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Everlasting Swamp Hydrodynamic Modelling Study

WRL TR 2017/02 | March 2019

By W C Glamore, J E Ruprecht, A J Harrison, T A Tucker,
D S Rayner and A N Smith

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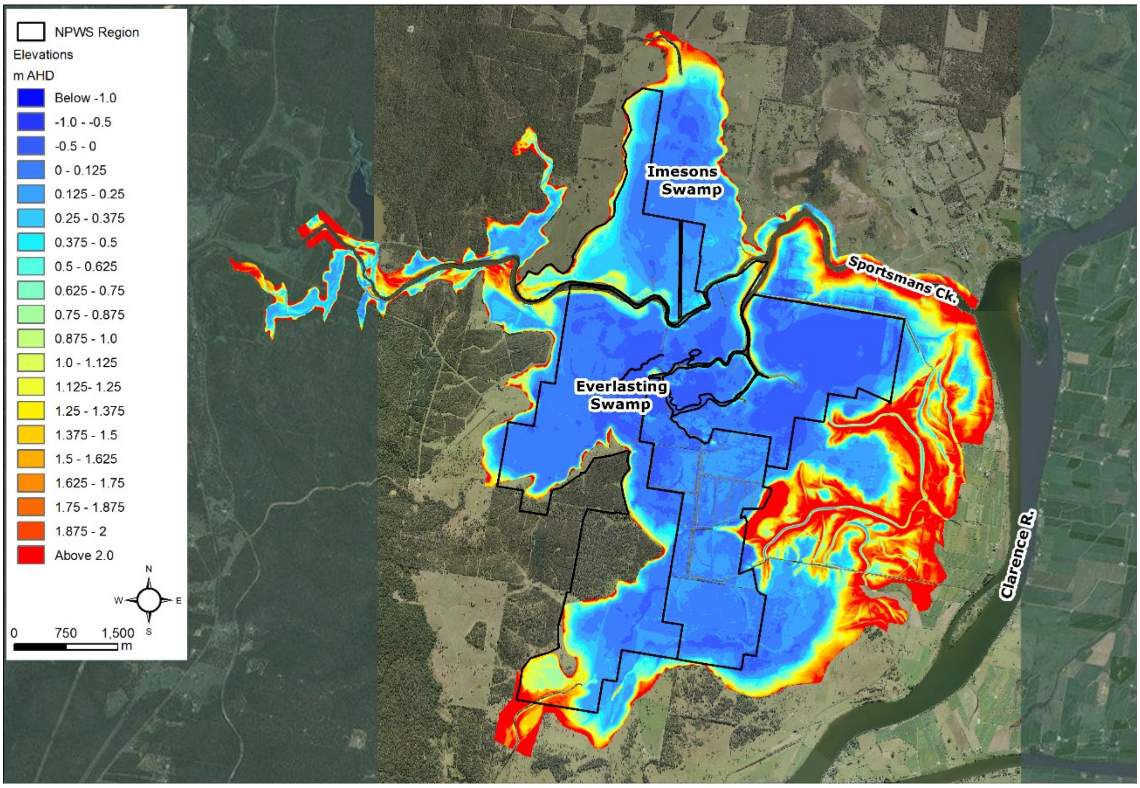
Executive Summary

The Everlasting Swamp wetland complex (Figure ES.1), located on the Clarence River floodplain adjacent to Sportsmans Creek, is one of the largest remaining coastal floodplain wetlands in NSW, and is recognised by the State and Federal Governments as a site of ecological significance. Over the past century, flood mitigation works across the Clarence River floodplain have resulted in agricultural benefits to some landholders and adverse environmental impacts to the broader estuary. The agricultural areas are valued by local landholders and the flood mitigation works are a vital component, ensuring that the landscape remains arable and accessible. Unfortunately, the flood mitigation drainage network is also responsible for the decline in environmental values (e.g. fish, birds, vegetation, etc.) and the production of acidic runoff to the broader estuary from drained acid sulfate soils. Remediation strategies to improve degraded areas of the site and re-establish natural flow patterns must consider hydrologic impacts to the surrounding floodplain and landholders.



ES.1: The study area (model domain) showing site topography and NPWS management area

In 2007, a portion of Everlasting Swamp (462 hectares) was acquired by Northern Region National Parks and Wildlife Service (NPWS) and managed as a State Conservation Area (SCA). This was the single largest wetland reserve on the Clarence River floodplain and was the first state government managed local area of a wetland supporting potentially high-quality waterbird habitat. However, as the SCA was located between privately-owned agricultural land, limited on-ground works could be undertaken at the time to rehabilitate the site. In 2014, an additional 1,769 hectares were acquired by NPWS. This additional land located both north and south of Sportsman Creek provided significant area for wetland rehabilitation, removed several private holdings, and reduced the overall management risk of changing onsite hydrologic conditions.

In 2016, the NPWS released a Statement of Management Intent for the Everlasting Swamp National Park and State Conservation Area that outlined the values, issues, management directions and priorities for the site. The return of natural flow regimes back into the swamp to improve the ecosystem functions and overall health of the surrounding environment was recognised as the primary long-term management objective for NPWS. However, any changes to the current situation depends on the agreement of stakeholders, including adjacent landholders and Clarence Valley Council.

At present, the NPWS manage over 80% of the Everlasting Swamp wetland complex, with the Everlasting Swamp National Park mostly surrounded by private landholdings, some of which have areas that are mapped as SEPP 14 (Coastal Wetlands). While past and present landholders on the floodplain have cooperated with Clarence Valley Council since 1998 to examine options and investigate ways to better integrate agriculture and environmental management, achieving the optimal management strategy has been met with strong opposition due to the potential risks associated with water management on adjoining private properties. Of particular concern is the flooding of properties with tidal waters, or muted tidal waters that currently penetrate upstream of the Sportsmans Creek Weir, where existing drainage must be maintained. Other concerns related to the inundation of upstream properties from manipulation or removal of the Sportsmans Creek Weir, or uncontrolled inundation on the NPWS land resulting in undesirable environmental outcomes (e.g. poor water quality, poor ecosystem management, mosquitoes, etc.) for the whole area.

To date, the Sportsmans Creek Weir, a 73 m tidal barrage constructed in 1927, remains a dominant structure controlling surface and groundwater hydrology across the Everlasting Swamp wetland complex. However, the ageing weir is deteriorating and at risk of failure. While the community sees value in the weir, recent community feedback suggested that the risks (e.g. failure, litigation) outweigh the benefits (e.g. prevents powerboats, maintains water levels, allows freshwater fish to breed), associated with a 'do-nothing' option. As such, the status and operation of the Sportsmans Creek Weir must be the priority consideration for the possible restoration of the Everlasting Swamp wetland complex.

This study, through the use of purpose-collected field datasets and calibrated computer models, has detailed the existing hydrodynamics of Everlasting Swamp and Imesons Swamp, and tested various remediation options for the site. Field observations and measurements over a 9-month period from November 2016 to August 2017 were taken to provide information on how the site functions. The field data collected during this study, included:

- Detailed surveys of floodplain topography, drainage infrastructure and bathymetry;
- Aerial drone photos before and after flooding in March and April 2017;
- Water level and water quality monitoring; and
- An assessment of acid sulfate soils from soil profiles.

Based on extensive field work, computer modelling software was used to simulate flow conditions across the site. The computer model was developed to compare the relative impacts of proposed remediation options on neighbouring properties adjacent to the Everlasting Swamp National Park. The model results highlighted the influence of changes across the study area over time for a range of management options. For each scenario tested, the model results were analysed for inundation extents (maximum, minimum, mean) and changes to wetting-drying patterns (hydroperiod). The model was developed based on the best available information of the site and this approach has been successfully applied in many locations across the country.

The model geometry and boundary conditions were based on the field observations and measurements. Boundary conditions for the model included local catchment inflows and tides at Lawrence. The hydrodynamic model was calibrated by adjusting model parameters so that when a known set of external boundary conditions are applied, the model accurately reproduces the observed tidal flow dynamics as compared to, and represented by, the field measurements. Water level data at several locations across the study area were used for calibration. Recorded and predicted water levels matched to within ±0.1 m for all locations.

Potential on-ground management options were rationalised into a series of scenarios for model testing. The tested scenarios focused on manipulating existing flow control structures to allow for varying levels of tidal inundation across the study site under existing climate conditions. A baseline model simulation period from November 2016 to February 2017 was established based on the recorded datasets available and so that the model best represents the most recently observed conditions at the site. A longer duration model for a 12-month period in 2010 was also simulated to provide an indication of the relative impacts of tidal restoration on localised flooding of neighbouring properties adjacent to the Everlasting Swamp National Park. This information was also used to inform the ecological response of the site under future management scenarios.

Following the review of background information, community feedback and discussions, and an assessment of onsite data/processes via model simulations, a short-list of management options was developed and assessed. The proposed options were formulated to respond to existing community concerns and aim to address the long-term management objectives of the NPWS via a staged-restoration approach. Ultimately, the modelling has shown that a staged-approach to restoration of Everlasting Swamp wetland complex could maximise potential environmental outcomes, without significantly impacting most adjacent landholders.

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1. Introduction

The study area, the Everlasting Swamp and Imesons Swamp of the Everlasting Swamp wetland complex, is located adjacent to Sportsmans Creek, a major tributary of the Clarence River, approximately 37 km from the ocean entrance at Yamba, NSW. The study area is shown in Figure 1.1, with a list of local names given to places and major flood mitigation drainage lines, provided in Figure 1.2 and Table 1.1. The study area is characterised by high-surrounding hills that drain to low-lying areas of the floodplain and covers an area of approximately 4,250 ha (42.5 km^2), or less than 1% of the total Clarence River Valley catchment area. Over 25% of the study area contains SEPP 14 Coastal Wetlands, with the majority of Everlasting Swamp and approximately half of Imesons Swamp owned/managed by the North Coast Region National Parks and Wildlife Services (NPWS).

Over the past century, flood mitigation works across the Clarence River floodplain have resulted in agricultural benefits to some landholders and caused environmental harm to the broader estuary. The agricultural areas of the floodplain are valued by local landholders and the flood mitigation scheme is a vital component, ensuring that the landscape remains arable. Unfortunately, the flood mitigation drainage network is also responsible for the decline in the environmental values of the area (e.g. fish, birds, native vegetation, etc.), and the production and release of acid sulfate soil (ASS) by-products to the broader estuary. However, remediation strategies to improve onsite conditions and re-establish natural flow patterns must consider hydrologic impacts to the surrounding floodplain and landholders.

The primary aim of this study is to provide a comprehensive scientific analysis and risk assessment of the hydrologic impacts of various on-ground remediation options at Everlasting Swamp and Imesons Swamp. While previous studies have generally focused on management options associated with the Sportsmans Creek Weir, this study provides the opportunity to focus on water movement across the wider study area under a range of different flow conditions. This study also provides the relative impacts of the remediation options on neighbouring properties adjacent to the NPWS management area.

Community feedback and discussions were an integral part of the outcomes of this study. Local landholders, the Sportsmans Creek Drainage Union, 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 model outputs and ecological study results to establish viable management options for the study area. Additional outcomes from the study include a detailed literature review, site-specific field measurements, and calibrated catchment and hydrodynamic numerical models.

1.1 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 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 water that flows from the upland catchment;
- ‘Hydraulics’ defines the flow of water in and around structures (e.g. culverts and weirs);

- 'Hydrodynamics' is used to define water movement in terms of levels and flow distributions across the landscape. Hydrodynamic modelling is used to quantify water movement over the floodplain both before and after on-ground works; 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 restoration of the study area;
- **Chapter 3** provides the management areas at Everlasting Swamp and Imesons Swamp;
- **Chapter 4** provides an integrated discussion on management supported by modelling; and
- **Chapter 5** provides a summary of the study and key findings.

This report has been structured to highlight the key findings of the study. Following a list of references (Section 6), significant tasks that do not form the core outcomes of the study have been documented as appendices, rather than in the main body of the report, including:

- **Appendix A** provides background theory on acid sulfate soils;
- **Appendix B** provides a summary of existing data and literature;
- **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 calibration
- **Appendix F** provides a summary of scenario modelling;
- **Appendix G** provides a summary of community feedback and discussions; and
- **Appendix H** provides an ecological assessment of hydrologic restoration at the study site.

