater flooding protection, significant bunds and levees to an elevation of +1.1 m AHD would need to be constructed.

11.4 Management Option 5b: results and mitigation measures

The Management Option 5b configuration involves decentralising the Menarcobrinni floodgates to two (2) main locations downstream of the low-lying floodplain management areas where elevated existing drain levee banks are above high tide level and provide the same level of backwater flooding protection as the existing Menarcobrinni floodgates. To determine the extent of potential inundation and risks to private property, a three (3) month model simulation during dry conditions was completed.

To understand the impact of Management Option 5b on wetting of the low-lying floodplain management areas, after the initial three (3) month dry period, an additional three (3) month wet period with the same 2EY (6 month) event simulated in the base case was modelled (i.e. there was a total 6 month simulation period). This allowed for the impact of flood storage for downstream sections of the drainage network to be assessed for day-to-day conditions.

Following these simulations, analysis was completed to assess inundation risk to private property. Where it was found there was inundation of private property, an indicative assessment was completed to determine additional infrastructure required to mitigate tidal inundation risk.

11.4.1 Maximum inundation extent

Numerical modelling was completed to determine the maximum likely tidal extent under the Management Option 5b configuration. Model results indicated that limited inundation of private land with tidal water would occur. Minor inundation of private land occurred at two (2) locations as shown in Figure 11.6.

- To the south of McAndrews Drain due to a small drainage channel that is used to export water from the floodplain at salinity up to 10% of the salinity at Menarcobrinni floodgates; and
- On private land to the west of Humpty-back Creek within a swale drain at salinity up to 91% of the salinity at the Menarcobrinni floodgates.

To mitigate against inundation of private land, the following measures could be implemented (Figure 11.7):

- Modify the existing culvert on the drain to the south of McAndrews Drain to have floodgates; and
- Install a levee bank with a floodgate where the swale drain meets Humpty-back Creek.

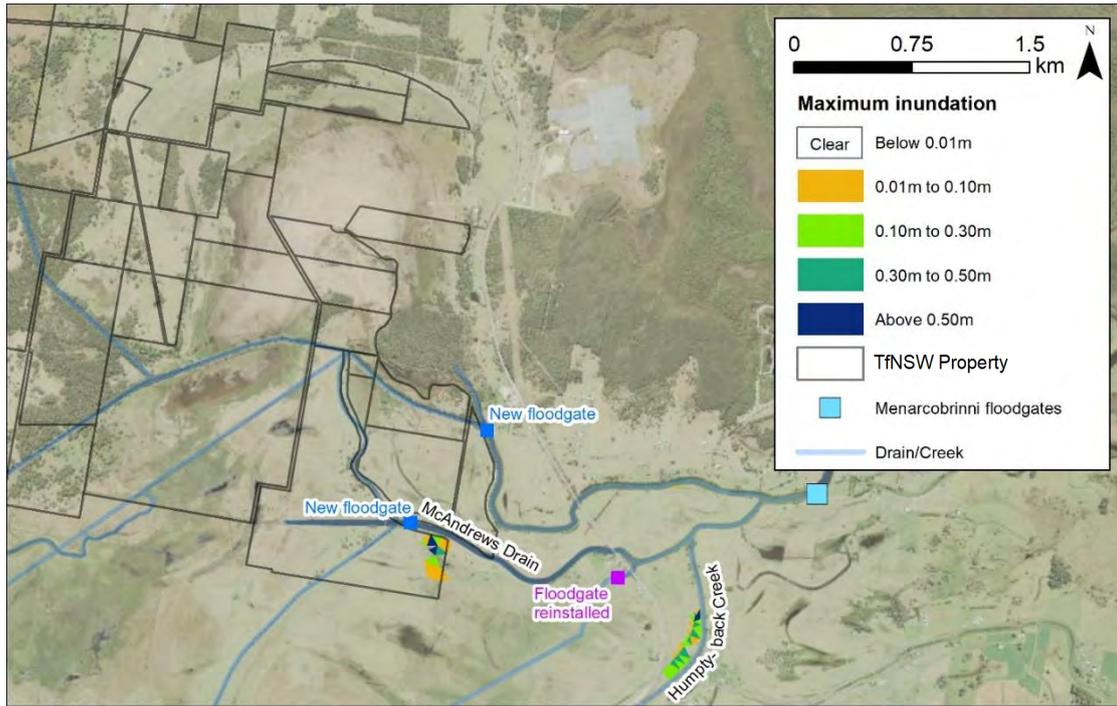


Figure 11.6: Maximum predicted tidal inundation extent under Management Option 5b over a three (3) month period

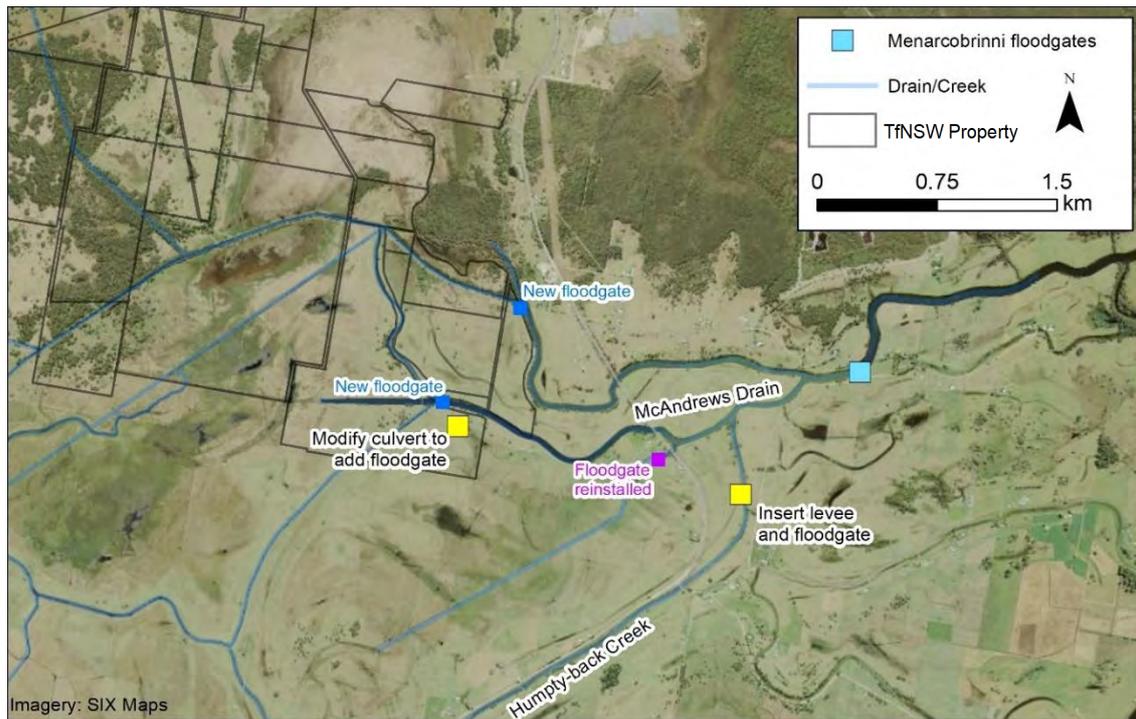


Figure 11.7: Location of new infrastructure required to limit inundation of private land for Management Option 5b

11.4.2 Day-to-day inundation depth, extent and frequency

Results regarding the influence of Management Option 5b on day-to-day drainage are presented in Figure 11.8 and Figure 11.9 for the change in inundation depth, extent and frequency compared to the base case. There is a small change in day-to-day inundation across the floodplain with inundation duration across the floodplain increasing by up to 20% and inundation depth increasing by less 0.1 m in most locations. These changes are most likely due to slight differences in the tidal boundary being further upstream than the present day Menarcobrinni floodgates.

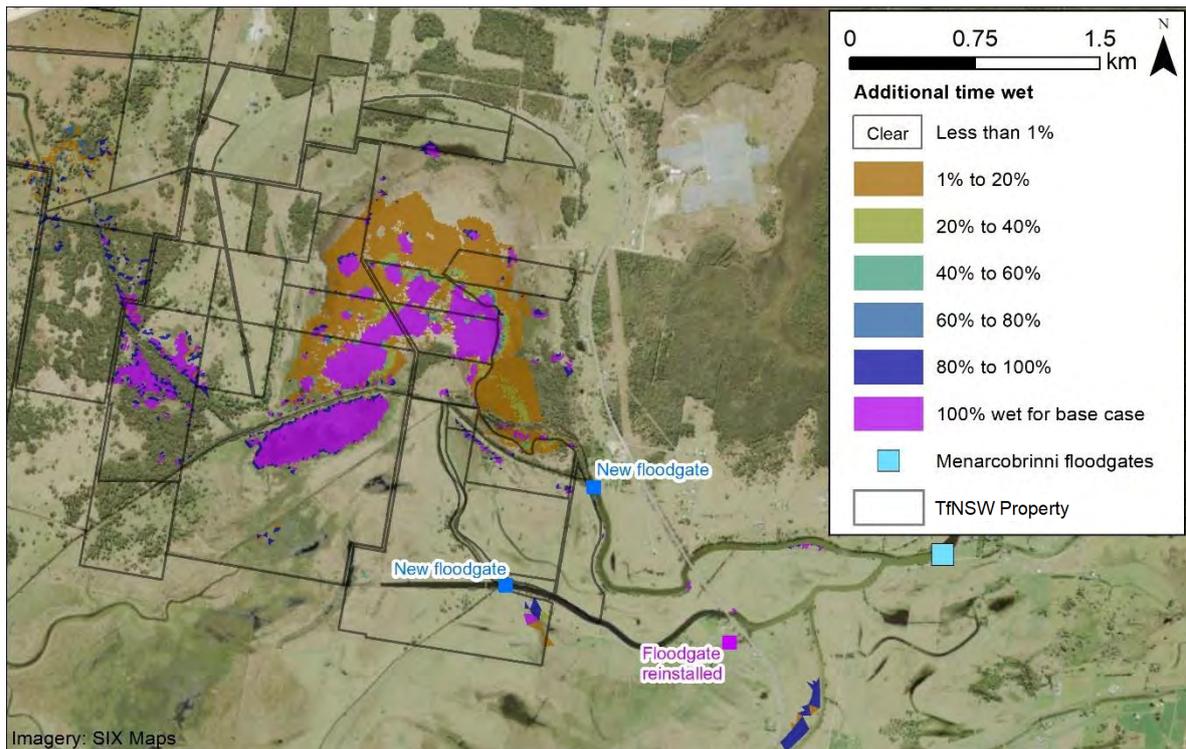


Figure 11.8: Difference in freshwater inundation time between the base case and Management Option 5b over a three (3) month period following a 2EY (6 month) event

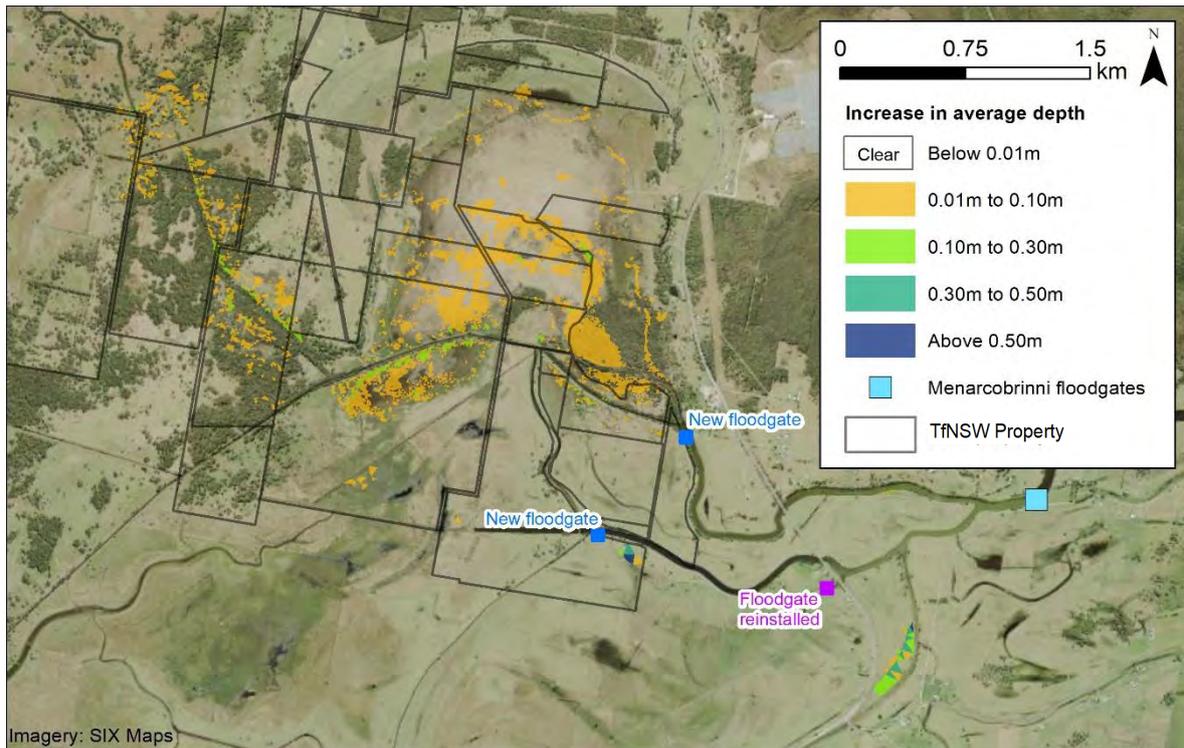


Figure 11.9: Difference in freshwater inundation depth between the base case and Management Option 5b over a three (3) month period following a 2EY (6 month) event

11.4.3 Summary of findings

Decentralisation of the Menarcobrinni floodgates to two (2) upstream locations will result in full tidal flushing of 6.6 km of drain with limited on-ground works required to mitigate tidal inundation risk to private land. These works will include the modification of a culvert to turn it into a floodgate and the construction of 20 m of levee bank with a floodgate.

12 Management Option 6: Floodgates fully open

12.1 Description

Historically the Clybucca floodplain was freshwater and disconnected from the estuary. With the construction of extensive flood mitigation works completed in the 1960's and the creation of Andersons Inlet, the hydrology of the floodplain and wetland areas was permanently altered and tidal water now has the potential to propagate into areas that were historically isolated from direct tidal influences (provided it isn't held back by structures such as the Menarcobrinni floodgates). Management Option 6 investigates how tidal water will flow in the absence of floodgates at Menarcobrinni.

For Management Option 6, the floodgates at Menarcobrinni are fully hinged opened to allow uncontrolled flow in both directions. Figure 12.1 shows an example of a floodgate structure similar in size to the Menarcobrinni gates that has been winched open to allow uncontrolled tidal flows through it. In this situation the floodgates are shut prior to large flood events to prevent backwater flooding from the Macleay River estuary.

There are a number of possible operation configurations for implementation of Option 6. These configurations include:

1. Fully removing the existing floodgate structure;
2. Removing just the floodgate flaps from the existing structure; and
3. Maintaining the existing structure while having the flaps hinged open.



Figure 12.1: Example of floodgates being winched fully open at Rocky Mouth Creek, Richmond River

The main difference between each of the configurations is costs of modification and maintenance. There are also different risk levels associated with each configuration, for example Configuration 1 and 2 would result in backwater flooding from the river, as opposed to Configuration 3 backwater flooding risk could be easily managed. Configuration 3 was assumed for further assessment in Management Option 6.

Implementation of this option at Menarcobrinni is likely to have a significant impact on existing land use, existing drainage and private property. Management considerations that need to be accounted for include (but are not limited to):

- Other management options implemented;
- Change of floodplain from ecology;
- Value and extent of habitat creation;
- Impact of climate change on drainage;
- Change in land use;
- Land ownership;
- Changes to flood risk; and
- Overall change in floodplain hydrology.

12.2 Results and assessment

Management Option 6 has been assessed for a dry weather scenario over a three (3) month period with no catchment inflows. This allows the floodplain to “pump up” with tidal water and determine the maximum extent of tidal inundation on the floodplain.

Salinity was modelled as a function of the salinity at Menarcobrinni floodgates, with salinity presented as a percentage of the salinity at the floodgates. For example, if there was a salinity of 20 PSU at the floodgates, a location that has 50% of the salinity at the floodgates has a salinity of 10 PSU.

Measurements of salinity at Menarcobrinni (presented in Appendix C) showed that salinity at the floodgates can vary from 0 PSU (equivalent to freshwater) to 35 PSU (equivalent to the salinity in the ocean). These concepts have been further detailed in Appendix G.

Results for Management Option 6 are presented in Figure 12.2, Figure 12.3 and Figure 12.4. These figures display inundation depth, extent, frequency and maximum extent of saline intrusion, for normal tidal conditions three (3) month period following permanent opening of the floodgate flaps on the

Menarcobrinni floodgates. Note that the catchment inflow conditions are different from the base case and are therefore not directly comparable for this management option.

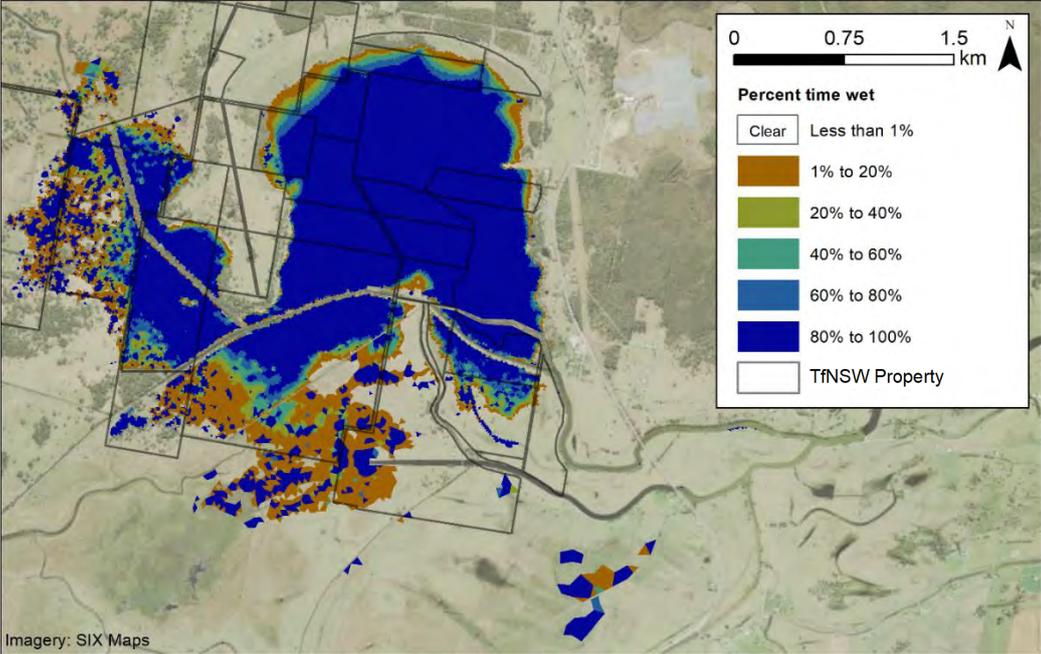


Figure 12.2: Tidal inundation duration for a three (3) month period following opening of the Menarcobrinni floodgates for Management Option 6

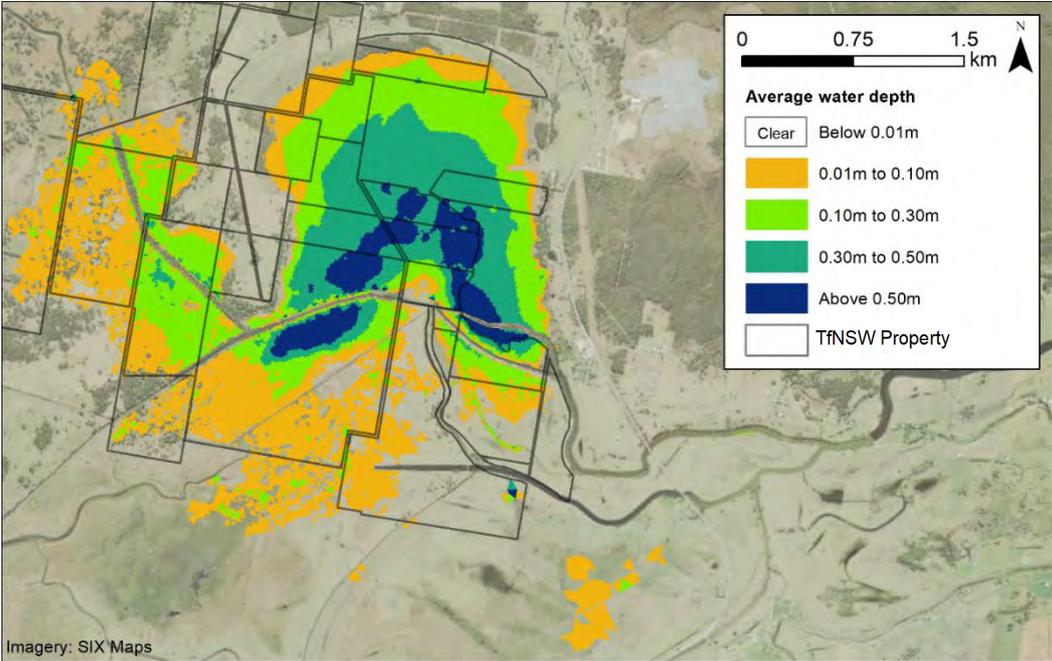


Figure 12.3: Average tidal inundation depth over a three (3) month period following opening of the Menarcobrinni floodgates for Management Option 6

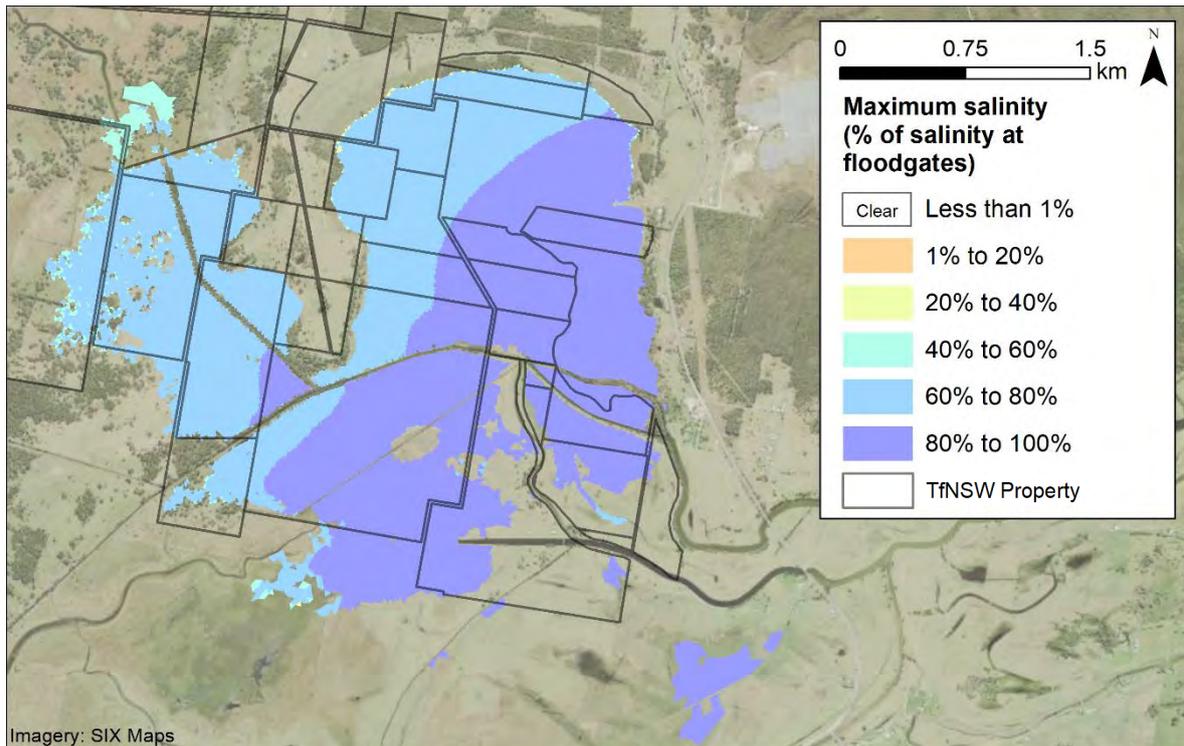


Figure 12.4: Maximum saline intrusion over a three (3) month period following opening of the Menarcobrinni floodgates for Option 6

Model results indicate that hinging open the Menarcobrinni floodgates would result in significant tidal inundation across the floodplain. For TfNSW property and private properties located within Mayes Swamp, inundation would be permanent and range in depth from 0.10 m to above 0.50 m. There would be inundation of private property on the south west of Doughboy Swamp (at depths between 0.01 m and 0.10 m), which in some instances would occur for extended periods of time. Similarly, there would be inundation for long durations on private property to the south of Seven Oaks Drain and south of McAndrews Drain at depths of up to 0.30 m. Where private property becomes inundated with tidal water, concentrations of salinity on the floodplain will reach a maximum of between 60% and 100% of the salinity at the Menarcobrinni floodgates.

These model results highlight that in terms of floodplain management there would need to be careful consideration of impacts to private landholders before the Menarcobrinni floodgates could be opened. Opening the floodgates would allow tidal water onto the floodplain which would have negative effects on the production value of agricultural land which, in turn, would need to be weighed against potential environmental benefits. Land use changes across large areas of private land would need to occur for Management Option 6 to be feasible. The risk of backwater flooding from the Macleay River can be minimised by hinging the floodgates open and closing the gates prior to flooding.

13 Flood impact assessment

The management options outlined in Section 5 and detailed in Sections 6 and 12 are designed to remediate sources of poor water quality from the Collombatti-Clybucca floodplain and rehabilitate wetland values. These options utilise proven remediation strategies (Section 4), many of which rely on modifying or restoring the day-to-day hydrology of the floodplain. Changes to drainage infrastructure and floodplain topography have the potential to impact flooding during large design flood events, for example the 1% AEP (annual exceedance probability) (i.e. the 1 in 100-year flood event). It is important that any changes to the Collombatti-Clybucca floodplain proposed as a part of these management options do not impact flooding during large flood events.

To assess the impact of proposed Clybucca wetland management options on design flood events in the Macleay River floodplain, selected management options were assessed using the adopted Macleay River flood model (Jacobs, 2018). A regional flood impact assessment was completed by Engeny Water Management in consultation with WRL (Engeny, 2020). A summary of the flood impact assessment is provided in this section, and the Engeny (2020) flood impact assessment report is provided in Appendix H

13.1 Flood model scenarios

The flood impact assessment was completed using the 1D/2D TUFLOW numerical model of the lower Macleay River floodplain developed by Jacobs (2019) and adopted by Kempsey Shire Council. The assessment was undertaken for the existing (base case) and design case scenarios to assess the impact of management options. The options assessed were:

- Management Option 2;
- Management Option 3;
- Management Option 5b; and
- Management Option 6.

Other management options considered in Sections 5 to 12 (i.e. Option 1, Option 4a/4b, and Option 5a) were not considered in the flood impact assessment. This is because the above management options that were assessed in detail using the flood model are either; well represented by the options that were assessed; or, were within the bounds of the existing model assumptions. Changes to the flood model bathymetry and/or initial conditions to incorporate management option configurations are detailed in Appendix H

Design flood scenarios were simulated for existing conditions (base case) and for two (2) design flood scenarios:

- 0.2 Exceedances per Year (EY) (equivalent to a 18.13% AEP or 5-year ARI flood); and
- 1% Annual Exceedance Probability (AEP) (equivalent to a 100-year ARI flood).

13.2 Results

Results were extracted at selected locations across the Collombatti-Clybucca floodplain as shown in Figure 13.1. The difference in peak flood level at these locations is detailed in Table 13.1 and difference in the time to peak flood level is detailed in Table 13.2. Flood impact mapping for all scenarios and design conditions are provided in Appendix H

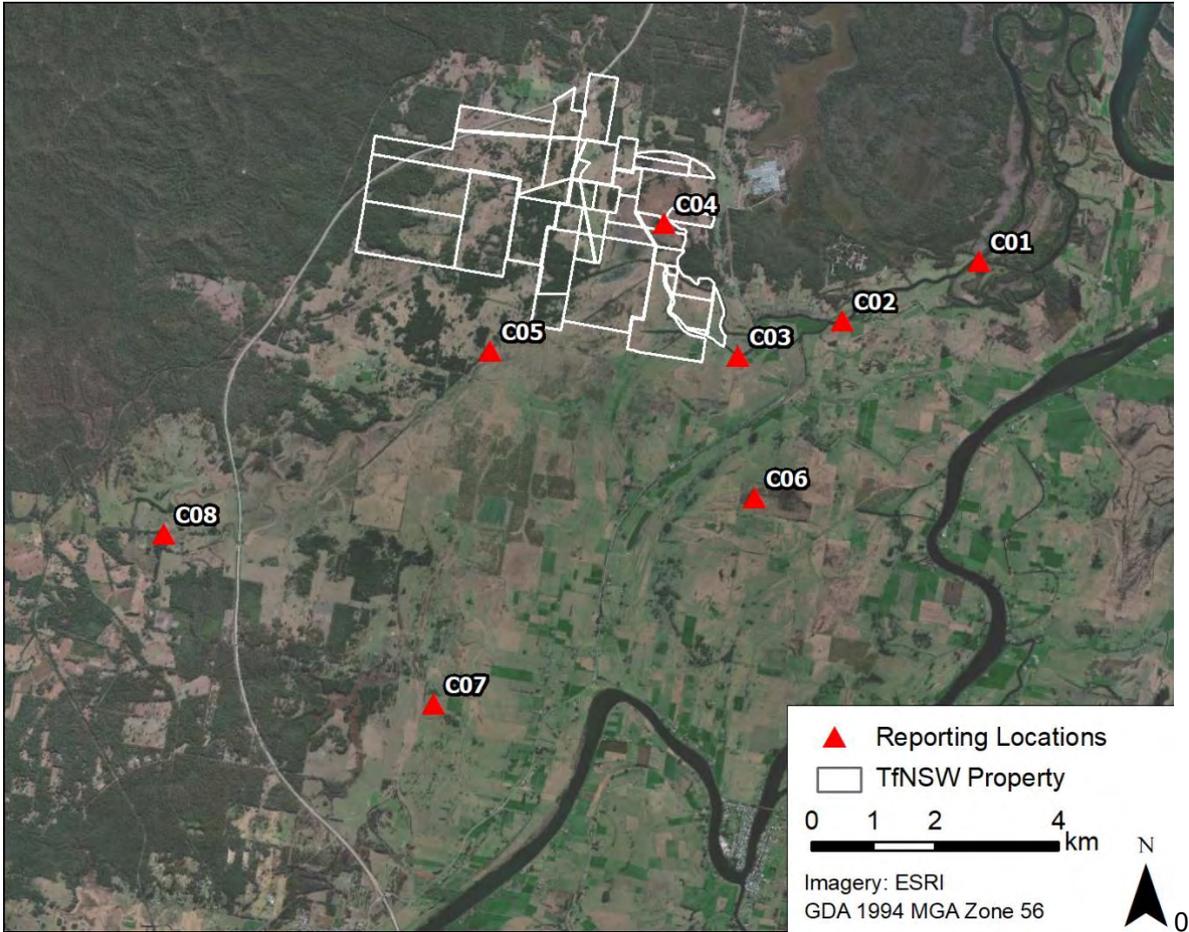


Figure 13.1: Flood difference reporting locations

Table 13.1: Peak flood level difference

Reporting Location	Peak flood level		Difference to existing base case flood level							
	Base 0.2 EY (m AHD)	Base 1% AEP (m AHD)	Option 2 0.2 EY (m)	Option 2 1% AEP (m)	Option 3 0.2 EY (m)	Option 3 1% AEP (m)	Option 5b 0.2 EY (m)	Option 5b 1% AEP (m)	Option 6 0.2 EY (m)	Option 6 1% AEP (m)
C01	2.23	4.21	-0.07	0.00	-0.07	0.00	0.03	0.01	0.00	0.00
C02	2.45	4.33	-0.08	-0.01	-0.08	-0.01	0.02	0.00	-0.01	0.00
C03	2.75	4.40	-0.06	-0.01	-0.06	-0.01	0.01	0.00	-0.01	0.00
C04	2.76	4.42	-0.06	-0.01	-0.06	-0.01	0.02	0.00	-0.01	-0.01
C05	2.77	4.42	-0.07	-0.01	-0.07	-0.01	0.02	0.01	-0.01	0.00
C06	2.66	4.40	-0.04	-0.01	-0.04	-0.01	0.01	0.00	0.00	0.00
C07	2.81	4.46	-0.08	-0.01	-0.08	-0.01	0.02	0.01	-0.01	0.00
C08	2.80	4.46	-0.06	-0.01	-0.06	-0.01	0.03	0.01	0.00	0.00

* Instabilities noted in 0.2 EY model simulations. Refer to Appendix H

Table 13.2: Time to flood peak level difference (hours)

Reporting Location	Time to peak flood level		Difference to existing base case flood level							
	Base 0.2 EY (hours)	Base 1% AEP (hours)	Option 2 0.2 EY (hours)	Option 2 1% AEP (hours)	Option 3 0.2 EY (hours)	Option 3 1% AEP (hours)	Option 5b 0.2 EY (hours)	Option 5b 1% AEP (hours)	Option 6 0.2 EY (hours)	Option 6 1% AEP (hours)
C01	55.8	51.2	0.3	0	0.3	0	-0.4	0	0.1	0
C02	55.5	50.7	0.6	0	0.5	0	-0.3	0	0.1	0
C03	54.6	50.4	1.3	0	1.2	0	-0.5	0	0.2	-0.1
C04	54.6	50.3	1.5	0.1	1.2	0.1	-0.5	0	0.2	0.1
C05	54.5	50.3	1.4	0.1	1.3	0.1	-0.5	-0.1	0.2	0
C06	52.8	50.3	-6	0.1	-5.9	0.1	-0.2	0	0	0.1
C07	52.1	49.9	1.4	0.1	1.3	0.1	-0.5	0	0.2	0
C08	54.7	50	1.5	0.1	1.3	0.1	-0.6	0	0.2	0

* Instabilities noted in 0.2 EY model simulations. Refer to Appendix H

13.3 Flood impact assessment summary

The flood impact assessment indicates no impact of regional flood levels for the 1% AEP design event due to the proposed management options. Engeny (2020) notes that changes to the flood model configuration as a part of the management options resulted in instabilities in the model for the 0.2 EY simulations. This is likely due to changes in topography (e.g. weirs and drain levee banks) influencing the adopted model ocean boundary conditions, which are simulated as a Level vs. Time boundary condition. This instability results in oscillations of water levels within the model domain, and subsequent minor differences in peak flood level and time to the peak flood level. Based on Kempsey Shire Council's definition of adverse (above a 0.05 m increase in flood level within the floodplain), the proposed management options do not result in any adverse impacts to flooding (Engeny, 2020).

14 Sea level rise

14.1 Preamble

In the future, climate change will pose a significant risk to estuaries (Heimhuber et al., 2019b). It is within estuaries that impacts of climate change from the ocean (e.g. sea level rise) and upstream catchments (e.g. extreme rainfall events) will be most strongly felt (Heimhuber et al., 2019b). Quantifying the changes of these impacts on the estuary is multi-faceted and extremely complex.

As part of this study, sea level rise has been chosen as a key climate driver that will alter hydrological and environmental conditions across the Clybucca floodplain. Present day floodplain hydrology and drainage is predominantly controlled by estuarine tidal levels, with the low tide elevation determining drainage potential. Future sea level rise, and future low tide elevations, will significantly alter floodplain hydrology and the corresponding environmental values and agricultural practices. As a key driver of change, the impact of sea level rise has been modelled and quantified across the Clybucca floodplain. A high-level discussion regarding the effects of climate change on the environment has been provided.

14.2 Hydrodynamic modelling

14.2.1 Model setup

Numerical modelling of the management options was completed based on present day hydrological conditions and did not incorporate any effects of climate change or SLR. In a future climate, sea levels will rise and reduce the drainage efficiency of the drainage network causing increased inundation depth, extent and frequency. Values of +0.4 m for 2050 and +0.9 m of rise for 2100 have been used for flood modelling across the Macleay River estuary (Jacobs, 2019).

To assess the impact of sea level rise on floodplain drainage of the Clybucca Floodplain, two (2) simulations have been completed by adjusting the downstream tidal boundary of the numerical model:

Near future (2050): +0.4 m of sea level rise; and

Far future (2100): +0.9 m of sea level rise.

All other model conditions and parameters remain unchanged from the present day 'base case' scenario, with the present day management of the Menarcobrinni floodgates being maintained (i.e. one-way floodgates operation).

14.2.2 Near future 2050 (+0.4 m sea level rise)

Results showing the increase in average inundation depth, extent and frequency for the 2050 simulation (+0.4 m of sea level rise) are presented in Figure 14.1 and Figure 14.2.

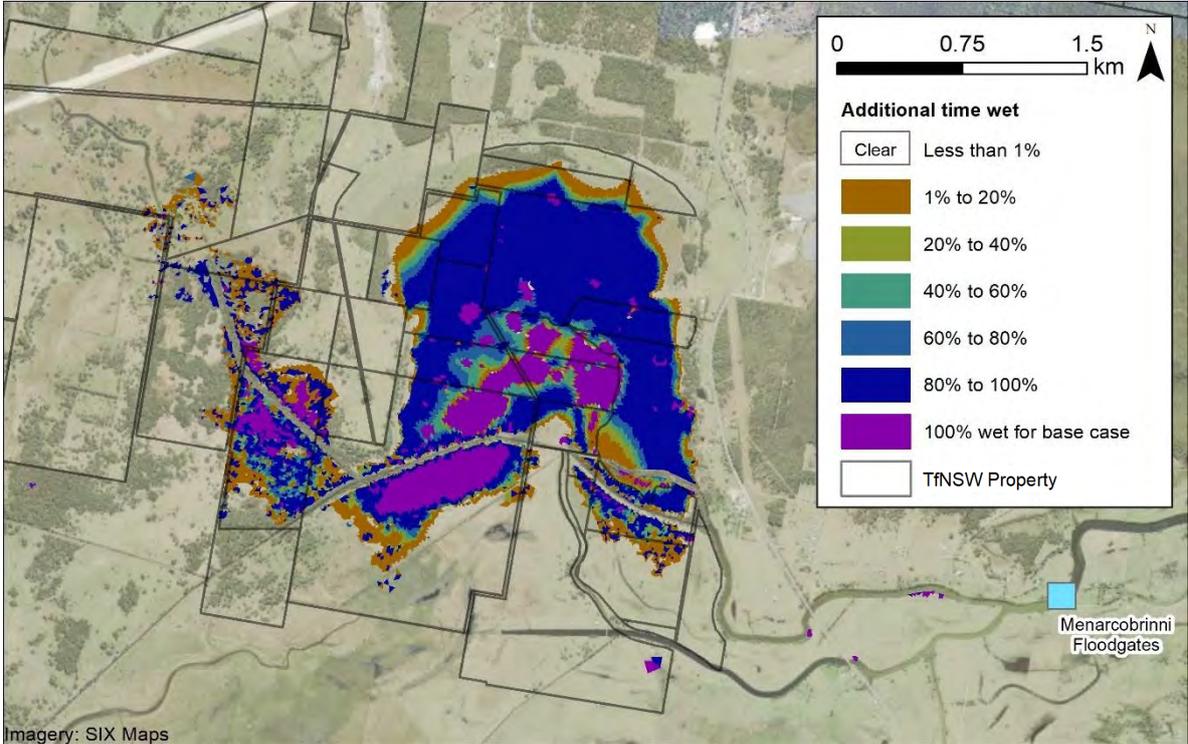


Figure 14.1: Difference inundation duration between the base case and the near future 2050 scenario (+0.4 m SLR) over three (3) months following an equivalent runoff event

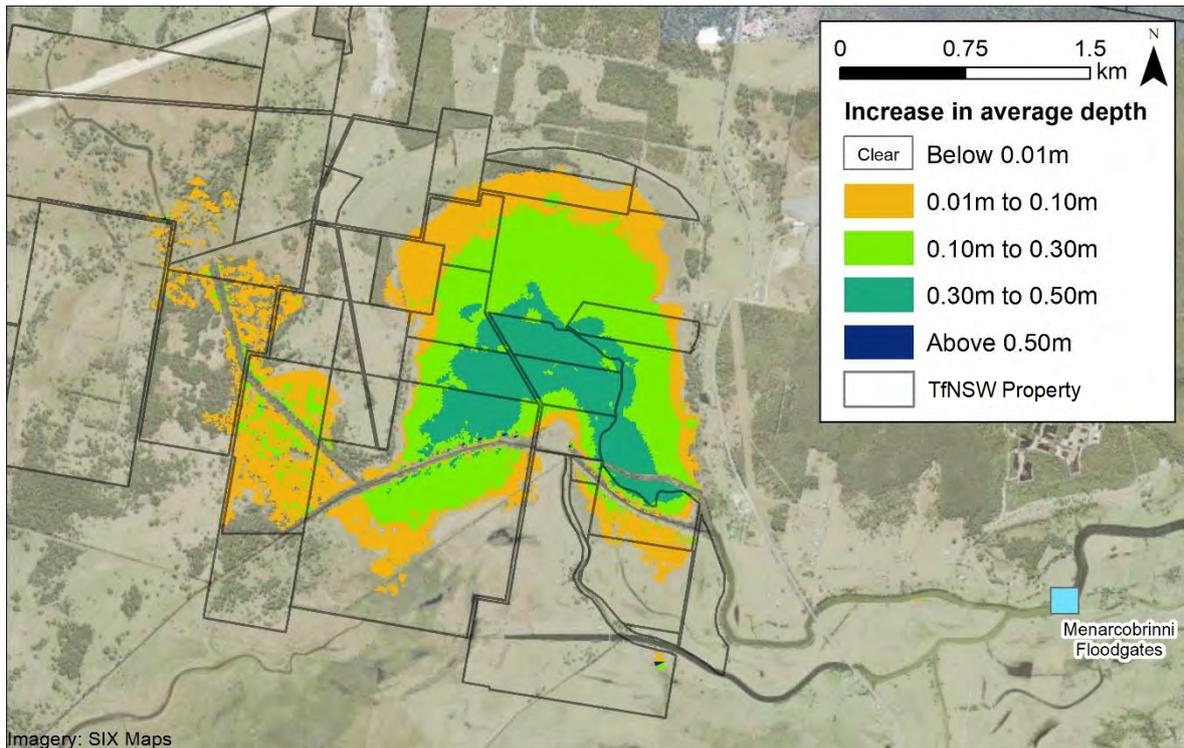


Figure 14.2: Difference in inundation depth between the base case and the near future 2050 scenario (+0.4 m SLR) over three (3) months following an equivalent runoff event

The near future 2050 simulation for sea level rise indicates that there will be an increase in freshwater inundation depths of 0.10 m to 0.50 m across low-lying floodplain management areas within Mayes Swamp and Yerbury's Scald. Average inundation across Doughboy Swamp will increase by up to 0.30 m. Inundation generally occurred for longer durations across the low-lying floodplain including some locations which were inundated 100% more of the time when compared to the base case.

Private property will be affected on the east of the Mayes Swamp area. This increase in inundation is caused by catchment flooding due to reduced drainage resulting from elevation in the low tide levels at the Menarcobrinni floodgates.

14.2.3 Far future 2100 (+0.9 m sea level rise)

Results showing the increase in average inundation depth, extent and frequency for the 2100 simulation (+0.9 m of sea level rise) are presented in Figure 14.3 and Figure 14.4.

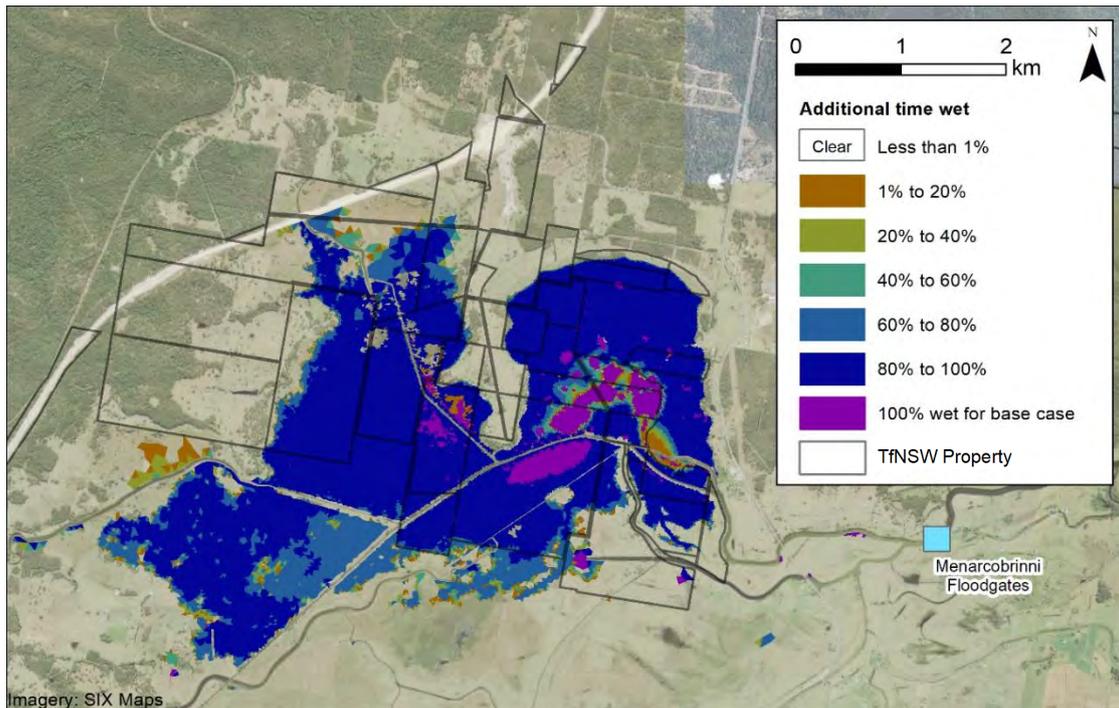


Figure 14.3: Difference in freshwater inundation duration between the base case and the 2100 scenario (+0.9 m SLR) over three (3) months following an equivalent runoff event

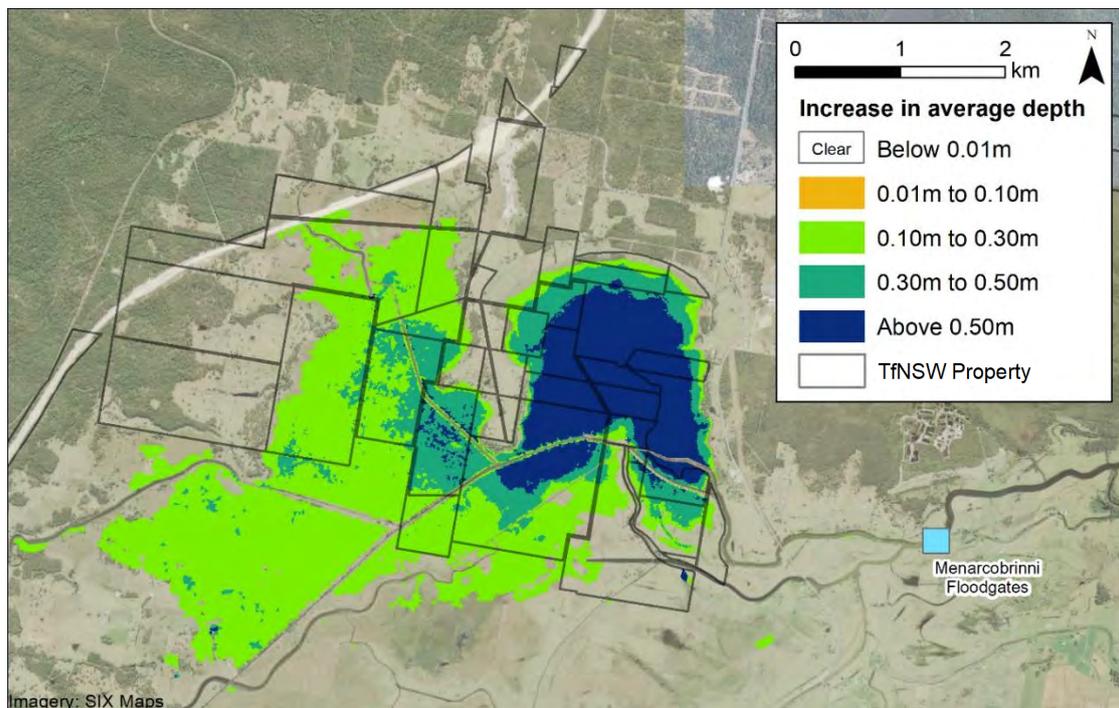


Figure 14.4: Difference in freshwater inundation depth between the base case and the 2100 scenario (+0.9 m SLR) over three (3) months following an equivalent runoff event

Results for the 2100 (+0.9 m SLR) simulation for sea level rise scenario indicate that the drainage potential of the floodplain will be significantly reduced, with future low tide levels being near in elevation to the present-day high tide elevation. Subsequently drainage of large areas of the Clybucca floodplain will not be possible and will have an average inundation depth of 0.10 m to 0.30 m more than the base case. Low-lying floodplain management areas within Mayes Swamp and Yerbury's Scald will be inundated by over 0.50 m of additional water. Doughboy Swamp will receive between 0.10 m and 0.50 m of additional inundation. Inundation will generally be between 60% to 100% of the time for the majority of floodplain areas affected.

14.3 Climate change discussion

Within estuaries the impact of climate change is not only on sea level but several other factors including (Heimhuber et al., 2019a):

- Air temperature;
- Sea surface temperature;
- Ocean acidity;
- Rainfall; and
- Winds, storms and waves.

Changes in these processes will result in physical impacts to the broader estuary which, in turn, affect chemical and biological processes. Considerably more research is required to quantify the effects of climate change on the ecology within the estuary (Heimhuber et al., 2019c and Dominguez et al., 2019). This means that there is a large uncertainty for wetland habitat (both freshwater and intertidal).

It is important that the future management of the Clybucca floodplain considers management approaches which are adaptable with regards to SLR and the uncertainty surrounding the future climate. This will ensure that the floodplain can continue to positively contribute to the health of the broader Macleay River estuary. In designing the management options and remediation strategies, a flexible approach was taken. This approach was adopted so that as the climate changes, adaptive management of the floodplain can ensure wetland habitats persist, resulting in the safekeeping of the health of the estuary into the future.

15 Indicative costs and benefits

15.1 Preamble

The magnitude of the costs and benefits associated with each of the six (6) management options (Section 5) varies substantially. Implementation costs vary from low-to-high for the different management options investigated. Similarly, benefits of the management options vary substantially. Many of these benefits are largely environmental (i.e. water quality and habitat). There is an increasing body of research that shows that the ecosystem services from improved water quality and remediated wetland areas have a real economic benefit (both direct and indirect) that should be considered (Harrison et al., 2019).

This report section provides a summary of the relative costs and benefits associated with each management option. This is not an attempt to put actual dollar values to the costs and benefits for each option (which requires environmental values and ecosystem services to be monetised), but rather to emphasise the types and sources of costs and benefits involved and the potential magnitude of costs and benefits relative to one another.

It is important to recognise that not all management options are mutually exclusive. For example, freshwater Management Options 1 and 2 could be combined with the saltwater Management Options 4 and 5 to improve overall outcomes. However, for the purpose of providing an indicative cost and benefit of each option they have been considered independently.

15.2 Relative costs

The costs associated with each of the management options vary considerably. Some options include higher upfront costs such as substantial on-ground works, while others may incur low upfront costs but higher on-going management and maintenance costs. Detailed costings of all the aspects of each management option has not been undertaken. Rather, the relative magnitude of the expenditure associated with each option has been assessed with respect to a number of commonly occurred costs associated with floodplain remediation. The scope of the costs considered is outlined in Table 15.1.

For each of the costs outlined in Table 15.1, a qualitative rating (minimal change, very low, low, moderate, high and very high) was assigned to each management option, summarised in Table 15.2. The qualitative rating is relative in magnitude and cannot be compared between costs (e.g. a very high

cost of on-ground works may not be the same as a very high cost of impact management). The purpose of this table is to highlight which options may present low cost options overall.

A semi-quantitative measurement of total comparative cost has been provided in Figure 15.1. Note that the total costs include both upfront costs and on-going costs for a management horizon of 30 years. The order of magnitude of costs has been determined based on model results, previous experience at other remediated sites and an estimate of the resources required.

Table 15.1: Scope of costs considered

Cost	Description
Community consultation and engagement	Community consultation and engagement includes conversations with landholder and stakeholder groups (such as the Seven Oaks Drainage Union), as well as individual consultation for adjusted land management on private properties.
Asset management	Costs associated with asset management including long-term management of floodgates (including opening and closing sluice gates), new infrastructure and drain maintenance. Asset management costs have been considered where they are in excess of estimated costs of existing management.
Compensation (incl. consultation)	Compensation for loss of productive land has been considered based broadly on the values from the NSW Valuer General.
Environmental assessment	Where applicable, the cost of an environmental assessment (EIS or REF) has been considered.
Social costs and land use changes	Where there is land that can no longer be used for agricultural production, the annual loss in productivity from that land has been considered where land use has not already changed.
Habitat changes	Costs associated with changing habitat (e.g. from freshwater meadows to estuarine wetland) has been assessed based on water level and salinity modelling for each management option.
Technical assessment/design	Each management option may require further technical assessment and detailed design prior to implementation and the associated cost have been considered.
On-ground works and implementation (including sub-contractors and access facilitation)	The cost of on-ground works and implementation includes access facilitation, machinery, materials and other up-front costs. It does not include the on-going management of new structures or drains.
Impact management	Management of any impacts (e.g. salinity or changes to flood storage) will be an on-going cost associated with some of the management options. This includes additional monitoring and other minor on-going works that might be required.

Table 15.2: Relative cost matrix for each management option

Costs	Option 1: Land management only	Option 2: Shallow freshwater on TfNSW	Option 3: Shallow freshwater on TfNSW and new swale drain	Option 4a: Tidal flushing in-drain	Option 4b: Tidal flushing overland	Option 5a: Decentralised floodgates – overland	Option 5b: Decentralised floodgates – in-drain	Option 6: Open floodgates
Community consultation	Minimal change	Moderate	Low	Low	High	Very High	Very High	Very High
Asset management	Very Low	Low	Low	Moderate	High	Very High	High	Low
Compensation	Minimal change	Very Low	Very Low	Minimal change	Low	Minimal change	Minimal change	Very High
Environmental assessment	Minimal change	Very Low	Moderate	Very Low	High	Moderate	Low	Very High
Land use changes	Minimal change	Minimal change	Minimal change	Minimal change	Moderate	Minimal change	Minimal change	Very High
Habitat changes	Minimal change	Minimal change	Minimal change	Minimal change	High	Moderate	Minimal change	Very High
Technical design	Very Low	Moderate	High	Moderate	Moderate	Very High	High	Moderate
On-ground works	Very Low	Low	Moderate	Low	Low	High	Very High	Very Low
Social	Minimal change	Minimal change	Minimal change	Minimal change	Moderate	Minimal change	Minimal change	Very High
Impact management	Minimal change	Moderate	Low	Very Low	Moderate	Very Low	Very Low	High

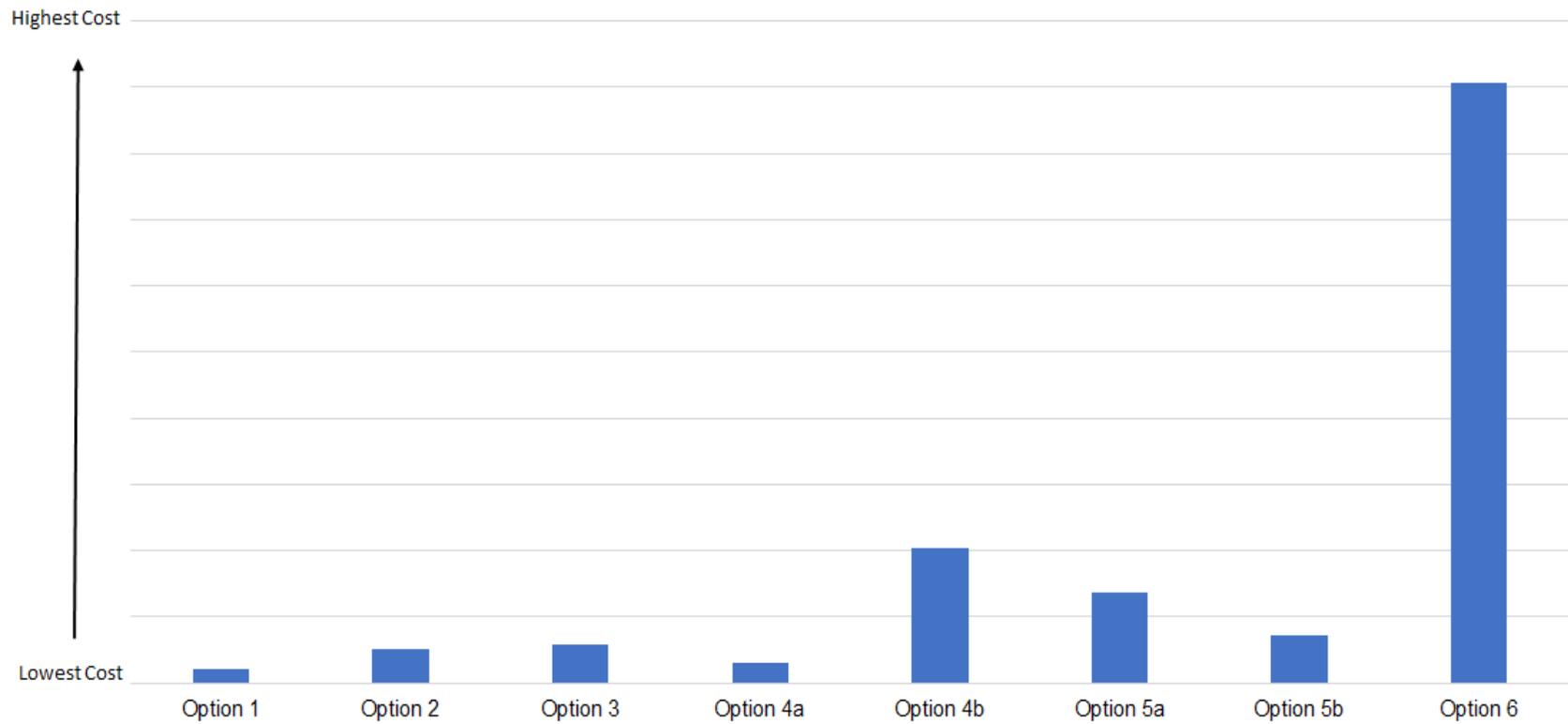


Figure 15.1: Order of magnitude of total costs associated with each management option

15.3 Relative benefits

Environmental resources and natural capital have historically not been consistently included in economic decision making, as they are generally not bought or sold in traditional markets and therefore may be difficult to monetise. However, there is an increasing awareness that natural capital interacts with human environments and provides a positive contribution to human welfare (Harrison et al., 2019).

The management options investigated for the Clybucca floodplain focussed on remediating wetland environments and improving water quality within the low-lying floodplain management areas and throughout the wider Macleay River estuary. The benefits associated with these types of remediation works are largely environmental and are commonly referred to as “ecosystem services”. Ecosystem services is the term used to refer to the “benefits people obtain from ecosystems” (Millennium Ecosystem Assessment, 2005), including both the direct and indirect contributions of ecosystems to human welfare (Costanza et al., 1997). Ecosystem services include a wide array of benefits, such as food production (e.g. improved fisheries production resulting from improved water quality), climate regulation (e.g. carbon sequestration) and recreational use of environmental resources (e.g. recreational fishing or boating).

Similar to the costs, a range of different types of benefits could result from implementing each management option. Table 15.3 summarises the scope of the benefits considered (which may not be exhaustive). For the purpose of comparing relative benefits, a qualitative rating (minimal change, very low, low, moderate, high and very high) was assigned to each management option, summarised in Table 15.4.

A semi-quantitative measurement of total normalised benefit has been provided in Figure 15.2. This figure is not intended to show the actual dollar benefit of each option, but to emphasise the different orders of magnitude of benefits. As the benefits of each management option is not easily quantifiable, the following subjective measures have been used to compare the potential benefits:

- Length of drain reducing advective acid transport (through tidal flushing, weirs or reshaping);
- Opportunities for increased fish passage (e.g. gate opening) and area of increased fish habitat (area inundated by tidal water);
- Area of grassed floodplain remediated, reducing blackwater potential; and
- Improved habitat through increased average inundation (fresh or tidal water).

Table 15.3: Scope of benefits considered

Benefit	Description
Acidity	Highly acidic water has been recorded throughout the low-lying Clybucca floodplain and the receiving waters of the Macleay River estuary over an extended period. Benefits of remediation have been considered in respect to acidity during normal (i.e. non flood) periods (for example long-term median and average pH) and acidity immediately following rainfall (for example, minimum pH after a rainfall event).
Metals	The ASS that occur in the low-lying Clybucca floodplain region are also related to the release of high concentrations of metals including iron and aluminium. The benefits relating to reduced metal concentrations have been considered during normal (i.e. non flood) periods and immediately following rainfall.
Dissolved oxygen/blackwater	Blackwater (i.e. water with low dissolved oxygen) events can occur on drained coastal floodplains after flood events when inundation intolerant vegetation dies due to prolonged floodwater retention or due to mobilisation of MBOs. Some remediation options may reduce the impact of blackwater discharging from Clybucca on the wider Macleay River estuary. The benefits relating to dissolved oxygen have been considered during normal (i.e. non flood) periods and immediately following rainfall.
Aquatic connectivity	The installation of one-way floodgates effectively prevents fish passage into many drained coastal floodplains in NSW. Improved fish passage is considered a benefit of changing the management of floodgates like the Menarcobrinni floodgates.
Fisheries nursery habitat	Coastal backswamps provide important fisheries nursery habitat to aquatic fauna. Installation of floodgates, poor water quality and removal of natural estuarine vegetation (e.g. mangroves and saltmarsh) reduce or eliminate nursery habitat. The benefits of each remediation option with respect to the creation of nursery habitat has been considered.
Terrestrial habitat	Wetlands play an important role as habitat for terrestrial flora and fauna, including migratory birds. Encouraging a natural remediation of the low-lying Clybucca floodplain could potentially provide suitable habitat for a range of terrestrial fauna.
Fisheries production	Tidal wetlands are significant areas for estuarine primary production, with almost 70% of commercially caught fisheries in eastern Australia spending some part of their life cycle in estuaries (Creighton, 2013). Saltmarsh in particular has been shown to be important to fisheries productivity in NSW estuaries (Taylor et al., 2018).
Nutrient reduction	Wetlands have the capacity to remove significant amounts of nutrients (total phosphorus and total nitrogen) from catchment inflows. Wetlands are also associated with sediment retention and stabilisation that would reduce the total suspended loads delivered to the estuary.
Biodiversity protection	Wetland ecosystems are important to biodiversity. Improving estuarine vegetation recruitment, such as saltmarsh and mangroves, provides important support to biodiversity in the region.
Increased groundwater levels	Increase in groundwater and surface water levels, particularly during droughts improve drought resilience on surrounding properties.
Carbon sequestration	Estuarine vegetation, such as saltmarsh, is recognised as an important ecosystem for carbon sequestration (Kelleway et al., 2005), which is important for regulating the climate.

Table 15.4: Relative benefit matrix for each management option

Benefits	Option 1: Land management only	Option 2: Shallow freshwater on TfNSW	Option 3: Shallow freshwater on TfNSW and new swale drain	Option 4a: Tidal flushing in- drain	Option 4b: Tidal flushing overland	Option 5a: Decentralised floodgates – overland	Option 5b: Decentralised floodgates – in-drain	Option 6: Open floodgates
Acid	Minimal change	Moderate	Moderate	Moderate	High	Very High	Moderate	Very High
Dissolved oxygen	Minimal change	High	High	Low	High	Moderate	Very Low	Very High
Aquatic connectivity	Minimal change	Minimal change	Minimal change	Low	High	High	Moderate	Very High
Fisheries nursery habitat	Minimal change	Minimal change	Minimal change	Very Low	High	Moderate	Very Low	Very High
Terrestrial habitat - birds	Very Low	High	High	Minimal change	High	Moderate	Very Low	Very High
Fisheries production	Minimal change	Low	Low	Low	High	Moderate	Low	Very High
Nutrient reduction	Low	Moderate	Moderate	Low	High	Moderate	Moderate	Very High
Increased GW levels	Minimal change	High	High	Very Low	Low	Low	Very Low	High
Biobanking offset extent	Minimal change	High	High	Minimal change	High	Moderate	Minimal change	Very High
Carbon sequestration	Low	Low	Low	Minimal change	High	Low	Minimal change	Very High

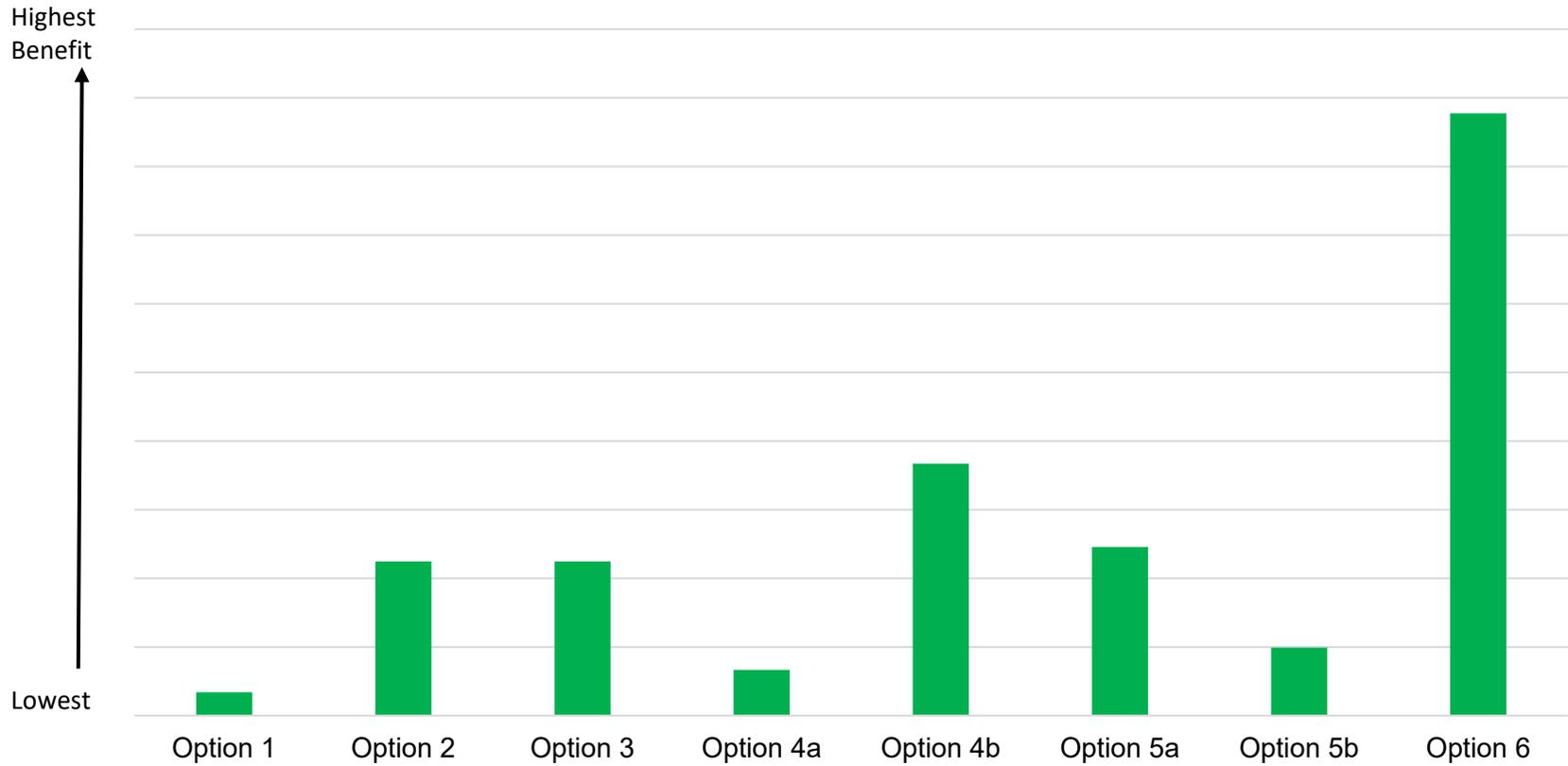


Figure 15.2: Order of magnitude of total benefit associated with each management option

16 Summary and conclusions

16.1 Preamble

Water quality within the Macleay River estuary has for many years been significantly impacted by runoff from degraded backswamps including the Collombatti-Clybucca floodplain. Low-lying ASS affected land has caused widespread impacts to the estuary. Historically, remediation of the floodplain has been conducted on a paddock scale, however remediation actions have been somewhat ineffective with poor water quality and low environmental values persisting. For the first time, remediation of the Clybucca floodplain has been made possible due to acquisition of the majority of the worst ASS affected low-lying land by TfNSW as part of the biodiversity offset requirements for the construction of the Oxley Highway to Kempsey Pacific Highway upgrade project. Furthermore, the NSW EPA has approved a supplementary offset strategy whereby the low-lying wetlands can be used to meet biodiversity offset requirements.

The remediation approach for the Clybucca floodplain involves modifying the current floodplain and drainage infrastructure to provide positive environmental outcomes on TfNSW owned land. It is important in this process that drainage of surrounding privately owned land is not negatively impacted. A detailed numerical model of the floodplain was developed based upon extensive field investigations to test different management options for the floodplain and enable outcomes to be quantified and risks identified. This model allows for quantifiable results of changes to the floodplain infrastructure to be measured and assessed prior to on-ground works. A detailed data collection program was completed to provide accurate data for model development, ensuring that results are reliable. Management options that were tested using the numerical model are detailed in Table 16.1.

The design of these options is such that a staged approach can be adopted for their implementation. For example, land management only (Option 1) can be implemented alongside each of the five (5) other management options. Similarly, modification of the floodgates to allow in-drain tidal flows (Option 4) can be implemented in combination with management of freshwater only on TfNSW land (Option 2) on upstream sections of the floodplain in Doughboy Swamp. Management Option 1 and Management Options 6 represent the least (Management Option 1) and greatest (Management Option 6) change to floodplain hydrology. It is envisaged that a staged implementation of management options will allow for remediation of the floodplain to occur with the best outcomes for all stakeholders while ensuring there is flexibility to cater to all stakeholder needs utilising an adaptive management approach.

Table 16.1: Summary of management options

Management option		Freshwater/tidal	Description
1	Land management only	Freshwater	Only land management actions such as fencing, weed control, native bush regeneration and acid scald remediation. No modifications to be made to the drainage network.
2	Shallow freshwater on low-lying wetland areas	Freshwater	Modification of weirs and levees to allow for freshwater inundation across low-lying wetland areas.
3	Shallow freshwater on low-lying wetland areas with extension of McAndrews Drain	Freshwater	The same as Management Option 2 with a new swale drain constructed connecting McAndrews Drain to Seven Oaks Drain.
4a	Modified floodgates to allow controlled in-drain tidal flushing	Tidal*	Modification of eight (8) floodgates to allow tidal water into the drainage network up to an elevation of -0.4 m AHD.
4b	Modified floodgates to allow controlled overland tidal flushing	Tidal*	Modification of eight (8) floodgates to allow tidal water into the drainage network and onto the floodplain up to an elevation of 0.0 m AHD.
5a	Decentralise floodgates to multiple locations – overland inundation	Tidal*	Decommission the Menarcobrinni floodgates after installing four (4) smaller floodgate structures upstream to allow overland inundation within Mayes and Doughboy Swamps.
5b	Decentralise floodgates to multiple locations – in-drain only	Tidal*	Decommission the Menarcobrinni floodgates after installing two (2) smaller floodgate structures upstream to allow in-drain tidal only flushing.
6	Fully open floodgates	Tidal	Hinge the floodgate flaps at Menarcobrinni open to allow unrestricted tidal flow.

*Freshwater management options can still be implemented in upstream sections of the drainage network.

16.2 Summary of numerical modelling results

Results from the numerical modelling process have been used to quantifiably assess the feasibility of each management option in terms of whether environmental remediation will be effective and whether drainage of private land will be affected.

Key findings from the study include:

- Management Option 1: Involves land use management only (no hydrological changes) so can proceed independently of this investigation.
- Management Option 2: Improved natural wetting (from catchment runoff) and drying of large areas of Mayes and Doughboy Swamp (the majority of which is within TfNSW property) can be achieved with minimal impacts to floodplain drainage, however private property on the eastern side of Mayes Swamp will experience increased frequency and time of freshwater inundation.
- Management Option 3: Extension of McAndrews Drain to join Seven Oaks Drain results in a minor improvement in drainage for upstream floodplain areas whilst maintaining the remediation outcomes in wetland areas (as investigated for Management Option 2).
- Management Option 4a: Modification of the Menarcobrinni floodgates to allow controlled in-drain tidal flushing results in tidal impacts to private land on the eastern side of Mayes Swamp unless a low tidal cut of level (-0.4 m AHD) is implemented. Tidal flushing with a -0.4m AHD cut off level only occurs during spring tides periods.
- Management Option 4b: Modification of the Menarcobrinni floodgates to allow controlled overbank tidal flushing to a tidal cut off level of 0.0m AHD results in permanent tidal inundation of Mayes Swamp and Yerbury's Scald, creating extensive intertidal wetlands. Private land on the eastern side of Mayes Swamp is inundated with tidal water.
- Management Option 5a: Relocation of the Menarcobrinni floodgates to multiple locations at the upstream boundary of TfNSW property results in permanent tidal inundation of Mayes Swamp, Doughboy Swamp and Yerbury's Scald. Private land on the eastern side of Mayes Swamp and south of TfNSW property is inundated with tidal water. Extensive additional on-ground works (e.g. levees, bunds and small floodgates) are required to mitigate impacts to private land). Vulnerability of the floodplain to backwater flooding from the Macleay River would be increased. Humpty-back Creek (adjacent to Macleay Valley Way) is inundated with tidal water.
- Management Option 5b: Relocation of the Menarcobrinni floodgates to two (2) locations at the downstream boundary of TfNSW property within Clybucca Creek and McAndrews Drain results in flushing of 6.6 km of drainage channel. Humpty-back Creek (adjacent to Macleay

Valley Way) is inundated with tidal water. Inundation of private land can be mitigated with minor additional on-ground works.

- Management Option 6: Implementation of full tidal flushing by hinging open the Menarcobrinni floodgates results in extensive tidal inundation across the Collombatti-Clybucca floodplain. The risk of backwater flooding from the Macleay River can be managed by closing the floodgates prior to flooding.

Findings from the numerical modelling for the remediation benefits of each of the management options have been summarised in Table 16.2. “Kilometres of drain remediated” in Table 15.2 has been assessed for freshwater as length of drain with an increase in water level and for tidal water as length of drain from the floodgates to the tidal extent. “Hectares of wetland” created has been assessed as the area upstream below a weir invert for freshwater options, or as the maximum tidal extent for tidal options.

Table 16.2: Summary of remediation benefits for each management option

Option number	Management option	Kilometres of drain remediated	Drain remediation strategy	Hectares of wetland	Wetland type
1	Land management only	None	-	None	-
2	Freshwater on low-lying wetland areas	12.5	Fresh	285	Fresh
3	Freshwater on low-lying wetland areas with extension of McAndrews Drain	12.5	Fresh	285	Fresh
4a	Modified floodgates to allow controlled in-drain tidal flushing	13.0	Tidal	None	Tidal
4b	Modified floodgates to allow controlled overland tidal flushing	22.5	Tidal	240	Tidal
5a	Decentralise floodgates to multiple locations – overland inundation	16.0	Tidal	115	Tidal
5b	Decentralise floodgates to multiple locations – in-drain only	6.6	Tidal	None	Tidal
6	Fully open floodgates	51.5	Tidal	725	Tidal

Selected management options were assessed for regional flood impact by Engeny (2020). Options 2, 3, 5b and 6 were assessed for the 0.2 EY and 1% AEP design events and compared to present day conditions. Based on Kempsey Shire Council's definition of adverse (above a 0.05 m increase

in flood level within the floodplain), the proposed remediation options do not result in any adverse impacts to flooding (Engeny, 2020).

16.3 Summary of costs and benefits

An indicative cost and benefit assessment has been completed to assist in determining the relative value of each management option. This is not an attempt to put an actual dollar value to the costs and benefits for each option, but rather to emphasise the types and sources of costs and benefits involved and the potential magnitude of them relative to each other. Furthermore, while some options can be implemented together (for example Management Option 2 and Management Option 4a), for the purpose of this assessment they were considered separately. A summary of the findings is provided in Table 16.3 which ranks each management option from lowest to highest in terms of its normalised cost and benefit.

Table 16.3: Relative indicative costs and benefits for each management option

Option number	Management option	Rank Cost	Rank Benefit
1	Land management only	Lowest	Lowest
2	Freshwater on low-lying wetland areas	Low	Upper middle
3	Freshwater on low-lying wetland areas with extension of McAndrews Drain	Lower middle	Upper middle
4a	Modified floodgates to allow controlled in-drain tidal flushing	Very low	Very low
4b	Modified floodgates to allow controlled overland tidal flushing	Very high	Very high
5a	Decentralise floodgates to multiple locations – overland inundation	High	High
5b	Decentralise floodgates to multiple locations – in-drain only	Upper middle	Low
6	Fully open floodgates	Highest	Highest

16.4 Summary of climate change impacts

The Macleay River estuary, inclusive of the Clybucca floodplain, is expected to be impacted by climate change manifested in both downstream (e.g. sea level rise) and upstream areas (e.g. extreme rainfall events) (Heimhuber et al., 2019b). To quantify the effects of climate change on the Clybucca floodplain, sea level rise was chosen as a key climate driver to assess. Note, this is one

factor within a complex mechanism of change the estuary will experience and considerably more research will be required to quantify the effects of climate change on estuary (Heimhuber et al., 2019c and Dominguez et al., 2019). The influence of sea level rise on present day floodplain hydrology (i.e. Menarcobrinni floodgates management maintained) for near future (2050 +0.4m SLR) and far future (2100 +0.9m SLR) scenarios was investigated.

The assessment of sea level rise indicated that near future (2050) and far future (2100) sea levels under climate change will significantly and permanently alter floodplain hydrology and increase inundation of floodplain areas (regardless of floodgate management). The climate change assessment indicates:

- There will be an average increase in depth from 0.10 m to 0.50 m across Mayes Swamp and Yerbury's Scald due to sea level rise by 2050, and in excess of 0.5 m by 2100;
- There will be an average increase in depth of 0.30 m across Doughboy Swamp due to sea level rise by 2050;
- Inundation frequency will increase to up to 100% of the time within low-lying floodplain management areas due to sea level rise by 2050;
- There will be an average increase in depth of between 0.10 m and 0.30 m across large extents of low-lying floodplain including privately owned land due to sea level rise in 2100;
- Inundation frequency will increase to up to 100% of the time on areas that become inundated, including privately owned land, due to sea level rise in 2100; and
- Inundation will be freshwater and caused by catchment inflows being unable to drain due to elevated water levels in the Macleay River estuary.

16.5 Recommendations

Management options have been assessed for day-to-day drainage for catchment runoff and minor inundation events (~1 year catchment event). Management options are currently being assessed for impacts to design flood levels using the lower Macleay River flood model (Jacobs, 2019), with outcomes from the flood assessment due in March 2020.

Based on the investigations completed to date, the recommendations for the future management of the Clybucca Wetlands include:

- Determining the long-term tenure of the TfNSW property;
- Continued consultation with floodplain landholders, particularly the Seven Oaks Drainage Union and private landholders on Mayes Swamp;

- Continued consultation with key stakeholders;
- Implementation of Management Option 1 (land management);
- Implementation of Management Option 2 or 3 (shallow freshwater on Mayes Swamp, Doughboy Swamp and Yerbury's Scald) in consultation with the Seven Oaks Drainage Union and private landholders on Mayes Swamp;
- Further investigation of implementation of tidal flushing remediation solutions in consultation with floodplain landholders and Kempsey Shire Council (floodgate owners); and
- Strategic planning regarding the future of floodplain land use under climate change.

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Appendix A Acid sulfate soil theory

A 1 Preamble

Early experiences with Acid Sulfate Soils (ASS), formerly known as ‘cat clays’, date back to the 17th century in the Netherlands, and the late-19th century in Australia, but it was not until the early 1970s that acidic clays on coastal floodplains were causing problems worldwide. Since then the various manifestations and impacts of ASS has been extensively researched and are consequently well known, both overseas and in Australia. This section provides an introduction to the pertinent aspects of ASS theory, including its formation, mobilisation, and the various land and water impacts.

A 2 What are acid sulfate soils?

Acid Sulfate Soils is the common name given to soils and sediments containing iron sulfides, the most common being pyrite (FeS_2) (DERM, 2009). ASS is chemically inert whilst in reducing (anaerobic) conditions, including when situated below the water table, and are known as potential acid sulfate soils (PASS). When PASS is exposed to atmospheric oxygen due to climatic, hydrological, or geological changes, oxidation occurs. The oxidised layer produces sulfuric acid and is termed an actual acid sulfate soil (AASS).

Ahern et al. (1998) defines ASS as:

“Naturally occurring sediments and soils containing iron sulfides principally iron sulfide or iron disulfide or their precursors). The exposure of the sulfide in these soils to oxygen by drainage or excavation leads to the generation of sulfuric acid.”

AASS is defined as soils with an acidity level resulting in a pH of 4 or less. PASS are soils with a pH greater than 4 which contain iron sulfides or sulfidic material which will oxidise when exposed to air and form AASS.

A.2.1. Formation

ASS are predominantly located within five (5) metres of the surface and are found extensively on Australia’s coastline (DERM, 2009). Pyrite is formed in reducing environments where there is a supply of easily obtained decomposed organic matter, sulfate, iron and reducing bacteria (Figure A - 1). The deposition of these sands and muds occurs in low-lying coastal zones characterised by

low energy environments, such as estuaries and coastal lakes. ASS that are of concern on Australia's coastal floodplains were formed during the last 10,000 years (i.e. the Holocene epoch).

DERM (2009) stipulates that the formation of pyrite requires:

- A supply of sulfur (usually from seawater);
- Anaerobic (oxygen-free) conditions;
- A supply of energy for bacteria (usually decomposing organic matter);
- A system to remove reaction products (e.g. tidal flushing of the system);
- A source of iron (most often from terrestrial sediments); and
- Temperatures greater than 10°C.

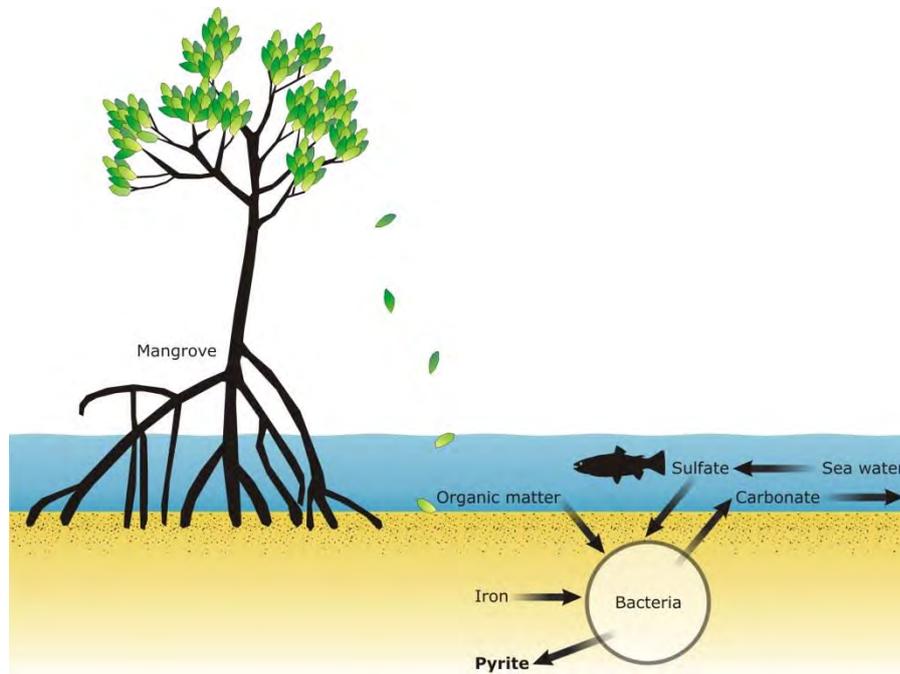


Figure A - 1: Pyrite formation (NRM, 2011)

A.2.2. Acidification

The pH scale (Figure A - 2) is used to grade acidity and is a measure of the hydrogen ion (H^+) concentration. The pH scale is logarithmic, ranging from 0 (strongly acidic) to 14 (strongly alkaline). Due to the logarithmic scale, a soil with a pH of 4 is 10 times more acidic than a soil with a pH of 5, and 1,000 times more acidic than a soil with a pH of 7 (NRM, 2011).