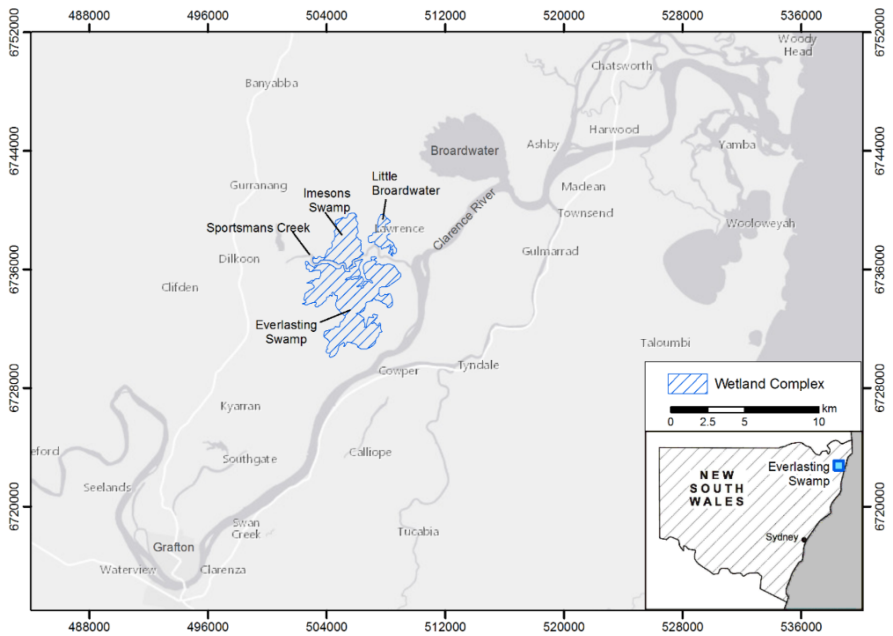


Figure 1.1: Location of Everlasting Swamp

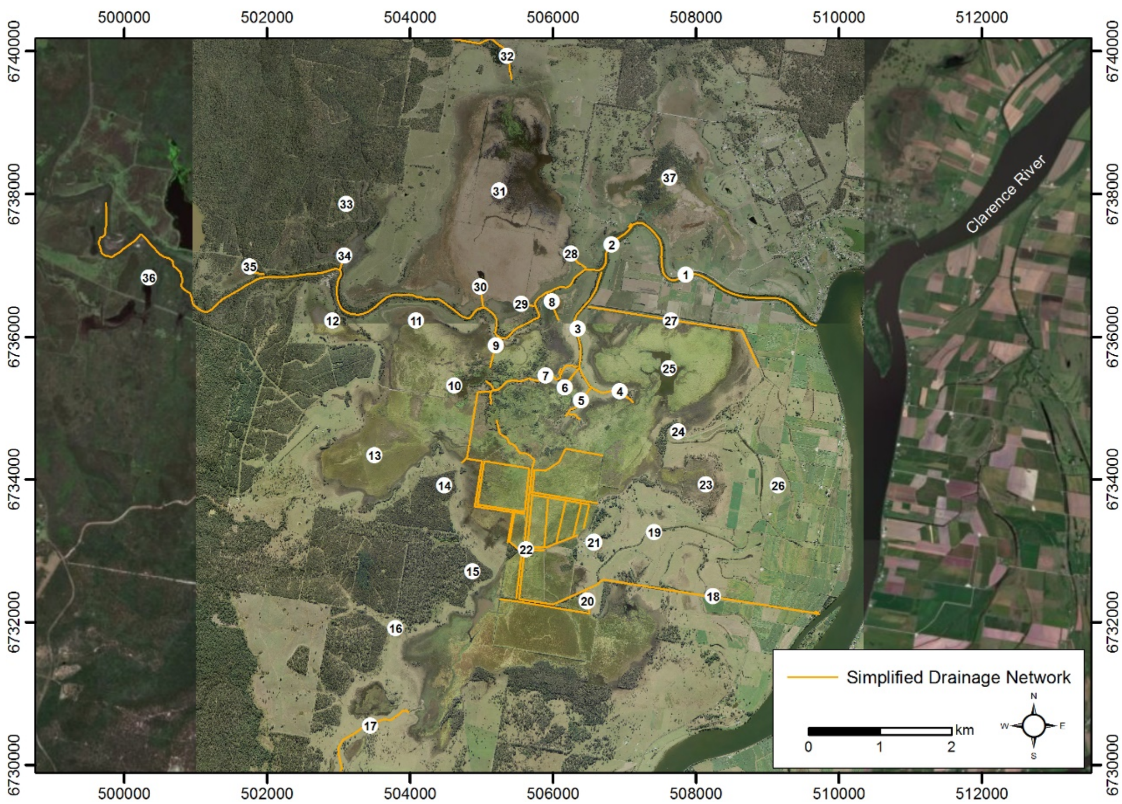


Figure 1.2: Common Place Names and Drainage Lines at the Study Site

Table 1.1: Keys Relating to Common Place Names and Drainage Lines at the Study Site

Key	Name	Key	Name
1	Sportsmans Creek	21	Round Mountain
2	Sportsmans Creek Weir	22	Old SCA Pump Station
3	Woody Creek	23	The Horseshoe
4	Sportsmans/Woody Creek 33	24	Coxs Point
5	Sportsmans/Woody Creek 33/1	25	Coxs Swamp
6	Sportsmans Creek 34	26	Lawrence Road
7	Sportsmans-Reedy Creek 34/1	27	Sportsmans-Everlasting South Levee 32
8	Sportsmans Creek 35	28	Lawrence No.1
9	Sportsmans Creek 35/1	29	Lawrence No.2
10	Teal Lagoon	30	Lawrence No.3
11	Murphy's Flat	31	Imesons Swamp
12	Bullock Swamp	32	Duck Creek
13	Grasshopper Swamp	33	State Forest
14	Gospers Point	34	Upper Sportsmans Low Area 1
15	Andersons Point	35	Upper Sportsmans Low Area 2
16	Rush Gully	36	Upper Sportsmans Low Area 3
17	Warragai Creek	37	Little Broadwater
18	Blanches Drain		
19	Harrisons Creek		
20	Harrisons Creek Weir		

2. Background Information

2.1 Preamble

This section provides background information describing the legacy issues associated with drainage and flood mitigation, and the distribution of ASS across the study area. Further detailed information on the formation, mobilisation and impacts of ASS in the coastal estuaries of NSW is provided in Appendix A.

2.2 Legacy Issues

2.2.1 Floodplain Drainage History

Everlasting Swamp and Imesons Swamp are local names given to large areas of low-lying land located adjacent to Sportsmans Creek, a major tributary of the Clarence River. The site covers an area of approximately 4,250 ha (42.5 km^2), or less than 1% of the total Clarence River Valley catchment area. Historically, the study area would have been predominately open and seasonally fresh/brackish/salt water tidal backswamps, with the wettest areas dominated by reeds or open water (Gordos, 2012). These open swamps, included not only lands that would today be regarded as drained wetlands, but extending to somewhat higher elevations as well, including areas that are now productive agricultural landscapes. The lowest point of the floodplain is found at Woody Creek/Coxs Swamp, an eastern section of the Everlasting Swamp at Lower Southgate, and is around 0.0 m Australian Height Datum (AHD), as shown in Figure 2.1. Furthermore, most of the backswamp is located below mean high spring tide, which is reported as 0.32 m AHD at Lawrence. Note that AHD is approximately equal to mean sea level (MSL). Further information on the development of this Digital Elevation Map (DEM) is provided in Appendix D.2.

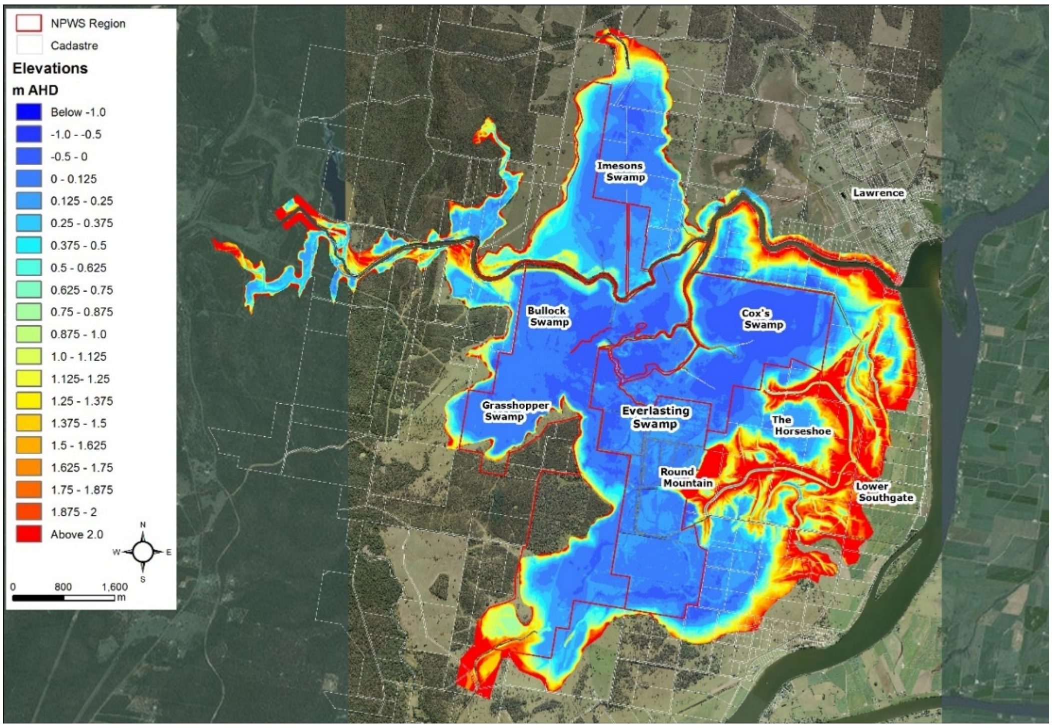


Figure 2.1: Digital Elevation Map of the Study Area

Since 1926, the Everlasting Swamp region has undergone extensive drainage and hydrologic manipulation, including the installation of agricultural drains, levees and tidal floodgates. Significant floodplain drainage works throughout the latter part of the 20th century were primarily undertaken for flood mitigation, to promote dry land agricultural production, and prevent saline intrusion onto the backswamp areas of the floodplain. A brief timeline of key events and drainage works on the study area floodplain (Smith, 1999, Tulau, 1999, Tulau, 2011), includes:

- 1859 – Sugar cane cultivation was introduced to the northern rivers of NSW and Colonial Sugar Refining (CSR) Company opened its first mill on the Clarence River at Southgate;
- 1860 to 1880 – Most of the higher land around the margins of the Everlasting Swamp were surveyed and primarily alienated for agriculture. By 1880, it was remarked of the Clarence River region that *"the whole of the banks of the navigable portion of the river from end to end [was] occupied by farmers"*.
- 1880s – Commercial dairying commenced, with the inauguration of the Pioneer dairy cooperative at Ulmarra;
- 1898 – First blocks in Everlasting Swamp were noted as being subdivided;
- 1911 – Everlasting Swamp drainage works were in contemplation;
- 1912 – Everlasting Swamp works were planned, and surveys had commenced, Little Broadwater works were completed, and the Everlasting Swamp Drainage Trust was gazetted;
- 1925 – Lowest parts of Everlasting Swamp were surveyed;
- 1926 – Sportsmans Creek Drainage Union (SCDU) formed prompting the alienation of the final blocks at Everlasting Swamp. Much of the low-lying land at Everlasting Swamp remained Crown land until the 1940s and 50s, as shown in Figure 2.2. Alienation of the swamp occurred considerably later than similar backswamp floodplain further south, including the Macleay and Manning Rivers (Lucas, 2004);
- 1927 – Sportsmans Creek weir constructed to enhance agricultural prospects in the region by preventing salt water moving upstream and inundating low-lying land;
- 1930s – Floodplain drainage works started at Everlasting Swamp (Creighton, 2012);
- 1953 to 1976 – Major flood mitigation and drainage works across the Clarence floodplain completed by Clarence Valley Council (formerly Clarence River County Council) in response to a series of damaging floods in the 1940s and 1950s, including drainage at Sportsmans Creek (1966) and Southgate (1966). The Everlasting Swamp wetland complex subsequently was changed to a predominantly fresh water system during this time;
- 1978/80 – The Sportsmans Creek – Everlasting Swamp levee was constructed from Woody Creek in the north to Blanches Drain in the south, to protect sugar cane crops and improve pasture in Everlasting Swamp;
- 1980s/90s – Drainage works in the central part of Everlasting Swamp completed in early 1980s, with further works undertaken in 1998 to increase drainage north into Teal Lagoon.

Flood-mitigation across the Clarence River floodplain was one of the largest schemes completed on the North Coast of NSW. By 1985, 92% of wetlands on the Clarence River floodplain were considered degraded (Pressey, 1987). While the 1980s generally marked the end of new, large-scale drainage works in NSW coastal floodplains, by this stage on the Clarence River floodplain, there were approximately 950 km of mapped drains, including 78 km at Everlasting Swamp, and 142 floodgates. Along with the 12 major drains across the Everlasting Swamp wetland complex, there has also been an extensive amount of private drainage works undertaken until the present day, which connect into these larger drains. Ultimately, following years of intensive drainage from the 1950s to 70s, the floodplain was flooded less frequently, overland flow paths were altered, post-flood inundation periods were reduced, and permanent access was obtained, so more intensive agriculture became economic in the lower elevation areas across the floodplain (Tulau, 2011). A schematic of floodplain evolution indicating the influence of extensive drainage works and its conceptual progression from past to present hydrologic conditions is presented in Figure 2.3.

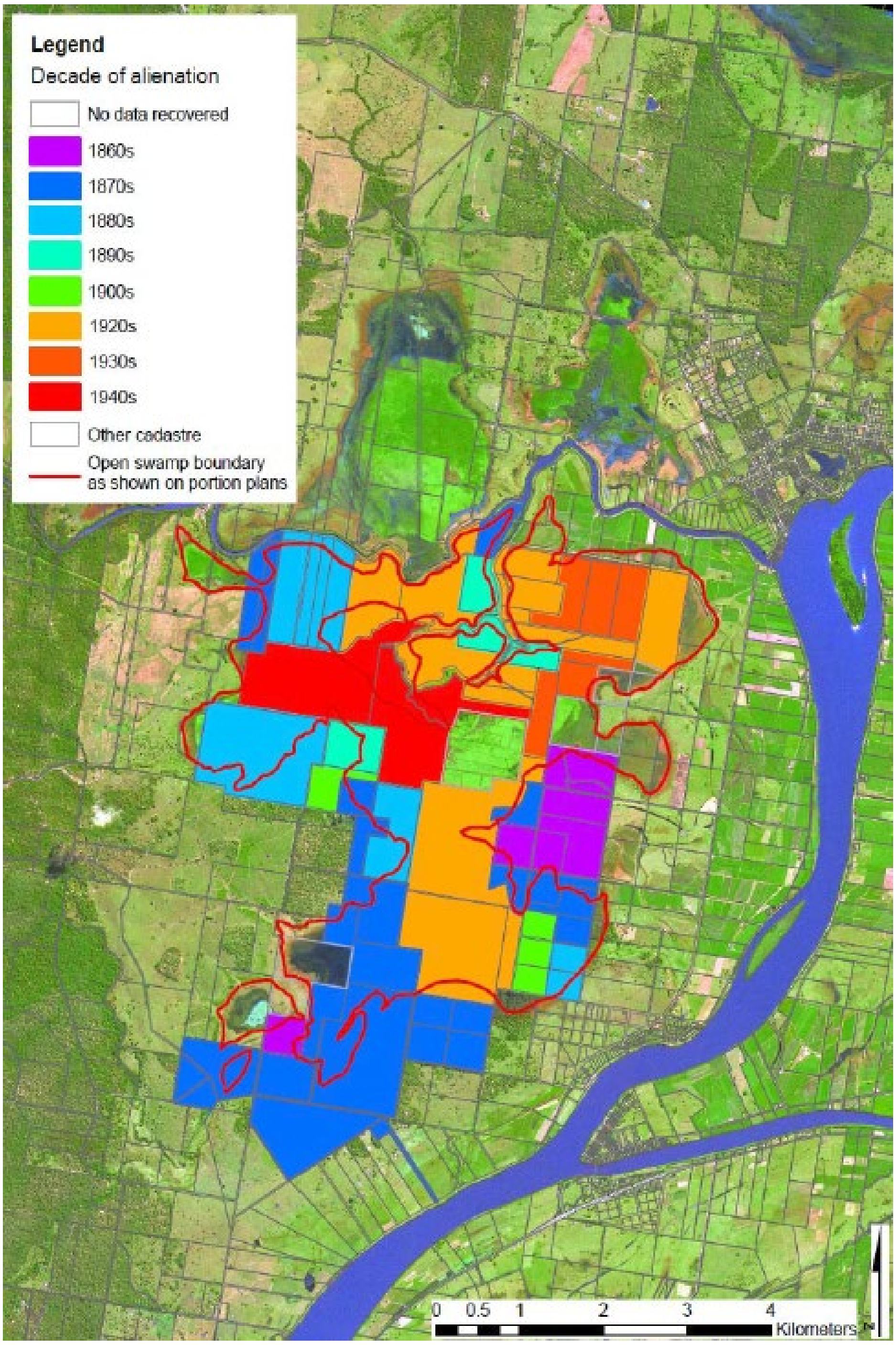


Figure 2.2: Everlasting Swamp, Showing Chronology of Land Alienation (Tulau, 2011)

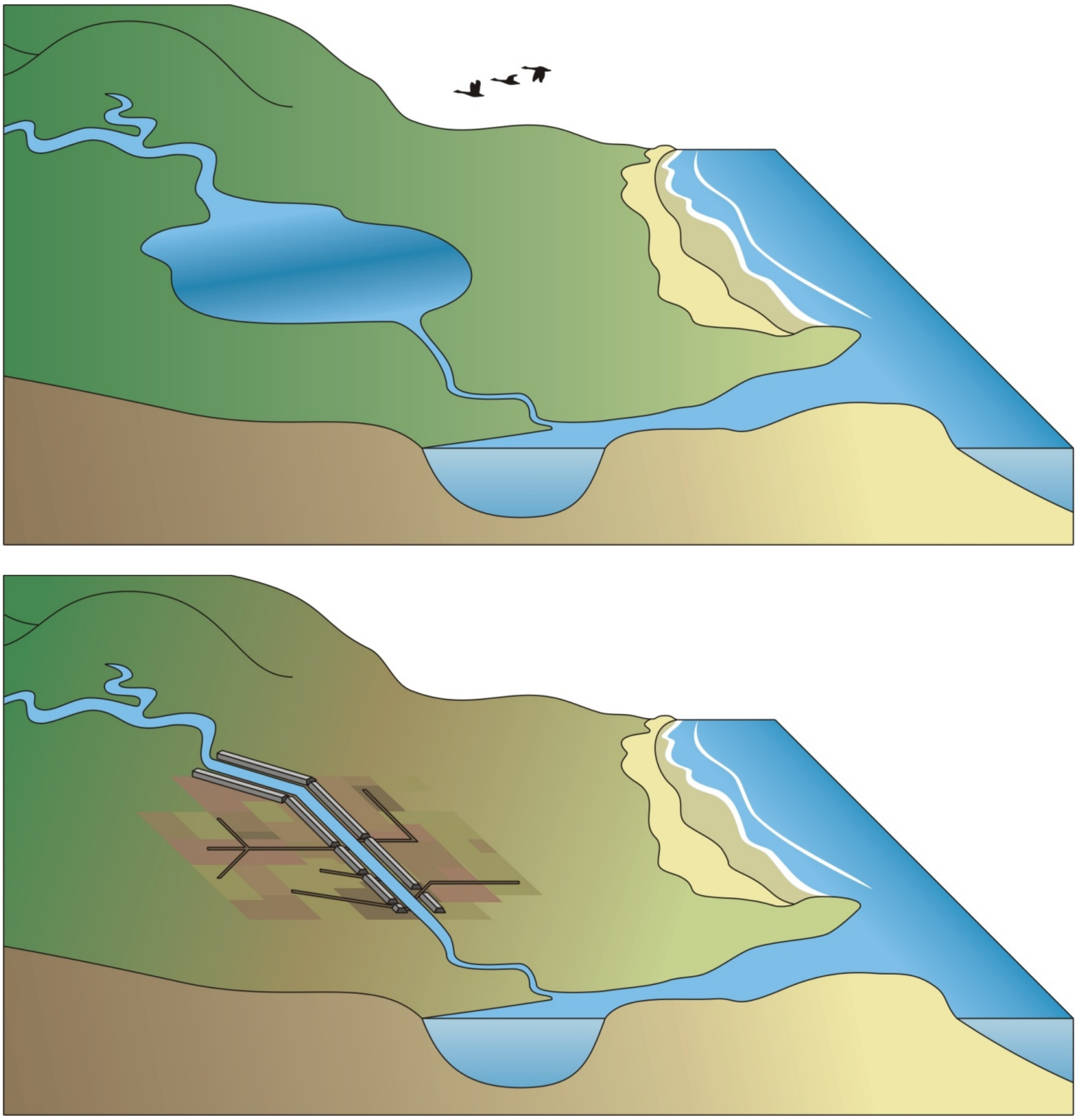


Figure 2.3: Schematic of Floodplain Evolution Following European Settlement

2.2.2 Sportsmans Creek Weir

Sportsmans Creek Weir (Figure 2.4), constructed in 1927 by the Sportsmans Creek Drainage Union, consists of 40 top-hinged floodgates (1.8 m wide by 1.2 m high), with a crest elevation of 0.583 m AHD and an invert of approximately -0.62 m AHD. Bed elevations immediately upstream and downstream of the structure were approximately -1.50 m AHD. Note that 'downstream' is defined by an observer looking towards the ocean entrance. Furthermore, elevations were measured using a Trimble R10 RTK-GPS and offset using the NSW CorsNET network to an accuracy of ±5 mm vertically and horizontally. Note that the observed weir invert of -0.62 m AHD was confirmed in Smith (1999), but is lower than previously reported in McElroy (2000) as -0.474 m AHD.

Sportsmans Creek Weir remains a dominant feature controlling surface and groundwater hydrology within Everlasting Swamp wetland complex (Gordos, 2012). The weir, in combination with onsite drainage works and flow control structures, effectively turned the site into a freshwater dominated system by restricting saline water intrusion to upstream creeks and backswamp areas, and diverting natural water flows from the catchment to the estuary. This ultimately altered the water quality across the site, lowered the groundwater table, and reduced the connectivity of the Everlasting Swamp wetland complex to the natural tributaries of the Clarence River estuary.

In addition, the weir restricts the movement of water from upstream to downstream in Sportsmans Creek, which impacts the rate of discharge of catchment inflows, and also holds water upstream of the weir during low-tide cycles (Gordos, 2012). Note that the weir was not designed to prevent overtopping by backwater flooding from the Clarence River. Smith (1999) reported that prior to the construction of the flood mitigation drainage channels, floodwaters within the Everlasting Swamp wetland complex could persist for up to 100 days at a water depth of 0.5 m. However, following flood mitigation, 90% of the floodwaters escape the floodplain within 6 to 10 days, depending on water levels in Sportsmans Creek and the Clarence River.

In 2000, an investigation was commissioned into the structural integrity and condition of the weir. The investigation concluded that the weir was structurally sound, including for most severe flood loadings, and would remain so for another 20 years (McElroy, 2000). The study also found that due to ongoing degradation, the weir was highly leaky with up to 23% of tidal flows at high tide penetrating upstream of the weir, or an average of 11.5% of the full range of flows. In addition, several large flooding events (e.g. 2001, 2008, 2011, 2013) since the 2000 assessment have resulted in significant damage to the weir structure and the floodgate flaps. Ongoing concerns have been raised by the SCDU about the cost of maintenance of the weir and the potential litigation risks without continued maintenance. The current condition of the weir (as of 8 February 2017) is shown in Figure 2.5. Further information on the weir, including a detailed review of its hydrologic impacts to wetland inundation and risk management was completed by Gordos (2012).

Figure 2.4: Aerial View of Sportsmans Creek Weir

Figure 2.5: Sportsmans Creek Weir in Operation (Photo by J. Ruprecht, 8 February 2017)

2.2.3 Acid Sulfate Soils

From the late 1800s to the 1960s, the dangers of excessively draining ASS gradually became understood in Australia amongst not only the scientific community, but also by land managers. However, in the post-war flood mitigation period, the advice from the NSW Department of Agriculture was consistent, the department "*indicated that no harmful effects were expected to ensue from drainage*", even though by 1960, there were already signs of the extent of the problem in NSW.

In 1978, the general understanding regarding ASS had been publicly summarised by the State Pollution Control Commission (SPCC) Inquiry into flood mitigation works in NSW:

"*The floodplains of NSW contain anaerobic, waterlogged estuarine areas with sediments rich in sulphides. Construction of drainage channels may lower the water table in these areas, aerate the soils, [and] convert sulphides to acid ... Materials leached from soils by this process generally include iron, which can form brown precipitates ... Drained areas sometimes become devoid of vegetation as a result of acid conditions. The brown precipitates and [acid] slicks arising from these conditions may contribute to the discolouration of river water before and after a flood*".

By the 1990s, the ASS issue emerged as one of the major environmental problems facing estuaries in coastal NSW. Over the next two (2) decades, there was confirmation of the disastrous impacts of acid drainage flowing from drains and floodgates in high-risk ASS landscapes (Tulau, 2011).

Clearing of vegetation and the construction of drainage channels lower the groundwater table, thereby exposing acidic sediments to oxygen which acidifies the groundwater and produces high concentrations of metal by-products (e.g. iron, aluminium, etc.). For further information on ASS see Appendix A.

Ultimately, the legacy of artificial drainage on estuarine floodplains in NSW over the past century has accelerated oxidation of naturally occurring soil and sediment that contain iron sulfides, by unnaturally oxidising ASS beneath many floodplain areas. The construction of the Sportsmans Creek Weir and the associated drainage network across the floodplain resulted in the oxidation of highly acidic soils across the Everlasting Swamp wetland complex. In 2001, the Everlasting Swamp wetland complex was identified as an NSW Acid Hotspot and remains one of the worst acid affected sites in NSW (Wilkinson, 2003b). Acidic soils have resulted in surface scalding and significant impacts to aquatic flora and fauna in Sportsmans Creek and the wider Clarence River estuary.

The acid pollution hazard in NSW was originally mapped on the Acid Sulfate Soil Risk Maps prepared by Morand (1995) and Milford (1995). These studies revealed that the Everlasting Swamp floodplain contained an area of over 30 km^2 of high-risk ASS soil up to an elevation of approximately 2 m AHD, as shown in Figure 2.6. The extent and severity of ASS across the study area has since been confirmed by several investigations, including Pollard and Hannan (1994), Beveridge (1998), Smith (1999), MHL (2001), Johnston et al. (2002), Johnston et al. (2003), Wilkinson (2003a), Wilkinson (2003b), Wilkinson (2004), Johnston et al. (2004), Johnston (2005), Johnston et al. (2005), Johnston et al. (2009), and Rayner et al. (2016). Further information on the available soil profile data across the study area is provided in Appendix B.

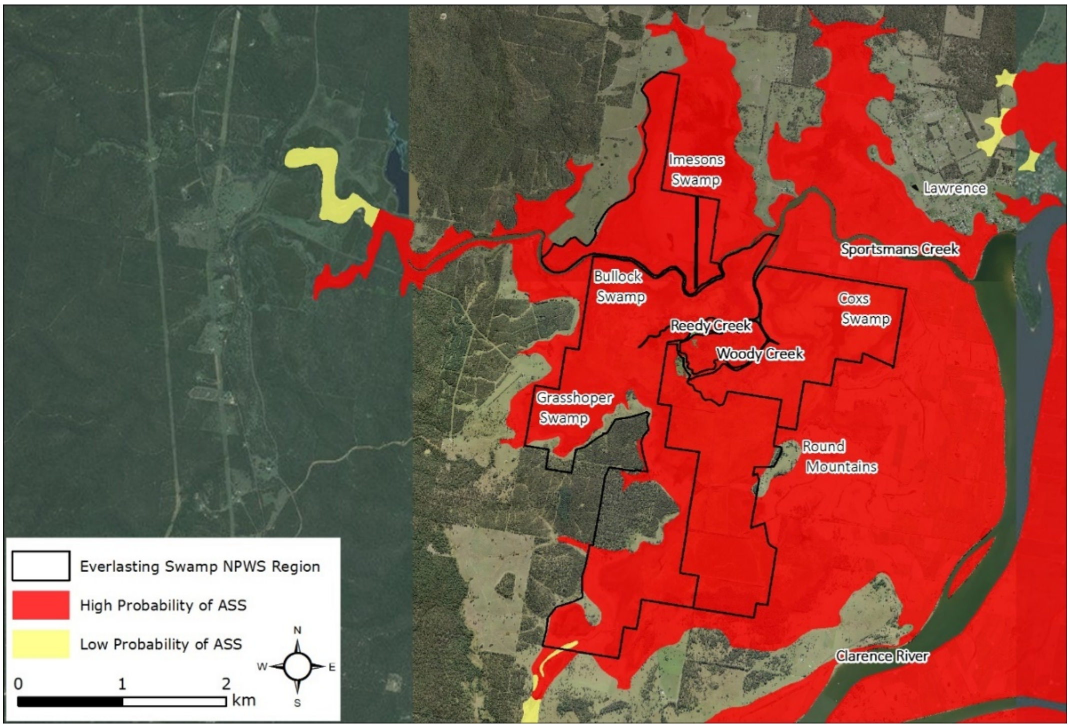


Figure 2.6: NSW Government ASS Risk Map of the Everlasting Swamp Floodplain, OEH (2011)

2.3 Towards an Everlasting Swamp Plan of Management

Despite the known impacts to the Everlasting Swamp wetland complex from drainage works and the issues associated with ASS, the site remains a highly significant waterbird habitat used by many species of migratory birds (OEH, 2016). Indeed, Everlasting Swamp is a nationally significant waterbird habitat, displaying the highest diversity of 13 wetlands surveyed on the Clarence floodplain, and was listed in 1978 on the 'Register of the National Estate'. Furthermore, the site was also listed in 'A Directory of Important Wetlands in Australia' after being identified as an area of significant conservation value, due to the presence of freshwater lagoons, marshes and non-tidal freshwater forested wetland areas. In conjunction with this recognition of wetland importance, the majority of the Everlasting Swamp wetland complex was gazetted as State Environmental Planning Policy (SEPP) 14 - Coastal Wetlands (No. 231, 231a, and 231b) by the Department of Planning and Infrastructure in December 1985.