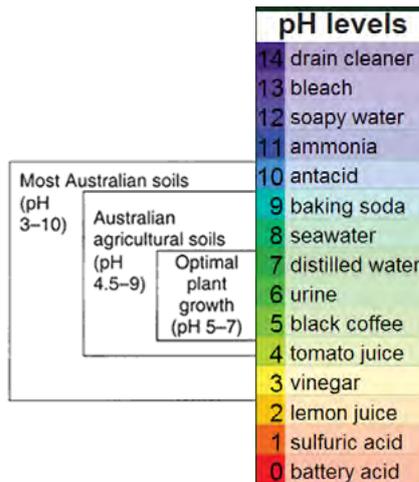
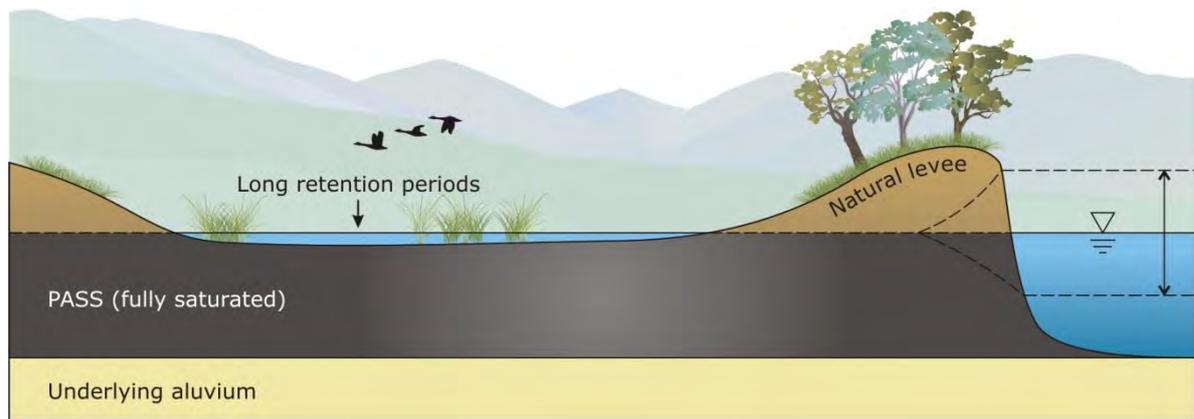


Figure A - 2: pH scale (NRM, 2011)

Potential Acid Sulfate Soils (PASS) are oxidised to form Actual Acid Sulfate Soils (AASS) by clearing of coastal land for agriculture, resulting in extensive drainage and a lower groundwater table, introducing gaseous oxygen into the soil matrix. When pyrite is exposed to atmospheric oxygen, the iron sulfides react to form sulfuric acid and numerous iron cations (e.g. Fe^{2+} and Fe^{3+}). The acid generated can break down the fine clay particles in the soil profile, causing the release of metals, including aluminium (Al^{2+}). Generated acid is often mobilised from the soil matrix by rainfall raising the groundwater table, resulting in discharge into the drainage network or other receiving waters (Figure A - 3). Depending on the pyrite content of the soil, acidity levels can fall below a pH of 4.5. At a pH of 4.5, iron and aluminium concentrations become soluble and can greatly exceed environmentally acceptable levels.

The soil structure of coastal floodplains is typically comprised of five (5) distinct zones of varying thickness. On the surface, an organic peat layer exists comprised largely of roots and decomposing matter. This layer transforms into an alluvial/clay zone. An AASS layer commonly exists below this and can be identified by the presence of orange/yellow mottling caused by the oxidation of pyrite. This soil layer often overlies a PASS layer characterised by dark grey, saturated estuarine mud. The PASS layer often has a pH near neutral, as pyritic material in the soil is unoxidised. The PASS layer is underlain by non-acidic sub-soil.

Undisturbed Environment



Drained Paddock



Figure A - 3: Soil acidification by lowering of groundwater levels

A 3 Groundwater drainage

The construction of deep drainage channels on floodplains acts to drain the low-lying backswamp and wetland areas, to allow for agricultural production. However, on coastal floodplains, drainage channels also allow tidal water to potentially inundate pasture and groundwater. As such, one-way floodgates are commonly installed to reduce tidal inundation of backswamp areas. The tidal floodgates restrict saline intrusion and may provide livestock with a source of drinking water (Figure A - 4).

In areas affected by ASS, the combination of deep drainage channels and one-way floodgates increases ASS oxidation, create acid reservoirs, and restrict potential buffering (or neutralisation) of acid by tidal waters. Floodgates and drainage structures are usually designed to maintain drain levels at the low tide mark to drain backswamp areas and reduce pasture water logging (Glamore,

2003). Since the pyritic layer is normally at the mid to high tide level, by maintaining drain water elevations lower than the pyritic layer, such as the low tide elevation, one-way floodgates increase the hydraulic gradient between the drain water and the surrounding acidic groundwater (Glamore, 2003).

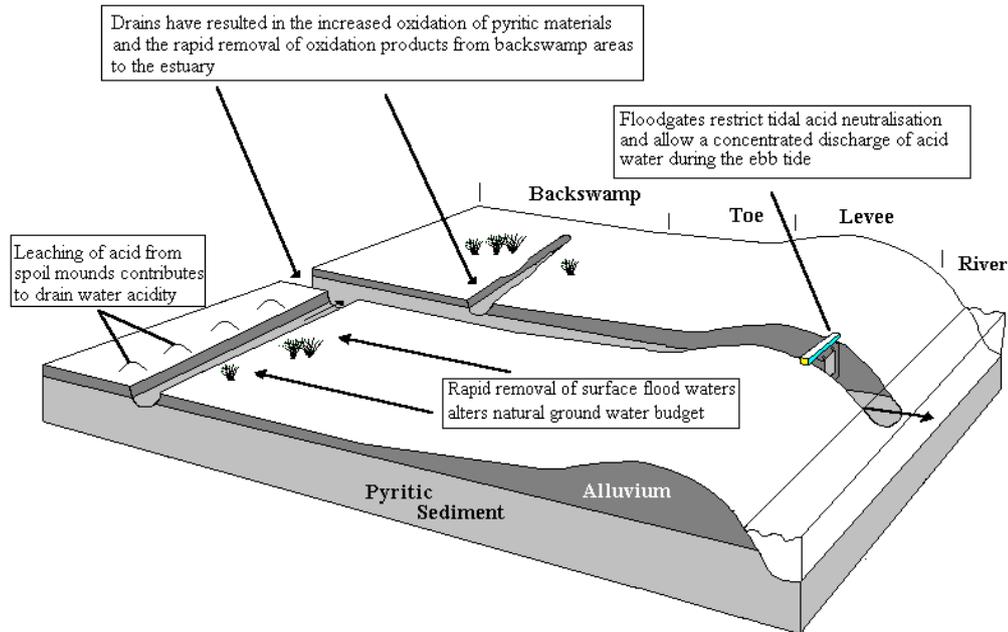


Figure A - 4: Schematic of a backswamp drainage and floodgate network (Naylor et al., 1998)

The difference in the hydraulic gradient between the groundwater table and the drain, caused by the one-way tidal floodgates, promotes the transport of oxygen into sulfidic subsoil material and the leaching of acid by-products into the drain (Blunden and Indraratna, 2000). This is particularly evident following large rainfall events when receiving water levels drop, groundwater levels remain elevated, and floodgates effectively drain surface waters from the floodplain causing low drain water levels (Glamore and Indraratna, 2001).

The depth of a drain (or drain invert) in relation to the acidic layer influences the potential risk of acid discharge. A deeply incised drain with a low invert constructed in a shallow AASS layer has a high risk, or potential, for acidic discharge. Conversely, a shallow drain constructed in the same shallow AASS layer floodplain will have a lower risk of acid discharge.

The ease at which groundwater flows through the soil and into a drain also influences the risk of acid discharge. Soil with a low potential groundwater flow rate, or low hydraulic conductivity, will export less acid compared to a soil with a high groundwater flow rate. This effectively relates back

to the porosity of the soil. Generally, gravel is more porous than sand, which is more porous than clay. The higher the porosity, the greater potential for rapid acid discharge into a drain.

A 4 Acid discharge

In a similar manner to geographical/geomorphological descriptions of estuaries internationally, Australian estuaries have recently been classified by Digby (1999). Digby (1999) describes an Australian estuary classification regime based on climate and hydrology. In Australia, most estuaries (approximately 70%) fall within the wet and dry tropical/subtropical category. These estuarine systems are dominated by episodic short-lived large freshwater inputs during summer, and very little or no flow during winter. Under high flows, saltwater may be flushed out of these estuaries completely. Many of these estuaries have a high tidal range, so following a flushing event, a salt-wedge intrudes along the estuary bottom, and the estuary progresses from a highly stratified salt-wedge estuary to a partially mixed estuary, to a vertically homogeneous estuary.

An understanding of estuarine systems in NSW under various climatic conditions has important implications for the cause and effect of acid discharges from coastal floodplains. While the water in drains on ASS-affected coastal floodplains can be highly acidic on a day-to-day basis, large plumes of acidic discharge are not typically recorded within estuaries during dry conditions. Conversely, large quantities of acid are often discharged following significant rainfall events. This typically occurs in the 5 to 14 days following the peak of a flood event. During other periods, the risk of widespread acidic contamination to the estuary is reduced.

Figure A - 5 depicts a period of strong tidal flushing, limited acid flux (concentration x discharge) and thereby, high tidal buffering. The acid buffering capacity of an estuary is directly proportional to the volume of buffering agents within the system (Rayner et al., 2015). In areas with limited upstream inflows of buffering agents, the primary buffering agents are sourced from the diffusion of marine constituents. During dry climatic conditions (little or no flow), bicarbonate-rich seawater diffuses upstream from the tidal ocean boundary creating a salinity gradient throughout the estuary creating low acid risk conditions.

Figure A - 6 depicts a period during or immediately following a flood event, whereby coastal floodplains are inundated with fresh floodwaters. As the floodwaters recede, large volumes of freshwater drain from the floodplain into the estuary. This process, in conjunction with large freshwater flows in the main river channel, reduces estuarine salinity. During these periods, acid is quickly flushed from the estuary and/or is highly diluted.

Figure A - 7 depicts a period after floodwaters have receded and tidal levels slowly re-establish. During this period, floodplain pastures are saturated and groundwater levels remain elevated, resulting in a steep gradient between drain water levels and the surrounding groundwater. This process mobilises acid from the soil towards drainage channels and receiving waters (Figure A - 8). As the natural buffering capacity of the estuary has been removed by the fresh floodwaters, acidic plumes comprised of low pH water and high soluble metal concentration remain in the open estuary.

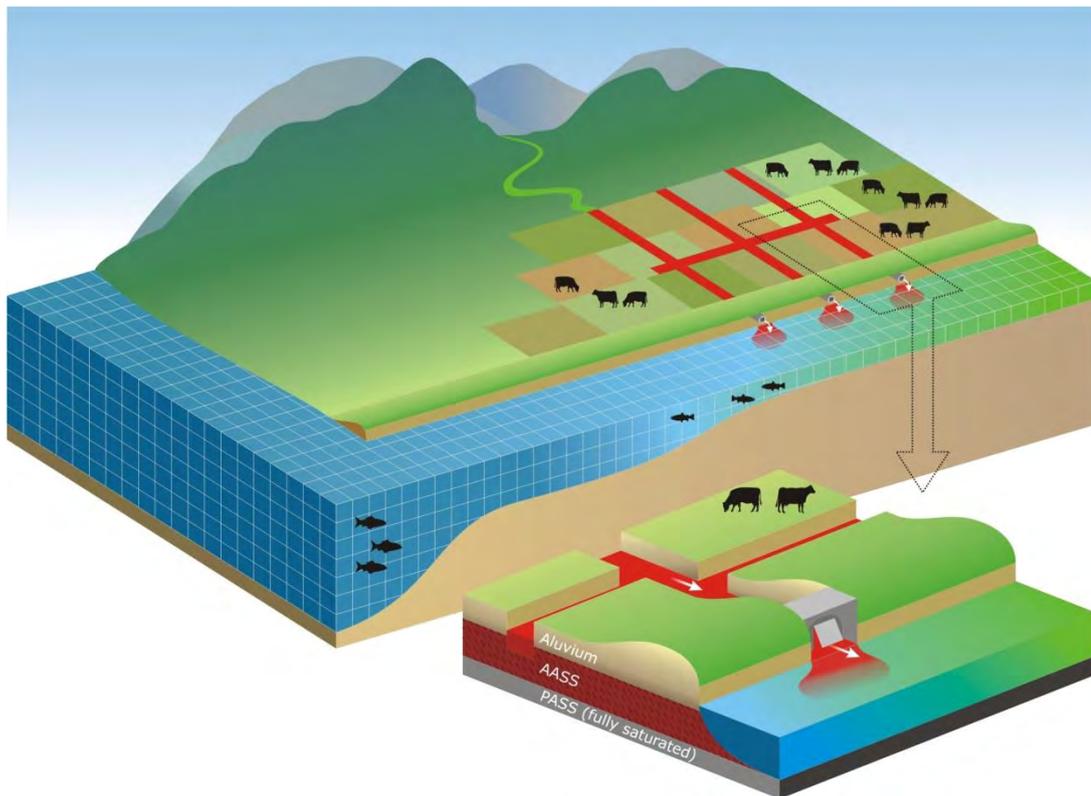


Figure A - 5: Period of tidal buffering and low acid risk

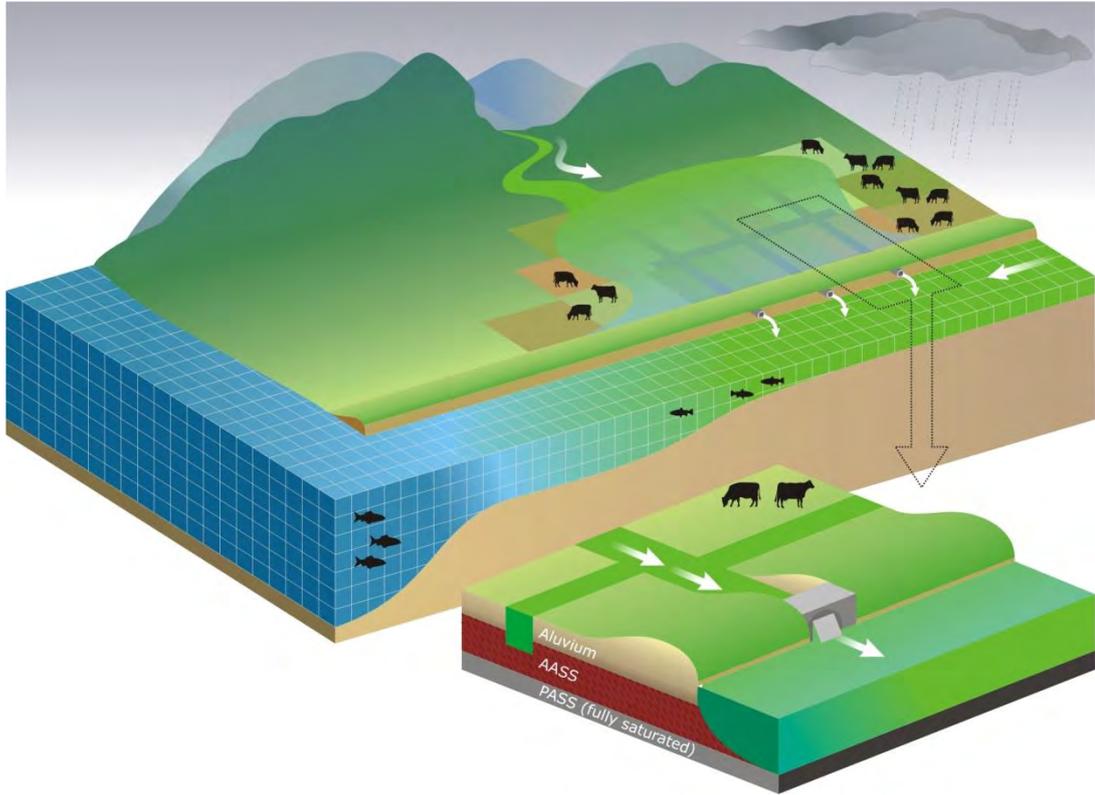


Figure A - 6: Flow dilution period as a result of a large rainfall event

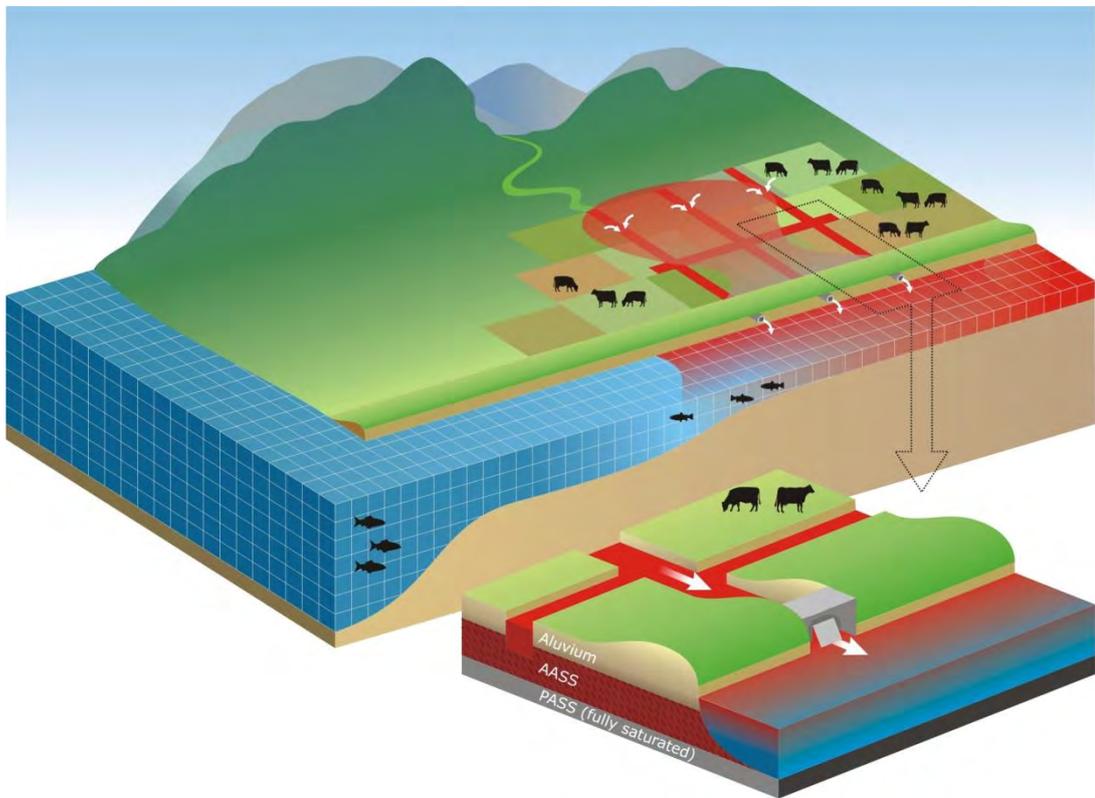


Figure A - 7: Period of acid impact following rainfall event

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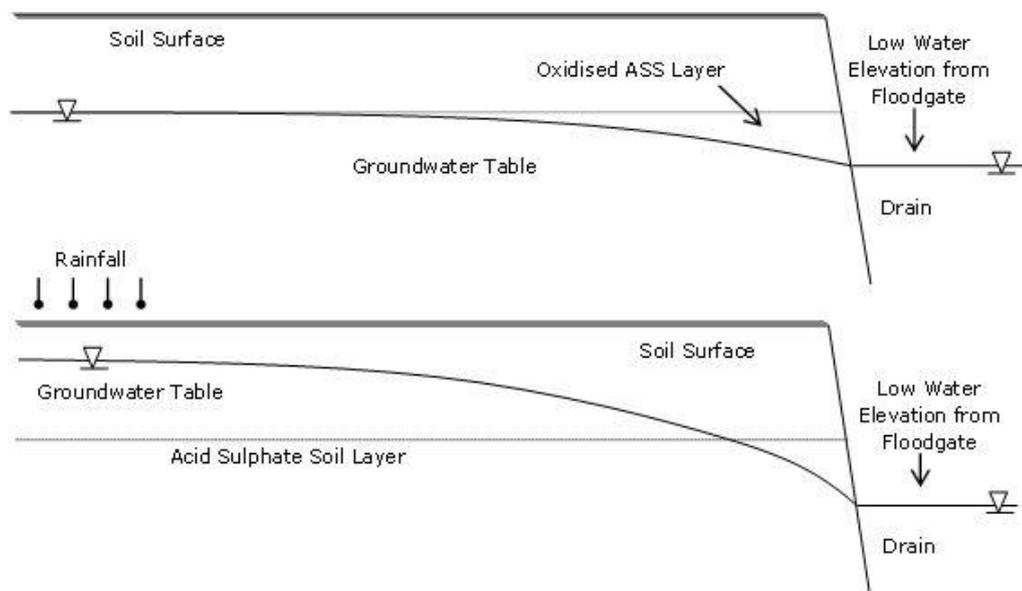


Figure A - 8: Influence of one-way floodgates on groundwater elevation under normal (top) and flood (bottom) conditions (Glamore, 2003)

A 5 Environmental impacts

Pyrite oxidation causes adverse environmental, ecological, and economic effects worldwide. Soil acidification can lead to a deficiency in essential plant nutrients and plant base minerals such as calcium, magnesium, and potassium, while at the same time, toxic metals such as, aluminium, iron, and other heavy metals may increase. Furthermore, the release of acidic plumes, containing aluminium and iron flocs, is well-known to cause widespread environmental pollution in tidal estuaries resulting in large scale fish kills and negatively impacts oyster health (Dove and Sammut, 2007).

In 2008, the NSW Office of Environment and Heritage (formerly the NSW Department of Environment and Climate Change (DECC, 2008)) identified numerous environmental impacts of acid discharge including:

- Habitat degradation;
- Fish kills;
- Outbreaks of fish disease;
- Reduced resources for aquatic food;
- Reduced ability of fish to migrate;
- Reduced recruitment of fish;

- Changes to communities of water plants;
- Weed invasion by acid-tolerant plants;
- Subsidence and structural corrosion of engineering structures; and
- Indirect degradation of water quality.

Aasø (2000) notes further chronic impacts, such as:

- Loss of spawning sites and recruitment failure in both estuarine and fresh-water species;
- Habitat degradation and fragmentation from acid plumes, thermochemical, stratification of waters and the smothering of benthos from iron oxy-hydroxide flocculation;
- Altered population demographics within species;
- Simplified estuarine biodiversity with invasions of acid-tolerant exotics and loss of native species; and
- Reduction in dissolved nutrients and organic matter entering the estuarine food web.

Key Points For Acid Sulfate Soils

- Pyrite is a natural soil, which when left undisturbed, does not produce acid;
- Acid is naturally buffered by bicarbonate (present in seawater);
- Drainage of soil containing pyrite results in oxidation and acid formation with a pH below 4;
- Deep drainage channels constructed in ASS increase acid export;
- A by-product of acid production is high concentrations of iron and aluminium;
- One-way floodgates maintain low drain water levels which results in a large gradient between the drain and surrounding groundwater, leaching acidic water into the drain;
- Acid drainage is greatest following flood events; and
- Acid plumes with high metal content are highly toxic to aquatic flora and fauna.

Appendix B Existing data

B 1 Preamble

This appendix summarises data that has previously been collected across the Clybucca floodplain that is relevant to this study. Data collected has been summarised in the following sections and includes:

- Ground surface elevation aerial survey (i.e. LiDAR);
- Other ground surface elevation survey;
- Structures;
- Bathymetry;
- Acid sulfate soils and groundwater;
- Water levels;
- Water quality; and
- Groundwater hydraulic conductivity.

B 2 Ground surface elevation aerial survey

Since 2009, the ground surface elevation on the Clybucca floodplain has been measured three (3) times. These measurements have been taken using either LiDAR or UAV (unmanned aerial vehicle) photogrammetry. Table B - 1 outlines the details of each survey.

Table B - 1: Aerial ground elevation survey details

ID	Date measured	Location	Survey technique	Resolution (m ²)
2009	10/2009 – 03/2010	Macleay Region	Lidar	1
2016	29/07/2016	Macleay Region	Lidar	1
2016	27-29/07/2016	Clybucca Floodplain	UAV photogrammetry	~0.6

Each of the three (3) surveys are shown in Figure B – 1 for comparison. An advantage of LiDAR and UAV photogrammetry is that the elevation across large areas can be measured quickly. However, due to the methodology of these surveys, the ground elevation of areas covered with water is not accurately measured. For this reason, areas such as Mayes Swamp or drainage channels, which during the time of surveys were covered with water, are not accurately represented in the surface elevation data and need to be measured using alternate methods.

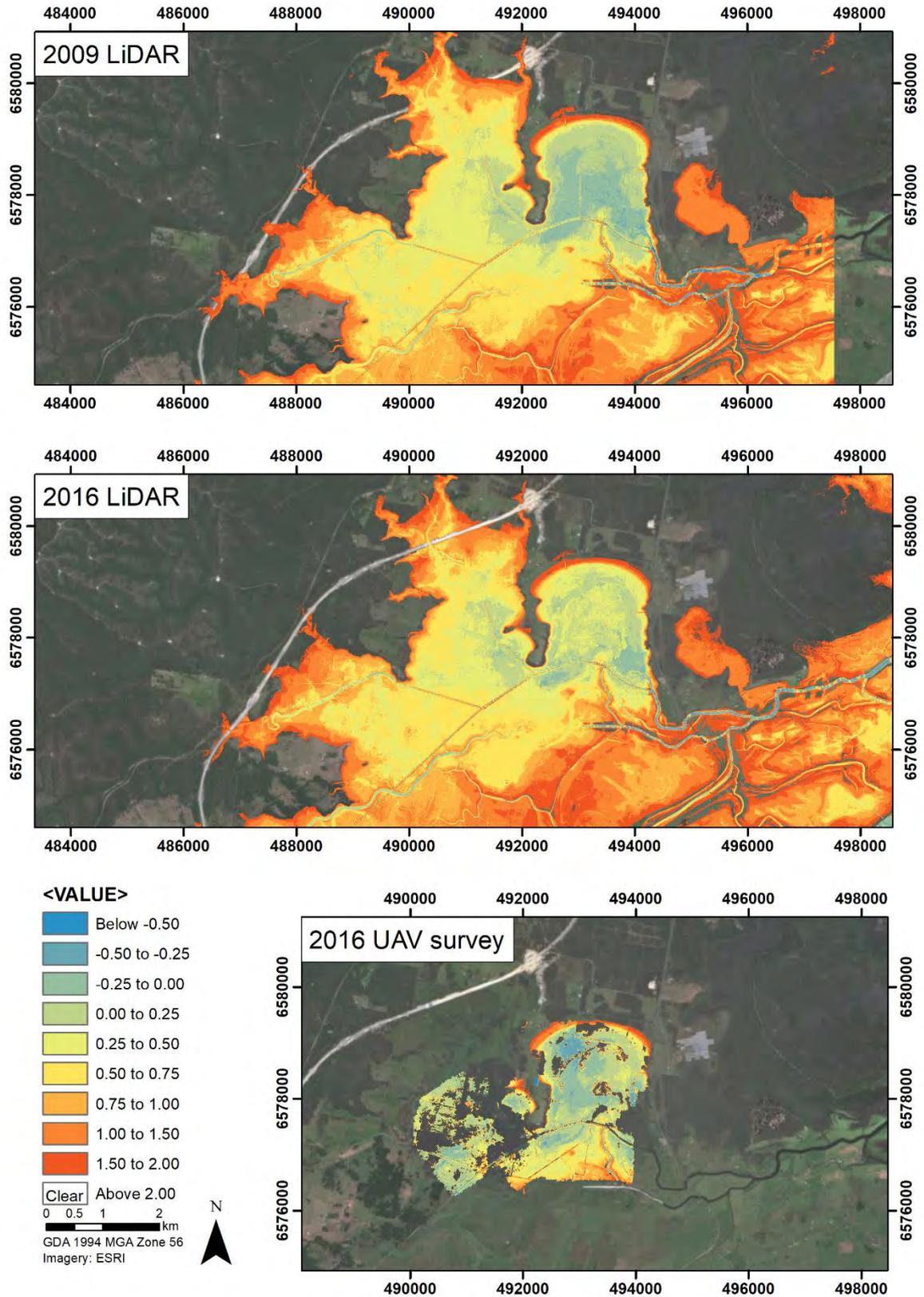


Figure B – 1: Aerial ground elevation survey data

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B 3 Other ground surface elevation survey

In addition to LiDAR and UAV photogrammetry, historic measurements of the ground surface were taken using differential GPS methods. As part of the ASS 'hot spot' program East Coast GPS Surveys (ECG) conducted a survey of the Clybucca floodplain (KSC, 2004). As part of this survey, ground surface elevation points, creek inverts, drain inverts and benchmarks were measured. The survey data was provided in MGA co-ordinates and using the Australian Height Datum (AHD). This data was converted from the ellipsoid height to AHD using the AUSGeoid98 model. For consistency, for this study the geoid model for this data was changed to AUSGeoid09 during data analysis. This survey data was used to verify the LiDAR and UAV surveys.

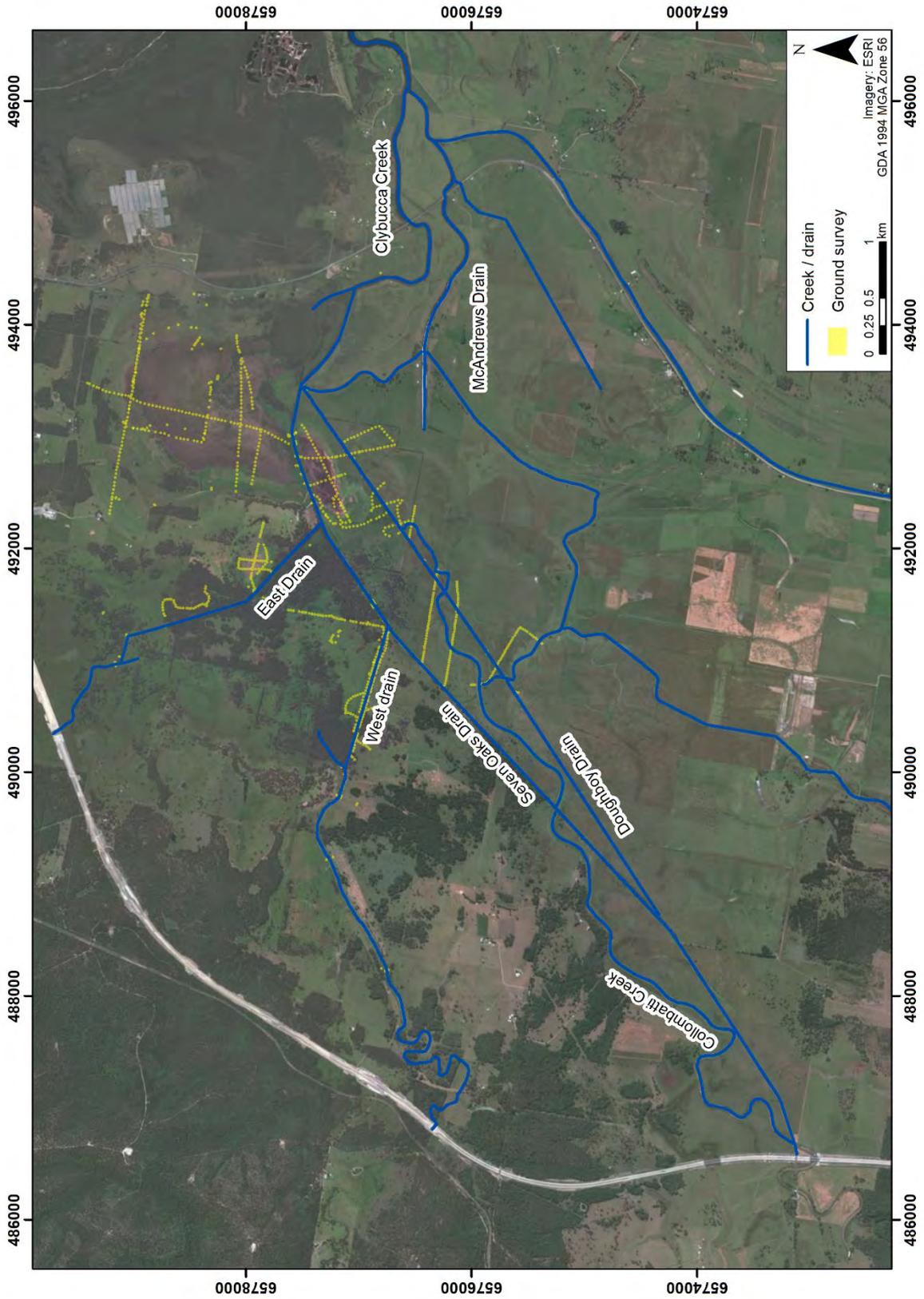


Figure B - 2: Additional ground surface elevation data (KSC, 2004)

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B 4 Structures

During investigations carried out as part of the Clybucca floodplain feasibility study, several of the main structures throughout the Clybucca floodplain were surveyed (Glamore and Rayner, 2017). These surveys were conducted from 2015 to 2016 are summarised in Table B - 2.

Table B - 2: Key hydraulic structures (Glamore and Rayner, 2017)

Structure	Location	Easting (GDA94)	Northing (GDA94)	Details
Floodgates	Menarcobrinni	496428	6576620	Crest = 1.5 m AHD Invert = - 2.1 m AHD 1.8 m wide x 2.1 m high 21 culverts
Weir	Seven Oaks Drain (Yerbury's Sill)	493015	6577593	Crest = - 0.3 m AHD Width = 14 m
Weir	East Drain	491627	6577901	Crest = - 0.2 m AHD Width = 9 m
Weir with low-flow culvert	West Drain	491123	6576796	Crest = 0.1 m AHD Width = 9 m Culvert invert = - 0.1 m AHD Culvert diam. = 450 mm
Weir	West Drain			Crest = 0.2 m AHD Width = 4 m

Information on structures throughout the floodplain were also outlined by as part of the 'hot spot' works conducted on the Clybucca floodplain (Enginuity Design, 2003 and KSC, 2004).

Furthermore, information on the designs for key drainage channels in the Seven Oaks area has been outlined by the Department of Public Works (PWD, 1978).

B 5 Bathymetry

Bathymetry data of the drainage network has been collected on three (3) separate occasions. Surveys conducted by ECG Surveys as part of the 'hot spot' program included the invert of drainage channels and creek beds (KSC, 2004). In 2015, WRL conducted a number of cross-section surveys along Seven Oaks Drain and West Drain. This was further supplemented by a hydro survey of McAndrews Drain, Clybucca Creek (upstream of the floodgates) and a section of Seven Oaks Drain. Coverage of the existing bathymetric datasets is shown in Figure B - 3.

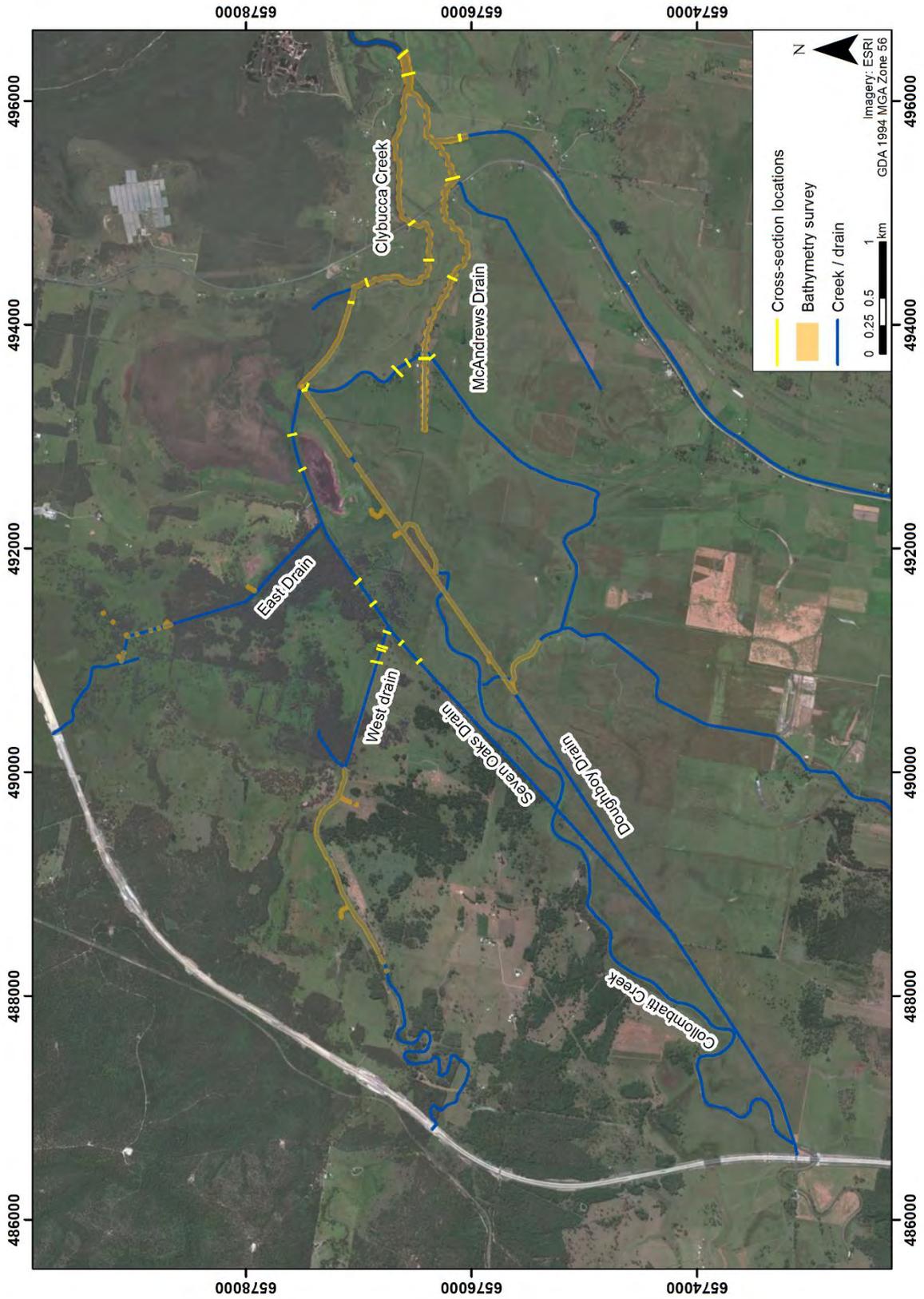


Figure B - 3: Existing bathymetric survey data

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B 6 Acid sulfate soils and groundwater

In 1998, the NSW Department of Land and Water Conservation (DLWC, now the Department of Planning, Industry and Environment) released acid sulfate soil (ASS) risk maps to provide information on land management and rehabilitation (Figure B - 4) (Naylor et al., 1998). These maps show large areas on the Clybucca floodplain which are classified as 'high risk.' Mayes Swamp and Yerbury's Scald are classified as 'high risk' with shallow ASS close to the surface. Due to its high risk and the observed impacts of ASS, the Clybucca floodplain was classified as an ASS 'hot spot' area (Enginuity Design, 2003). During the process of the Clybucca Floodplain being classified as a 'hot spot' area, and since, there has been several field investigations focused on identifying ASS. In particular, these investigations involved the collection of soil profile data.

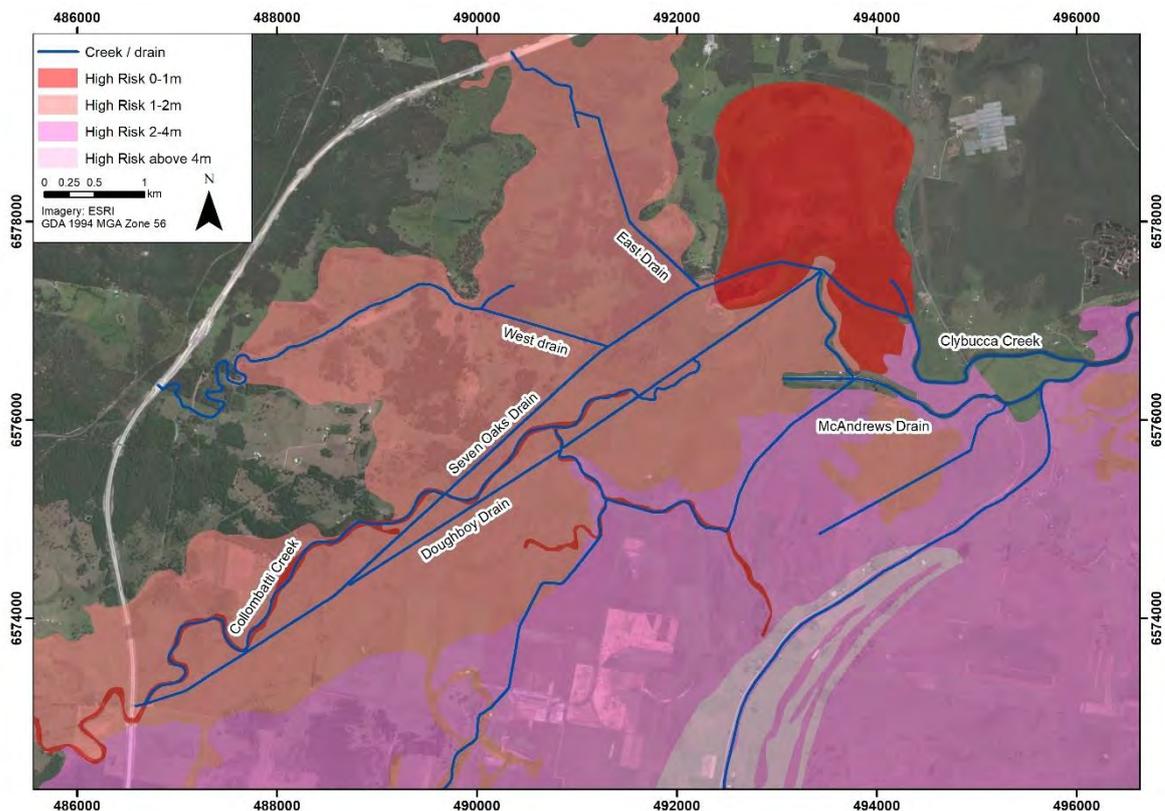


Figure B - 4: DLWC ASS risk map for the Clybucca region (Naylor, 1997)

In addition to this information, numerous soil profile datasets have been collected on the Clybucca floodplain. This has been sourced from:

- eSPADE (OEH, 2016);
- KSC (2004);

- Eddie (2000);
- NSW ESS (Cheeseman et al., 2004); and
- Edeson et al. (2004).

eSPADE (OEH, 2016) provides a substantial database of information collected by earth scientists and other technical experts. eSPADE contains descriptions of soils, landscapes and other geographic features, and is used by the NSW Government, other organisations, and individuals, to improve planning and decision-making for land management. Data for a total of 26 soil profiles were available within the study area from the eSPADE database (see Figure B - 6). This data was collected through multiple investigations including:

- Atkinson in 1990 and 1994;
- Eddie in 1996; and
- Naylor in 1994.