In 1999, the Healthy Rivers Commission (HRC) of NSW led an independent inquiry into the Clarence River (HRC, 1999). The inquiry was set up to help Government and the community make informed choices about ecological, social and commercial goals for the river. The report recommended the integrated management of the estuarine waterway, its interaction with ocean processes, and its interaction with land uses and processes operating on the floodplain. Various actions were identified to better integrate water quality concerns across the floodplain, including addressing ASS drainage in the lower estuary.

Furthermore, HRC (1999) identified the Clarence Floodplain Project (CFP) as having an exceptional degree of goodwill and cooperation in addressing environmental issues on the Clarence River floodplain and estuary, and recommended that the success of the project be built upon. The CFP began in 1997 and was the first project of its kind on the North Coast of NSW. The CFP was an initiative of Clarence Valley Council to improve management of the floodplain, flood control structures (e.g. floodgates, weirs and levees), water quality and habitat in cooperation with landholders, industry, community and government (Wilson, 2008). An important factor in the project's success was that landholders were actively engaged, operating and monitoring the flood control structures, according to previously agreed plans of management (Smith, 2011).

As part of the CFP, various studies and reports into management options for the Everlasting Swamp wetland complex have been carried out through funding from Local, State, and Federal Governments. Smith (1999) was the first to highlight the feasibility of a rehabilitation project at Everlasting Swamp, which received strong cooperation and support by the majority of landholders, as well as, other stakeholders. Smith (1999) recommended five (5) major management requirements of Everlasting Swamp, in terms of primary production and improved water quality, included:

1. Remove excess floodwaters quickly;
2. Keep saltwater off fresh pastures;
3. Control backwater flooding entering backswamps;
4. Pond seasonal flows within backswamps; and
5. Avoid over-drainage and acidification.

Furthermore, the report provided 17 feasible management options to control the quantity and quality of water discharges from floodgates, and included a synoptic assessment of risks and benefits of each of the 17 management options.

A timeline and brief description of studies and reports completed following the work of Smith (1999) on the management issues and remediation options at Everlasting Swamp, is provided below, including:

- Beveridge (1998) outlined the components of an ASS management plan for Everlasting Swamp, including future research priorities and management options.
- Tulau (1999) identified Everlasting Swamp as a priority area for the management of ASS in the lower Clarence River floodplain.
- Morand (2001) completed extensive ASS soil investigations as part of the ASS risk mapping program.
- Morand (2002) completed additional ASS soil investigations as part of the Everlasting Swamp ASS hotspot program.
- Umwelt (2003) prepared the Clarence Estuary Management Plan and recommended a range of objectives and actions that broadly applied to the Sportsmans Creek Weir and the Everlasting Swamp hotspot area, including:
    - E4: Formulate and implement incentive arrangements to encourage landholders to change the management of their properties;
    - E14: Continue to implement the Clarence Floodplain Project, particularly in relation to partnership development and adding habitat management to water quality considerations;
    - E24: Assess and prioritise floodplain and estuarine areas for inclusion in conservation reserves or to be managed for conservation on private land, with particular attention to habitats for migratory and resident waders;
    - W17: Modify the design and management of operation of floodgates at various sites; and
    - W20: Complete and implement Hotspot management plans for high risk ASS sub-catchments.
- Wilkinson (2003a) demonstrated the management technique of ponding an acid scalded backswamp area with fresh water to promote vegetation growth, soil organic matter, and to reduce the discharge of acidic waters and acid related products from the backswamp into Sportsmans Creek. Clarence Valley Council claimed the project was a success and used the study to encourage remediation at other ASS-affected areas on the floodplain.
- Wilkinson (2003b) developed the Everlasting Swamp Hotspot Remediation Management Plan, after Everlasting Swamp was identified as one (1) of 26 ASS priority management areas throughout NSW and was to be (partially) remediated as part of the ASS hotspot remediation program. The report provided a comprehensive background review of onsite conditions and infrastructure, and identified actions and implementation plans for nine (9) major management sub-areas (see Section 3).
- Wilkinson (2004) provided an overview of the outcomes of the Everlasting Swamp ASS hotspot project and on-ground works completed (Figure 2.7). As part of the ASS hotspot project, floodgate lifting devices were installed on the following drains within Everlasting Swamp, including:
    - Sportsmans Creek/South Levee-32;
    - Reedy and Woody Creeks;
    - Blanches Drain;
    - Harrisons Creek;
    - Sportsmans 35/35-1 (Teal Lagoon); and
    - Lawrence No1-111 (Imesons Swamp/Duck Creek). Note in-drain, low-level water retention structures were constructed in Lawrence No. 1, 2 and 3 drains.

  These structural modifications were intended for landholders to actively manage floodgates, and encouraged seasonal retention of catchment inflows or environmental water diversion onto paddocks, to reduce impacts of onsite ASS and promote pasture growth. To date, it appears that these structures are still operational onsite, but are only sometimes manipulated during periods of high freshwater catchment inflows.

- More recently, Gordos (2012) provided an informative report on the Sportsmans Creek Weir, including a review of its hydrologic impacts to wetland inundation and risk management, as well as, recommended various management options. Six (6) weir management options were discussed by Gordos (2012), in terms of the risks and benefits to social, economic and environmental considerations. The six (6) management options, included:
    - Minor maintenance;
    - Weir maintenance and repair;
    - Replacement of all gates and seals;
    - Weir reconstruction;
    - Weir removal and upstream levee construction; and
    - Weir removal and land acquisition by a public authority.

In 2007, a portion of Everlasting Swamp (462 hectares) was acquired by NPWS and managed as a State Conservation Area (SCA). This was the single largest wetland reserve on the Clarence floodplain, and was the first state government managed local area of a wetland supporting potentially high-quality waterbird habitat (Smith, 2011). However, as the SCA was located between privately-owned agricultural land, limited on-ground works could be undertaken at the time to rehabilitate the site.

In 2014, an additional 1,769 hectares were acquired by NPWS/OEH, with the Everlasting Swamp National Park and SCA management areas provided in Figure 2.8. This additional land located both north and south of Sportsmans Creek provided significant area for wetland rehabilitation, removed several private holdings, and reduced the overall management risk of changing onsite hydrologic conditions.

In 2016, NPWS released a Statement of Management Intent for the Everlasting Swamp National Park (ESNP) and State Conservation Area (SCA) that outlined the main values, issues, management directions and priorities for the site (OEH, 2016). The return of natural flow regimes back into the swamp to improve the ecosystem functions and overall health of the surrounding environment was recognised as the priority long-term management objective for NPWS. Furthermore, OEH (2016) clearly outlined that any changes to the current situation would be dependent on the agreement of adjacent neighbours and Clarence Valley Council. Ultimately, the outcomes of this study would directly inform a plan of management to set out the ongoing management objectives for the Everlasting Swamp National Park.

Note that further information on several studies presented in this section, that contained background information and data relevant to this study, is provided Appendix B.

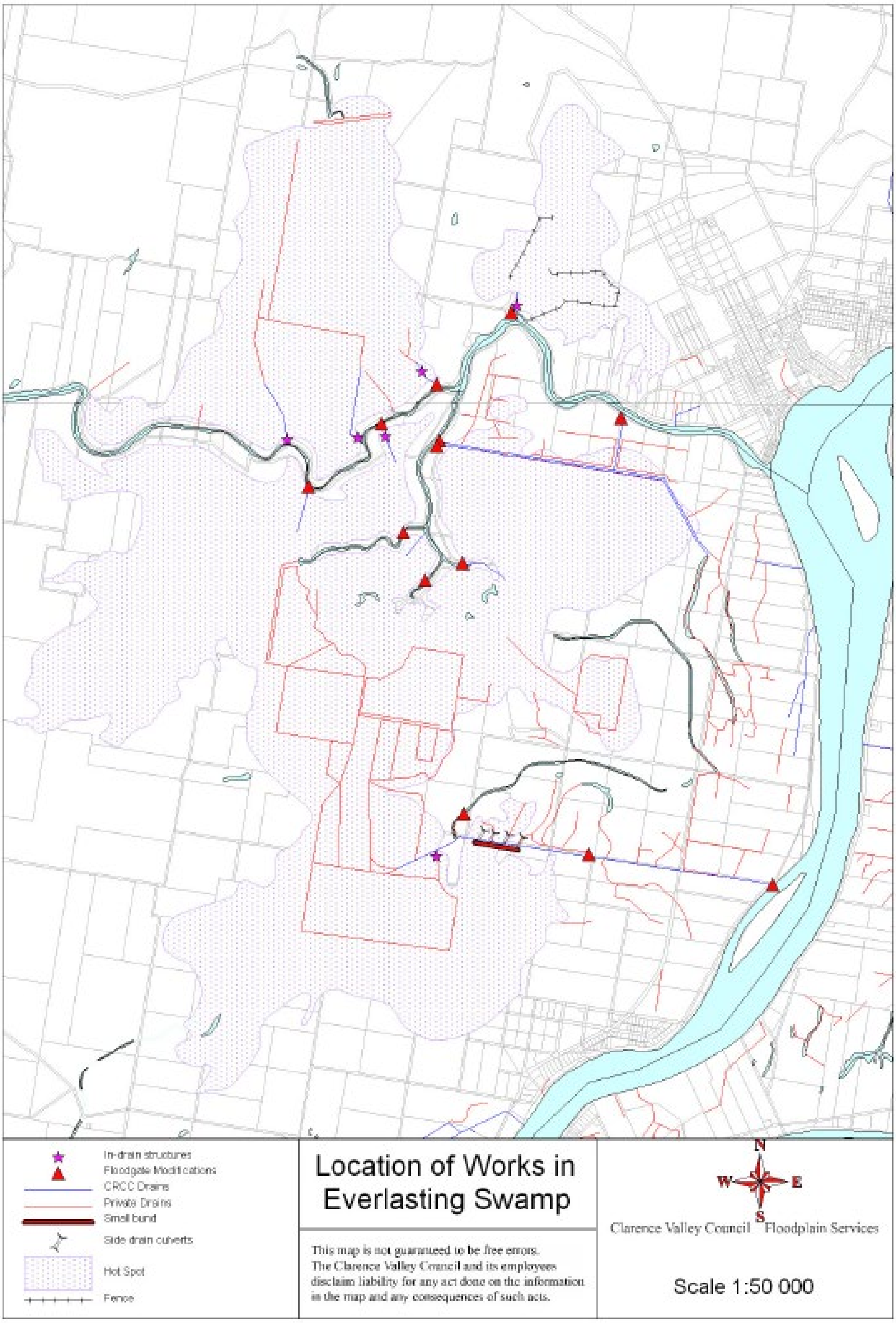


Figure 2.7: Location of On-ground Works Implemented at Everlasting Swamp as Part of the ASS Hotspot Project (Wilkinson, 2004)

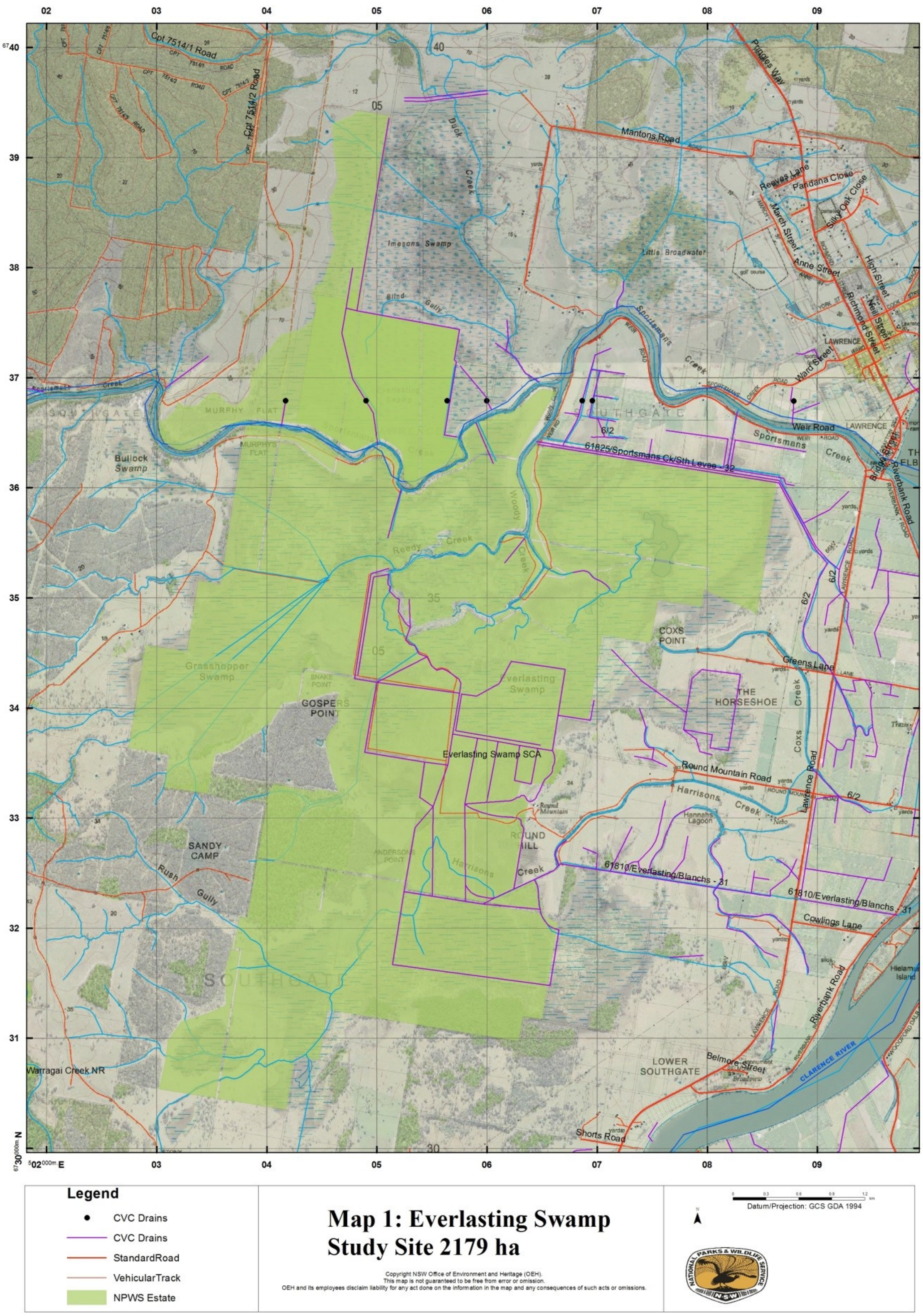


Figure 2.8: Everlasting Swamp National Park and State Conservation Area

3. Management Areas of the Everlasting Swamp Wetland Complex

In Wilkinson (2003b), the Everlasting Swamp wetland complex was divided into several management areas based on historical land management, cadastral subdivisions, major hydrologic catchments and drainage infrastructure. This information was summarised as follows:

1. Imesons Swamp;
2. Little Broadwater;
3. Coxs Swamp;
4. Sportsmans Creek – 35;
5. Teal Lagoon area, including Bullock Swamp and Grasshopper;
6. Upper Woody Creek towards Round Mountain;
7. Blanches Drain and Round Mountain;
8. Sugar Cane area outside the levee; and
9. The Sportsmans Creek Weir (SCDU).

The proposed management areas of the Everlasting Swamp wetland complex are shown in Figure 3.1. Note that for consistency between previous studies, these management areas will be referenced in the management discussion provided below in Section 4. Note also that Management Areas 2 and 8 are outside the scope this study.

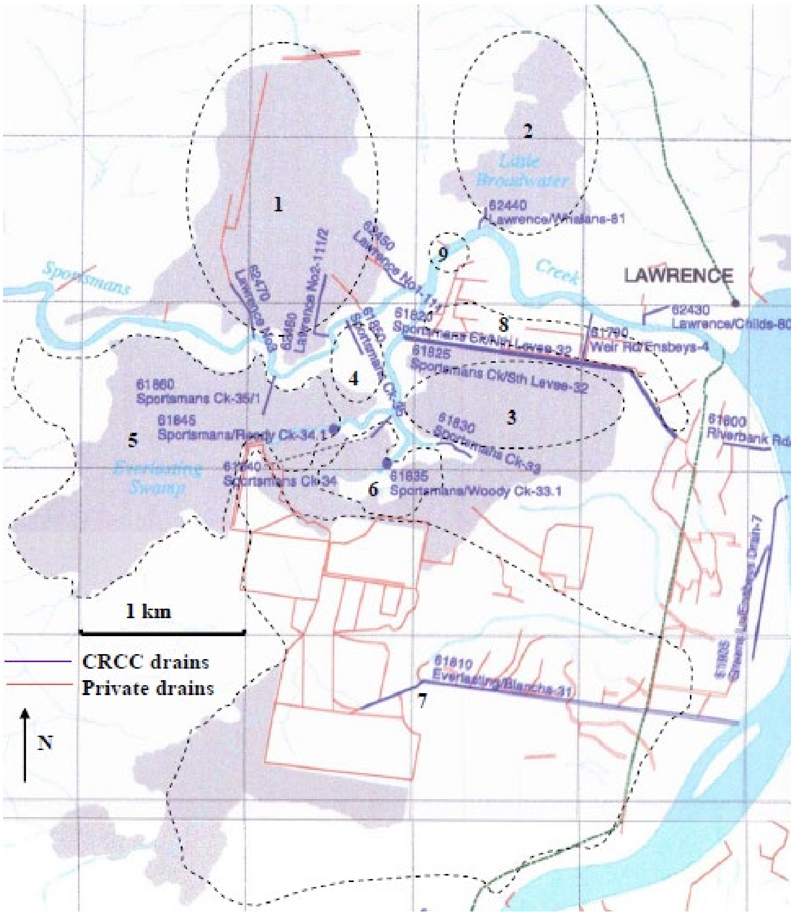


Figure 3.1: Management Areas of the Everlasting Swamp Wetland Complex (Wilkinson, 2003b)

4. Management Options

4.1 Preamble

Following the review of background information, community feedback and discussions, and an assessment of onsite data/processes, several management options were developed and assessed. These options were formulated to respond to existing community concerns and aim to achieve the long-term management objectives of the NPWS, as outlined in OEH (2016), with particular focus on the return of natural flow regimes to the study area. Furthermore, while the options proposed build on previous work (Gordos, 2012, Smith, 1999, Wilkinson, 2003b), the current study acknowledges the changes to the existing environment, land use and tenure, and the implications of these changes in achieving restoration.

The options proposed for further investigation, and community and stakeholder discussion, include:

1. Do-Nothing.
2. Restoration of natural flow paths for Duck Creek and Warragai Creek.
3. Maximise in-drain tidal flushing of Blanches Drain.
4. Restoration of natural creeks to encourage flushing of Teal Lagoon and Coxs Swamp.
5. Full opening or complete removal of Sportsmans Creek Weir.
6. Fully re-create the natural flow regimes across the wider Everlasting Swamp National Park.

The dynamic and complex nature of estuarine ecosystem restoration requires a strategic and adaptive, systems-based approach, recognising physical, socio-economic, political and cultural aspects of the connected river and human systems (UNESCO, 2016). To enhance this process, UNESCO (2016) provides a framework that highlights the need for restoration strategies to identify and respond to the links between external drivers, catchment and river processes, river health, and the provision of ecological, economic and social/cultural priorities. For this study, the restoration priorities identified in UNESCO (2016) form the assessment criteria used in the comparison of the proposed management options. A description of each restoration priority is provided as follows:

Ecological considerations involve the provision of ecosystem services over time, including flow regimes, water quality, habitat and biota.

Economic considerations include the financial resources that are required to support implementation, as well as to manage ongoing costs.

Social/Cultural considerations involve identifying and managing the different human demands on the river/floodplain system. Agriculture and farming, tidal inundation and flood management, commercial and recreational fishing, and heritage, for example, all have different and, at times, conflicting needs of the services provided by a river system.

A rationale, required mitigation measures, and the potential implications for the proposed management options are provided below. Where appropriate, results of numerical hydrodynamic model simulations and scenario testing of the proposed management options have been included in the following discussion. Further supplementary information is provided as appendices to this report, including model development (Appendix D), model calibration (Appendix E), scenario modelling (Appendix F), a summary of community feedback and discussions (Appendix G), and an ecological assessment report (Appendix H).

4.2 Option 1: Do-Nothing (Management Areas 1, 3, 4, 5, 6, 7, 9)

4.2.1 Description

This option details a 'do-nothing' scenario, which represents the current status quo (or existing conditions) at the site. The characteristics of this option, include:

- No change to the existing flow regimes, land management practices, or the design, operation and maintenance of the existing floodplain drainage network or infrastructure;
- Clarence Valley Council would continue responsibility for the management of floodgates, drainage channels and major flood levees;
- NPWS would follow their key management directions, as outlined in OEH (2016), including ASS, vegetation, fire, and pest management programs; and
- Landholders would maintain responsibility for the Sportsmans Creek Weir through the Sportsmans Creek Drainage Union, whereby the condition of the weir continues as is, with minor maintenance carried out as required.

4.2.2 Rationale

This option was included to compare the various engineered management options, in terms of inundation extents (maximum, minimum, mean) and changes to wetting-drying patterns (hydroperiod) across the study area, with the existing conditions. Numerical simulations were undertaken using a coupled 1-D and 2-D hydrodynamic model to simulate the existing conditions, including water levels, flow through structures and tidal inundation dynamics across the study area. The results of these 'baseline' simulations, depicting the extent of mean inundation and the associated hydroperiods at the study site during typical dry weather conditions, are provided in Figure 4.1. Model results for long-term, average rainfall conditions under baseline conditions are provided in Figure 4.2. Note further information and results from these simulations are provided in Appendix F.

4.2.3 Implications – Baseline Conditions

The model results are shown for average dry weather conditions in early 2017 (Figure 4.1) and an average rainfall year in 2010 (Figure 4.2). The results provide an indication of the areas of the floodplain that experience tidal inundation upstream of the Sportsmans Creek Weir and the areas susceptible to freshwater ponding following long-term, average rainfall conditions.

For typical dry weather conditions (Figure 4.1), the results indicated that:

- Teal Lagoon and the adjacent water bodies fed by Reedy Creek are the main permanent water bodies at Everlasting Swamp;
- Mean inundation depths in the Teal Lagoon area are greater than 0.2 m for the majority of the time (i.e. wet for more than 80% of the simulation period); and
- Other areas of the floodplain remained dry, since no rainfall was recorded during the simulation period, and the existing flow control structures restricted tidal inundation across the site.

For long-term, average rainfall conditions (Figure 4.2), the results indicated that:

- Low-lying areas of the floodplain experience regular wetting-drying during an average rainfall year. The model showed that areas outside of the Everlasting Swamp National Park, including the northern portion of Imesons Swamp, The Horseshoe, Warragai Creek and low-lying properties in the upper portions of Sportsmans Creek, regularly experienced mean inundations of up to 0.2 m (i.e. for up to 80% of the simulations period).

- The flow paths of inflows from the Warragai Creek and Duck Creek catchments to the study area followed the existing drainage lines and topography of the landscape.

4.2.4 Potential Benefits/Advantages for Option 1

For this option, the potential benefits were assessed, in terms of ecological, economic, and social/cultural considerations at the site, and are provided in Table 4.1.

Table 4.1: Potential Benefits or Advantages for Management Option 1

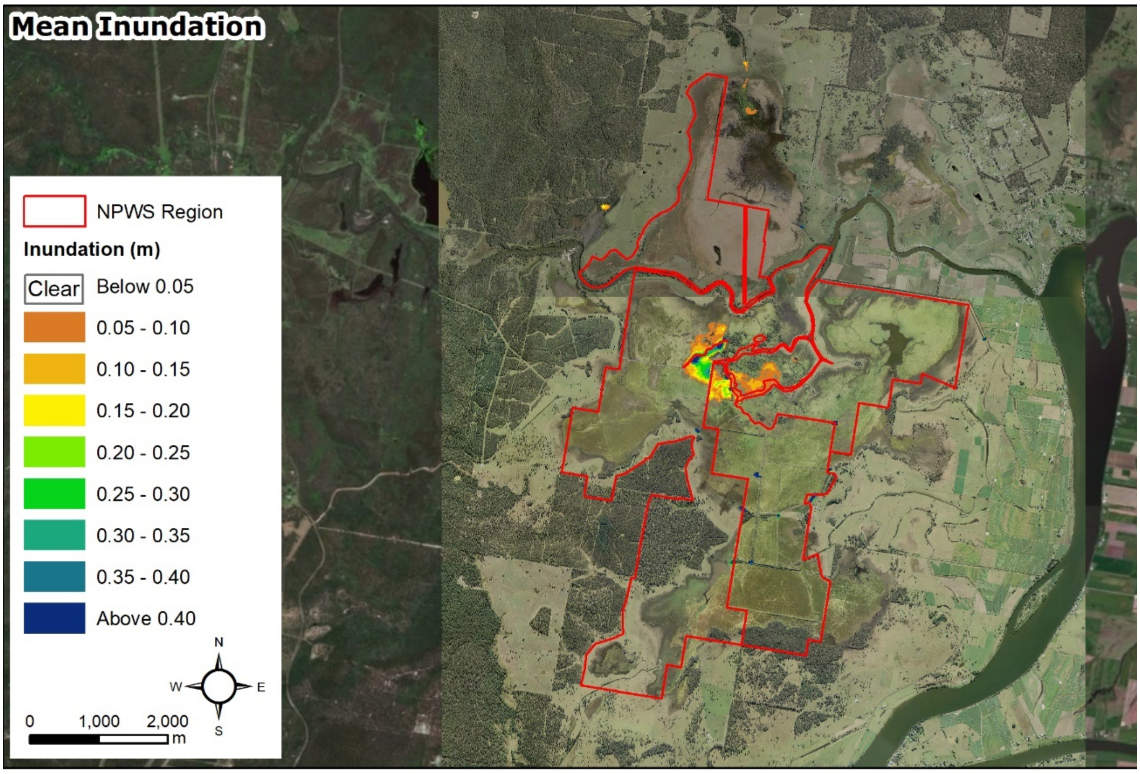
Considerations	Potential Benefits or Advantages
Ecological	Existing freshwater ecology remains.
Economic	Minor maintenance expenditure on Sportsmans Creek Weir such as, clearing flood debris and re-attaching floodgates when damaged by floods.
Social/Cultural	No change to current land management.

4.2.5 Potential Risks/Disadvantages for Option 1

For this option, the potential risks were assessed, in terms of ecological, economic, and social/cultural considerations at the site, and are provided in Table 4.2.

Table 4.2: Potential Risks or Disadvantages for Management Option 1

Considerations	Potential Risks or Disadvantages
Ecological	Continued exposure of ASS, acid discharge or black water events following rainfall. Ongoing poor surface and groundwater water quality. Poor floodplain connectivity. Uncontrolled removal of surface waters. Encroachment of native tree species into swamp areas, thereby reducing suitable habitat for waterbirds. Fish passage remains limited. Feral pig populations and straying livestock within the National Park. Infestations of exotic weeds and vegetation.
Economic	Poor pastures and cattle stock production. No changes to floodgate management or water retention/diversion for increased agricultural production. Cost of structural failure of Sportsmans Creek Weir, requiring removal, and modification/construction of secondary flood mitigation structures upstream of weir.
Social/Cultural	No increase in community or public value of the Everlasting Swamp National Park. Continued deterioration of Sportsmans Creek Weir, with potential risk of litigation due to injuries or fatalities. Long-term security of upstream landholders against saline intrusion and inundation of low-lying land is not addressed. The SCDU is responsible for ensuring that the Sportsmans Creek Weir is maintained to current standards under Water Management Act 2000.