Eddie (2000) investigated the soil landscape at Seven Oaks as illustrated in Figure B - 5 and described in Table B - 3. Eddie (2000) classified the risk of acid sulfate soil exposure as 'high.' Due to the lowering of the water table below type se4 and se5 soils, occurrences of acid runoff into waterways has occurred. Soil profiles 1 and 2 (bold in Figure B - 5) are included in Figure B - 6.

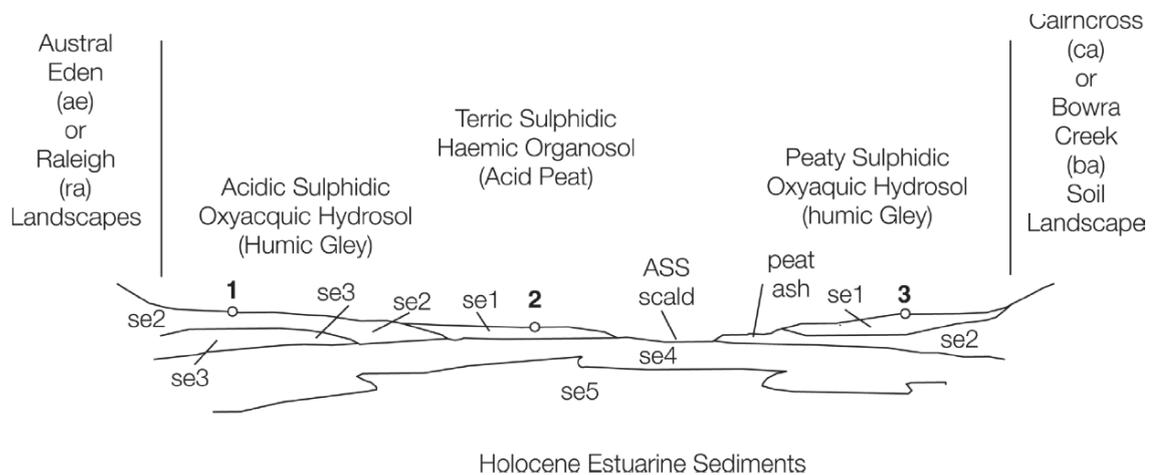


Figure B - 5: Seven Oaks soil landscape (Eddie, 2000)

Table B - 3: Seven Oaks soil landscape (Eddie, 2000)

Type	Description
se1	Dark peat (topsoil, P horizons). Black, brownish black to brown fibric or hemic peats, becoming more sapric and clayey with depth; occasionally with weak 2 - 5 mm crumb peds when dry; field pH 4.5 to 5.5.
se2	Dark clay loam (topsoil, A horizon). Brownish black or dark brown (occasional red mottles following root channels and on ped surfaces) clay loam or silty clay loam; massive or with moderate polyhedral or crumb peds when dry; field pH 4.5 to 5.5.
se3	Black organic clay (subsoil, B horizons). Brownish or olive-black (whole-coloured or with faint orange mottles) medium silty clay or clay; massive when wet or strongly structured with smooth-faced 50 - 200 mm prismatic or angular blocky peds parting to weak granular peds; field pH 4.5 to 5.0.
se4	Grey massive clay (subsoil, Gr/Gj horizon). Steely dark grey or brownish yellowish grey (often with distinct jarositic mottles) light to medium silty clay or clay; massive; saturated; field pH 3.0 (oxidised) to 9.0 (unripe); often contains fine shell fragments when unripe.
se5	Grey estuarine clayey sand (subsoil, Gr/Gj horizon). Grey or yellowish grey to yellowish brown (whole-coloured or with yellow mottles) fine clayey sand or fine sandy clay loam; single-grained or massive; field pH 3.5 (oxidised) to 7.0 (unripe); often contains fine shell fragments when unripe; saturated; often has H ₂ S smell when exposed.

In 2003, Enginuity Design developed a management plan for the Clybucca ‘hot spot’ area. As part of this plan several potential mitigation strategies were outlined with the aim of managing acid on the Clybucca floodplain. From 2003 to 2004 a number of the mitigation strategies were implemented on the Clybucca floodplain by Kempsey Shire Council (KSC, 2004). As part of these works various field investigations were conducted across the floodplain including the analysis of seven (7) soil profiles. The specific locations of these soil profiles were not specified.

As part of the NSW Environmental Services Scheme a study was conducted in 2004 to determine the effectiveness of changing physical characteristics of Yerbury’s Scald (Cheeseman et al., 2004). As part of this study six (6) soil profiles were sampled along a transect extending south from Seven Oaks Drains across Yerbury’s Scald.

In a study aimed at assessing the effectiveness of freshwater ponding on ASS, Edeson et al., (2004) completed 14 soil profiles along a transect spanning across Mayes swamp. The study included taking soil cores, measuring surface water elevation and testing soil pH, moisture, percentage of organic matter, electrical conductivity and percentage pyrite. The location of all soil profiles is shown in Figure B - 6.

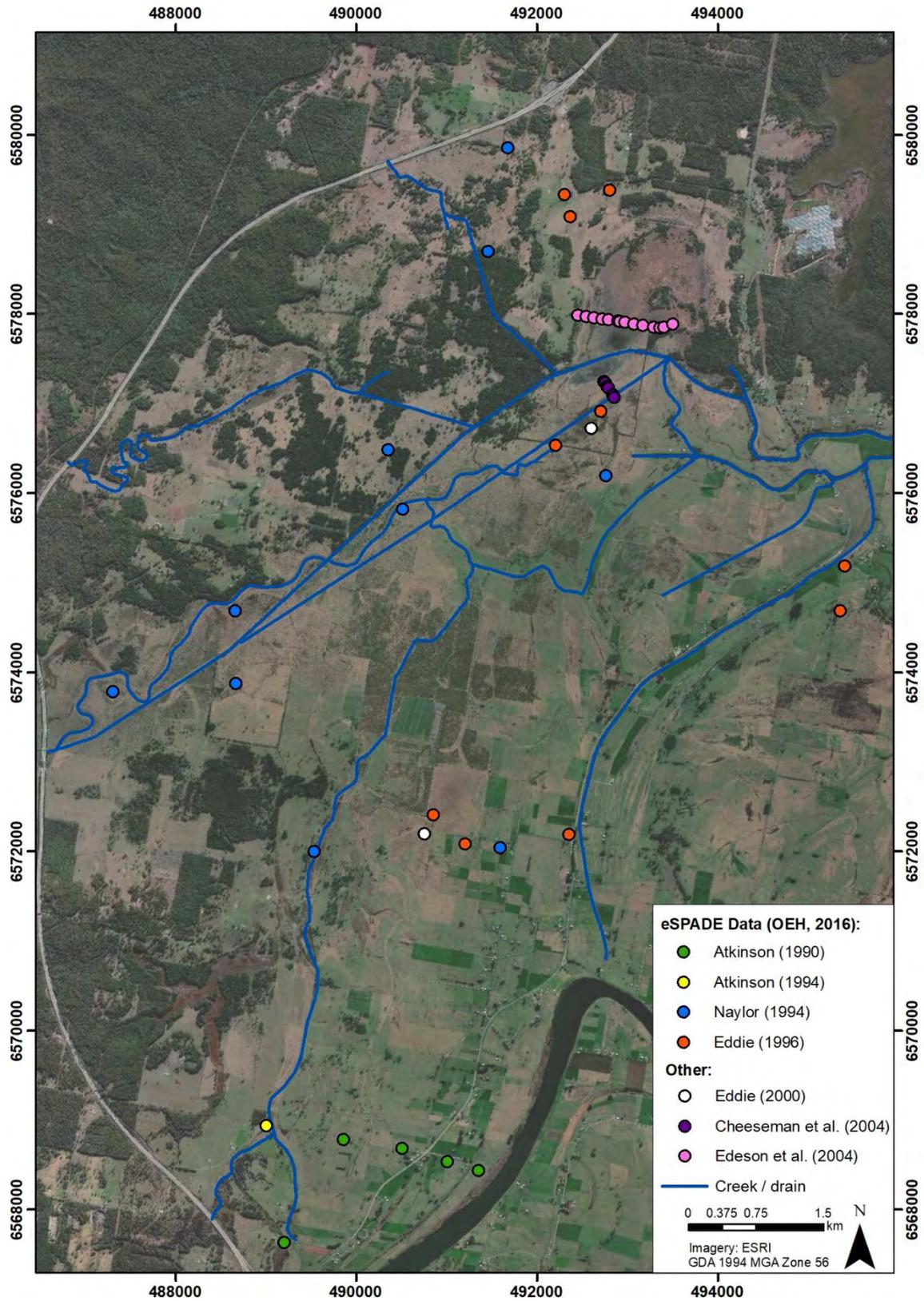


Figure B - 6: Historical soil profile data on the Clybucca floodplain

B 7 Water levels

There are multiple existing datasets for water levels across the Clybucca floodplain. These are summarised in Table B - 4. In addition to these measurements, as summarised by Glamore and Rayner (2017), MHL and Water NSW are currently collecting continuous water level measurements across the Macleay River Estuary. The data collected by Glamore and Rayner (2017) is presented in Figure B - 7 compensated barometrically and corrected to AHD.

Table B - 4: Summary of historical water level data collected

Source	Location	Start date	End Date
Greenspan (KSC, 2004)	Upstream and downstream of Menarcobrinni floodgates	1/07/1999	30/07/2004
MHL (2004)	Menarcobrinni floodgates	15/04/2003	22/05/2003
KSC (2004)	Piezometers upstream and downstream of East Drain, West Drain and Seven Oaks Drain structures	02/07/2002	01/07/2004
Bush et. al., (2006)	Upstream and downstream of Menarcobrinni floodgates	01/03/2002	01/07/2005
Glamore and Rayner (2017)	Various locations within drains on the Clybucca floodplain	11/02/2015	06/08/2015

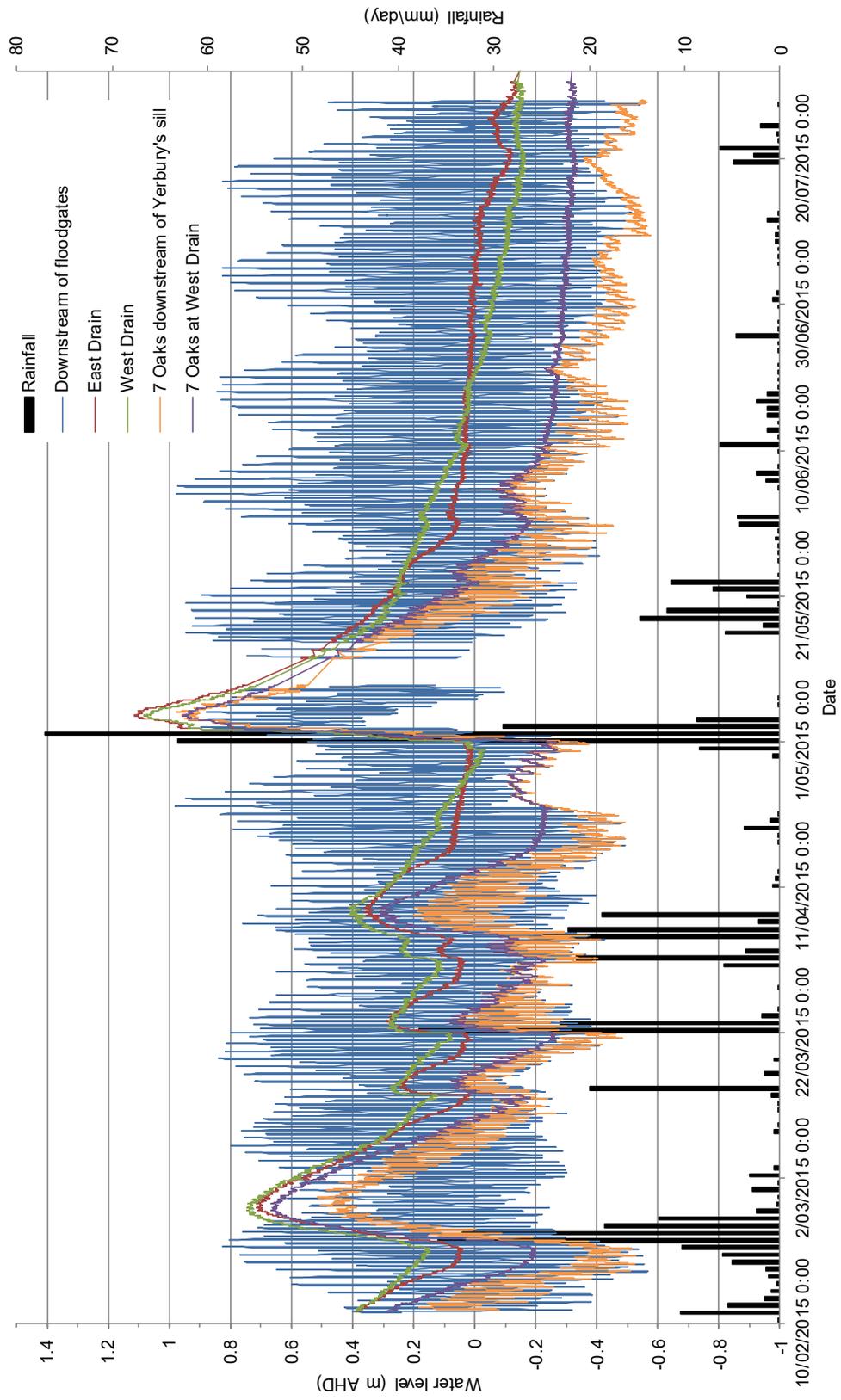


Figure B - 7: Water level data collected by Glamore and Rayner (2017)

B 8 Water quality

The Clybucca floodplain has been the focus of numerous studies which have collected water quality data, including:

- PWD: 1977 (PWD, 1978)
- Greenspan: 1998 to 2004 (KSC, 2004)
- KSC: 2002 to 2004 (KSC, 2004)
- Bush et al.: 2002 to 2005 (Bush et al., 2016)
- Cheeseman: 2004 (Cheeseman et al., 2004)
- Glamore and Rayner: 2015 (Glamore and Rayner, 2017)
- Weekly Kempsey Shire Council at Menarcobrinni Gates (Glamore and Rayner, 2017): 2009 to 2017

As part of the development of the environmental impact statement for additional drainage of the Seven Oaks area, the NSW Department of Public works collected various water quality measurements (PWD, 1978). These water quality measurements were timed to coincide with a flood event occurring on May 19, 1977 and included multiple measurements with the last being four (4) months after flood conditions had receded (in September 1977). Water quality characteristics measured included pH, turbidity, chlorides, suspended solids and salinity. Measurements were taken at seven (7) locations from Andersons Inlet to the Menarcobrinni floodgates.

In addition to measuring water levels from August 1998 to August 2004, Greenspan measured electrical conductivity, pH, oxidation-reduction potential and dissolved oxygen both upstream and downstream of the Menarcobrinni floodgates (KSC, 2004). This data set consists of a continuous timeseries measured on an hourly interval. It was completed as part of the Clybucca 'hot spot' program (Enginuity Design, 2003).

Kempsey Shire Council (KSC) also collected multiple water quality measurements throughout the 'hot spot' area between 2002 and 2004 (KSC, 2004). Monitoring data as part of this program is summarised in Table B - 5. Monitoring was conducted for surface water and groundwater.

**Table B - 5: Summary of water quality monitoring performed by KSC at Clybucca
(Table 2, KSC, 2004)**

Monitoring Point	Surface Water	Groundwater
Seven Oaks Drain	Real time data logger – pH, DO, EC, ORP, WL, Temp	
Southern Pond (Yerbury’s Scald)	Hand held monitor – pH, DO, EC, WL Temp	9 piezometers – WL, pH, EC
Mayes Swamp	Hand held monitor – pH, DO, EC, WL Temp	4 piezometers – WL, pH, EC
East Drain	Hand held monitor – pH, DO, EC, WL Temp	7 piezometers – WL, pH, EC
West Drain	Hand held monitor – pH, DO, EC, WL Temp	7 piezometers – WL, pH, EC

Between 2002 and 2005, Bush et al. (2006) conducted water quality measurements upstream and downstream of the Menarcobrinni floodgates. These measurements included pH, electrical conductivity, dissolved oxygen and oxidation-reduction potential. This work was conducted to assess the effectiveness of the on-ground works completed in 2004 as part of the ‘hot spot’ program.

During the NSW Environmental Services Scheme (ESS) the effectiveness of restoration to Yerbury’s Scald was assessed through surface water and groundwater quality monitoring (Cheeseman et. al., 2004). Measurements included pH, electrical conductivity and reduction potential. Measurements were taken along a transect beginning within Yerbury’s Scald and extending south for approximately 300 metres. Samples were taken continuously for one (1) day (April 22, 2004).

Glamore and Rayner (2017) measured electrical conductivity downstream of the Menarcobrinni floodgates and on Seven Oaks Drain downstream of Yerbury’s Sill. The results of these measurements are shown in Figure B - 8. Measurements were taken from February 11 to May 5, 2005.

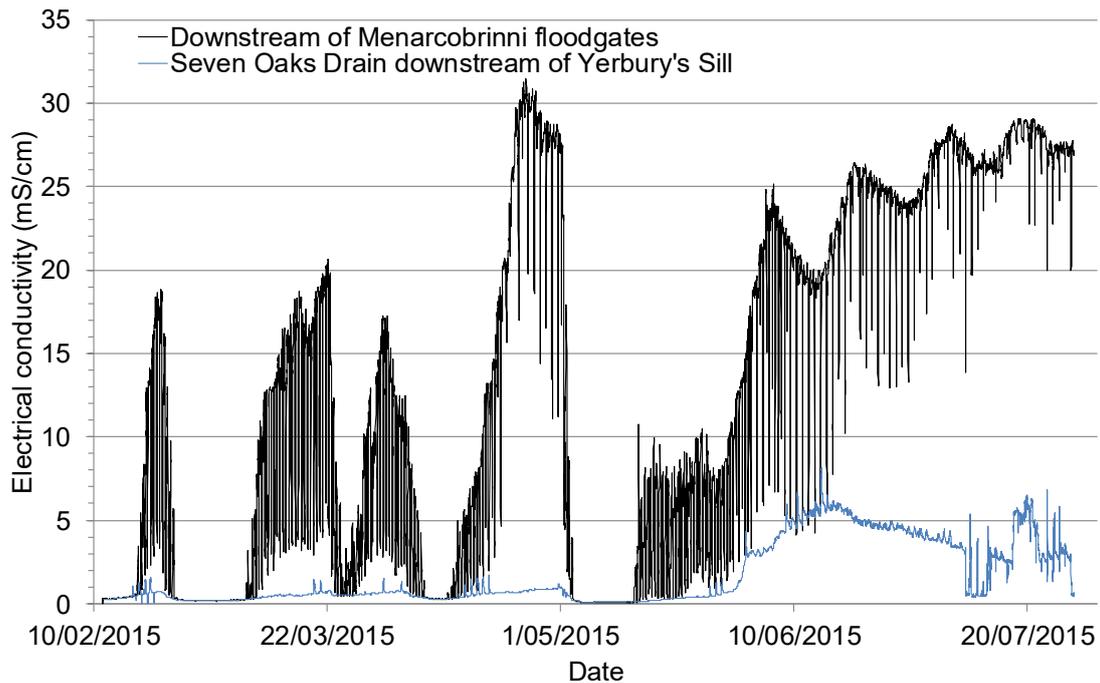


Figure B - 8: Salinity measurements downstream and upstream of the Menarcobrinni floodgates (Glamore and Rayner, 2017)

Recent water quality monitoring has been conducted by Kempsey Shire Council (Glamore and Rayner, 2017). This monitoring has been conducted weekly at the Menarcobrinni floodgates. Parameters measured include temperature, pH, oxidation-reduction potential, electrical conductivity, dissolved oxygen and salinity.

B 9 Groundwater hydraulic conductivity (K_{sat})

The hydraulic conductivity of soil is defined as the constant of proportionality in Darcy's Law, which describes the flow of a fluid (usually water) through a porous medium. The law was formulated by Henry Darcy based on the results of experiments on the flow of water through beds of sand, and is expressed as:

$$V = K \left(\frac{dh}{dx} \right)$$

where,

V = apparent velocity of the groundwater (m/d)

K = hydraulic conductivity (m/d)

h = hydraulic head (m)

x = distance in the direction of groundwater flow (m).

Unconfined aquifers (e.g. coastal floodplains) of shallow to intermediate depth (e.g. up to 10 m depth) are associated with the presence of a free-water table, so the groundwater can flow in any direction, however the flow of groundwater to subsurface drains is mainly horizontal. A schematic of an unconfined aquifer of shallow to intermediate depth is provided in Figure B - 9. The K-value of a saturated soil (K_{sat}) represents its average hydraulic conductivity, which depends mainly on the size, shape, and distribution of the pore spaces in the soil profile. Measurement of K_{sat} by the open pit method outlined in Johnston et al., (2003a), can produce varying results depending on the presence of macropores in the pit. The presence of macropores (large pores in the soil created by gaps left from roots and organic matter that has broken down) can increase measured K_{sat} rates from extreme low (<0.0001 m/day) to high (>15 m/day). Subsequently, hydraulic conductivity measurements across ASS-affected floodplains can be highly variable, and should be taken as estimates of the flow connectivity between shallow groundwater and subsurface drains, and the potential risk for ASS discharges. Table B - 6 outlines the risk classifications for various hydraulic conductivities.

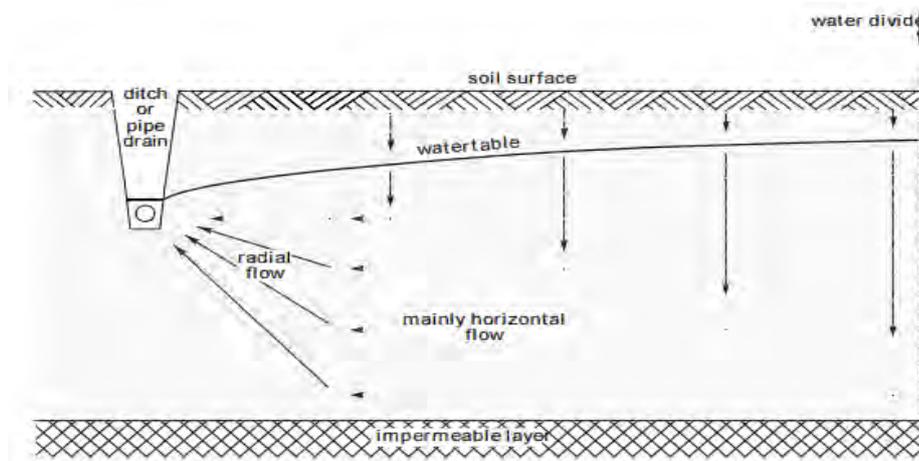


Figure B - 9: Groundwater flow to subsurface drains in unconfined aquifers of intermediate depth

Table B - 6: Risk classification for approximate rates of hydraulic conductivity

Risk Classification	Approximate K_{sat} (m/day)
Extreme	~100
High	15 to 100
Moderate	1.5 to 15
Low	<1.5

Measurements of hydraulic conductivity across the Clybucca floodplain were undertaken as part of the 'hot spot' program (KSC, 2004). Using the method outlined by Johnson et al., (2003), two (2) tests were conducted to determine hydraulic conductivity. Results from a test pit completed in Latham's Scald (on the eastern bank of East Drain) are shown in Figure B - 10. Results from a test pit completed in Mayes Swamp are shown in Figure B - 11. K_{sat} pits in these locations had a risk classification from moderate to high.

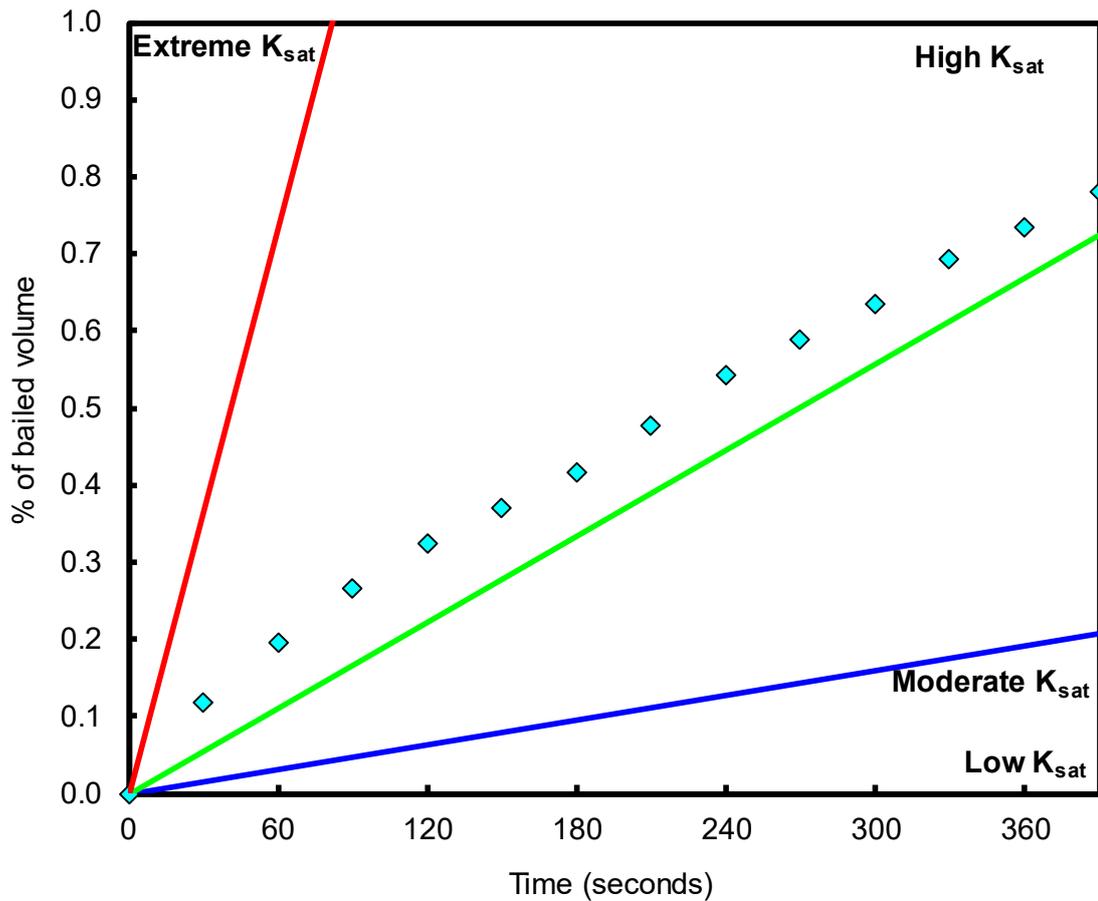


Figure B - 10: Hydraulic conductivity measured at Latham's Scald

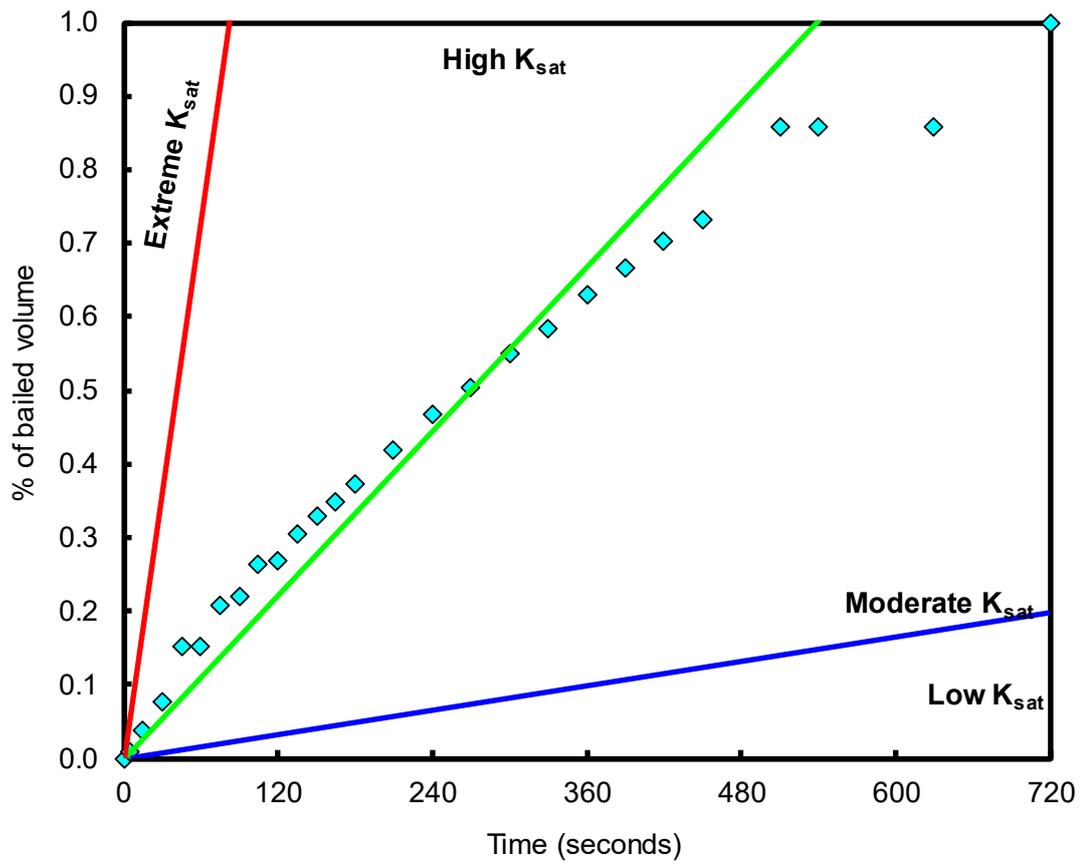


Figure B - 11: Hydraulic conductivity measured on Mayes Swamp

Appendix C Field investigation

C 1 Preamble

To develop the numerical model of the Clybucca floodplain further data needed to be gathered. The following section details data that has been collected by WRL over four (4) field campaigns completed in 2018 and 2019. This data was targeted to fill specific gaps within the existing dataset to allow for improved understanding of the hydrological process on the Clybucca floodplain. Data collected includes:

- Additional ground elevation survey;
- Structures;
- Drain and creek channel cross-sections;
- Water levels;
- Water quality;
- Acid sulfate soils; and
- Groundwater hydraulic conductivity.

C 2 Data accuracy

The majority of elevation data was collected using Trimble R10 RTK-GPS GNSS receiver (R10) survey equipment. The R10 acts as a roving unit which connects to a network of continuously operating stationary reference stations (CORS), specifically CORSnet-NSW. Data collected at Clybucca has been referenced to either the Macksville or Willawarrin CORSnet-NSW base stations. By comparing the current GNSS position of the roving R10 receiver with satellite position data being gathered simultaneously by the CORS network, an accurate location and elevation can be obtained. When only a single base CORS station is used the vertical accuracy of the R10 position is ± 15 mm plus 1 mm for every kilometre the R10 roving unit is from the base station. Network RTK positioning is possible when two or more base stations are used for correcting position data. This allows for the vertical accuracy of the R10 position to be ± 15 mm plus 0.5 mm for every kilometre the R10 unit is from the closest base station. Note this is the maximum accuracy. Further uncertainty in measurements is associated with atmospheric conditions, signal multipath, obstructions and satellite geometry.

In total 34,509 RTK survey points were taken across the Clybucca floodplain. Of these points, 90% had an accuracy of up to ± 42 mm and 99% had an accuracy of 96 mm or better. Key percentile values are shown in Table C - 1 with all percentile values shown in Figure C - 1.

Table C - 1: Vertical accuracy of Trimble R10 GNSS survey measurements

Percentile value (%)	Vertical accuracy (m)
5	0.017
10	0.019
25	0.022
50	0.026
75	0.032
90	0.042
95	0.056
99	0.096

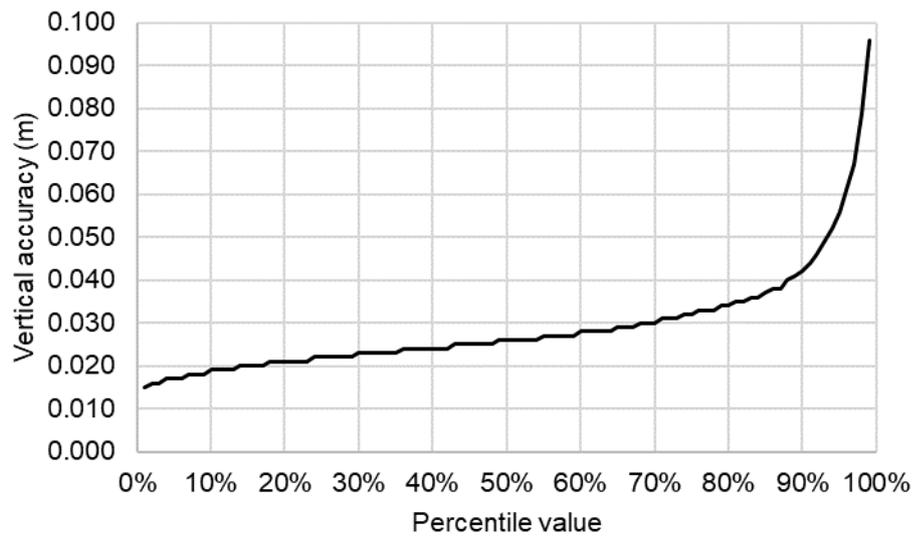


Figure C - 1: Percentile distribution for the vertical accuracy of Trimble R10 survey measurements

Accuracy of water level loggers varies from 5 mm to 15 mm. Individual accuracy for each logger has been specified in Section C 6. Accuracy of EXO2 and Hach water quality measurements are specified in Table C - 2.

Table C - 2: Water quality measurement equipment accuracy

Equipment	Sensor	Accuracy
EXO2	Conductivity	±1% of reading
EXO2	Dissolved oxygen	±1% of reading or 1% of air saturation (whichever is greater)
EXO2	pH	±0.2 pH units
EXO2	Chlorophyll	±0.01 µg/L with R ² >0.999
HACH	pH	±0.1 pH units

C 3 Additional ground elevation survey

WRL has taken an extensive number of survey measurements of the ground elevation on the Clybucca floodplain to verify the existing LiDAR levels using Trimble R10 GNSS receiver survey equipment. The extent of the survey is shown in Figure C - 2. Surveys were conducted using WRL's quadbike with a custom built mount for the Trimble R10 GNSS receiver designed to allow accurate coverage of large areas. In conjunction to the quadbike surveys, traditional point elevation measurements were taken on foot where the quad bike could not gain access; this included areas such as Mayes Swamp. Accuracy of the quadbike survey system is to ±0.2 m. This takes into account error associated with the Trimble R10 GNSS receiver unit in addition to error associated with the pitch roll and suspension of the quadbike.

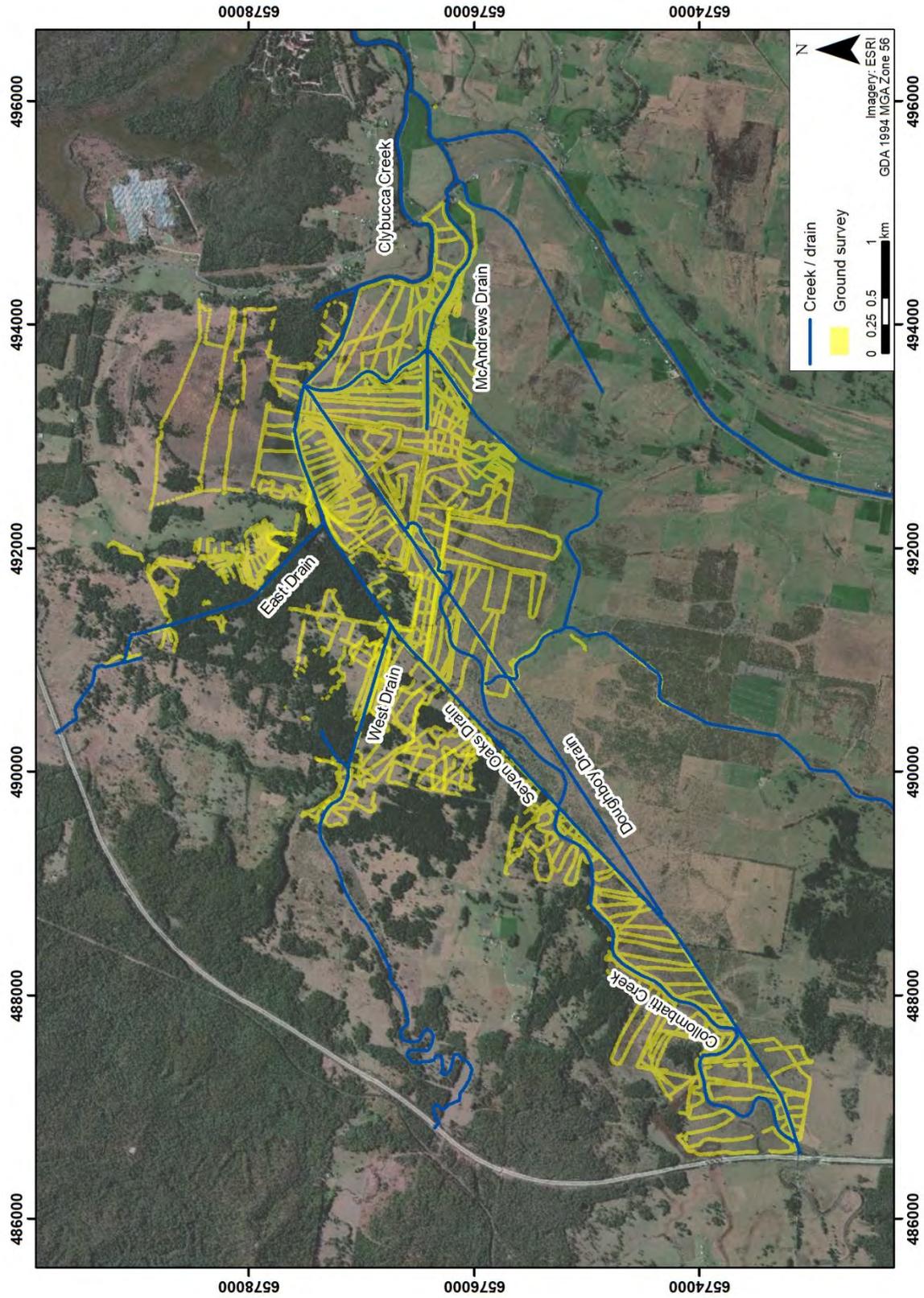


Figure C - 2: Extent of ground elevation data collected to verify LiDAR measurements

C4 Structures

During field investigations a total 60 structures were identified and surveyed across the Clybucca floodplain. Structures were surveyed using Trimble R10 GNSS RTK GPS receiver equipment. These structures included weirs, culverts and bridges. Figure C - 1 outlines the location of each structure surveyed. Table C - 3 outlines key attributes of each structure referenced in Figure C - 1.