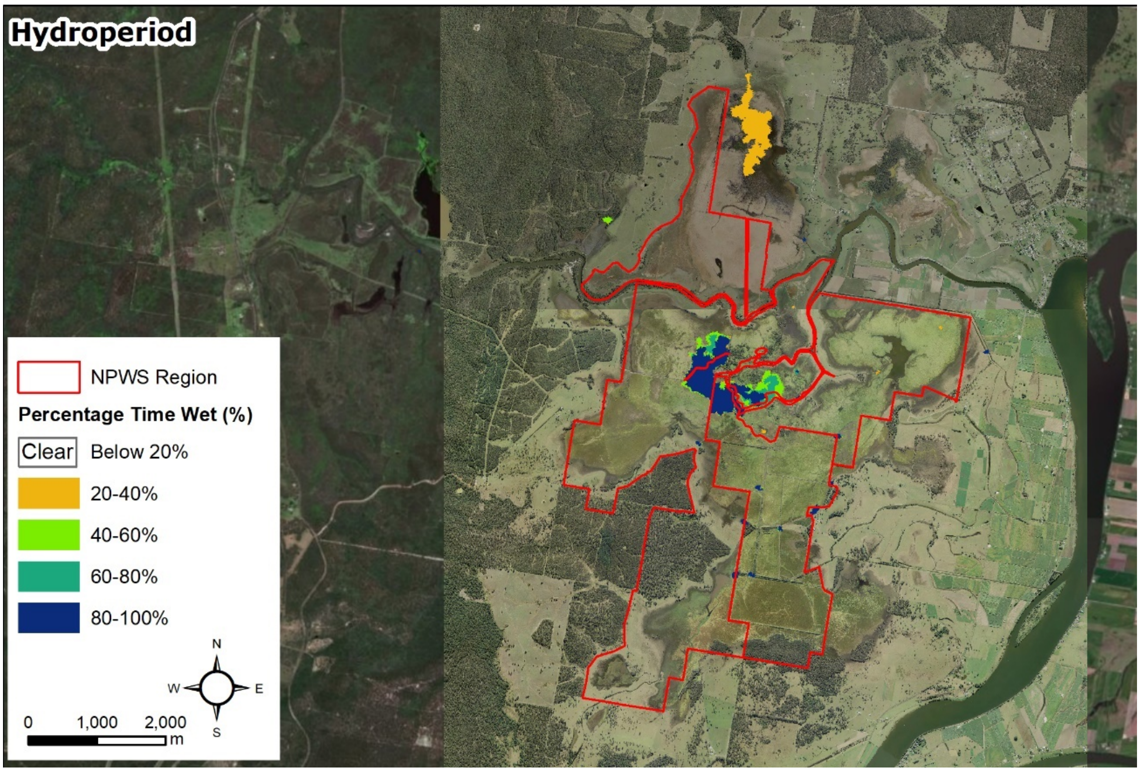


Figure 4.1: Scenario 16 – Existing Conditions – Average Dry Weather Period – 1 January to 22 February 2017

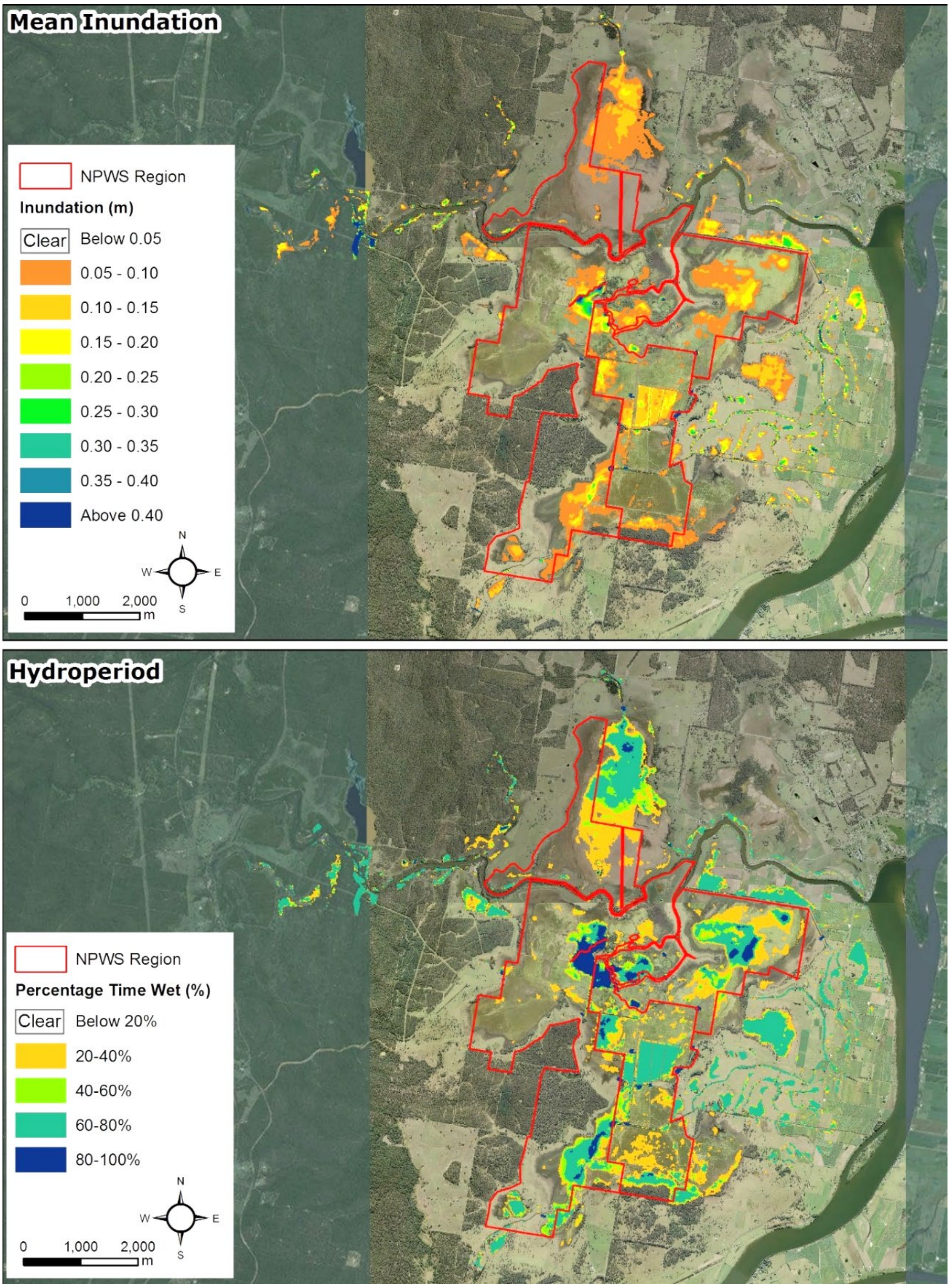


Figure 4.2: Scenario 14 – Existing Conditions – Average Rainfall Year – 1 January to 30 September 2010

4.3 Option 2: Restoration of the natural flow paths of Duck Creek and Warragai Creek (Management Areas 1 and 7)

4.3.1 Description

This option details a partial restoration scenario, whereby only the natural flow paths of Duck Creek at Imesons Swamp (Management Area 1) and Warragai Creek at Everlasting Swamp (Management Area 7) are restored. The characteristics of this option, include:

- No change to existing land management practices, or the design, operation and maintenance of the existing floodplain drainage network or infrastructure, outside of the Everlasting Swamp National Park;
- Removal of artificial impedances (e.g. levees, redundant structures, etc.) to restore natural flow paths and improve floodplain connectivity with natural creeks;
- Land re-shaping, to create wide, shallow swale drains above the potential acid sulfate soil (PASS) layer to reduce the impacts of onsite ASS, maintain or improve surface drainage, and provide a means of delivering freshwater onto actively managed pasture areas;
- Active floodgate management, to control in-drain vegetation through tidal flushing (where possible), seasonally hold upper catchment inflows, or for environmental flow diversions across low-lying areas; and
- Acquisition of low-lying land in the northern area and along the eastern boundaries of Imesons Swamp, to secure landholder support and ensure project success.

4.3.2 Rationale

Local landholders have suggested via discussion forums (Appendix G), that changed historical flow paths and poor management of the existing drainage channels is a major concern in the southern area of Everlasting Swamp and at Imesons Swamp (Table G.2, P4 and P7). This option was included to address these concerns raised by landholders adjacent to the Everlasting Swamp National Park. A summary of the concerns raised for each management area is provided below.

Warragai Creek: A former tea-tree plantation at Everlasting Swamp, covering an area of approximately 250 ha between Andersons Point and Round Mountain (Smith, 1999), required the construction of intensive drainage channels and levees, to protect crops and improved pasture from the effects of low-level flooding in the swamp area. These changes to the landscape in the central portion of Everlasting Swamp, altered the historical flow paths from Warragai Creek to Sportsmans Creek, and diverted the majority of the overland flow towards Blanches drain. This has resulted in increased and unwanted inundation of private properties, combined with longer residence times of floodwaters, and impacted on landholder access to low-lying land for maintenance, in the southern area of Everlasting Swamp. Further, these works reduced freshwater flow delivery to The Horseshoe and Coxs Swamp. It is worth noting that the crest heights of the drain levee banks in this area are approximately 0.4 – 0.6 m AHD, as reported in Wilkinson (2003b), and were confirmed during recent field investigation surveys by WRL.

Duck Creek: Imesons Swamp receives water from Duck Creek, whereby catchment inflows that enter the swamp can drain via three (3) flood mitigation drains with floodgates. Note that the majority of the catchment inflows are captured by Lawrence No. 1 drain, which drains the low-lying area in the northern part of Imesons Swamp. Community feedback has suggested that low-lying land across Imesons Swamp is often too wet, with small to moderate catchment inflows rendering these areas inaccessible and unusable, and no levees exist to protect private properties adjacent to the Everlasting Swamp National Park from flooding during larger events. Landholders also indicated that floodgates are poorly managed, and drains are infrequently maintained, because Imesons Swamp is a SEPP 14 coastal wetland (No. 231c), and drain cleaning is restricted by Clarence Valley Council.

Further, there was a general consensus via community feedback that landholders at Imesons Swamp supported the opportunity to seasonally hold upper catchment inflows and freshwater diversions from Sportsmans Creek across low-lying areas, to promote vegetation growth for grazing during summer, and improved existing soil conditions and ecology. This being the case, the landholders adjacent to the Everlasting Swamp National Park also wished to maintain the existing drainage and productive capacity of their land. Note that landholder support for this type of management option has been documented previously by Wilkinson (2003b).

4.3.3 Implications – Changes from Baseline Conditions

Following the completion of the numerical model scenario testing, community concerns were raised related to restoring the natural flow paths from Warragai Creek and Duck Creek to Sportsmans Creek. As such, on-ground manipulation of levees and drains in the central areas of Everlasting Swamp and at Imesons Swamp were not directly model tested. However, the results of several scenarios that were tested can be used to assess the existing flow paths of catchment inflows from Warragai Creek and Duck Creek, and the potential for in-drain tidal flushing at the proposed management areas.

For this option, the results from numerical model scenarios 5, 9, 11, 14, 16 and 17 were assessed to determine the hydrologic impacts of the proposed changes in Management Areas 1 and 7. Further information on the modelled scenarios is provided in Appendix F. The results from the analysed scenarios are discussed here, in terms of the changes to the predicted mean inundation extents and hydroperiods, when compared to baseline conditions (Option 1). The modelling results indicated that:

- Freshwater inflows from the Warragai Creek and Duck Creek catchments are highly dependent on the prevailing weather conditions (Scenarios 14 and 16);
- Freshwater inflows from the Warragai Creek catchment were shown to be held up in the southern area of Everlasting Swamp, with majority of the overland flows diverted towards Blanches Drain, while the remainder of flows drained towards Teal Lagoon, past Andersons Point;
- Retention of freshwater inflows from the Warragai Creek and Duck Creek catchments were variable between dry and wet weather periods, and temporary storage was limited to the low-lying areas of the landscape. It is expected that these areas "dry out" via losses from evaporation and seepage into the ground;
- Harrisons Creek weir and the main floodgates on Blanches Drain are important hydrologic controls for tidal inundation in the Warragai Creek area (Scenarios 5 and 11);
- By removing Harrisons Creek weir and opening the main floodgates on Blanches Drain (Scenario 11), it is predicted that regular tidal inundation would occur in the Warragai Creek area and Round Mountain area, with mean inundation levels of less than approximately 0.2 m for the majority of the time; and
- Tidal flushing at Imesons Swamp was only predicted following the removal of the floodgates on the Sportsmans Creek Weir (Scenarios 9 and 17). In this manner, increased inundation was predicted in the eastern portion of Imesons Swamp, with mean depths up to 0.1 m for extended periods of the time (Scenario 17).

4.3.4 Potential Benefits/Advantages for Option 2

For this option, the potential benefits were assessed, in terms of ecological, economic, and social/cultural considerations at the site, and are provided in Table 4.3.

Table 4.3: Potential Benefits or Advantages for Management Option 2

Considerations	Potential Benefits or Advantages
Ecological	Improved surface drainage and floodplain connectivity. Improved water quality and biodiversity in areas of restoration. Increased capacity of the floodplain wetland areas to store and release floodwaters at appropriate times. Reduced impacts of onsite ASS.
Economic	Relatively low-cost on-ground solutions, potential funding provided by Government environmental restoration grants. Minor maintenance expenditure on Sportsmans Creek Weir such as, clearing flood debris and re-attaching floodgates when damaged by floods.
Social/Cultural	Restoring natural heritage through floodplain connectivity and restored wetlands. Minimal impacts or inconvenience to landholders unwilling to support changed land management practices.

4.3.5 Potential Risks/Disadvantages and Risk Mitigation Measures for Option 2

For this option, the potential risks and mitigation measures were assessed, in terms of ecological, economic, and social/cultural considerations at the site, and are provided in Table 4.4.

Table 4.4: Potential Risks and Mitigation Measures for Management Option 2

Considerations	Potential Risks or Disadvantages	Possible Mitigation Measures
Ecological	Continued exposure of ASS outside restored areas, and acid discharge or black water events following rainfall. Poor surface and groundwater water quality across the wider area. Limited floodplain connectivity. Encroachment of native tree species into swamp areas, thereby reducing suitable habitat for waterbirds. Fish passage remains limited. Feral pig populations and straying livestock within the National Park. Infestations of exotic weeds and vegetation.	Management of onsite ASS at a property scale using techniques recommended in the ASS Management Manual. Land-reshaping in areas outside of Management Areas 1 and 7. Ongoing land management programs by NPWS.
Economic	Cost of structural failure of Sportsmans Creek Weir, requiring removal, and modification/construction of secondary flood mitigation structures upstream of weir.	Ongoing maintenance, provisions for raising levee heights and construction of secondary flow control structures. Application for Government Environmental Grants to encourage landholders to improve land management practices.
Social/Cultural	Environmental freshwater flow diversions from Sportsmans Creek are generally limited during dry periods, when salinity concentrations in Sportsmans Creek are high. Overgrown drains can restrict floodplain drainage capacity and may result in an increased risk of unwanted inundation of private properties, following moderate to large catchment inflows. No change in overall community or public value of the Everlasting Swamp National Park. Continued deterioration of Sportsmans Creek Weir, with potential risk of litigation due to injuries or fatalities. Long-term security of upstream landholders against saline intrusion and inundation of low-lying land is not addressed. The SCDU is responsible for ensuring that the Sportsmans Creek Weir is maintained to current standards under Water Management Act 2000.	Development of a long-term monitoring program for water quality in Sportsmans Creek to determine salinity triggers for diverting environmental flows from Sportsmans Creek to floodplain areas. Construction of in-drain drop-board structures or low-lying levees to prevent unwanted inundation on private properties of landholders unwilling to sell or change their land management practices. Continue promotion of the long-term objective of restoring the wider Everlasting Swamp National Park to encourage public interest and awareness.

4.4 Option 3: Maximise in-drain tidal flushing of Blanches Drain (Management Area 7)

4.4.1 Description

This option details a partial restoration scenario to maximise the in-drain tidal flushing of Blanches Drain, and the connecting drains in the Round Mountain area at the Everlasting Swamp National Park. The characteristics of this option, include:

- No change to existing land management practices, or the design, operation and maintenance of the existing floodplain drainage network or infrastructure, outside of the Everlasting Swamp National Park, except for the manipulation of the floodgates in Blanches Drain;
- Active management and regularly opening (i.e. using the existing horizontal lifting device) of the main floodgates in Blanches Drain, located at the channel junction with the Clarence River;
- Removal of the floodgates located half-way along Blanches Drain; and
- Review and update the existing Blanches Drain Management Plan. An updated management plan would require agreement between all stakeholders, including identifying who would be responsible for managing any floodgates requiring manual operation.

Further, this option could be integrated with the outcomes of Option 2 to maximise the interim environmental benefits, while working towards a holistic restoration of the Everlasting Swamp National Park.

4.4.2 Rationale

The on-ground works completed as part of the Everlasting Swamp ASS hotspot project (Figure 2.7), were designed to provide greater tidal water exchange in Blanches Drain, Harrisons Creek, and the connecting drainage network throughout the Round Mountain area (Wilkinson, 2004). These works were completed so that the wetland and Blanches Drain could be managed separately, or as a single hydrologic unit. However, only approximately 25% of the planned works for Blanches Drain and the Round Mountain area were completed during the hotspot project (Wilkinson, 2004). The majority of these works were completed in Blanches Drain. Furthermore, local landholders have suggested via the recent discussion forums that the floodgates in Blanches Drain are no longer actively managed, in accordance with the Drain Management Plan. As such, the existing drainage network in Management Area 7 is poorly flushed, acidic and heavily choked with exotic weeds.

4.4.3 Implications – Changes from Baseline Conditions

For this option, the results from numerical model scenarios 5 and 17 were assessed to determine the hydrologic impacts of the proposed changes in Management Area 7. The main floodgates on Blanches Drain were partially opened (i.e. auto-tidal floodgate only, Scenario 5) and fully opened (i.e. using the existing horizontal lifting device, Scenario 17) to assess the potential impact of an increased tidal range on inundation of adjacent private landholdings. Further information on these scenarios is provided in Appendix F.

The results from the analysed scenarios are discussed here, in terms of the changes to the predicted water levels in Blanches Drain, and the predicted mean inundation extents and hydro-periods, when compared to baseline conditions (Option 1). The modelling results indicated that:

- By lifting the main floodgates in Blanches Drain there was a predicted increase in the maximum water level of up to 0.5 m (Figure 4.3). As such, this option would create a natural flushing regime in Blanches Drain, whereby the water levels in Blanches Drain would be driven by tidal variations in the Clarence River, and tidal flushing of the channel would occur twice daily;

- No tidal inundation of the floodplain is expected when the auto-tidal floodgates are operational in Blanches Drain. This option would provide limited flushing of Blanches Drain due to the muted water levels in the drain and would be ineffective at clearing in-drain vegetation (Figure 4.3);
- Any impact from the channel fully opening the main floodgates in Blanches Drain would be minimal and largely localised to the area immediately surrounding the channel, within the Everlasting Swamp National Park (Figure 4.4); and
- Inundation is predicted to occur on the private property at the base of Round Mountain (Figure 4.4), with mean waters levels of up to 0.35 m, along the boundary of the Everlasting Swamp National Park. Note this depression was also shown to hold water following large rainfall events (Figure 4.2). This area requires further investigation before proceeding with this option.

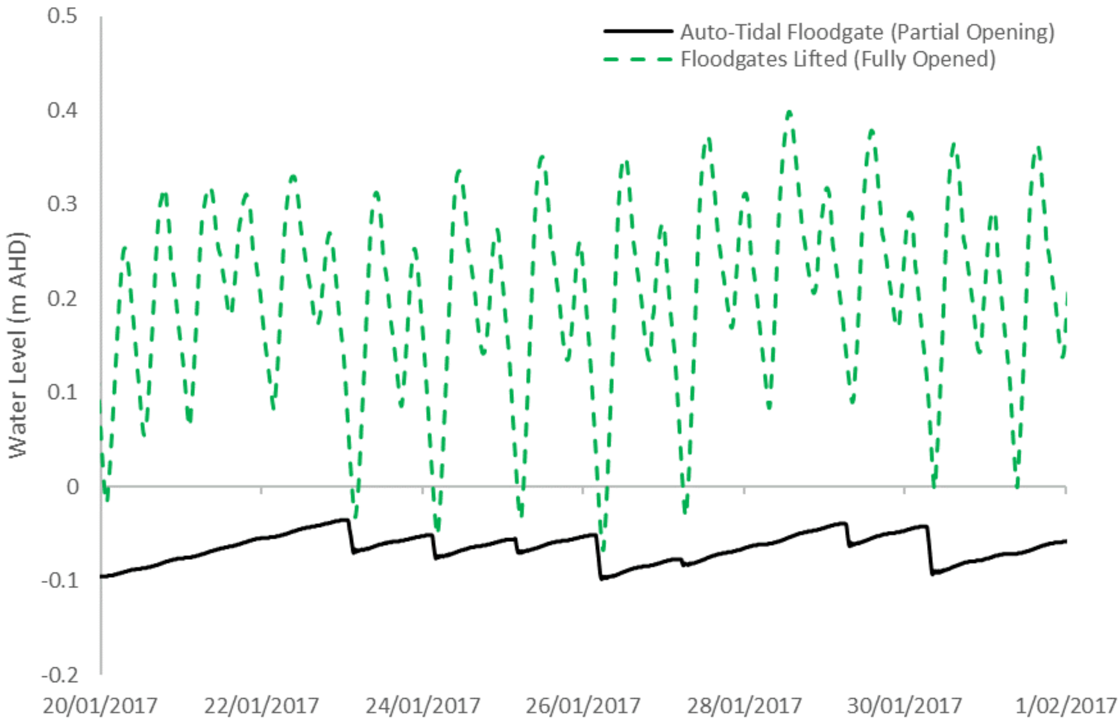


Figure 4.3: Comparison of Predicted Water Levels From 20 January to 1 February 2017 in Blanches Drain for Partial (Auto-Tidal Floodgates only) and Fully Opened (Gate Removed) Scenarios

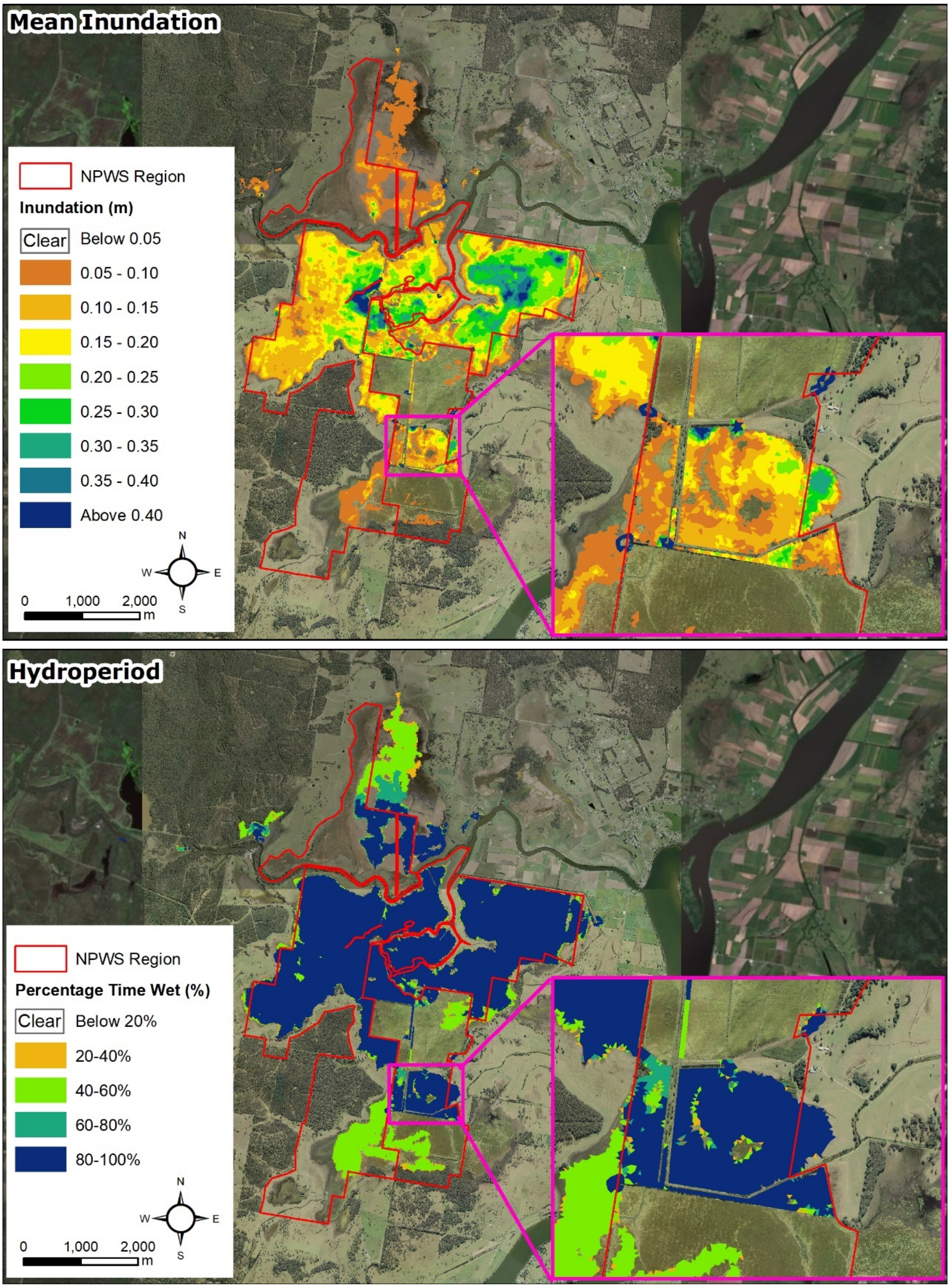


Figure 4.4: Scenario 17 - Mean Inundation Results for the Fully Opened Floodgate Scenario in Blanches Drain

4.4.4 Potential Benefits/Advantages for Option 3

For this option, the potential benefits were assessed, in terms of ecological, economic, and social/cultural considerations at the site, and are provided in Table 4.5.

Table 4.5: Potential Benefits or Advantages for Management Option 3

Considerations	Potential Benefits or Advantages
Ecological	Increased fish passage. Improved floodplain connectivity. Increased foraging habitat, particularly during prolonged inundation. Improved water quality and biodiversity in Blanches Drain. Reduced impacts of onsite ASS from inundation and buffering/dilution of in-drain acidity. Reduced restrictions on diversion of flows from Clarence River to inundation area. Improved flushing of Blanches Drain.
Economic	Relatively low-cost on-ground solutions, potential funding provided by Government environmental restoration and fisheries grants. Use of existing floodgate lifting devices and previous infrastructure/levees to prevent unwanted inundation of adjacent private landholdings. Minor maintenance expenditure on Sportsmans Creek Weir such as, clearing flood debris and re-attaching floodgates when damaged by floods.
Social/Cultural	Demonstration site to showcase ecological and agricultural benefits associated with increased drain water levels and regular flushing. Ecotourism (e.g. bird watching opportunities). No impacts or inconvenience to landholders outside of the restoration area.

4.4.5 Potential Risks/Disadvantages and Risk Mitigation Measures for Option 3

For this option, the potential risks and mitigation measures were assessed, in terms of ecological, economic, and social/cultural considerations at the site, and are provided in Table 4.6.

Table 4.6: Potential Risks and Mitigation Measures for Management Option 3

Considerations	Potential Risks or Disadvantages	Possible Mitigation Measures
Ecological	Transition from freshwater to salt-tolerant pastures and vegetation. Continued exposure of ASS outside restored areas, and acid discharge or black water events following rainfall. Poor surface and groundwater water quality across the wider area. Limited floodplain connectivity. Encroachment of native tree species into swamp areas, thereby reducing suitable habitat for waterbirds. Fish passage remains limited. Feral pig populations and straying livestock within the National Park. Infestations of exotic weeds and vegetation.	Management of onsite ASS at a property scale using techniques recommended in the ASS Management Manual. Land reshaping in areas outside of Management Area 7. Ongoing land management programs by NPWS.
Economic	Ongoing maintenance costs for flow control infrastructure. Cost of structural failure of Sportsmans Creek Weir, requiring removal, and modification/construction of secondary flood mitigation structures upstream of weir.	Application for Government Research and Environmental Grants. Ongoing maintenance, provisions for raising levee heights and construction of secondary flow control structures.
Social/Cultural	Impacts from unwanted inundation of adjacent private landholdings. Limited change in overall community or public value of the Everlasting Swamp National Park. Continued deterioration of Sportsmans Creek Weir, with potential risk of litigation due to injuries or fatalities. Long-term security of upstream landholders against saline intrusion and inundation of low-lying land is not addressed. The SCDU is responsible for ensuring that the Sportsmans Creek Weir is maintained to current standards under Water Management Act 2000.	Trial opening of the main floodgates on Blanches Drain and monitoring of tidal inundation levels across the floodplain. Acquisition of affected properties. Land reshaping to improve surface drainage and low-height levees to prevent inundation. Landholder engagement and negotiations to encourage change in land management practice. Continued promotion of the long-term objective of restoring the wider Everlasting Swamp National Park to encourage public interest and awareness.