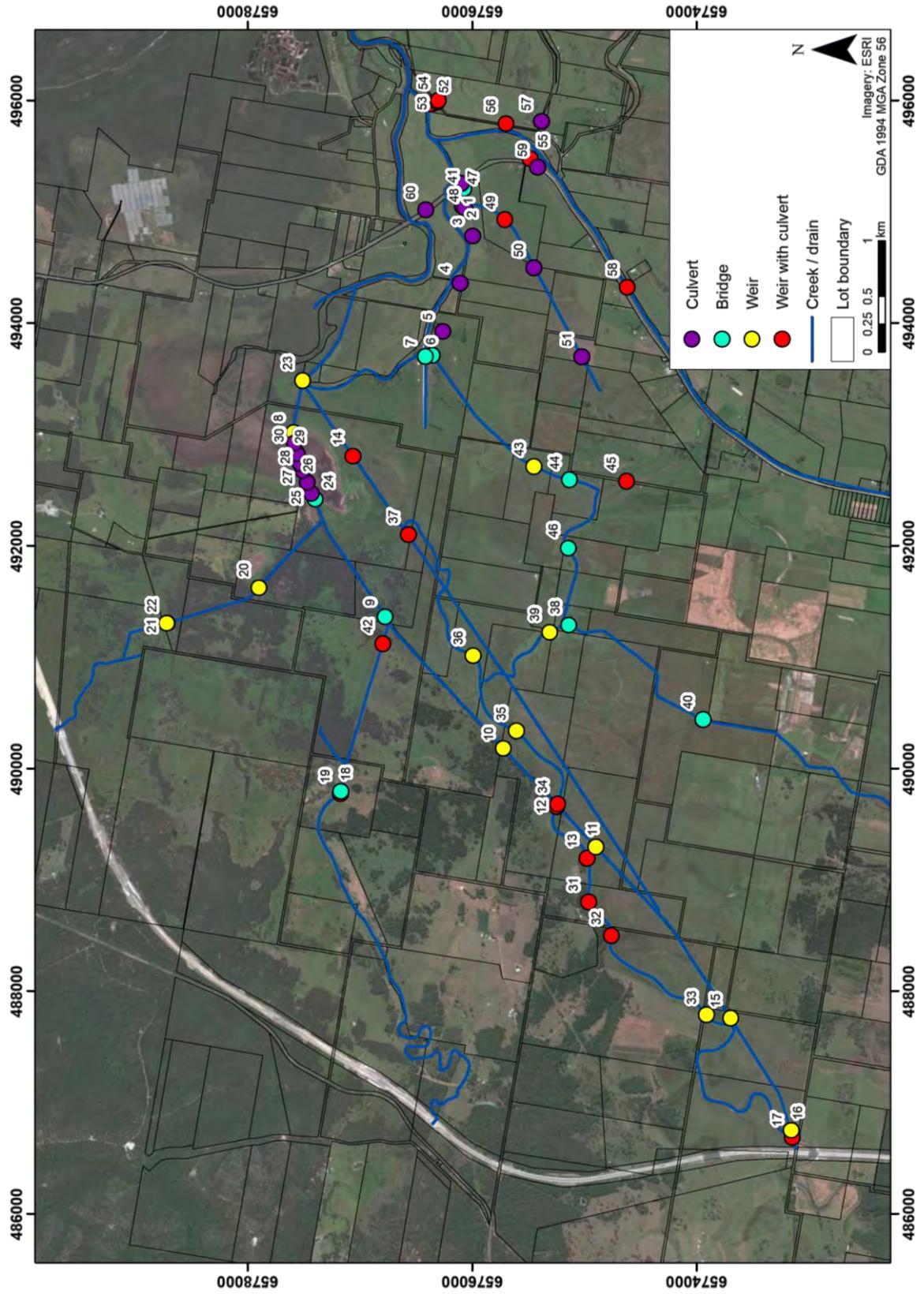


Figure C - 3: Location of structures surveyed

Table C - 3: Dimensions of structures surveyed

ID	Creek/drain	Type	Easting	Northing	Diameter (m)	Width (m)	Height (m)	Number of culverts	Length (m)**	Upstream invert (m AHD)*	Downstream invert (m AHD)*	Crest elevation (m AHD)*
1	McAndrews Drain bank	Culvert	495050	6576088	0.4			1	5	0.94	1.01	
2	McAndrews Drain bank	Culvert	495032	6576066	0.4			1	5	0.85	0.80	
3	McAndrews Drain bank	Culvert	494783	6575995	0.3			1	5	0.97	0.85	
4	McAndrews Drain bank	Culvert	494359	6576108	0.4			1	6	0.83	0.83	
5	McAndrews Drain bank	Culvert	493928	6576260		0.5	0.95	1	3.5	0.33	0.30	
6	Shackles Drain	Bridge	493709	6576355					15			1.47
7	McAndrews Drain	Bridge	493700	6576416					50			1.47
8	Seven Oaks Drain (Yerbury's Sill)	Weir	493017	6577592								-0.35
9	Seven Oaks Drain	Bridge	491364	6576776					15			0.79
10	Seven Oaks Drain	Weir	490184	6575719								-0.10
11	Collombatti Creek	Weir/Culvert	489659	6575247	0.4			5	2		-0.3	0.36
12	Seven Oaks Drain	Weir	489296	6574898								0.12
13	Collombatti Creek	Weir/Culvert	489195	6574975	0.45			1	5		-0.25	0.46
14	Doughboy Drain	Weir/Culvert	492808	6577061	0.5			3	5	0.10		0.90
15	Seven Oaks Drain	Weir	487759	6573696								-0.18
16	Seven Oaks Drain	Weir	486751	6573157								0.22
17	Collombatti Creek	Weir/Culvert	486688	6573148	0.45			5	5	-0.05		0.44
18	West Drain	Bridge	489795	6577169					10			0.20
19	West Drain	Weir/Culvert	489775	6577174	0.45			1	5	-0.15	-0.20	0.15
20	East Drain	Weir	491624	6577899					9			-0.19
21	East Drain	Weir/Culvert	491307	6578717	0.37			5	5	-0.26		0.84

ID	Creek/drain	Type	Easting	Northing	Diameter (m)	Width (m)	Height (m)	Number of culverts	Length (m)**	Upstream invert (m AHD)*	Downstream invert (m AHD)*	Crest elevation (m AHD)*
22	East Drain	Weir	491307	6578720								0.25
23	Seven Oaks Drain	Weir	493484	6577510								0.52
24	Seven Oaks Drain	Bridge	492420	6577397					20			0.65
25	Seven Oaks Drain (to Mayes Swamp)	Culvert	492472	6577432	0.375			1	5	-0.33		
26	Seven Oaks Drain (to Mayes Swamp)	Culvert	492570	6577469	0.375			1	5	-0.41		
27	Seven Oaks Drain (to Mayes Swamp)	Culvert	492676	6577508	0.45			2	5	-0.60		
28	Seven Oaks Drain (to Mayes Swamp)	Culvert	492738	6577530	0.45			1	5	-0.48		
29	Seven Oaks Drain (to Mayes Swamp)	Culvert	492825	6577560	0.45			2	5	-0.54		
30	Seven Oaks Drain (to Mayes Swamp)	Culvert	492923	6577585	0.45			1	10	-0.35		
31	Collombatti Creek	Weir/Culvert	488800	6574962	0.50			1	5	-0.11	-0.23	0.52
32	Collombatti Creek	Weir/Culvert	488499	6574759	0.5			1	5	0.10	0.14	0.54
33	Collombatti Creek	Weir	487787	6573912								-0.01
34	Collombatti Creek	Weir/Culvert	489681	6575236	0.4			5	5	-0.24	-0.30	0.14
35	Collombatti Creek	Weir	490336	6575605								-0.27
36	Collombatti Creek	Weir	491016	6575991								-0.27
37	Doughboy Drain	Weir/Culvert	492102	6576569	0.3			4	5		0.06	0.23
38	Shackles Drain	Bridge	491289	6575138					25			1.01
39	Shackles Side Drain	Weir	491224	6575308								0.13
40	Shackles Drain	Bridge	490440	6573944					12			1.82
41	South Floodplain Drain	Culvert	495255	6576097		2.45	2.15	4	12	-0.20	-0.17	
42	West Drain	Weir/Culvert	491121	6576796	0.45			1	9	-0.08	-0.12	0.08
43	Shackles Drain	Weir	492710	6575448								-0.65

ID	Creek/drain	Type	Easting	Northing	Diameter (m)	Width (m)	Height (m)	Number of culverts	Length (m)**	Upstream invert (m AHD)*	Downstream invert (m AHD)*	Crest elevation (m AHD)*
44	Shackles Drain	Bridge	492591	6575130					15			1.74
45	Shackles Side Drain	Weir/Culvert	492580	6574623	0.5			2	9.5	-0.15	-0.16	0.99
46	Shackles Drain	Bridge	491979	6575143								0.83
47	South Floodplain Drain	Weir/Culvert	495231	495231		1.05 & 1.30	1.10 & 1.15	2	~0.2	-0.32 & -0.39		1.33
48	South Floodplain Drain	Bridge	495206	6576075								1.17
49	South Floodplain Drain	Weir/Culvert	494928	6575707	0.45			4	3		-0.27	0.68
50	South Floodplain Drain	Culvert	494494	6575449	0.45			1			0.13	
51	South Floodplain Drain	Culvert	493695	6575021	0.1			1			0.40	
52	McAndrews Drain Side	Weir/Culvert	495968	6576359	0.38			1			-0.1	1.22
53	McAndrews Drain Side	Weir/Culvert	495985	6576311	0.4			1	6	0.1	0.01	1.55
54	McAndrews Drain Side	Weir/Culvert	495998	6576300	0.45			1	~5		0.31	1.31
55	Humpty-back Creek Side	Weir/Culvert	495478	6575484	1.2			1	7	0.64	0.11	1.22
56	Humpty-back Creek Side	Weir/Culvert	495792	6575698		1.5	0.9	2	7		0.07	1.72
57	Humpty-back Creek Side	Culvert	495811	6575382		1.5	0.7	2	9		-0.11	
58	Humpty-back Creek	Weir/Culvert	494324	6574616	1.2			2	5	-0.25		1.22
59	Humpty-back Creek Side	Culvert	495398	6575415		1.5	0.9	2	14	0.06		

ID	Creek/drain	Type	Easting	Northing	Diameter (m)	Width (m)	Height (m)	Number of culverts	Length (m)**	Upstream invert (m AHD)*	Downstream invert (m AHD)*	Crest elevation (m AHD)*
60	Clybucca Creek Side	Culvert	495015	6576411		1.8	1.4	3	14		0.18	

* Australian Height Datum (AHD) = Mean sea level

** Length refers to the bank to bank span for bridges, and width from upstream to downstream for weirs and culvert

C 5 Cross-sections

As part of the field investigations a total of 359 cross-sections were surveyed across the Clybucca floodplain covering over 25 km of creek and drainage channels. The majority of measurements were taken using standalone Trimble R10 GNSS receiver survey methods. For sections of East Drain and Seven Oaks Drain covered by dense trees traditional survey techniques were used to measure cross-sections. Figure C - 4 shows the locations of the cross-section measurements.

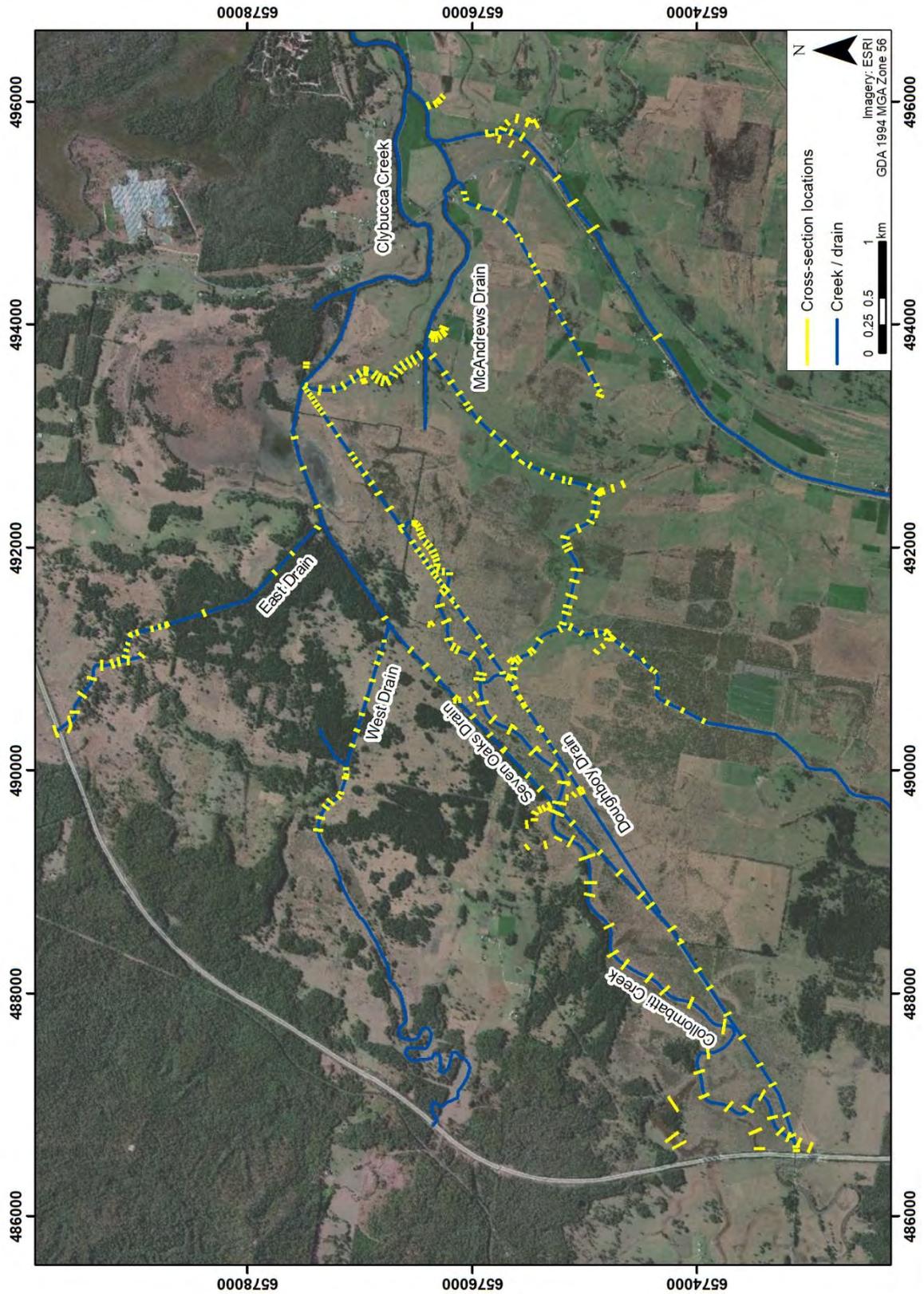


Figure C - 4: Location of cross-section measurements

C 6 Water levels

During 2018 continuous water level measurements were taken at ten (10) locations across the Clybucca floodplain beginning from 26 February, 2018. In addition to this, continuous salinity measurements were taken downstream of the Menarcobrinni Floodgates. Water level measurements were surveyed in using Trimble R10 GNSS receiver survey equipment accurate to ± 0.04 m (90% confidence interval). Barometric compensation was conducted using measurements from a specially designed logger. Logger accuracy varied from ± 5 to ± 15 mm. Table C - 4 outlines details for each logger deployment. Figure C - 5 shows the locations of each logger. Figure C - 6 shows the compensated water levels for each logger corrected to metres AHD.

Table C - 4: Water level logger information

ID	Logger type	Logger location	Date deployed	Date of last download	Logger accuracy (mm)
1	Solinst LTC Levellogger Edge	Downstream of Menarcobrinni Floodgates	26/02/2018	04/12/2018	± 5
2	Herron dipperLog NANO	Seven Oaks Drain at the swale connecting to McAndrews Drain	26/02/2018	06/11/2018	± 5
3	Herron dipperLog NANO	Bridge over McAndrews Drain	26/02/2018	05/12/2018	± 5
4	Herron dipperLog NANO	Bridge over Seven Oaks Drain near West Drain	28/02/2018	05/12/2018	± 15
5	Herron dipperLog NANO	Upstream of lower weir on West Drain	28/02/2018	05/12/2018	± 5
6	Herron dipperLog NANO	Upstream of upper weir on West Drain	28/02/2018	05/12/2018	± 15
7	Herron dipperLog NANO	Upstream of weir on Seven Oaks Drain	1/03/2018	05/12/2018	± 5
8	Herron dipperLog NANO	Upstream of lower weir on East Drain	2/03/2018	05/12/2018	± 5
9	Herron dipperLog NANO	Underneath the bypass on Johnsons Creek	2/03/2018	06/12/2018	± 15
10	Herron dipperLog NANO	Next to the bridge where Plummers Lane meets Macleay Valley Way	2/03/2018	05/12/2018	± 15
11	Herron barLog	In a shed next to McAndrews Drain	26/02/2018	05/12/2018	N/A

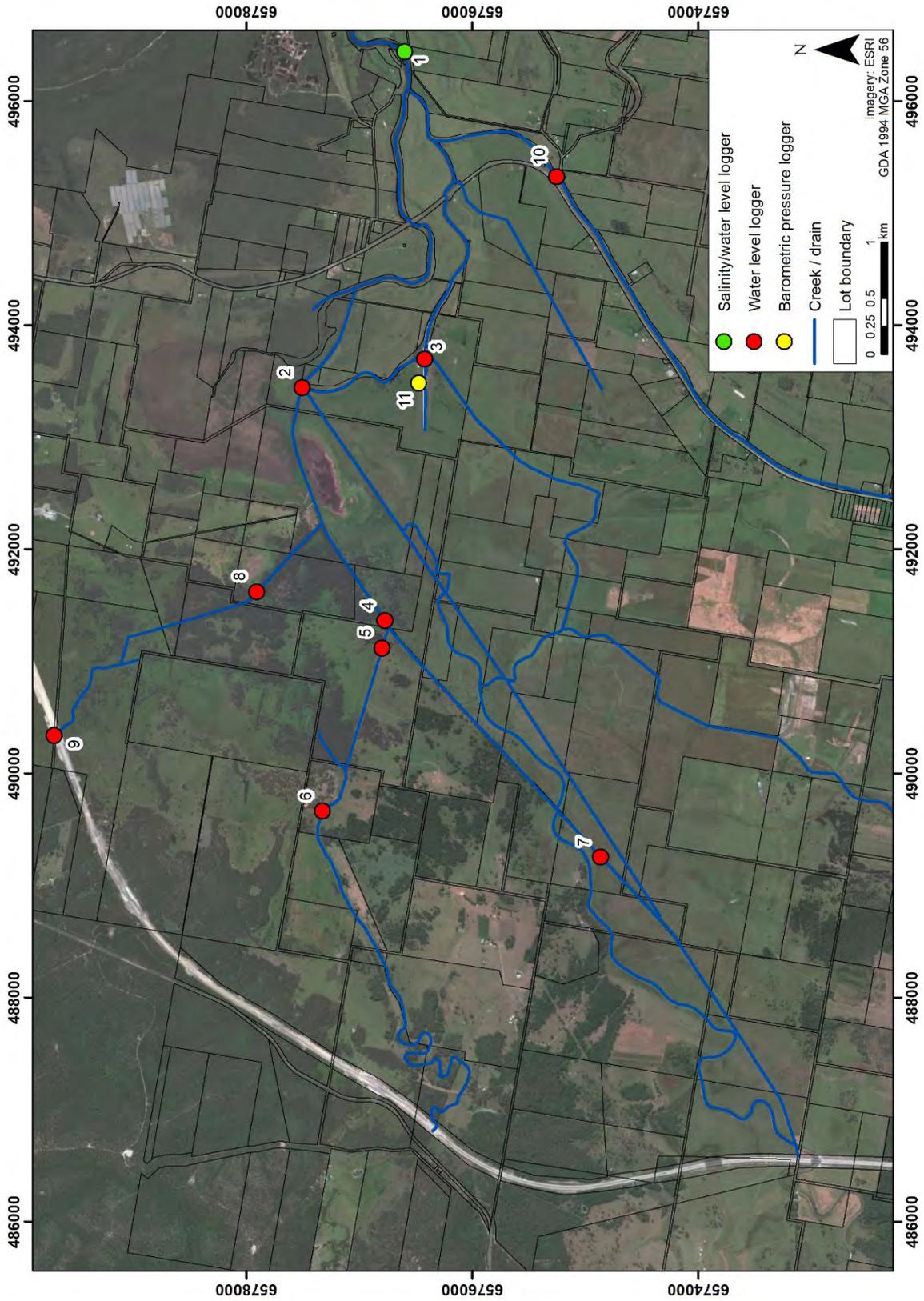


Figure C - 5: Locations of water level measurements

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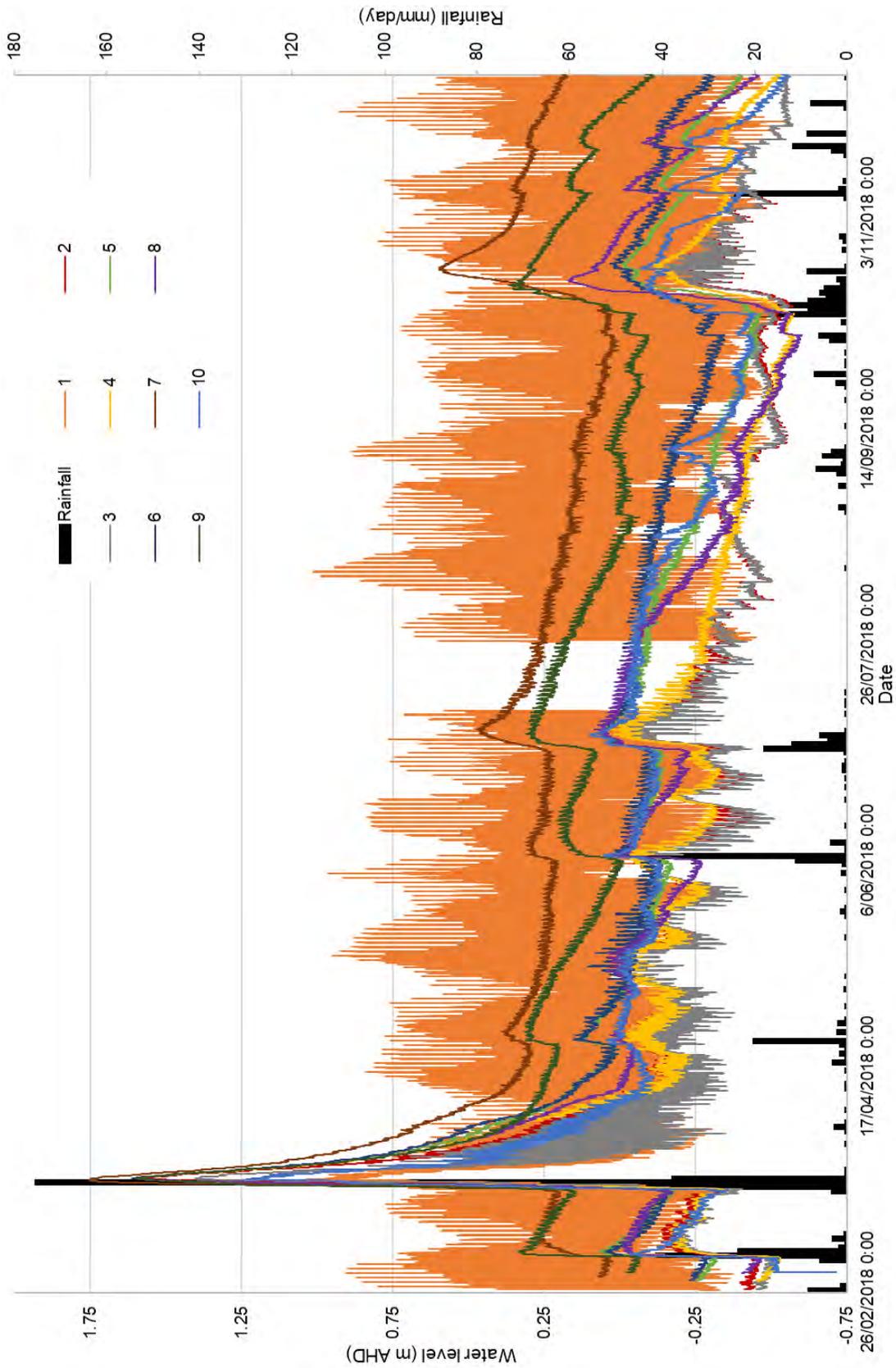


Figure C - 6: Water level measurements and daily rainfall

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C7 Water quality

Multiple point water quality observations were taken opportunistically on site throughout 2018. Measurements were taken using a YSI EXO2 multi-parameter water quality instrument (EXO2) and a HQ11D portable HACH meter (HACH). These observations are shown in Table C - 5. The locations of measurements, including within the K_{sat} pit (Section C 9) in the swale drain between McAndrews Drain and Seven Oaks Drain and at Yerbury's Sill, are shown in Figure C - 7.

Table C - 5: Water quality measurements

Location	Instrument	Date	Conductivity ($\mu\text{S}/\text{cm}$)	pH	Dissolved Oxygen (%)	Chlorophyll ($\mu\text{g}/\text{L}$)
1	EXO2	27/02/2018	9,857	3.65	24.8	17.12
2	EXO2	27/02/2018	2,396	6.69	65.6	69.32
2	EXO2	05/12/2018	1,250	4.70	75.2	24.57
3	EXO2	27/02/2018	2,401	6.69	65.6	69.32
3	EXO2	05/12/2018	4,862	4.52	71.8	20.08
4	HACH	24/07/2018	N/A	3.41	N/A	N/A
4	EXO2	05/12/2018	1,626	3.48	17.3	1.67
5	EXO2	04/12/2018	14,131	7.30	93.0	8.60
6	EXO2	04/12/2018	16,231	7.22	90.2	4.68
7	EXO2	04/12/2018	45,692	7.35	100	13.46

In addition to these water quality measurements, salinity was measured continuously on the downstream side of the Menarcobrinni floodgates. Salinity measurements are presented in Figure C - 8. Note that during the second deployment the salinity probe malfunctioned, resulting in a data gap from 26/07/2018 to 4/12/2018.

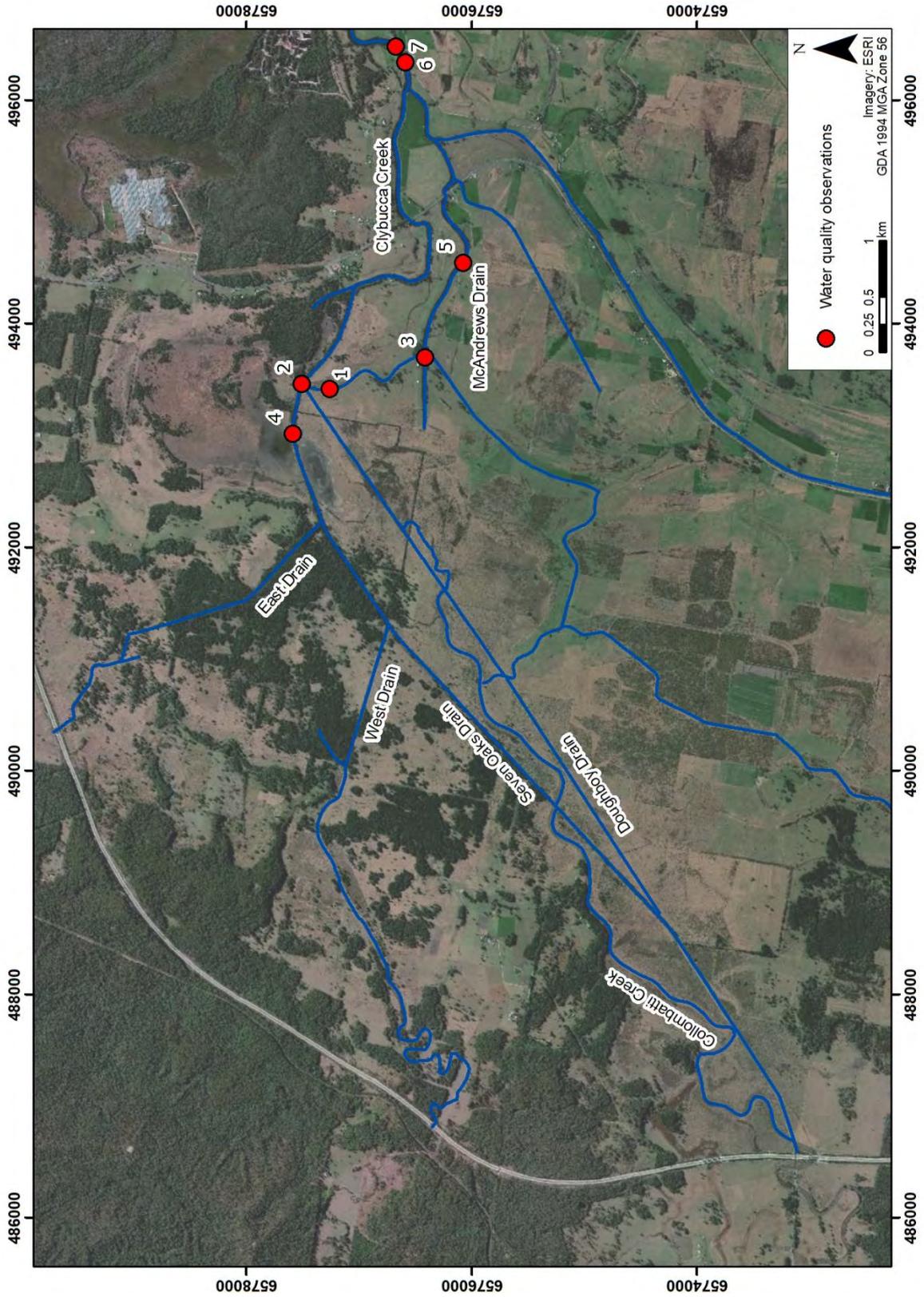


Figure C - 7: Location of water quality measurements

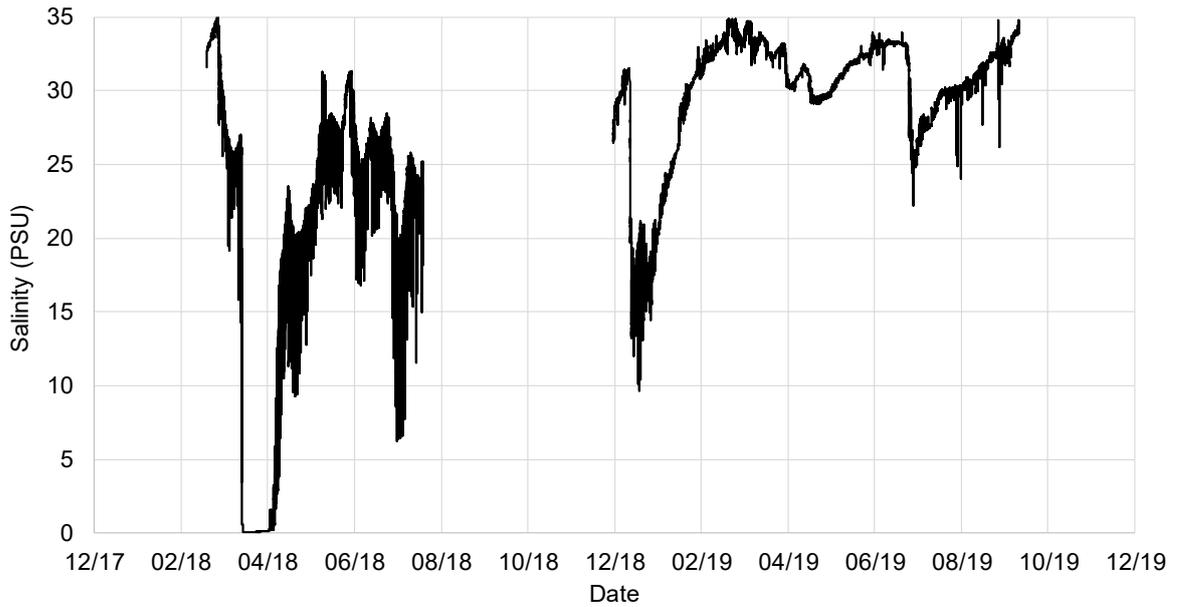


Figure C - 8: Salinity measurements taken on the downstream side of the Menarcobrinni floodgates

C 8 Acid sulfate soils

During the 2018 field investigations one (1) soil profile was sampled. This was taken between Doughboy Drain and the swale drain connecting Seven Oaks Drain and McAndrews Drain to the south of Seven Oaks Drain. An additional four (4) soil profiles were sampled in 2019 along the proposed alignment of the new swale drain connecting McAndrews Drain to Seven Oaks Drain outlined in Management Option 3. Location of soil profiles are shown in Figure C - 9. Soil profile logs are shown in Figure C - 10 through to Figure C - 14.

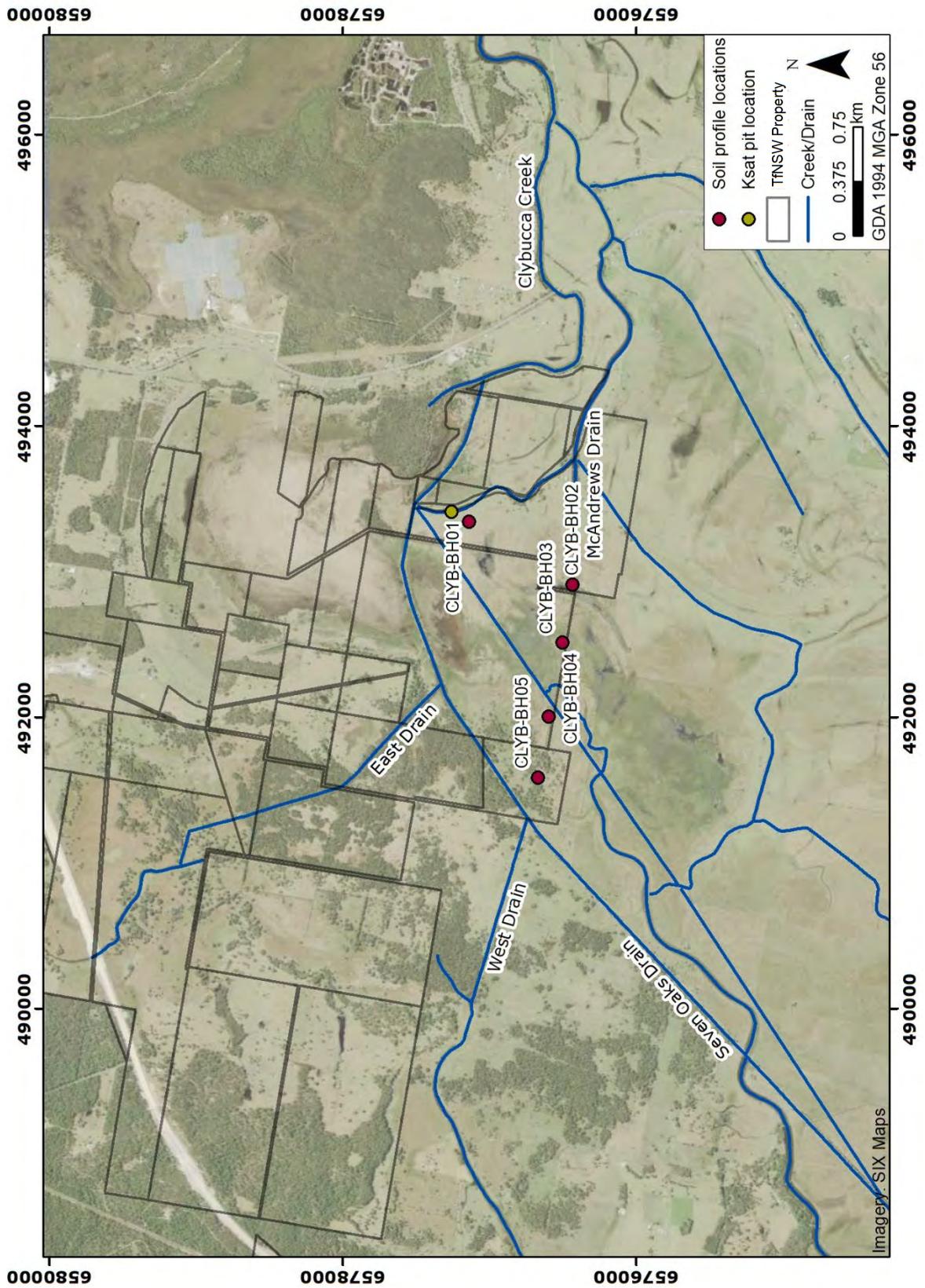


Figure C - 9: Location of soil profiles and K_{sat} measurement

Project Number: 2016106
 Location: Clybucca
 Profile ID: CLYB-BH01
 Sample date: 27/02/2018
 Logged by: DSR
 Drilled by: DSR
 Easting: 493341.5
 Northing: 657141.0
 Ground elevation (m AHD): 0.42



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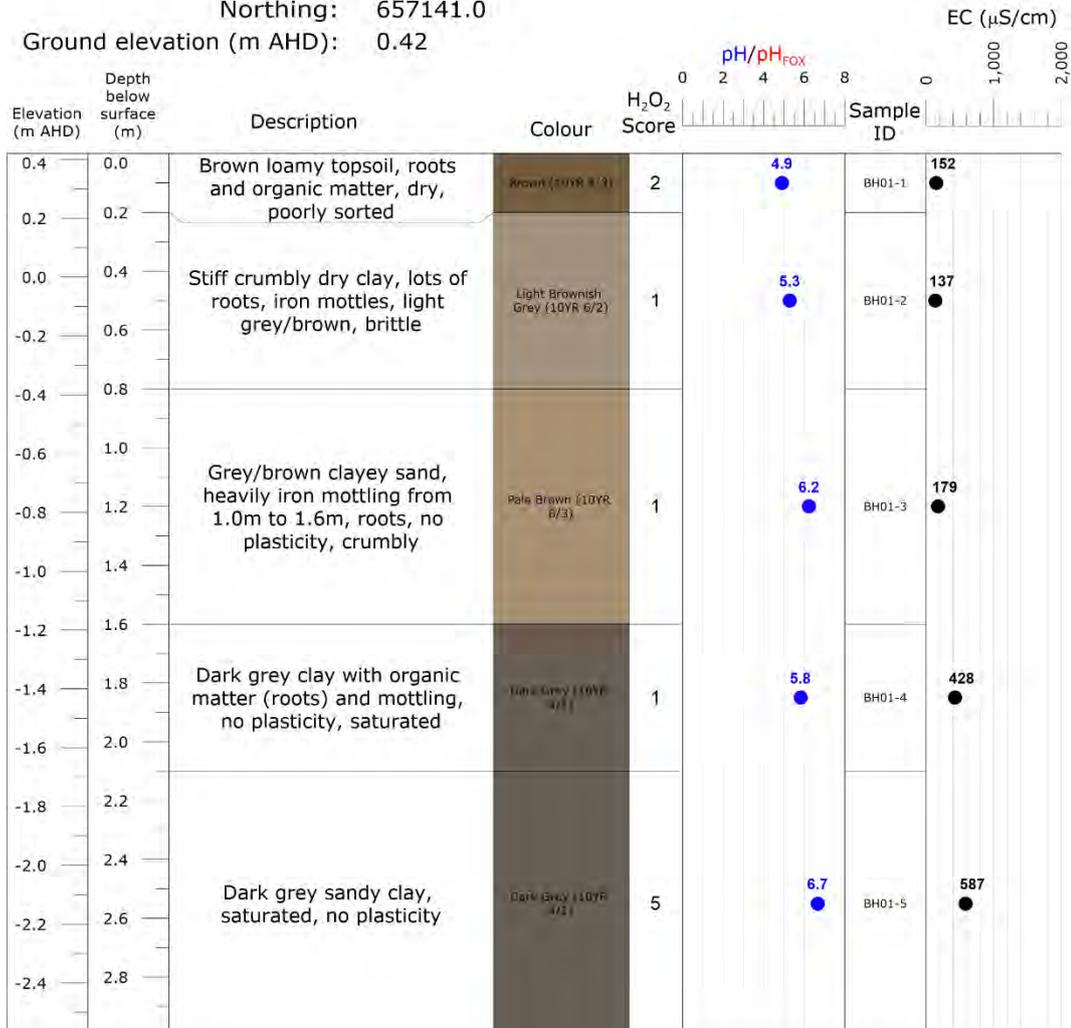


Figure C - 10: Soil profile information for CLYB-BH01

Project Number: 2016106
 Location: Clybucca
 Profile ID: CLYB-BH02
 Sample date: 22/11/2019
 Logged by: TAT DWJ
 Drilled by: TAT DWJ
 Easting: 492911.5
 Northing: 6576432.5
 Ground elevation (m AHD): 0.37



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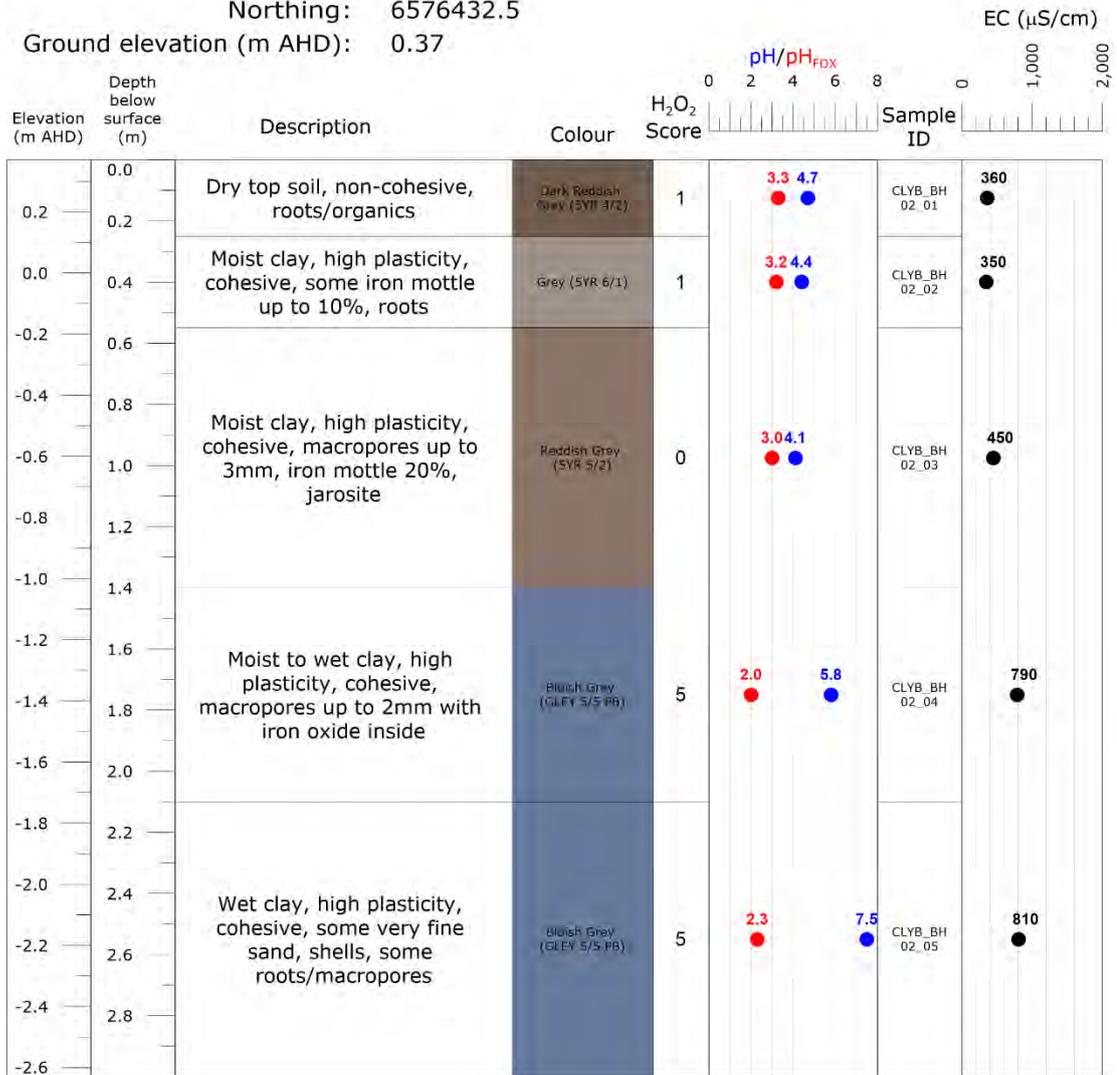


Figure C - 11: Soil profile information for CLYB-BH-02

Project Number: 2016107
 Location: Clybucca
 Profile ID: CLYB-BH03
 Sample date: 22/11/2019
 Logged by: TAT DWJ
 Drilled by: TAT DWJ
 Easting: 492510.2
 Northing: 6576502.0
 Ground elevation (m AHD): 0.37



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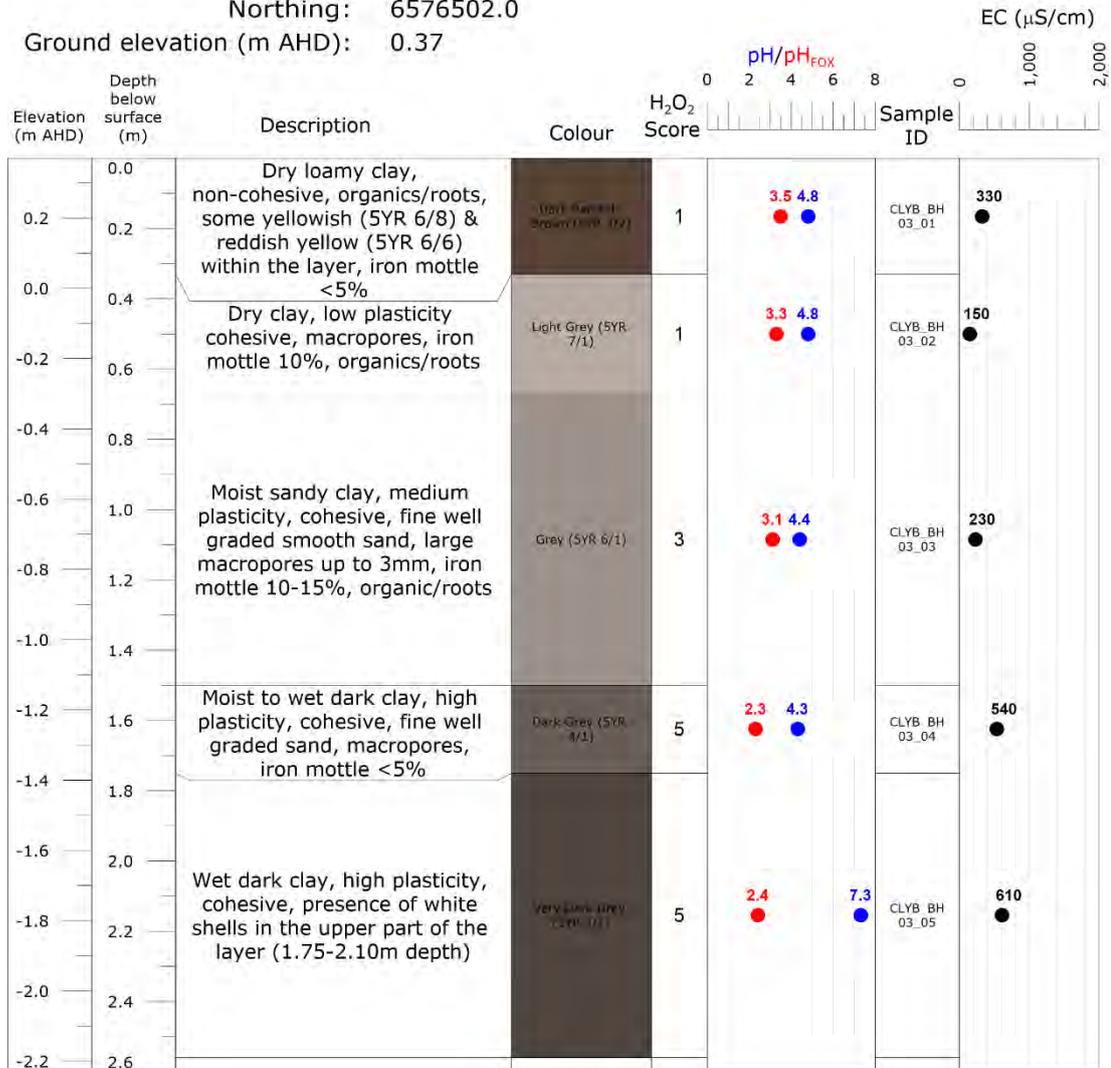


Figure C - 12: Soil profile information for CLYB-BH-03

Project Number: 2016108
 Location: Clybucca
 Profile ID: CLYB-BH04
 Sample date: 22/11/2019
 Logged by: TAT DWJ
 Drilled by: TAT DWJ
 Easting: 492005.4
 Northing: 6576596.8
 Ground elevation (m AHD): 0.28



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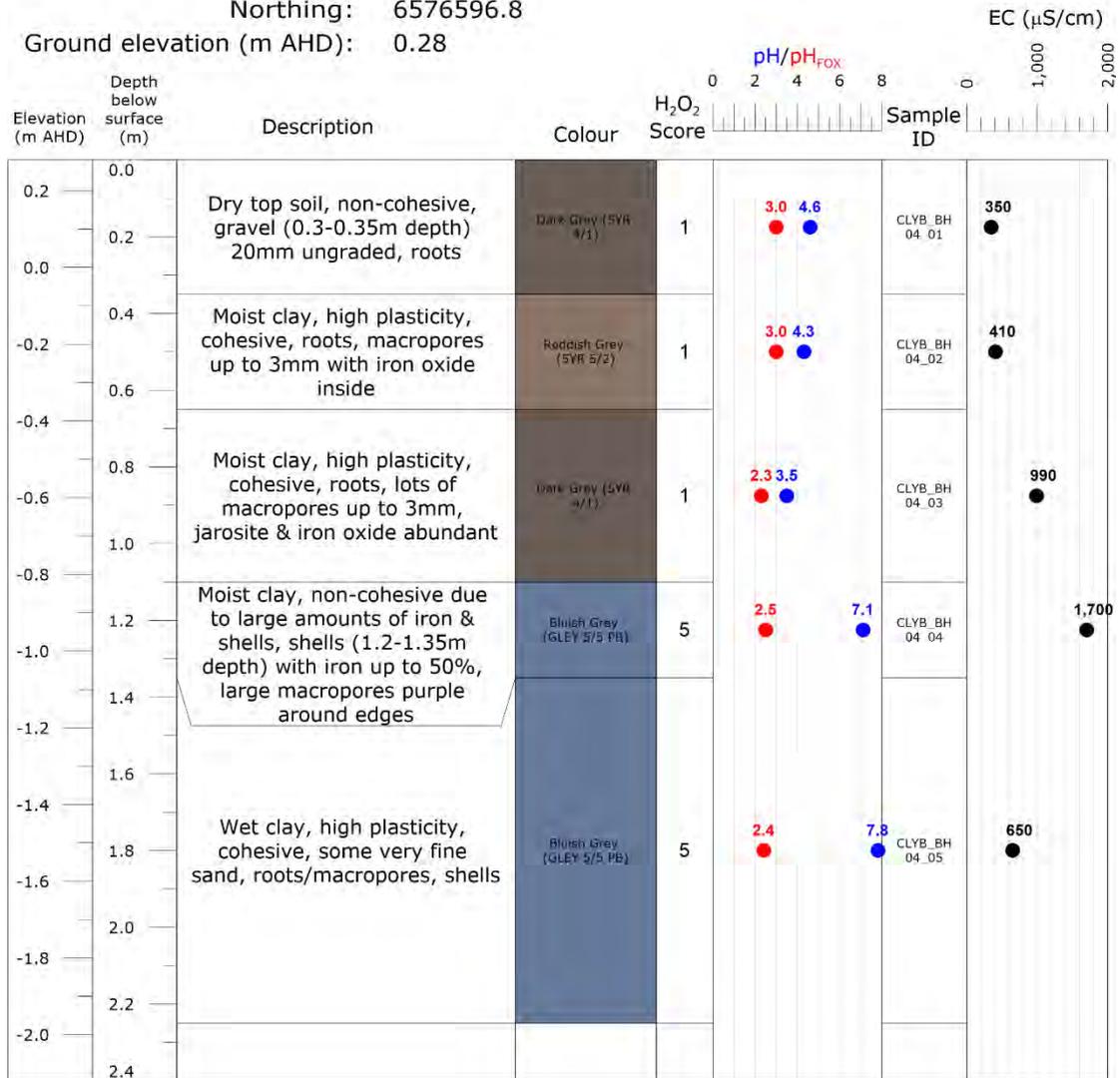


Figure C - 13: Soil profile information for CLYB-BH-04

Project Number: 2016109
 Location: Clybucca
 Profile ID: CLYB-BH05
 Sample date: 22/11/2019
 Logged by: TAT DWJ
 Drilled by: TAT DWJ
 Easting: 491586.0
 Northing: 6576670.2
 Ground elevation (m AHD): 0.34



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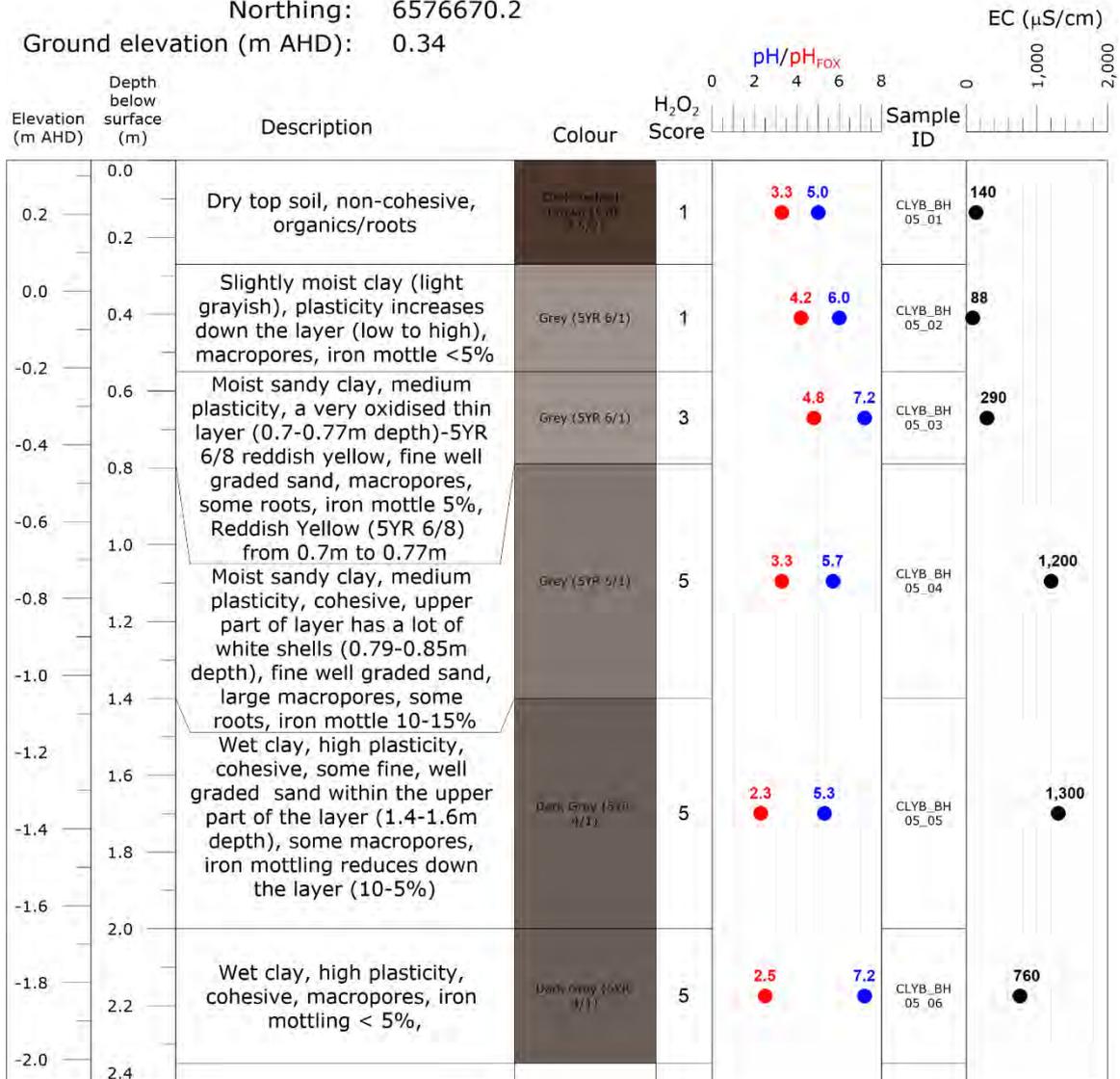


Figure C - 14: Soil profile information for CLYB-BH05

C9 Groundwater hydraulic conductivity (K_{sat})

Hydraulic conductivity was measured within the swale drain connecting Seven Oaks Drain and McAndrews Drain (see ID 1 in Figure C - 7). The measurement was obtained using the methodology outlined by Johnston and Slavich (2003). An extreme K_{sat} measurement was recorded at this location. Location of the K_{sat} measurement is shown previously in Figure C - 9. The results are shown in Figure C - 15.

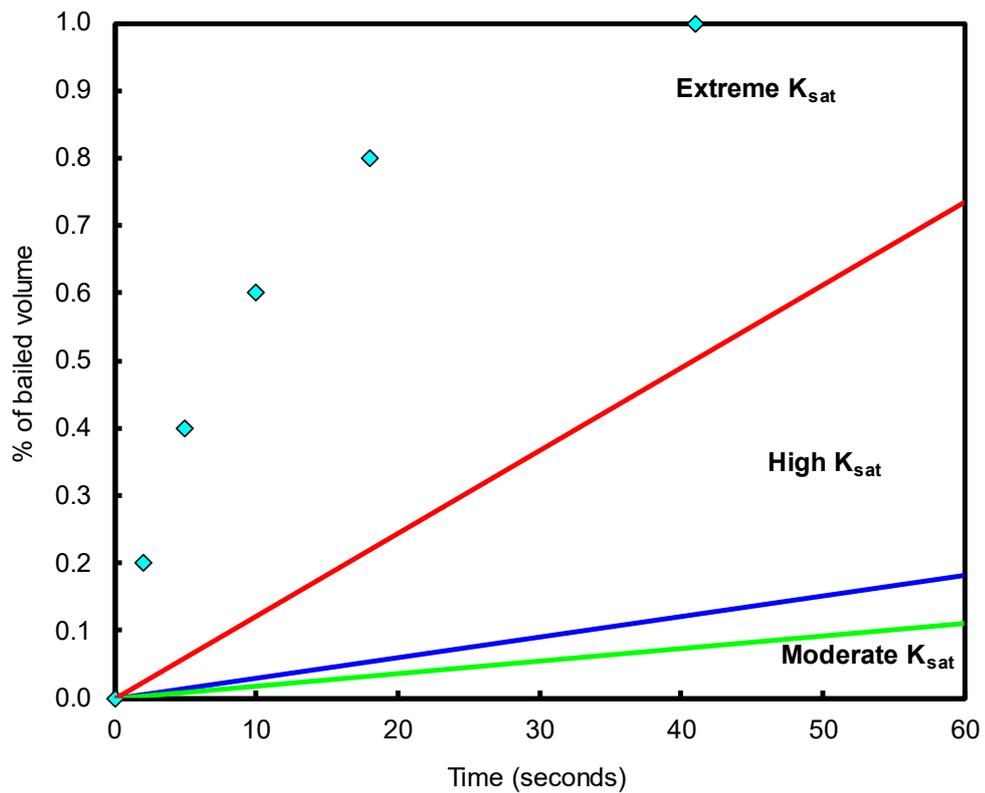


Figure C - 15: Hydraulic conductivity measurement results

Appendix D Model development

D 1 Preamble

This section describes the development of the Mike FLOOD 1D-2D numerical model constructed to simulate and assess management options across the Clybucca floodplain. Subjects such as data selection and data accuracy are discussed and justified for each stage of the model development process. In summary these stages are:

- Model bathymetry;
- Model boundaries; and
- Model parameter selection.

D 2 Bathymetry data

D.2.1 LiDAR ground truthing

Of the LiDAR datasets available, the 2009 survey was found to provide the most representative measurements of actual ground elevations (Figure D - 1). To further improve the accuracy of the digital elevation model (DEM), LiDAR measurements were combined with RTK-GPS survey measurements to produce an improved DEM of the floodplain ground surface. This involved removing low areas that were inundated with water (at the time of the LiDAR survey) and replacing them with point data that had been measured during the ground truthing surveys and subsequently interpolated using the natural neighbour technique. Areas that were adjusted include:

- Mayes Swamp;
- Doughboy Swamp (on the east and west side of East Drain);
- Yerbury's Scald; and
- The swale drain running south east to north west from Macleay Valley Way to Seven Oaks Drain.

Further adjustment involved lowering the entire DEM by approximately 0.01 m. The comparison between the corrected DEM surface and the measurements taken during the ground truthing survey is shown in Figure D - 2. The updated DEM is shown in comparison to the original 2009 LiDAR elevation surface in Figure D - 3. Note some discrepancies between the ground truthing survey measurements were found to be due to items such as bridges and were individually assessed and manually removed from the final DEM.

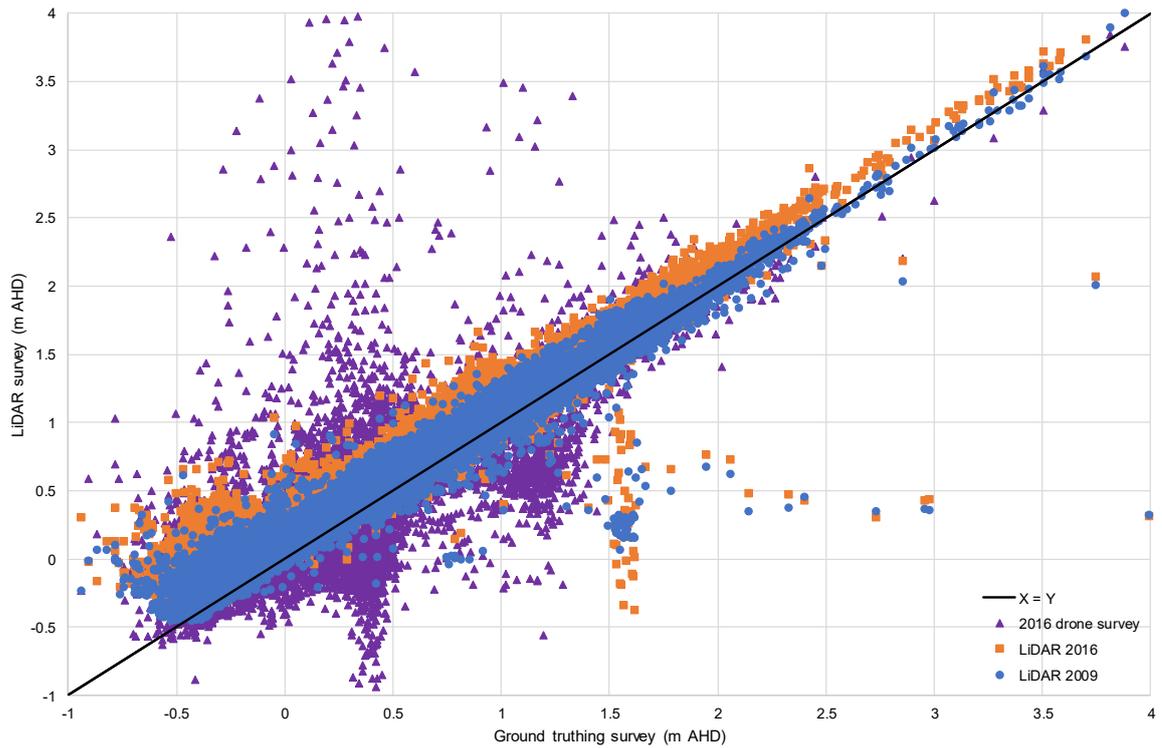


Figure D - 1: Comparison of remote sensing elevation data and ground truthing survey

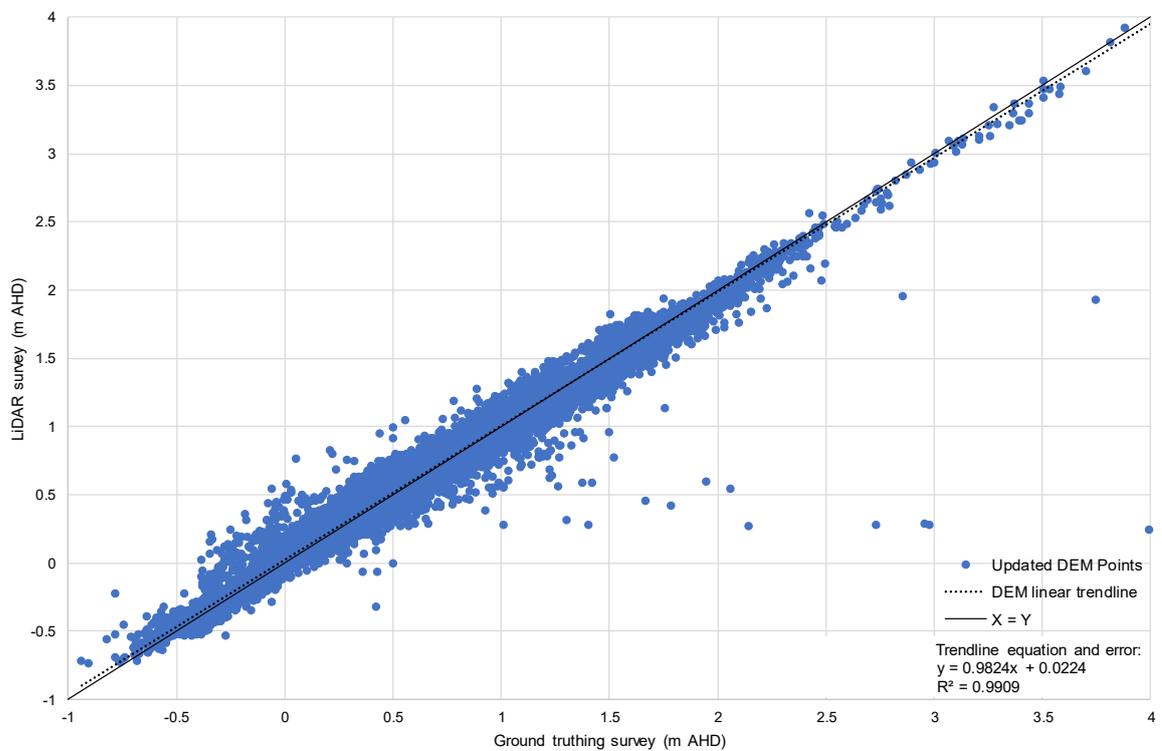


Figure D - 2: Comparison of updated DEM with ground truthing survey

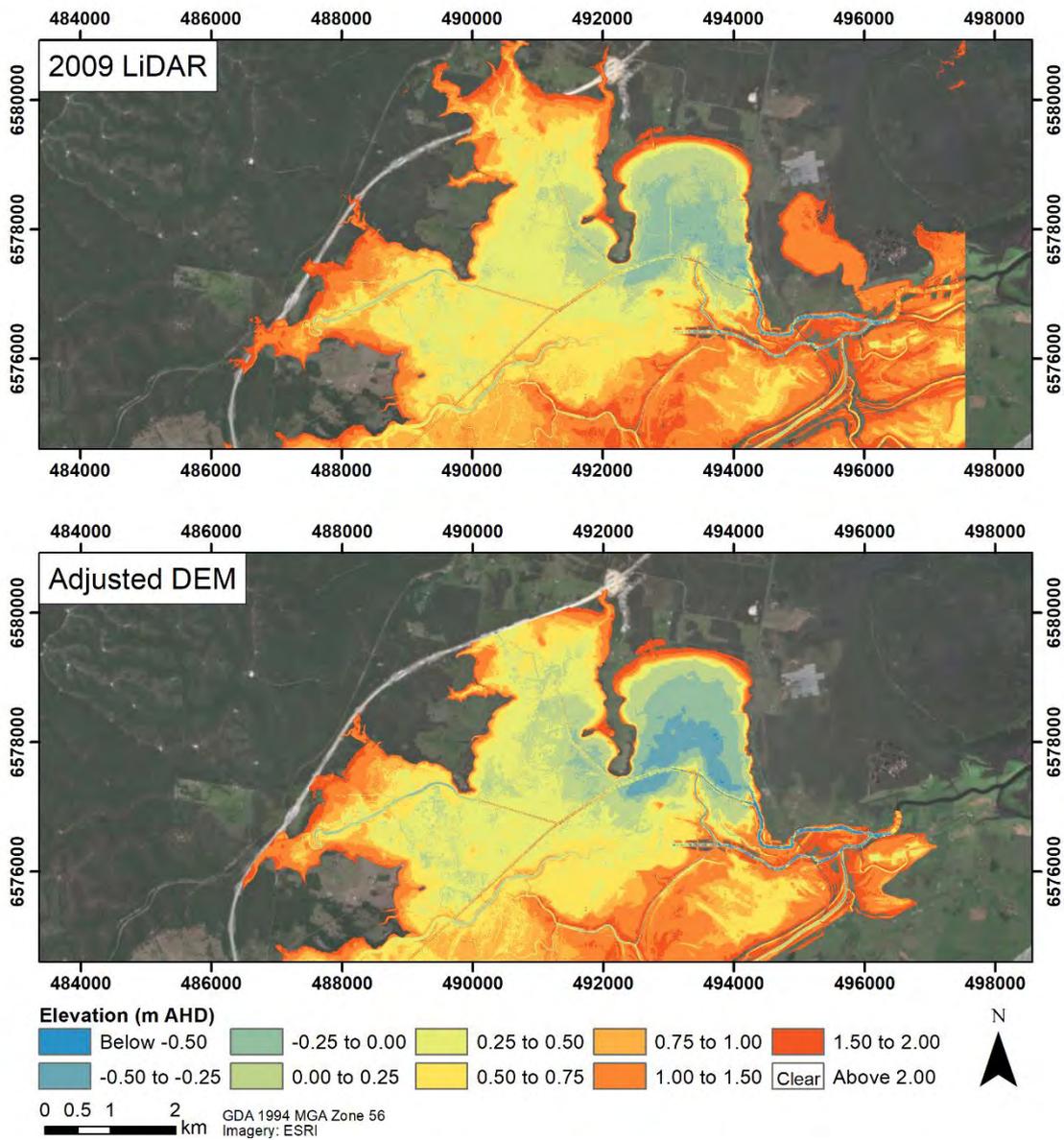


Figure D - 3: Updated ground surface DEM

D.2.2 Model domain

The model domain was determined based upon the topographical attributes of the Clybucca floodplain. Generally, there are three (3) barriers of higher elevation surrounding the Clybucca floodplain which constrain how water flows throughout the area. On the western side of the floodplain, the Pacific Highway Bypass forms one boundary. Inflow boundaries into the model have been set at key locations where the highway crosses waterways. On the southern side of the floodplain, Macleay Valley Way runs along a levee which is significantly higher than the rest of the

floodplain. A swale drain runs along the southern side of Macleay Valley Way with its southern bank forming the second boundary to the model. On the north eastern side of the floodplain there is significantly higher elevated land which forms the boundary to the model. The model domain is shown in Section D.2.3, Figure D - 7.

The MIKE Flood numerical model was used to simulate hydrodynamic flows through the Clybucca floodplain. This software comprises of a MIKE 21 Flexible Mesh (FM) module for modelling the two-dimensional (2D) floodplain and MIKE 1D module for simulating one-dimensional (1D) hydrodynamics within drains and creeks across the floodplain. These two modules are linked within MIKE Flood to allow for interaction between the 1D drainage network and 2D floodplain.

D.2.3 Stage volume

Within the MIKE 21 FM module, a flexible mesh or model grid is utilised to represent the 2D surface of the floodplain. The size of this model grid (made up of elements) is key in determining model run times ensuring that the correct volume of water is represented across the floodplain. Smaller element sizes within the model grid increases the accuracy of the model. Conversely, a larger number of elements increases the time for computation of a model solution. Table D - 1 shows the relationship between element size and number of elements for the Clybucca floodplain.

Table D - 1: Comparison of mesh sizing and the number of elements for the model domain

Individual element size (m ²)	Number of elements
50,000	6,852
10,000	12,738
5,000	21,550
1,000	97,098
500	192,603
100	957,601
50	1,916,554
25	3,828,134
10	9,576,118

By calculating the water elevation (or stage) versus volume relationship across the floodplain for varying model grid densities, the optimum element size can be selected. Note that this size can vary spatially across the model domain. The aim is to select the largest possible element size which still has a stage volume relationship comparable to the actual terrain being modelled. Of significant importance for a floodplain model is ensuring that for volumes corresponding to water levels to be assessed during the model simulation, in this case below 1 m AHD, represent that of the actual floodplain.

Figure D - 4 shows the relationship between stage (i.e. elevation) and volume for differing element sizes across the model domain. The solid black line is the actual stage volume relationship of the Clybucca floodplain. The solid blue line is the stage volume relationship of the selected model grid density. A model grid comprising of elements from 5 m² to 7,150 m² was chosen to simulate the model domain. A higher model grid resolution is used at key locations within the model domain to ensure key volumes are captured during simulation. The model grid contains 100,699 elements with:

- An average size of 610 m²;
- 75% of elements less than 500 m²; and
- 50% of elements less than 200 m².

The relationship between different stages and the difference between the actual versus modelled volume is shown in Figure D - 5. This shows that for tidal areas, approximately below 1 m AHD, the model volume is always represented by an element size less than 1,000 m². Above this stage the difference in volume of water is less than 2% of the actual volume across the floodplain (Figure D - 6). Below -0.4 m AHD the difference between actual and modelled volume is less than 1,000 m³. At this point the largest volume of water is contained within the 1D model domain, approximately 475,410 m³, so a 1,000 m³ discrepancy equates to 0.2% difference and can be considered negligible. The model grid and domain are presented in Figure D - 7.

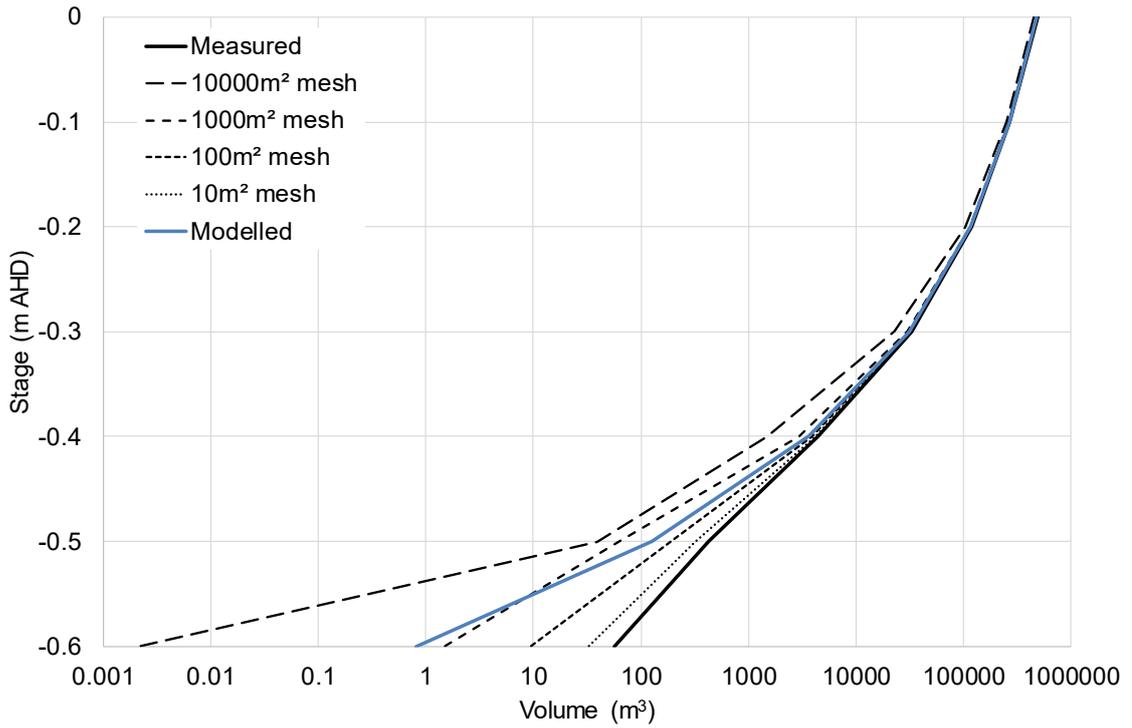


Figure D - 4: Stage volume relationship for varying mesh resolution in the model domain

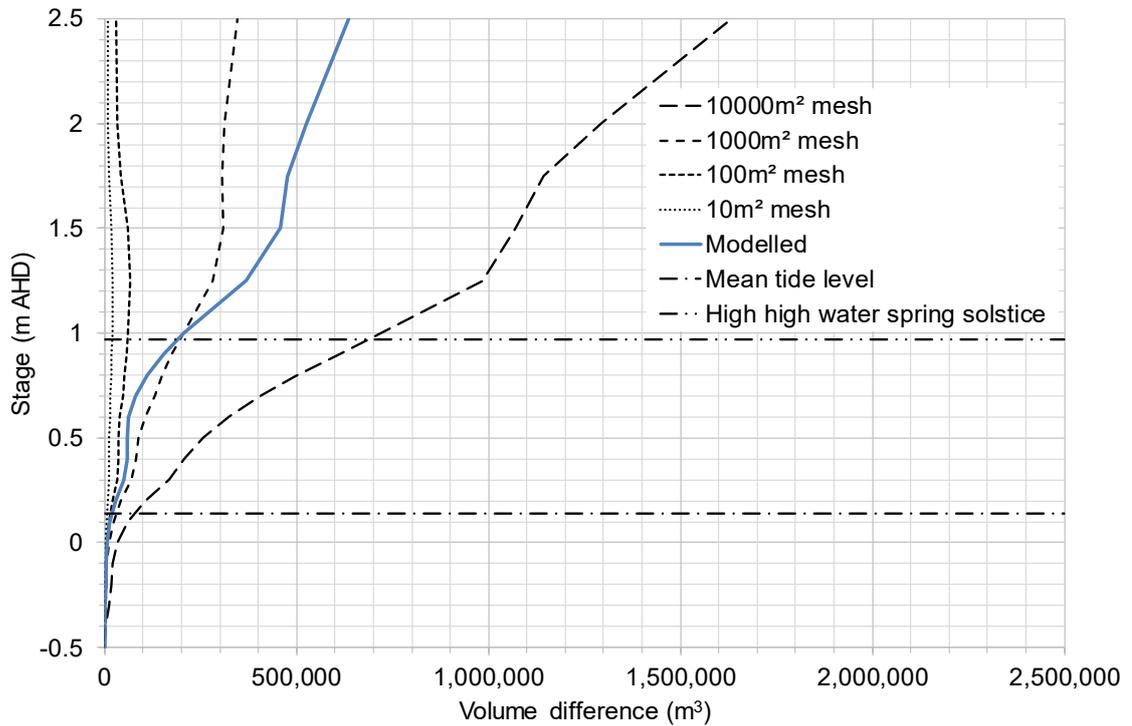


Figure D - 5: Comparison of stage with volume difference between the mesh resolution and DEM

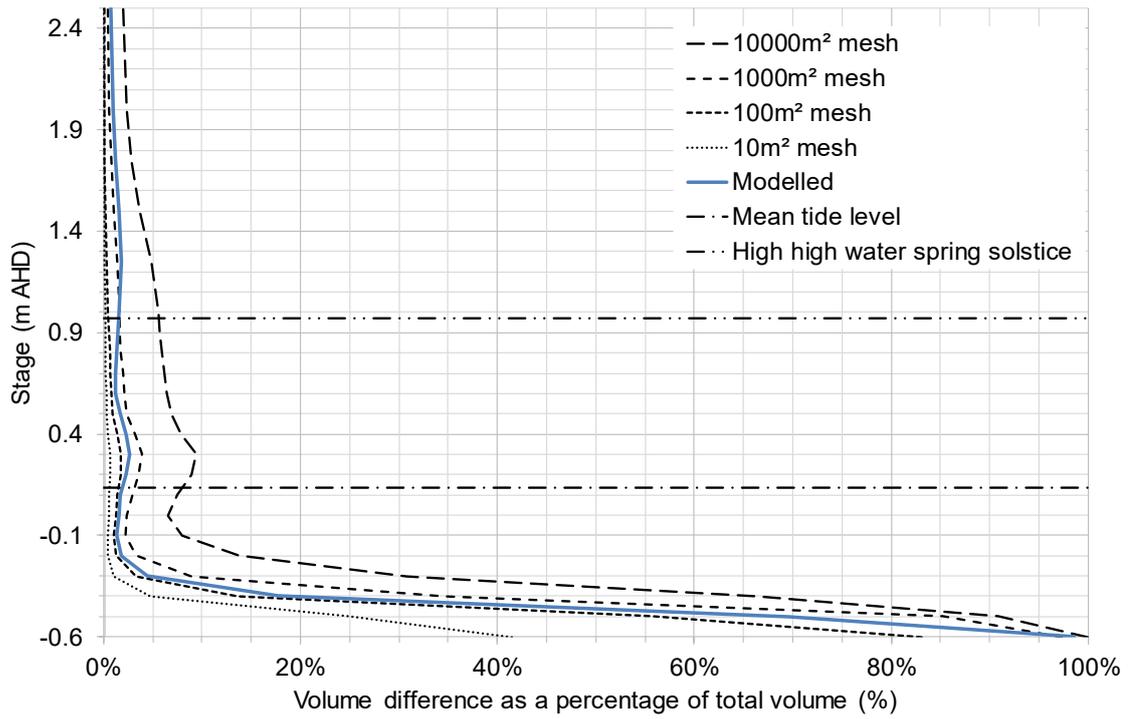


Figure D - 6: Comparison of stage with volume difference between the mesh surface and DEM expressed as a percentage of the total volume

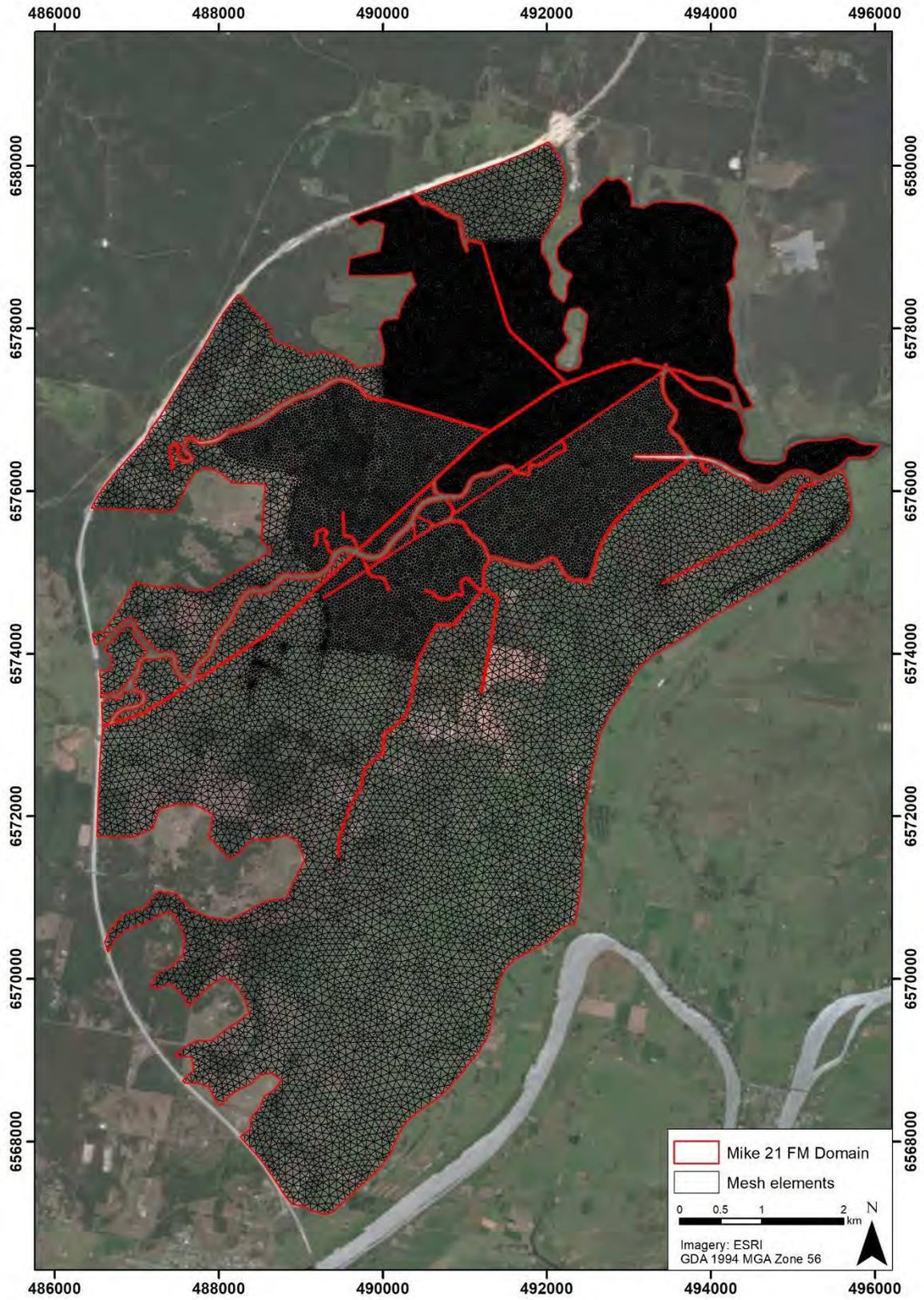


Figure D - 7: Model domain and mesh

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D 3 Boundary data

The hydrodynamic flow throughout Clybucca floodplain is controlled by two (2) key boundary conditions. At the Menarcobrinni floodgates the tide controls flow discharging from the system. Inflows from the catchments determine the volume of water entering the system. Other influences on the system include evaporation and precipitation within the model domain, groundwater discharges into drains, leaks from the floodgates, infiltration and transpiration from vegetation.

D.3.1 Tidal boundary

The lower limit of the model is located at the Menarcobrinni floodgates on Clybucca Creek. These floodgates comprise of 21 culverts (1.8 m by 2.1 m) with a crest elevation of 1.5 m AHD. Two (2) different boundary conditions were run at this location within the model:

1. Measured water levels (February 2018 – July 2018); and
2. Simulated water levels.

Measured water levels were run during the calibration and validation stage of the model. This ensured the correct tidal signal including factors such as runoff and storm surge were included within the boundary condition. This allowed for the comparison of water levels modelled to water levels measured throughout the Clybucca floodplain.

Simulated water levels were calculated using a unified tidal analysis and prediction framework known as 'UTide' (Codiga, 2011). Tidal analysis was performed on data collected by WRL from 26 July 2018 to 4 December 2018 on the downstream side of the Menarcobrinni floodgates (see Section C 6). WRL data was used to obtain the higher order constituents that are present within an estuary. Tidal constituents from this analysis were then used to create a synthetic tide for the scenario modelling. Constituents are shown in Table D - 2.

Table D - 2: Tidal constituents used for the boundary data

Constituent	Amplitude (m)	Amplitude 95% confidence interval	Phase lag (degrees)	Phase lag 95% confidence interval
MM	0.0343	0.00234	18.2	3.93
MSF	0.0279	0.00235	58.1	4.81
ALP1	0.00211	0.00259	260	70.4
2Q1	0.00658	0.00261	97.1	22.7
Q1	0.0137	0.00259	128	10.9
O1	0.0947	0.00255	144	1.55
NO1	0.00918	0.00293	263	18.3
K1	0.134	0.00248	183	1.06
J1	0.0101	0.00255	234	14.5
OO1	0.0125	0.00355	275	16.3
UPS1	0.00107	0.00345	285	184
EPS2	0.00615	0.0024	32	22.4
MU2	0.0266	0.00233	36.5	5
N2	0.0715	0.00231	301	1.85
M2	0.389	0.00231	309	0.339
L2	0.0231	0.00202	309	5.02
S2	0.0978	0.00235	341	1.38
ETA2	0.00358	0.00308	105	49.3
MO3	0.0189	0.0025	252	7.57
M3	0.00277	0.00228	46.4	47.1
MK3	0.011	0.00243	341	12.6
SK3	0.00482	0.00248	297	29.4
MN4	0.00843	0.00227	151	15.4
M4	0.0217	0.00226	174	5.96
SN4	0.0036	0.00231	193	36.8
MS4	0.0132	0.00231	199	9.99
S4	0.00281	0.00235	177	47.9
2MK5	0.00705	0.00238	139	19.3
2SK5	0.000981	0.00248	191	145
2MN6	0.00549	0.00222	250	23.2
M6	0.0116	0.00222	256	11
2MS6	0.00938	0.00226	292	13.8
2SM6	0.00183	0.00231	357	72.4
3MK7	0.00161	0.00233	274	83
M8	0.00195	0.00217	176	63.8

D.3.2 Catchment modelling

An Australian Water Balance Model (AWBM) was developed to determine the catchment inflows for the Clybucca floodplain due to rainfall. The AWBM is a lumped conceptual rainfall-runoff model that determines catchment runoff based upon evaporation and rainfall (Boughton, 2004). The model employs eleven parameters as described by Podger (2004) in Figure D - 8 where:

- C1, C2, C3: Surface storage capacities;
- A1, A2, A3: Partial areas represented by surface storages;
- BFI: Baseflow index – the ration between baseflow and total surface runoff;
- K: Daily baseflow recession constant;
- BS: Current Volume in baseflow storage;
- KS: Daily surface flow recession constant;
- SS: Current volume in surface routing storage;
- P: Precipitation; and
- E: Evaporation.

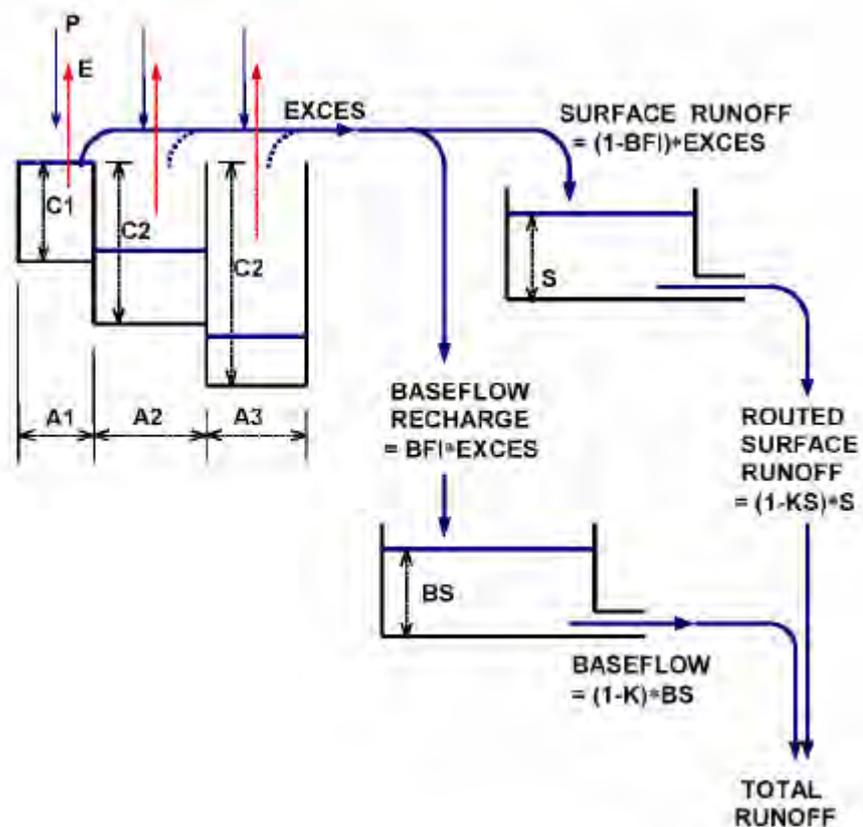


Figure D - 8: Conceptual diagram of the AWBM (Podger, 2004)

During the calibration process eight (8) of these parameters are set (A1, A2, C1, C2, C3, BFI, KB, KS). The calibration for the catchments surrounding the Clybucca floodplain was completed using a Monte-Carlo simulation of 21,466,368 different combinations of calibration parameters.

Inputs for the AWBM are rainfall and evaporation which was sourced from SILO (Jeffrey et al., 2001). SILO uses data provided by the Bureau of Meteorology (BOM) to create a spatially and temporally complete dataset. This meant that daily timeseries data was used and its variance across the catchment was taken into account.

The different catchments across, and feeding into, the Clybucca floodplain were delineated using the elevation information mentioned in Section B 2. A total of 17 catchments were defined as specified in Figure D - 9 and Table D - 3.

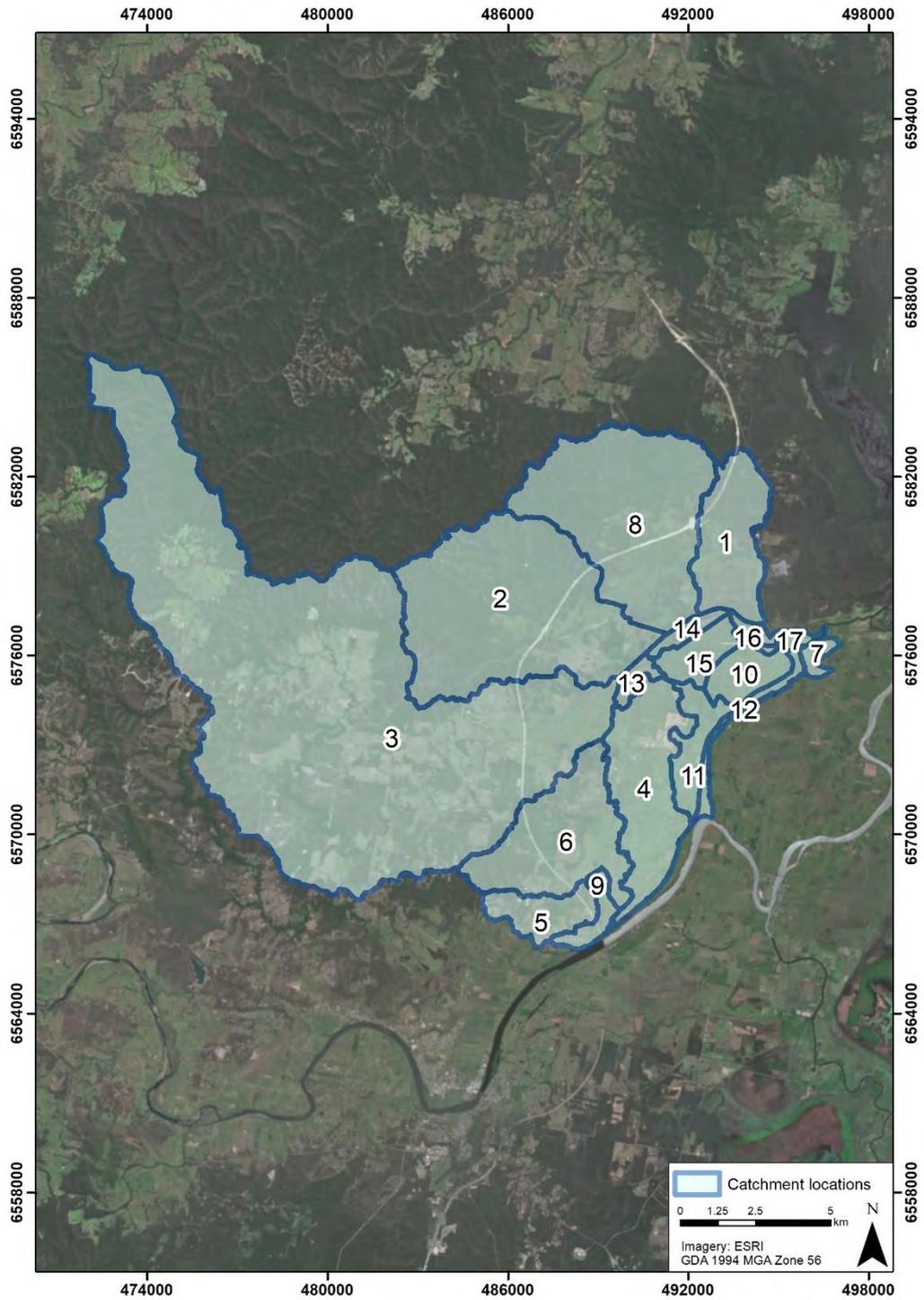


Figure D - 9: Catchment locations

Table D - 3: Catchment areas

Catchment ID	Area (ha)
1	1,081
2	3,678
3	12,477
4	1,468
5	476
6	1,605
7	104
8	2,927
9	208
10	384
11	435
12	206
13	132
14	138
15	349
16	86
17	100

Generally, a gauged point in a catchment provides runoff information to compare the predictions and allows for validation of the AWBM. No flow gauging occurs within the catchments. Therefore, to validate the AWBM, a discharge dataset was created from water level data measured at Location 7 (Figure C - 5, Section C 6), upstream of a weir located on Seven Oaks Drain (Figure D - 10).



Figure D - 10: Weir used to calculate runoff from water level measurements for AWBM validation

As presented in Section C 6, a water level timeseries was collected from March 1 to December 4, 2018. This data set spanned one significant catchment flood event with an annual exceedance of probability (AEP) of approximately 15%. A number of smaller events were also recorded that caused significant changes of the water level within Seven Oaks Drain. Since the model has been designed to simulate day-to-day drainage (events with an AEP greater than 63.2%, or probability of occurring once or more per year), the significant runoff event recorded in April 2018 was excluded from the AWBM calibration and a calibration period from May to December 2018 was selected.

The crest elevation of the weir downstream was measured using R10 as outlined in Section C 4. The flow over the weir was then calculated from the water levels using the broad-crested weir equation taking into account brink depth (Henderson, 1966). The Manning equation was used to determine flow velocities within Seven Oaks Drain (Manning, 1980). A Manning's 'n' of 0.03, representing channel roughness, was selected based on observation and literature guidelines (Chow, 1959). The flow calculated over the weir is inaccurate for large flows due to limitations, including:

1. For large flows, water will begin to spill the banks of Seven Oaks Drain so will be much larger than calculated; and
2. For high water levels where $L/H < 3$ (where L is the weir length and H is the total energy above the weir crest) backwater effects will influence the flow rate. This will mean flows are less than what is calculated by the equation.

This further validates the reasoning for removing the April 2018 rainfall event from the calibration process and utilising the AWBM for smaller runoff events where water remains in-channel. Generally, this was found to be applicable for water levels below 1 m AHD on this section of Seven Oaks Drain.

AWBM parameters were calculated using a Monte-Carlo simulation comparing modelled flows using the AWBM to those calculated using the broad-crested weir equation. Comparison of the selected AWBM model and flows calculated using the broad-crested weir equation are shown in Figure D - 11.

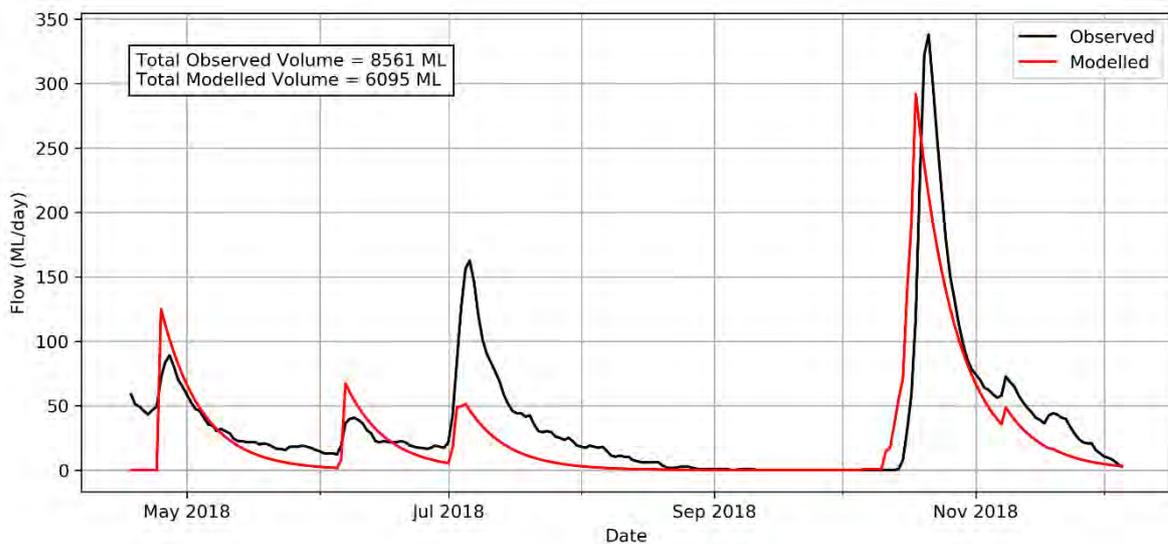


Figure D - 11: AWBM calibration results

During scenario modelling an event with a two exceedances per year (EY) probability was selected to simulate drainage during day-to-day conditions. This was based on a real event that occurred in August 2016 and was taken from the SILO data. The magnitude of the event was selected finding a rainfall event with between 136 mm and 189 mm (142.3 mm was selected) in a 144 hour period, as per the 2EY rainfall event criteria specified by BOM design rainfall data system (BOM, 2016).

D.3.3 Other boundary conditions

Other boundaries considered during the modelling process include:

- Evaporation/transpiration within the model domain;
- Precipitation within the model domain;
- Groundwater surface water interaction;

- Floodgate leaks; and
- Infiltration.

The effects of evaporation, transpiration and precipitation were taken into account during the AWBM catchment modelling. Each catchment inflows were selected based upon the local topography of the model domain and overland flow paths. This ensured that the effects of evaporation, transpiration and precipitation were distributed across the model.

During the model calibration process there was clear evidence to suggest that there is a strong interaction between groundwater and surface water within the model domain. This is substantiated by the extreme hydraulic conductivity measurements observed during field investigations. As a result, a constant inflow boundary was implemented within the numerical model with groundwater inflow rate of a total 0.6 m³/s distributed across the lower extent of the 1D drainage network.

Observations during field investigation indicated that there was some leakage of the floodgates. This was simulated within the 1D model as a point source inflow of 0.002 m³/s at the floodgates.

Infiltration was only considered within the groundwater factors of the AWMB model and added to the model within catchment inflow boundary conditions. Therefore, during dry periods the model would become conservative and overpredict water levels. Since, numerical modelling was only completed for day-to-day conditions and flood events this is considered negligible.

D 4 Model physical parameter selection

In addition to the boundary conditions there are various parameters that need to be applied which feed into the numerical calculations performed during model runs. For the MIKE model these parameters include:

- Roughness (i.e. Manning's n);
- Eddy viscosity; and
- Dispersion coefficients.

The Manning's n coefficient varied across the model domain. It was based upon on observations during field investigations and literature guidelines (Arcement and Schneider, 1989, BCC, 2003, and Chow, 1959,). The value of the Manning's n at certain locations across the model domain was further refined during the calibration process.

Eddy viscosity is included within the 2D numerical computations of the model to represent sub-grid scale effects (DHI, 2019). This has been implemented in the model as a constant across the model domain which was selected based on DHI (2019) and Madsen et al., (1988).

There is a lack of data concerning numerical dispersion coefficients that controls the mixing of saltwater. A range of dispersion coefficients (D) were tested to provide uncertainty bounds and indicate the potential likely range of salinity. For the one-dimensional drainage channels in the model, the coefficient was a function of the flow velocity and varied from $D = 0.5\bar{u}$ to $D = 1,000\bar{u}$ (where \bar{u} is the mean channel velocity). For the two-dimensional part of the model the dispersion coefficients were set as $D = 0.1$ as a minimum and $D = 1.0$ as a maximum. These values were based upon literature (Bowie et al., 1985, and Fischer et al., 2013), a sensitivity analysis incorporating drainage measurements collected during the field campaigns, and previous experience modelling similar environments. These maximum and minimum coefficients allowed bounds for possible salinity intrusion to be determined.

Appendix E Model validation

Preamble

This section provides the results of the hydrodynamic model validation. Model validation involves adjusting model parameters so that when a known set of external boundary conditions are applied, the model reproduces observed measurements within the model domain. To determine if the model is 'fit for purpose' in testing of any proposed drainage modifications, the model was run to simulate onsite conditions during 2018 (Section C 6). The model geometry and boundary conditions were based on observations and measurements as discussed in Appendix D.

Period of calibration

The MIKE hydrodynamic model was simulated for the period from 26 April 2018 to 10 July 2018, using a 5-second timestep. The period from April to July 2018 was determined on the basis of the recorded data sets available and so the model best represents the most recently observed conditions at the site. Observed (recorded) and predicted (modelled) comparisons were made for water levels from April to July 2018 and incorporate three (3) runoff events.

Internal model parameters

Model friction (Manning's n) was adjusted to match the observed water levels and phasings throughout the model domain. The adopted Manning's n values selected for the calibrated model are shown in Table E - 1. A roughness value of 0.05 was adopted for all elements throughout the 2D model domain and 0.04 for the majority of the 1D channel network. These roughness values are within the range of reported industry accepted values (Chow, 1959) for natural channels and floodplains with limited vegetation and weeds. For the lower sections of the drainage network, different Manning's n (ranging from 0.03 to 0.04) were applied to simulate the more efficient channel flow conditions observed during the field investigations. Similarly, within East Drain and Humpty-back Creek, Manning's n was increased (up to 0.15 in some locations) to reflect field observations of the significantly constricted drainage channels.

Table E - 1: MIKE model roughness parameters

Model	Location	Chainage from upstream (m)	Manning's n
2D	Floodplain	-	0.05
	Channels	-	0.04
1D	Clybucca Creek (downstream)	-	0.03
	East Drain	0 to 2,280	0.10
	Humpty-back Creek	0 to 3,290	0.15
	McAndrews Drain	-	0.03
	West Drain	-	0.03

During initial validation runs of the model, predicted water levels in West Dain were higher than observed. To overcome this issue, catchment inflows for this area were reduced by 50%. The limited data available for catchment inflows for this area indicates that this assumption is reasonable suggesting that this area has a different catchment hydrology to catchment 3 to which the AWBM was calibrated.

Water levels measured within Humpty-back Creek were significantly higher than modelled water levels. Consultation with community stakeholders indicated that there was an obstruction within the creek downstream of the monitoring location that had not been captured within the model. To simulate this, one cross-section was raised to provide an improved fit between measured and modelled data.

As discussed in Section D 4, field investigations indicated that there was a high groundwater flow potential (i.e. an extreme level of hydraulic conductivity) within the model domain. As a result, to better simulate recharge from groundwater which was observed during field investigations, a constant inflow of 0.6 m³/s was distributed across low sections of the model. This is equivalent to an inflow of 50 ml/m/s of drain.

Water surface elevations

Water surface elevation data at nine (9) locations across the study area were used for model validation (Figure C - 6). Figure E - 1 to Figure E - 9 show the observed (blue line) and predicted (dashed black line) water levels as simulated from 26 April 2018 to 10 July 2018. Recorded and modelled water levels matched to within 0.1 m for the majority of locations. The general shape of the water surface fluctuations, transforming from sinusoidal at the model boundary to a “saw-tooth” pattern upstream is well represented by the model.

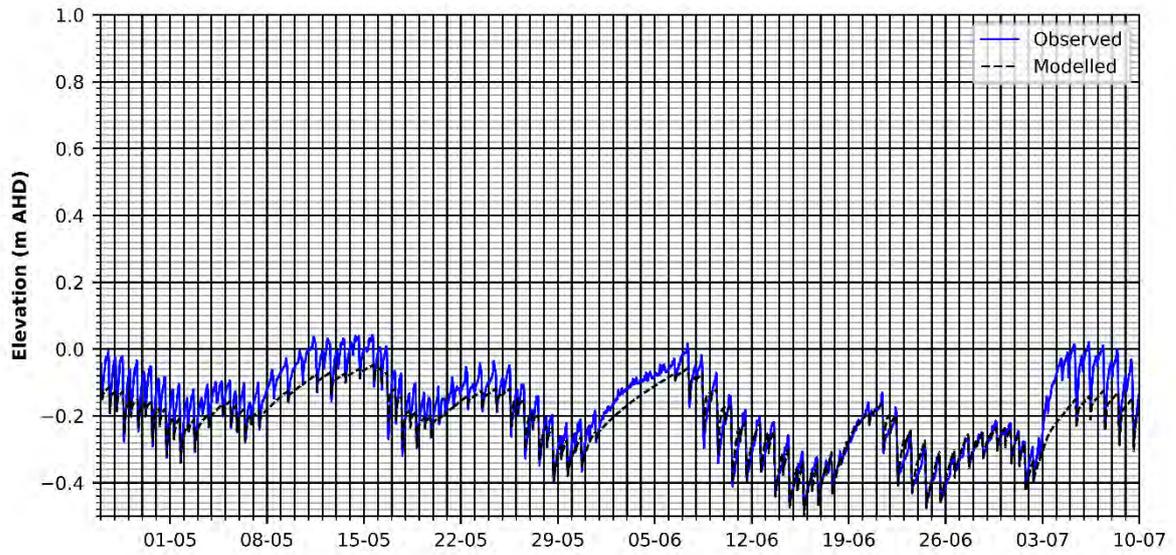


Figure E - 1: Observed and modelled water levels at location 2 - Seven Oaks Drain downstream of Yerbury's Sill

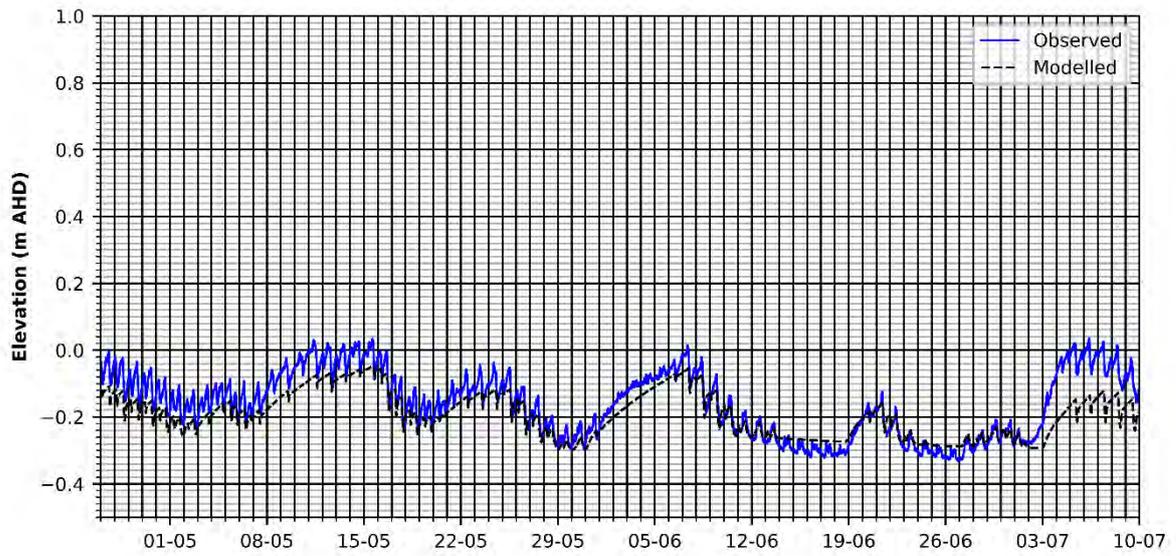


Figure E - 2: Observed and modelled water levels at location 4 - Seven Oaks Drain at West Drain

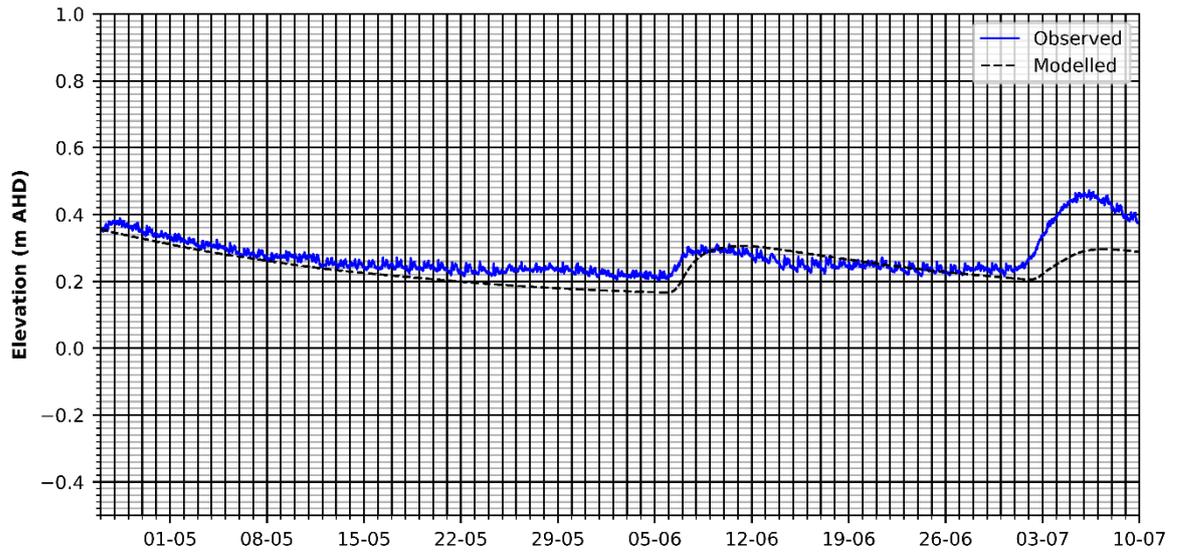


Figure E - 3: Observed and modelled water levels at location 7 - Seven Oaks Drain upstream

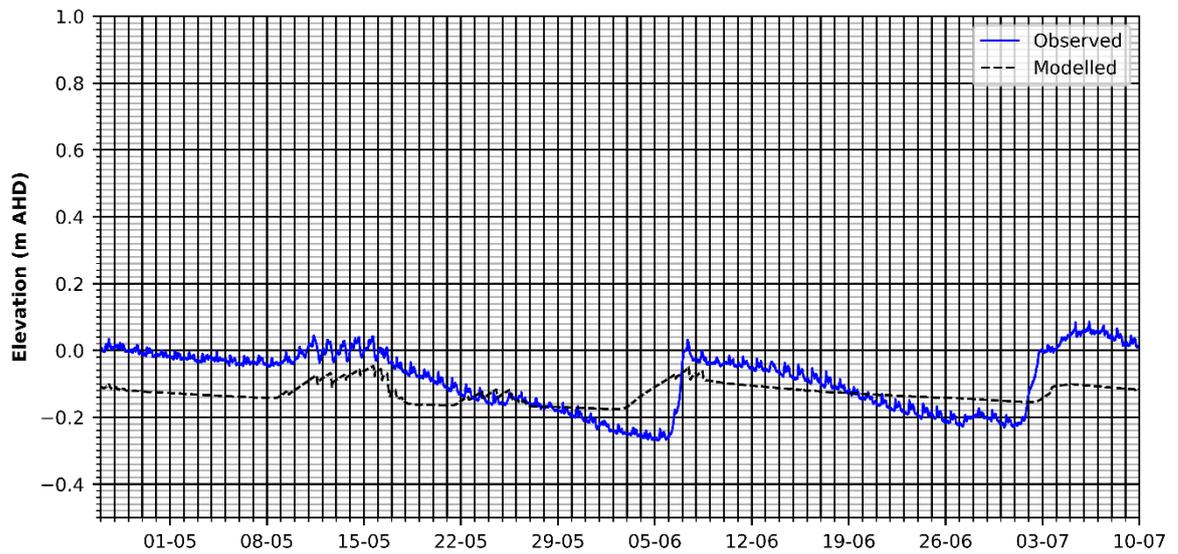


Figure E - 4: Observed and modelled water levels at location 8 – East Drain

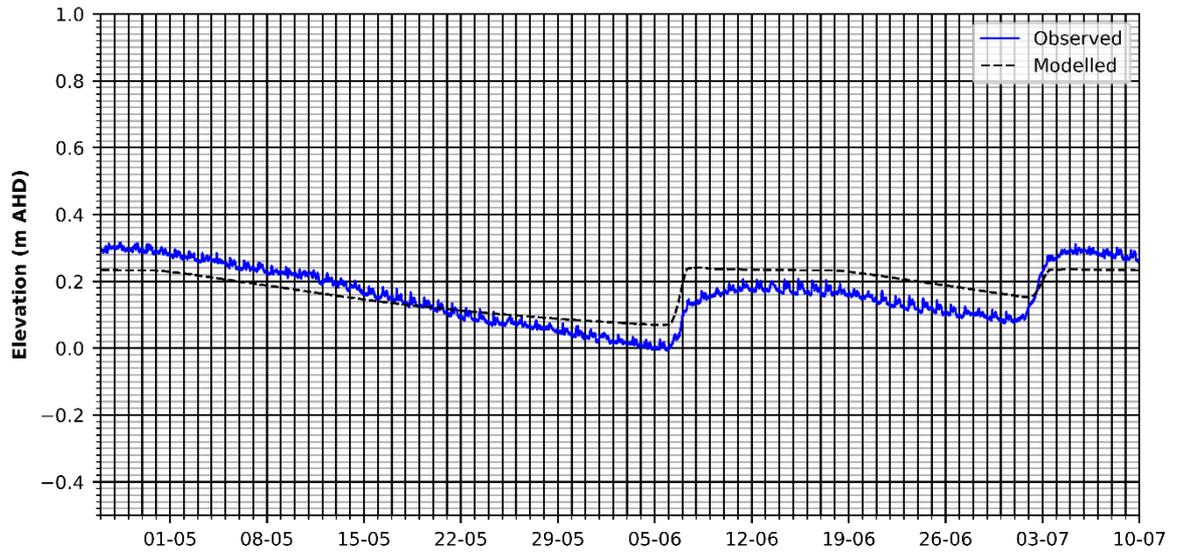


Figure E - 5: Observed and modelled water levels at location 9 – Johnsons Creek

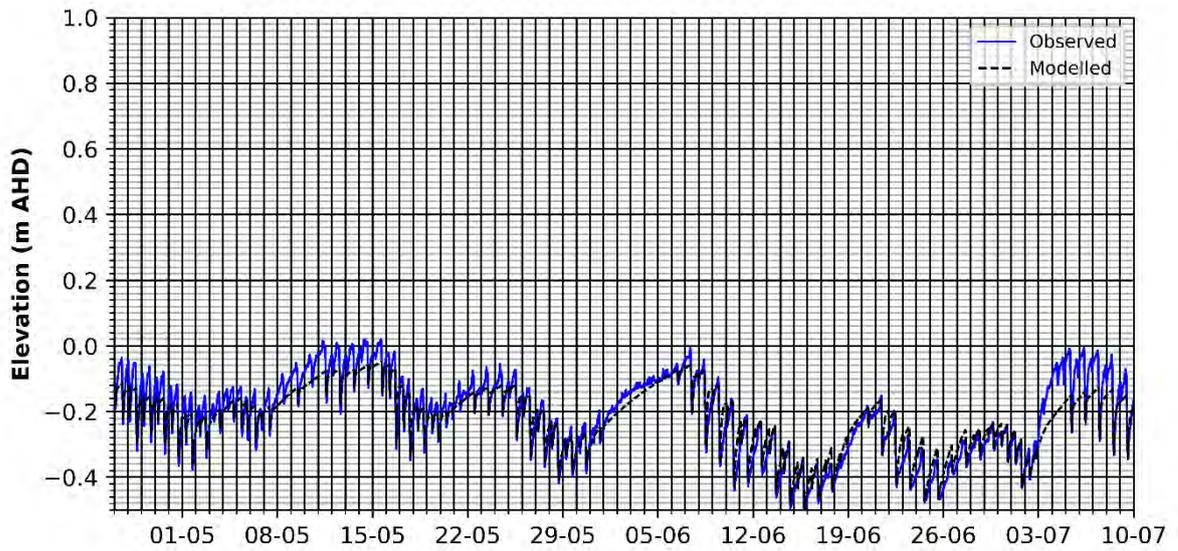


Figure E - 6: Observed and modelled water levels at location 3 – McAndrews Drain

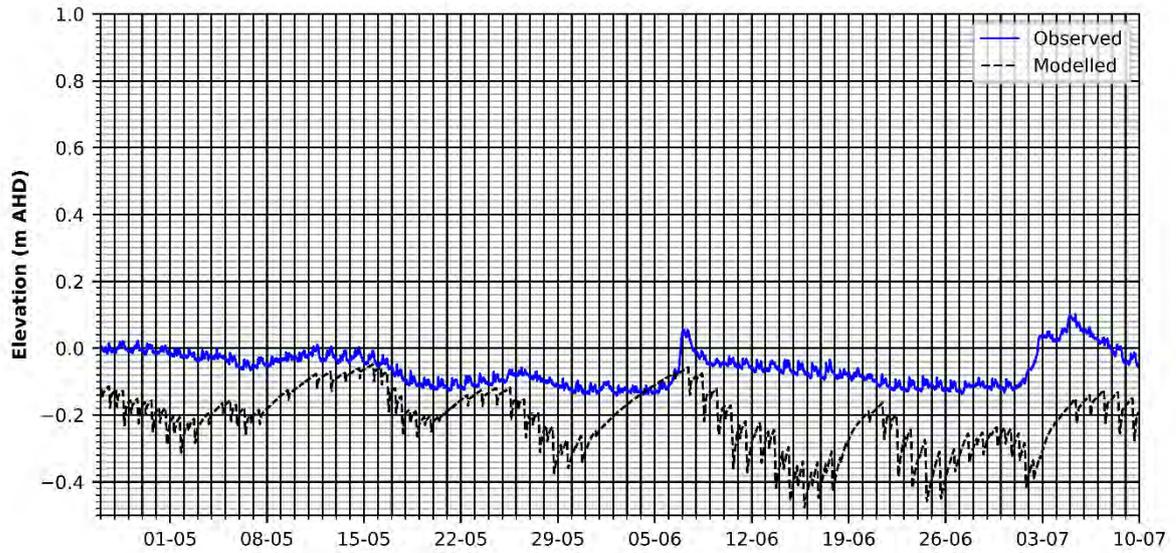


Figure E - 7: Observed and modelled water levels at location 10 - Humpty-back Creek

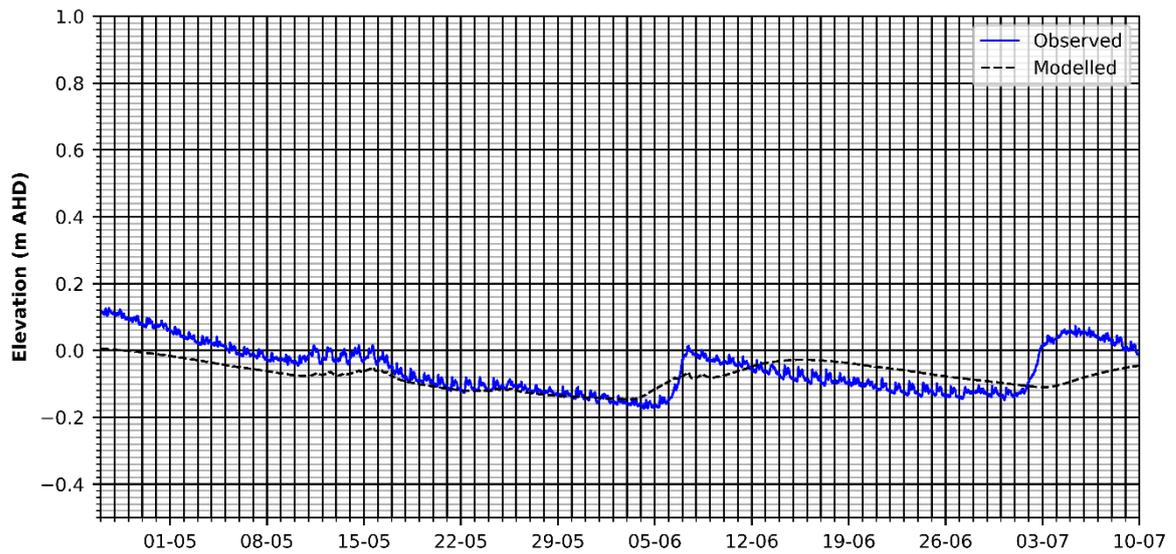


Figure E - 8: Observed and modelled water levels at location 5 – West Drain downstream

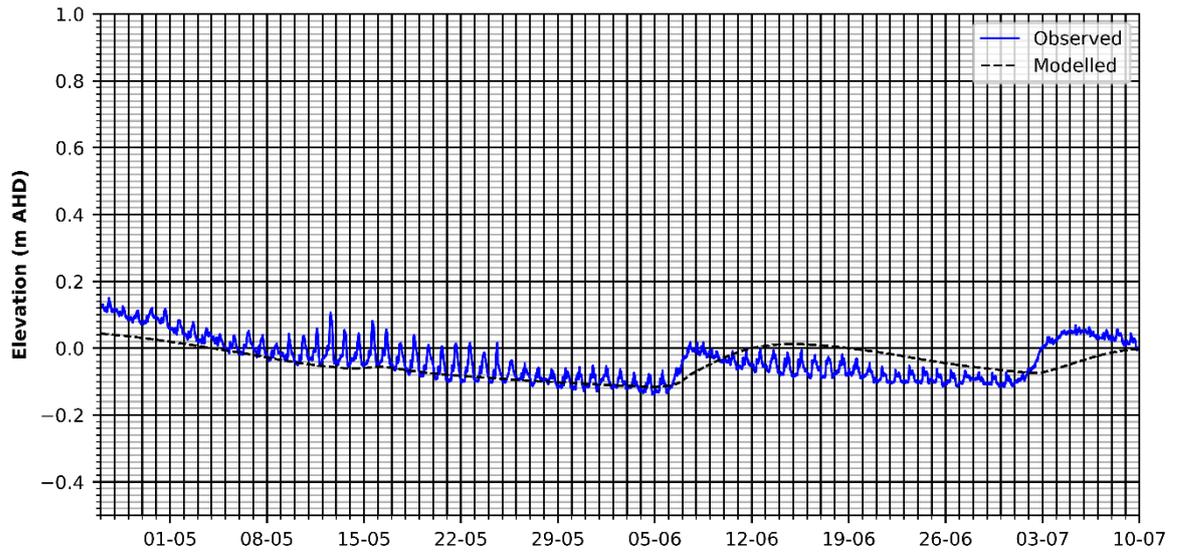


Figure E - 9: Observed and modelled water levels at location 6 – West Drain upstream

Appendix F Model processing

Two-dimensional model results were analysed in terms of inundation extents (maximum or mean) and changes to wetting-drying patterns (hydroperiod). The model hydroperiod was calculated as a dimensionless percentage of inundation time (i.e. a value between 0 and 100). For this study, the hydroperiod indicates the submergence duration of each element for the simulation period. For this calculation, inundation areas were defined by water depths of greater than 3 cm, which was consistent with model parameters adopted for defining wet/dry cell depths. Information used in the hydroperiod calculation was extracted from the 2-D output data files using the MIKE DataStatisticsFM analysis tool. The hydroperiod was calculated using the following equation:

$$\% \text{ time wet} = \left(\frac{E \times \bar{L} \times \Delta t}{T} \right) \times 100$$

where: E = 'Number of events', i.e. the average number of time steps where the water level exceeds the depth threshold

\bar{L} = 'Average length of events', i.e. the duration in which the water depth/level is above the depth threshold

Δt = Time step (in seconds), i.e. 900 seconds (15-minutes)

T = Total duration (in seconds), i.e. total duration where there is water in the elements, or the duration in each element where the analysis can be carried out.

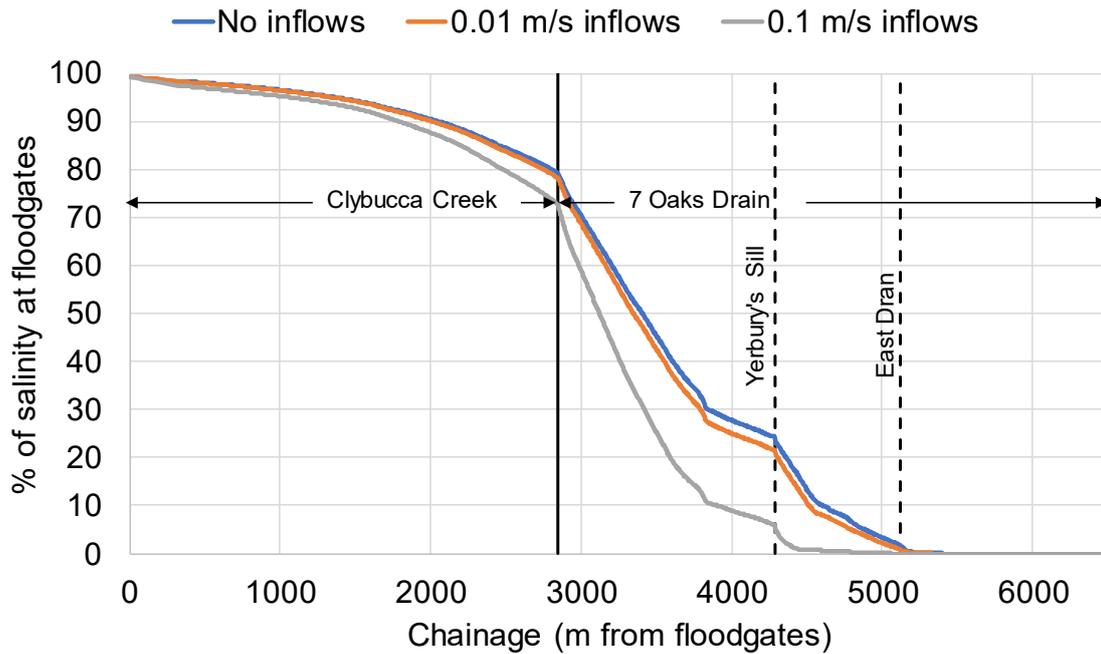
Appendix G Salinity sensitivity analysis

A sensitivity analysis has been completed to understand uncertainties that result from unknowns such as the level of dispersion within the drainage network and how catchment inflows will affect transport of saline water into the drainage network.

Since the level of salinity within the model is dependent on the salinity at the Menarcobrinni floodgates boundary, levels of salinity have been presented as a percentage of the salinity at the floodgates. For example, if there was a salinity of 20 PSU (Practical Salinity Units) at the floodgates, a location that has 50% of the salinity at the floodgates has a salinity of 10 PSU. Measurements of salinity (presented in Appendix C) showed that salinity at the floodgates can vary from 0 PSU (equivalent to freshwater) to 35 PSU (equivalent to the salinity in the ocean). Generally, during wet periods salinity within Clybucca Creek downstream of the floodgates is lower and during dry periods higher.

To understand maximum saline intrusion to the drainage network, the numerical model was run simulating a dry period. For this case there were no catchment inflows to the network (i.e. no freshwater flowing from upstream locations). This maximised the extent to which saline water entered the system. Note, when there are freshwater inflows to the network, salinity concentrations will be reduced.

To better understand the impact of catchment inflows, a sensitivity test was completed for the 0.0 m AHD cut off level. In addition to the zero catchment inflow simulation, two (2) cases were run where inflows of 0.01 m/s and 0.1 m/s were set as catchment inputs at the Seven Oaks Drain, West Drain and East Drain inflow points to the model (i.e. there was a total of zero, 0.03 m/s and 0.30 m/s inflow for each case respectively). Results are shown in Figure G - 1.



Note: Cut off level was set at 0.0 m AHD for each simulation. Inflows of 0.01 m/s and 0.10 m/s were set at three (3) locations upstream of Seven Oaks Drain, West Drain and East Drain (i.e. there was a total of 0.03 m/s or 0.30 m/s for the model for each case respectively).

Figure G - 1: Effect of catchment inflows on concentration of salinity within the drainage network

There is uncertainty for the level of dispersion that will occur within the drainage network as it is dependent on a range of factors that cannot be measured until the floodgates are modified. Using available literature and theoretical values, bounds for dispersion coefficients were calculated (details are outlined in detail in Appendix D). The bounds for dispersion within the drainage network have been calculated for the 0.0 m AHD cut off level case and are shown in Figure G - 2. For the two-dimensional network it was found that salinity transport was governed by hydrodynamics and as a result there was no noticeable difference in salinity concentration for the dispersion coefficients tested.

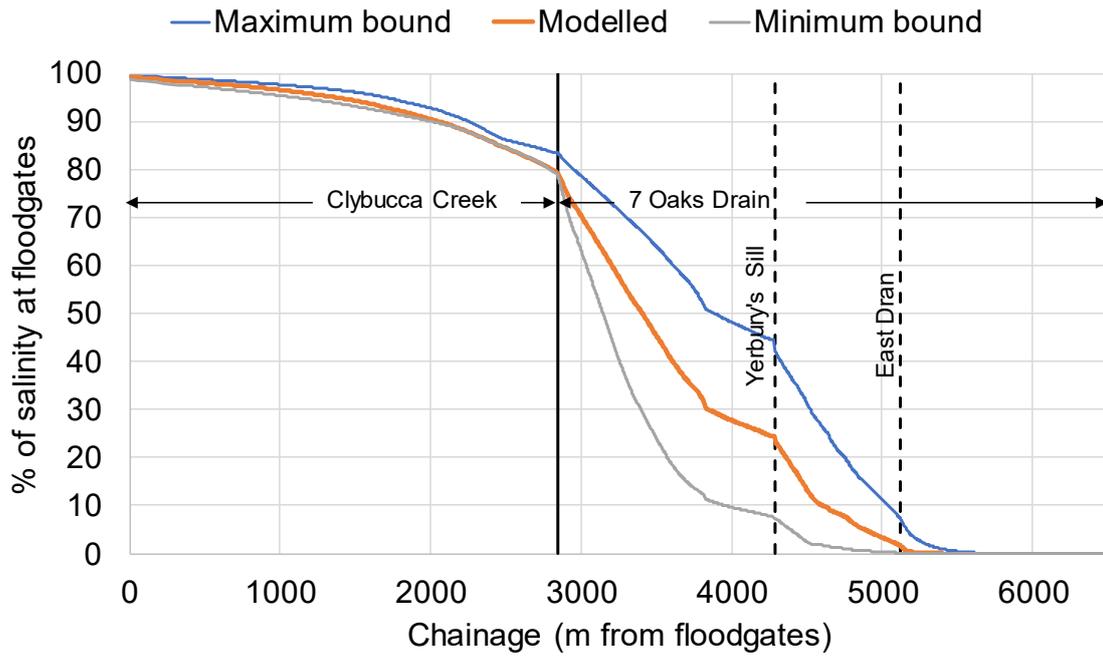


Figure G - 2: Uncertainty bounds within the drainage network due to the dispersion coefficient

Appendix H Flood impact assessment

Table 1: Clybucca Remediation Design Options

Design Scenario	Removal of Levee Banks	Change of Initial Water Level	Other Changes
1	Yes	To 0.0 m AHD	Addition of Weirs at: Seven Oaks Drain (Eastern extent of Mayes Swamp), Seven Oaks Drain and McAndrews Drain and East Drain (Near the Seven Oaks Drain confluence)
2	Yes	To 0.0 m AHD	Drain extension at McAndrews drain (connecting Seven Oaks Drain near West Drain)
3	No	No	Existing floodgates at Menarcobrinni barrage have been altered from a uni-direction to bi-directional.
4	No	To 0.5 m AHD	Existing floodgates at Menarcobrinni barrage have been altered from a uni-direction to bi-directional.

Figure 1: Design Case 1 – TUFLOW Model Changes

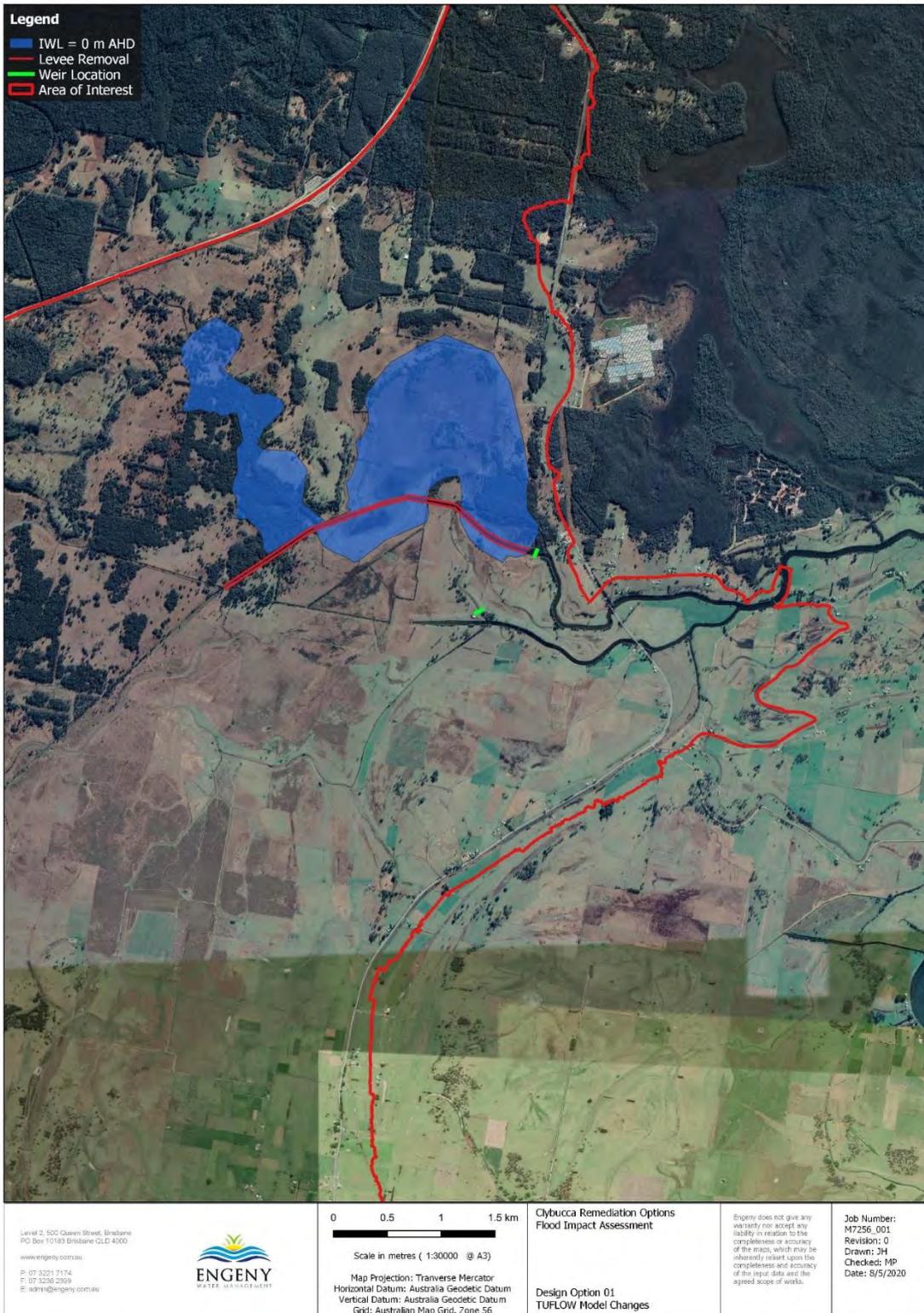


Figure 2: Design Case 2 – TUFLOW Model Changes

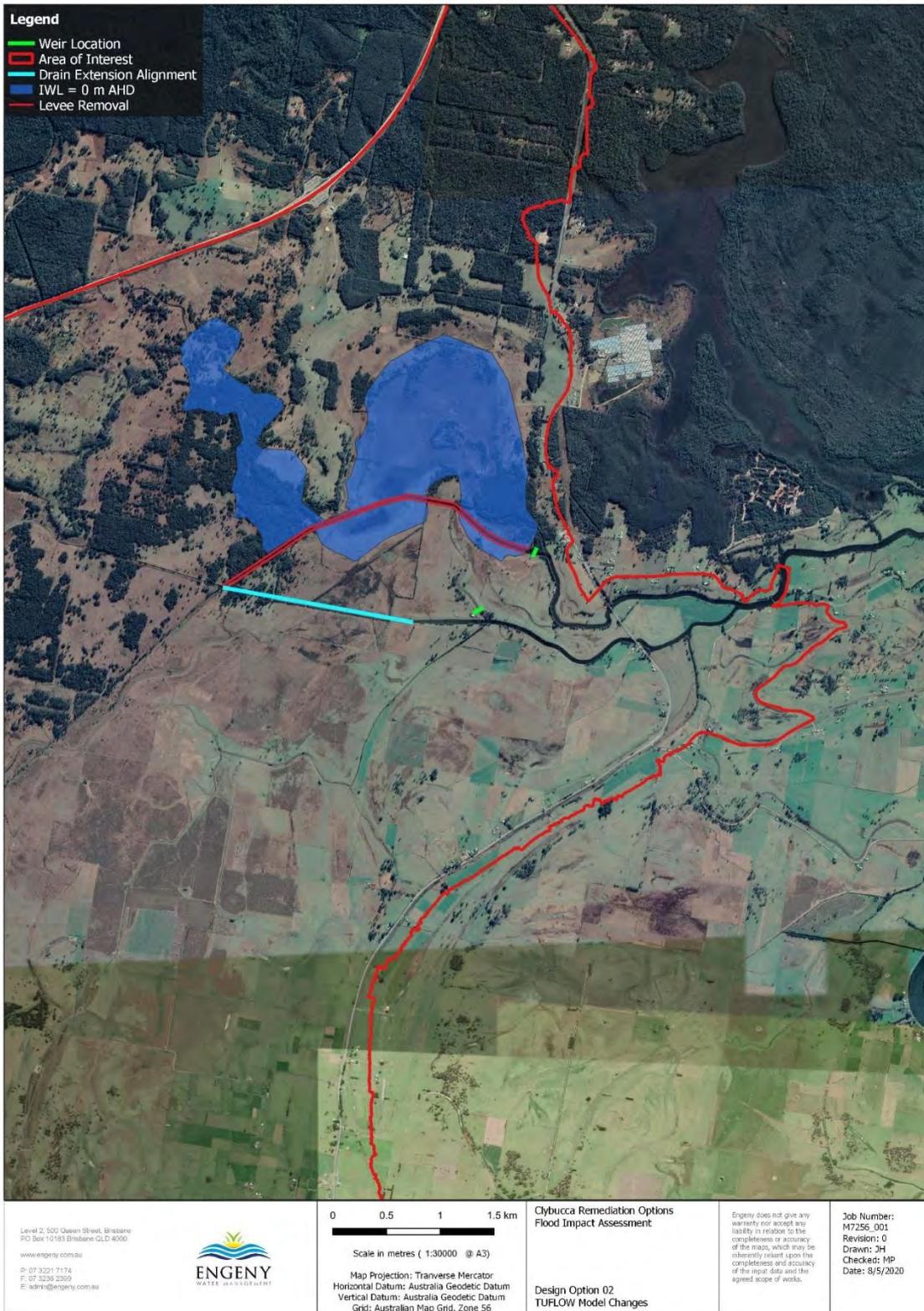


Figure 3: Design Case 3 – TUFLOW Model Changes

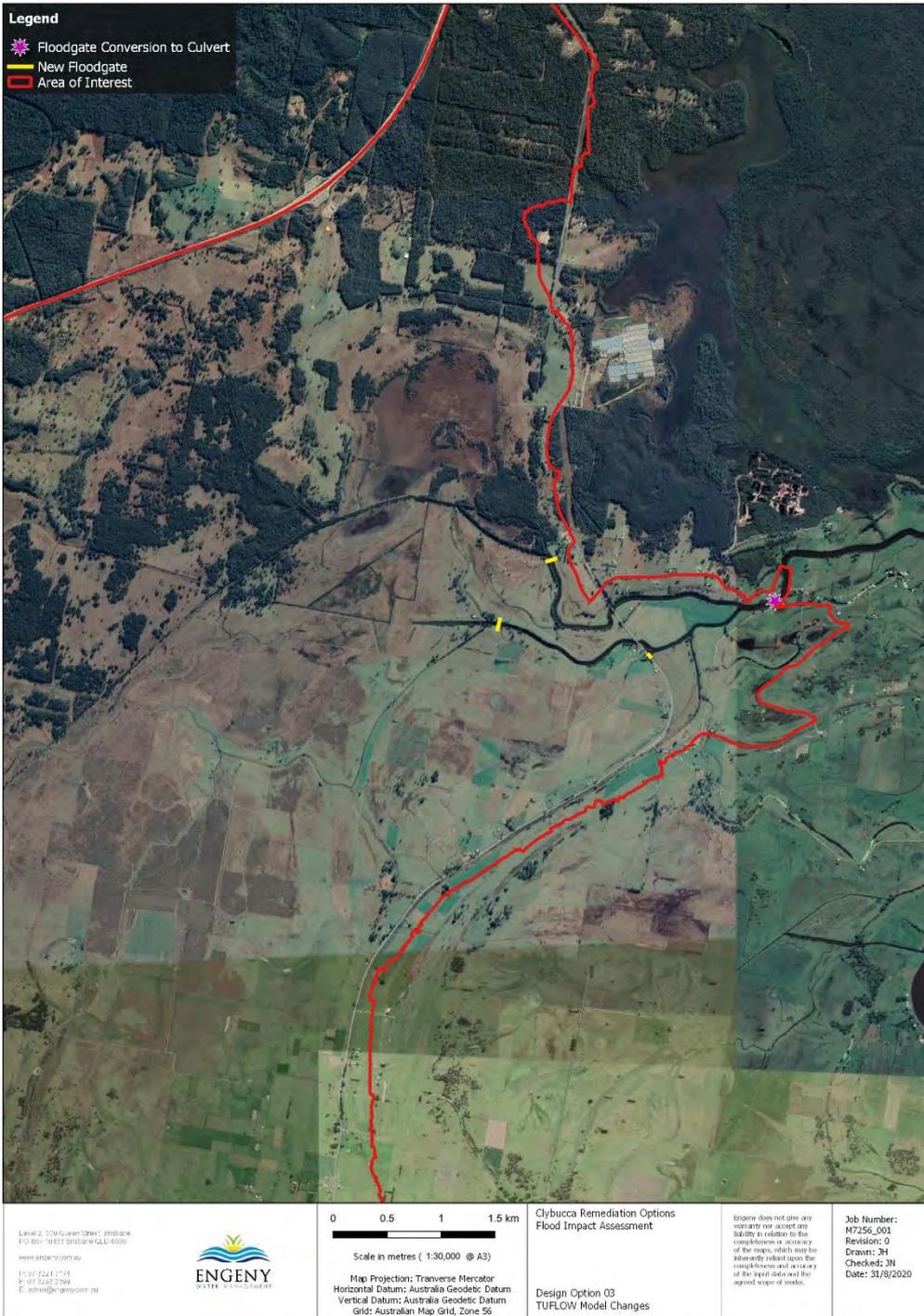


Figure 4: Design Case 4 – TUFLOW Model Changes



Hydraulic Model Development

The following model changes were made to accurately represent the proposed design cases. Aside from changes below, no other modifications were made to the model.

MODEL SOLUTION SCHEME (BASE AND DESIGN CASE)

The adopted 1D/2D TUFLOW hydraulic model was developed using a Multi-2D-Domain (M2D) Classic solution scheme. The M2D classic solution scheme allows for the model to separate areas into coarse and fine resolution areas, which provides higher resolution of results in areas of interest (the townships). The coarse domains were generally floodplains without dense development, whereas the fine resolution domains were densely populated areas such as the townships.

As part of this flood impact assessment, the solution scheme was altered to a HPC solution scheme, which allowed for a reduction in model simulation time, while maintaining reasonable model accuracy surrounding the floodplains and Clybucca wetland.

GRID CELL SIZES (BASE AND DESIGN CASE)

The entire model was converted into a 20 m grid cell size and the nested grids were removed (1 m grids in the nested area and 20 m in flood plain). This was considered appropriate as the assessment was considered high level and would not likely to impact any of the residing townships.

TOPOGRAPHY (DESIGN CASE ONLY)

For the base cause, no changes were undertaken for the topography.

For the design cases, the following changes were made (where applicable):

- **Removal of levee** – A 2D Z-shape was utilised to remove the drainage levee south of the Clybucca wetland.
- **McAndrews drain** – A 2D Z-shape was utilised to enforce the drain within the DEM.
- **Weirs** – 2D Z-lines were used to enforce a weir into the existing drains.

No other changes or modifications were undertaken to the LMRFS model topography.

HYDRAULIC STRUCTURES (DESIGN CASE ONLY)

For the base cause, no changes were undertaken for the hydraulic structures.

For the design cases, where applicable for **changes to existing floodgates at Menarcobrinni barrage**, the existing 1D pipe network was modified to represent bi-directional flow instead of the existing uni-directional flow. For design 3, additional flood gates were modelled as 1D pipe networks.

No other changes or modifications were undertaken to the LMRFS model 1D structures.

INITIAL WATER LEVEL (DESIGN CASE ONLY)

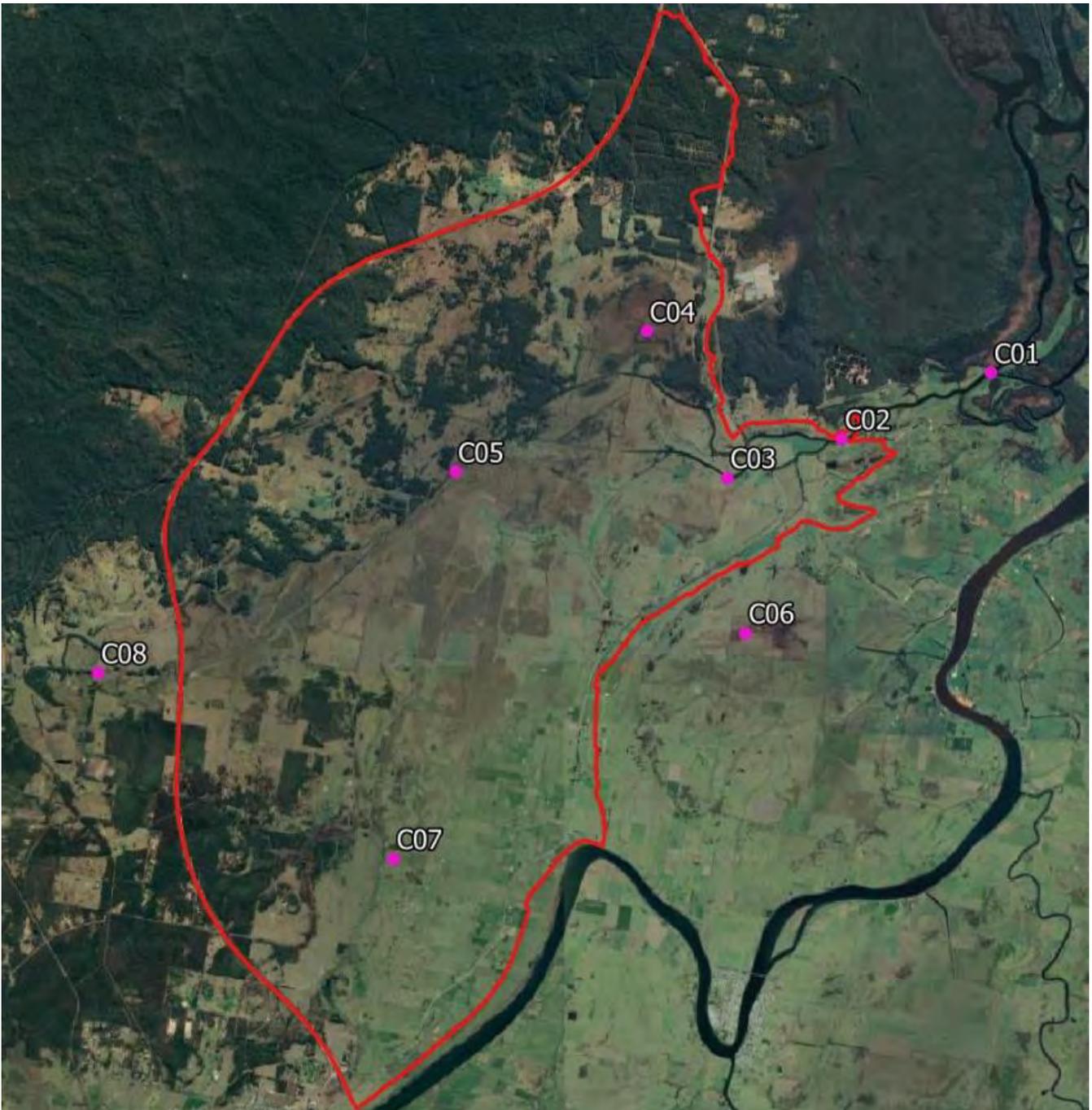
The initial water levels (where applicable) were altered to the proposed levels extents highlighted in Figure 1 to Figure 4.

Results

REPORTING LOCATIONS

Reporting locations were provided by UNSW WRL and are presented in Figure 5.

Figure 5: Reporting Locations



Peak flood levels are each of the reporting locations for the base and design events are shown in Table 2.

Table 2: Peak Flood Level at Reporting Locations

Reporting Location	Base	Base	Design 1	Design 1	Design 2	Design 2	Design 3	Design 3	Design 4	Design 4
	0.2 EY (m AHD)	1% AEP (m AHD)								
C01	2.23	4.21	2.16	4.21	2.16	4.21	2.26	4.22	2.23	4.21
C02	2.45	4.33	2.37	4.32	2.37	4.32	2.47	4.33	2.44	4.33
C03	2.75	4.40	2.69	4.39	2.69	4.39	2.76	4.40	2.74	4.40
C04	2.76	4.42	2.70	4.41	2.70	4.41	2.78	4.42	2.75	4.41
C05	2.77	4.42	2.70	4.41	2.70	4.41	2.79	4.43	2.76	4.42
C06	2.66	4.40	2.62	4.39	2.62	4.39	2.67	4.40	2.66	4.40
C07	2.81	4.46	2.73	4.45	2.73	4.45	2.83	4.47	2.80	4.46
C08	2.80	4.46	2.74	4.45	2.74	4.45	2.83	4.47	2.80	4.46

Table 3: Time to Max at Reporting Locations

Reporting Location	Base	Base	Design 1	Design 1	Design 2	Design 2	Design 3	Design 3	Design 4	Design 4
	0.2 EY (Hours)	1% AEP (Hours)								
C01	55.8	51.2	56.1	51.2	56.1	51.2	55.4	51.2	55.9	51.2
C02	55.5	50.7	56.1	50.7	56.0	50.7	55.2	50.7	55.6	50.7
C03	54.6	50.4	55.9	50.4	55.8	50.4	54.1	50.4	54.8	50.3
C04	54.6	50.3	56.1	50.4	55.8	50.4	54.1	50.3	54.8	50.4
C05	54.5	50.3	55.9	50.4	55.8	50.4	54.0	50.2	54.7	50.3
C06	52.8	50.3	46.8	50.4	46.9	50.4	52.6	50.3	52.8	50.4
C07	52.1	49.9	53.5	50.0	53.4	50.0	51.6	49.9	52.3	49.9
C08	54.7	50.0	56.2	50.1	56.0	50.1	54.1	50.0	54.9	50.0

PEAK FLOOD IMPACTS

Peak flood impact mapping is attached. Key observations based on the modelled results are as follows:

For the 0.2 EY Design 1 & 2 flood events:

- There are observed reductions of up to 90 mm in the Northern model extent in the Collombatti - Clybucca floodplain.
- There are adverse impacts of up to 80 mm in the Southern model extent towards the Belmore River-Kinchela floodplain.

For the 0.2 EY Design 3 flood event:

- There are adverse impacts up to 30 mm within the Clybucca floodplain, these impacts extend downstream to Yarrahappinni Wetlands National Park.
- There are adverse impacts up to 30 mm east of the Macleay River north of Hathead Rd.

For the 0.2 EY Design 4 flood event:

- There are no adverse impacts observed throughout the entire floodplain.

Based on the 0.2 EY flood results, there are reductions of up to 80 mm within the Clybucca floodplain (towards the top of the catchment) and impacts south of Macleay River 8 km from the Clybucca wetlands for Design cases 1 and 2. There are impacts up to 30 mm throughout the Clybucca floodplain, south-east of the Macleay River and significantly downstream of the Menarcobinni Bridge, however these are not captured within the attached figures. These impacts are likely attributed to model instabilities due to topography changes to the Clybucca levee and weir additions. The changes in the topography are likely influencing the boundary conditions that were adopted in the Jacobs model (Level vs Time boundary), which are heavily influencing the model stability. There is a clear separation of the impacts and reductions observed at the Macleay River, separated by the South West boundary and Korogoro Creek boundary, which may have affected the timing of the model. This statement is further supported by the 4 case which does not contain any changes to the topography, and model results shown no adverse impact to the flood levels.

Due to the model stabilities, it is not definitive whether the proposed design cases 1, 2 and 3 result in adverse impacts. However, based on Council's definition of adverse (above 0.05 m within the floodplain²), the proposed remediation options do not result in any adverse impacts to the floodplain.

Note: 2. Impacts of up to 0.05 m was based on a previous project with Council.

For the 1% AEP Design 1 & 2 flood events:

- There are observed reductions of up to 50 mm at the Frederickton township.
- There are adverse impacts of up to 30 mm observed at the Macleay River edge and south of Macleay River at the Austral Eden floodplain.
- No other adverse impacts of reductions are observed throughout the model.

For the 1% AEP Design 3 & 4 flood events:

- There are no adverse impacts observed throughout the entire floodplain.

No adverse impacts are observed in the 1% AEP flood event as a result of the proposed remediation options for all design cases. There are minor instabilities within the model which is likely attributed to the boundary conditions mentioned in the 0.2 EY flood events.

It is observed that the time to peak of the flood differs significantly between the design events and base case modelling.

Conclusion

Based on the Clybucca remediation design cases provided by WRL UNSW, a flood impact assessment for the 0.2 EY and 1% AEP was undertaken.

For the Design case 4, there were no adverse impacts observed in the 0.2 EY and 1% AEP flood event. Furthermore, there were no adverse impacts observed for Design Case 3 in the 1% AEP event. However for Design Case 1 and 2, there were observed reductions of up to 90 mm in the 0.2 EY flood event and minor reductions in the 1% AEP event, that is likely attributed to instabilities within the model due to topography changes. Finally, there were up to 30 mm of adverse flood level impacts within the Clybucca floodplain for the 0.2 EY.

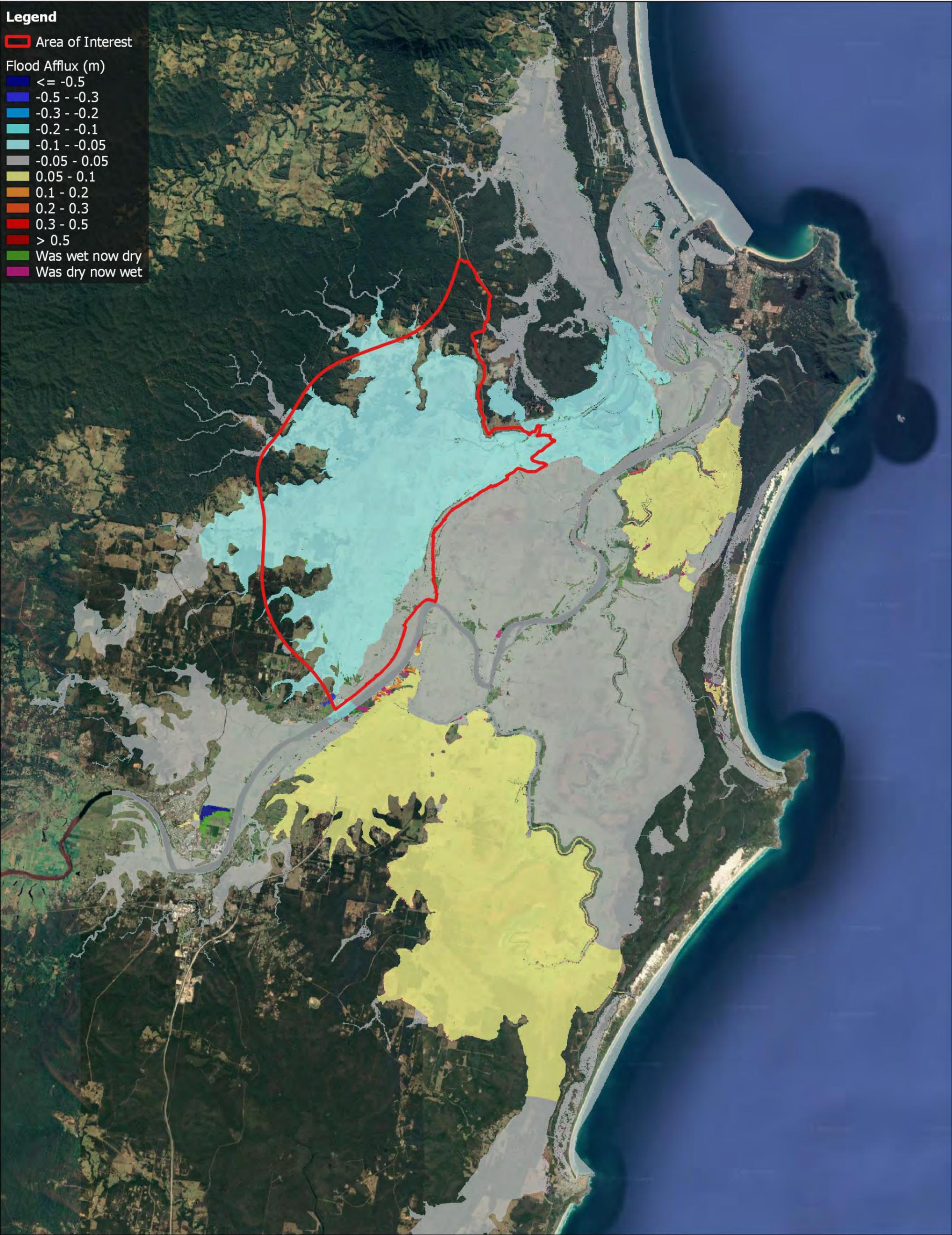
For a more accurate simulation of the model (without instabilities), it is recommended that a change in boundary condition from a Level vs Time to a static peak level be undertaken. Although there were model instabilities observed within the model, the model is within the boundaries of accuracy of +/- 0.05 m, which was determined by Council on a previous project (undertaken by Engeny with support from Council).

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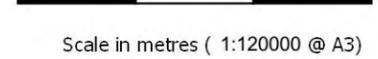
- Legend**
- Area of Interest
 - Flood Afflux (m)**
 - <= -0.5
 - 0.5 - -0.3
 - 0.3 - -0.2
 - 0.2 - -0.1
 - 0.1 - -0.05
 - 0.05 - 0.05
 - 0.05 - 0.1
 - 0.1 - 0.2
 - 0.2 - 0.3
 - 0.3 - 0.5
 - > 0.5
 - Was wet now dry
 - Was dry now wet



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0 2 4 6 km



Scale in metres (1:120000 @ A3)

Map Projection: Transverse Mercator
 Horizontal Datum: Australia Geodetic Datum
 Vertical Datum: Australia Geodetic Datum
 Grid: Australian Map Grid, Zone 56

Clybucca Remediation Options
 Flood Impact Assessment

Design Option 01
 0.2 EY Flood Level Afflux

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Job Number: M7256_001
 Revision: 1
 Drawn: JH
 Checked: JN
 Date: 30/9/2020

Legend

- Area of Interest
- Flood Afflux (m)**
- <= -0.5
- 0.5 - -0.3
- 0.3 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.5
- > 0.5
- Was wet now dry
- Was dry now wet



Scale in metres (1:120000 @ A3)

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 Vertical Datum: Australia Geodetic Datum
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Clybucca Remediation Options
 Flood Impact Assessment

Design Option 01
 1% AEP Flood Level Afflux

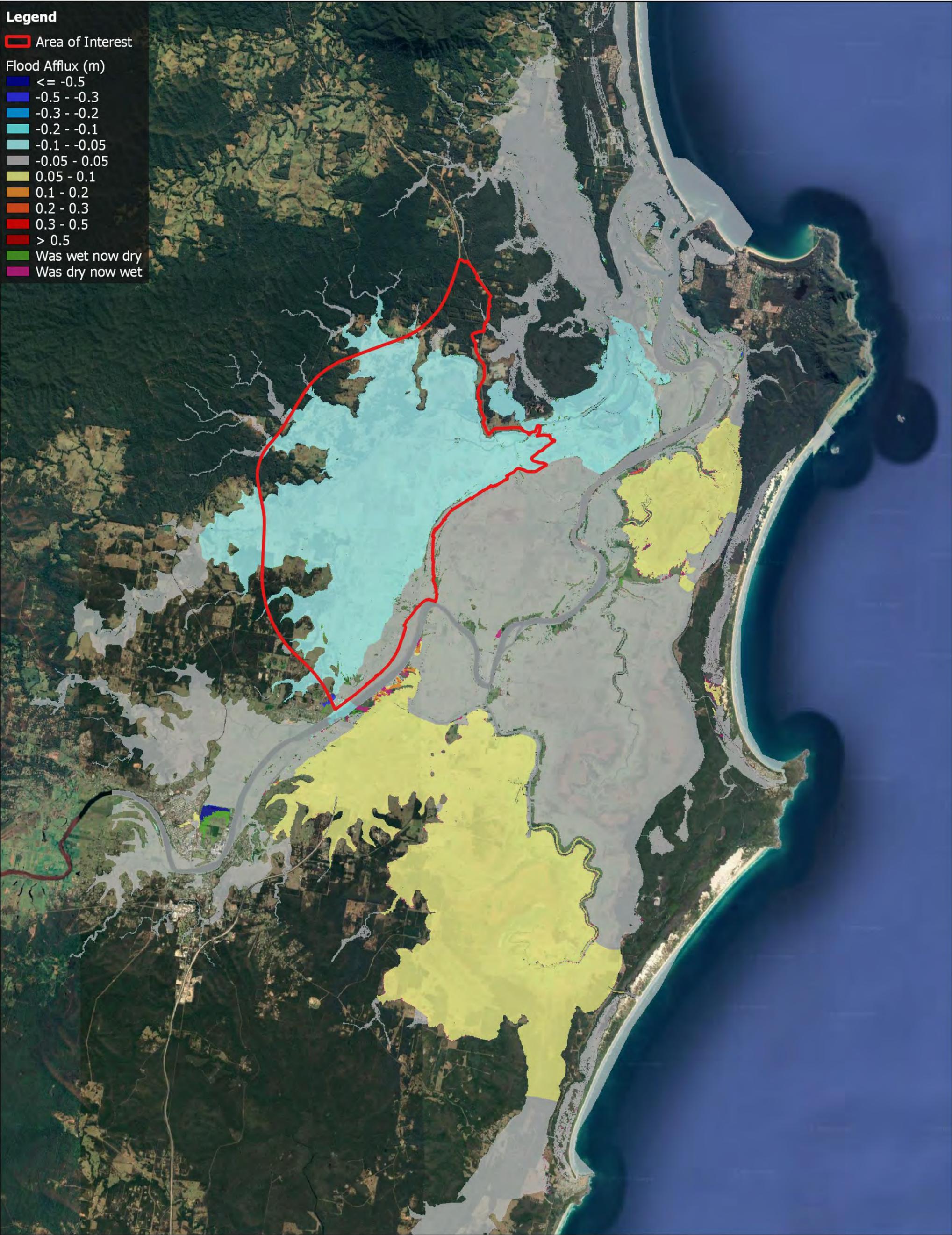
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- Legend**
- Area of Interest
 - Flood Afflux (m)**
 - <= -0.5
 - 0.5 - -0.3
 - 0.3 - -0.2
 - 0.2 - -0.1
 - 0.1 - -0.05
 - 0.05 - 0.05
 - 0.05 - 0.1
 - 0.1 - 0.2
 - 0.2 - 0.3
 - 0.3 - 0.5
 - > 0.5
 - Was wet now dry
 - Was dry now wet



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Clybucca Remediation Options
Flood Impact Assessment

Design Option 02
0.2 EY Flood Level Afflux

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Date: 30/9/2020

Legend

- Area of Interest
- Flood Afflux (m)**
- <= -0.5
- 0.5 - -0.3
- 0.3 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.5
- > 0.5
- Was wet now dry
- Was dry now wet



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0 2 4 6 km
 Scale in metres (1:120000 @ A3)
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Clybucca Remediation Options
 Flood Impact Assessment
 Design Option 02
 1% AEP Flood Level Afflux

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 Revision: 1
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Legend

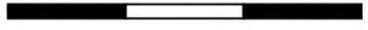
- Area of Interest
- Flood Afflux (m)**
- <= -0.5
- 0.5 - -0.3
- 0.3 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.5
- > 0.5
- Was wet now dry
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0 2 4 6 km



Scale in metres (1:120000 @ A3)

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Clybucca Remediation Options
 Flood Impact Assessment

Design Option 03
 0.2 EY Flood Level Afflux

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Legend

- Area of Interest
- Flood Afflux (m)**
- <= -0.5
- 0.5 - -0.3
- 0.3 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.5
- > 0.5
- Was wet now dry
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Clybucca Remediation Options
 Flood Impact Assessment
 Design Option 03
 1% AEP Flood Level Afflux

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- Flood Afflux (m)**
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- 0.5 - -0.3
- 0.3 - -0.2
- 0.2 - -0.1
- 0.1 - -0.05
- 0.05 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.5
- > 0.5
- Was wet now dry
- Was dry now wet



Scale in metres (1:120000 @ A3)

Map Projection: Transverse Mercator
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Clybucca Remediation Options
 Flood Impact Assessment

Design Option 04
 0.2 EY Flood Level Afflux

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- 0.1 - -0.05
- 0.05 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.5
- > 0.5
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Clybucca Remediation Options
 Flood Impact Assessment
 Design Option 04
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