4.5 Option 4: Restoration of natural creeks to encourage flushing of Teal Lagoon and Coxs Swamp (Management Areas 3, 4, 5, 6)

4.5.1 Description

This option details a partial restoration scenario, whereby Reedy and Woody Creeks are restored to encourage tidal flushing of Teal Lagoon and the re-creation of a semi-permanent wetland in the area of Coxs Swamp. This option was previously recommended in Wilkinson (2003b), and more recently in Rayner et al. (2016). The characteristics of this option, include:

- No change to existing land management practices, or the design, operation and maintenance of the existing floodplain drainage network or infrastructure, outside of the Everlasting Swamp National Park;
- Removal of artificial impedances (e.g. levees, redundant structures, etc.) to restore natural flow paths and improve floodplain connectivity with natural creeks;
- Land re-shaping, to create wide, shallow swale drains (above the PASS layer) that maintain existing surface drainage and encourage tidal flushing of acid scalds; and
- Active floodgate management at Reedy and Woody Creeks to maximise regular tidal exchange and enhance floodplain connectivity, while controlling drainage from Sportsmans 35/1.

Since these management areas are largely contained within the Everlasting Swamp National Park, this option considers the combined management of Reedy Creek/Teal Lagoon and Woody Creek/Coxs Swamp. Note Teal Lagoon and Coxs Swamp were gazetted as SEPP 14 (Coastal Wetlands), and therefore would require an Environmental Impact Statement (EIS) and development consent approval before any on-ground works (e.g. clearing, draining, filling, or levee construction) are undertaken.

4.5.2 Rationale

Teal Lagoon

Teal Lagoon is a large, open permanent water body located within the Everlasting Swamp National Park. The main open water body of Teal Lagoon has a surface area of approximately 17 ha (1.7 km^2), or less than 1% of the Everlasting Swamp floodplain area, and is connected to a series of smaller, permanent water bodies. This complex of wetlands attracts a variety of predominately freshwater waterbirds (Smith, 2010). While the Teal Lagoon complex historically received overland inflows from Warragai Creek and Sportsmans Creek, it was also likely recharged by regional groundwater sources. Following significant changes to the overland flow paths across the floodplain over the last century, the surface water drainage of Teal Lagoon was reduced to:

- Reedy Creek, a modified natural creek with two (2) x 1.5 m pipe culverts and floodgates that drain the lagoons into Woody Creek and then into Sportsmans Creek; and
- Sportsmans 35/1, a constructed drainage channel approximately 500 m long and 3 m wide, with a 0.9 m pipe culvert and floodgate, connecting Teal Lagoon to Sportsmans Creek.

On-ground works completed in management areas 3 – 6, as part of the ASS hotspot project, included the installation of an auto-tidal floodgate at Reedy Creek (Sportsmans 34), with horizontal lifting devices fitted on the floodgates located in:

- Sportsmans/Woody Creek 33 and 33/1;
- Sportsmans/Reedy Creek 34; and
- Sportsmans Creek 35 and 35/1.

At present, the flushing of the Teal Lagoon area is provided via the auto-tidal floodgate at Reedy Creek (Sportsmans 34), while the other gates with lifting devices remain closed. However, the exchange of water through Reedy Creek is limited, as it is controlled by the amount of leakage through the Sportsmans Creek Weir, located approximately 2.5 km downstream of the floodgates at Reedy Creek. Note that the previous landholder kept the floodgate on Sportsmans 35/1 open during dry periods, and was only closed during floods (pers. comms. P. Wilson, Clarence Valley Council).

It was noted during recent surveys by WRL, that bed elevations measured along a transect of Teal Lagoon ranged from approximately -0.4 m to -0.6 m AHD (Rayner et al., 2016). Further, the water surface elevation during the survey was approximately 0.0 m AHD. Note that mean high water (MHW) at Lawrence is 0.28 m AHD (MHL, 2012). As such, due to the low elevation of the lagoon, existing flow controls on connecting drainage lines, and its location upstream of the Sportsmans Creek Weir, the Teal Lagoon area remains poorly flushed, with sections of Reedy Creek heavily choked by exotic weeds.

Coxs Swamp

Coxs Swamp has an area of approximately 250 ha and is located on the area adjacent to Woody Creek. Coxs Swamp is bordered to the north by the Sportsmans-Everlasting South Levee 32, and natural high ground to the east and south. The area is also hydrologically connected to The Horseshoe, located south of the swamp. There are two (2) flood mitigation drains in the area, including:

- Sportsmans/Woody Creek 33, a modified natural creek with a 1.5 m pipe culvert and one-way floodgate (invert of -0.77 m AHD), that drains Coxs Swamp into Sportsmans Creek; and
- Sportsmans Creek-South Levee 32, a constructed drainage channel approximately 300 m long and 3 m wide, with a 0.9 m pipe culvert and floodgate, connecting to Sportsmans Creek.

The hydrology of Coxs Swamp is heavily influenced by prevailing weather conditions. The central portion of the swamp is significantly lower than the rest of the management area, and is connected to Sportsmans/Woody Creek 33 through some natural creek lines during flooding events. After rainfall the low-lying areas of Coxs Swamp usually store water as it is too low to drain through the old creek lines, and is subsequently lost via evaporation and seepage into the ground. During dry weather or persistent droughts, the area becomes void of vegetation, due to pyrite formation and oxidation near the surface, and lack of surface water exchange. Note that the average ground elevation is below 0 m AHD.

Landholders suggested via the recent discussion forums that the current management of the floodgates on Woody and Reedy Creeks has resulted in prolonged and unwanted inundation at Coxs Swamp and The Horseshoe area. As a result, the Woody Creek and Reedy Creek gates have been closed at different times recently by concerned landholders, to allow drainage of these areas. Therefore, based on the current management plan for the area, and the influence of the Sportsmans Creek Weir on controlling upstream water levels, the potential restoration outcomes of the Reedy Creek/Teal Lagoon complex, and Woody Creek/Coxs Swamp, are yet to be fully achieved.

4.5.3 Implications – Changes from Baseline Conditions

For this option, the results from numerical model scenarios 6, 7, 9, 10, 16 and 19 were assessed to determine the hydrologic impacts of the proposed changes in Management Areas 3, 4, 5 and 6. These scenarios involved manipulating flood-gated structures included in the 1-D model of the study area (Appendix D). Further information on these scenarios is also provided in Appendix F. The results from the analysed scenarios are discussed here, in terms of the changes to the predicted mean inundation extents and hydroperiods, when compared to baseline conditions (Option 1). The modelling results indicated that:

- Any impact from opening all of the internal floodgates gates across the study area would be minimal and largely localised to the Teal Lagoon area (Figure 4.5);
- Interestingly, the results of scenarios 6 and 7 showed that Sportsmans/Reedy Creek 34 and Sportsmans Creek 35/1 have a similar effect on the fluctuation of water levels in Teal Lagoon, and the extent and duration of inundation of the surrounding area;
- It was noted that water exchanged via Reedy Creek was generally more effective in flushing the Teal Lagoon area, and resulted in a greater area of inundation, combined with increased depths and hydroperiods;
- The results of scenarios 10 and 19 (Figure 4.7 and Figure 4.9, respectively) showed the potential environmental benefits that could be gained from the removal of the Sportsmans Creek Weir (See Management Option 5); and
- Sportsmans/Woody Creek 33 is the primary hydrologic control for the delivery of water from Sportsmans Creek to the areas of upper Woody Creek, Coxs Swamp and The Horseshoe.

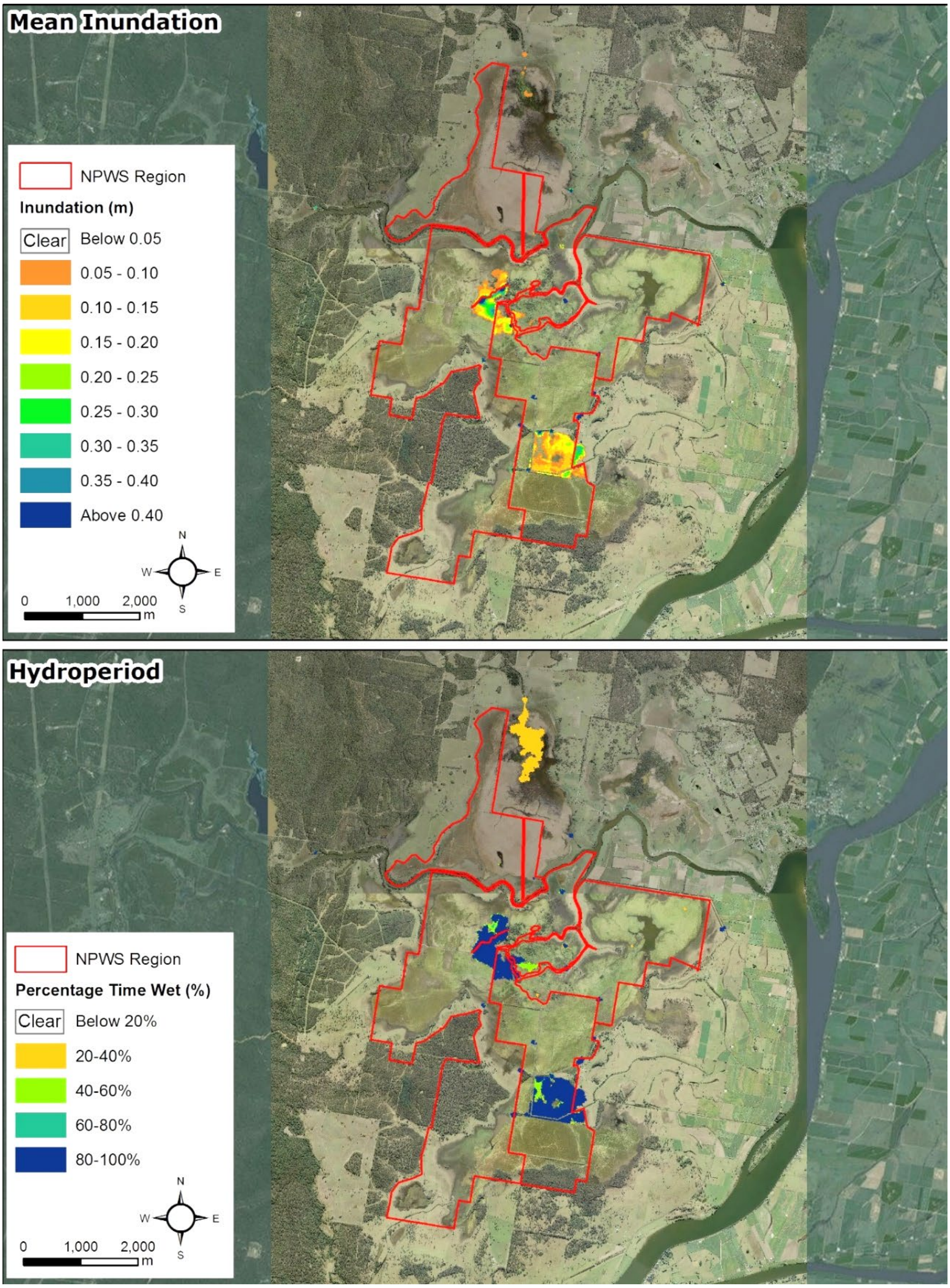


Figure 4.5: Scenario 9 – Sportsmans Creek Weir Operational (Existing Conditions and Leakage), with Internal Floodgates Removed – 1 January to 22 February 2017

4.5.4 Potential Benefits/Advantages for Option 4

For this option, the potential benefits were assessed, in terms of ecological, economic, and social/cultural considerations at the site, and are provided in Table 4.7.

Table 4.7: Potential Benefits or Advantages for Management Option 4

Considerations	Potential Benefits or Advantages
Ecological	Improved floodplain connectivity and surface and groundwater exchange. Improved fish passage. Increased foraging and waterbird habitat, particularly during prolonged inundation. Reduced impacts of onsite ASS from inundation and buffering/dilution of acidity.
Economic	Relatively low-cost on-ground solutions, potential funding provided by Government environmental restoration and fisheries grants. Use of existing floodgate lifting devices. Minor maintenance expenditure on Sportsmans Creek Weir such as, clearing flood debris and re-attaching floodgates when damaged by floods.
Social/Cultural	Improved landholder perception and understanding of the hydrologic conditions across the Everlasting Swamp National Park. Ecotourism (e.g. bird watching opportunities). No apparent impacts or inconvenience to landholders outside of the restoration area.

4.5.5 Potential Risks/Disadvantages and Risk Mitigation Measures for Option 4

For this option, the potential risks and mitigation measures were assessed, in terms of ecological, economic, and social/cultural considerations at the site, and are provided in Table 4.8.

Table 4.8: Potential Risks and Mitigation Measures for Management Option 4

Considerations	Potential Risks or Disadvantages	Possible Mitigation Measures
Ecological	Continued exposure of ASS outside restored areas, and acid discharge or black water events following rainfall. Poor surface and groundwater water quality across the wider area. Limited floodplain connectivity across the wider area. Encroachment of native tree species into swamp areas, thereby reducing suitable habitat for waterbirds. Fish passage remains limited. Feral pig populations and straying livestock within the National Park. Infestations of exotic weeds and vegetation.	Management of onsite ASS at a property scale using techniques recommended in the ASS Management Manual. Land reshaping in areas outside of proposed Management Areas. Ongoing land management programs by NPWS.
Economic	Ongoing maintenance costs for flow control infrastructure. Cost of structural failure of Sportsmans Creek Weir, requiring removal, and modification/construction of secondary flood mitigation structures upstream of weir.	Application for Government Environmental Grants. Ongoing maintenance, provisions for raising levee heights and construction of secondary flow control structures.
Social/Cultural	Impacts from unwanted inundation of adjacent private landholdings. No change in overall community or public value of the Everlasting Swamp National Park. Continued deterioration of Sportsmans Creek Weir, with potential risk of litigation due to injuries or fatalities. Long-term security of upstream landholders against saline intrusion and inundation of low-lying land is not addressed. The SCDU is responsible for ensuring that the Sportsmans Creek Weir is maintained to current standards under Water Management Act 2000.	Trial opening of the floodgates in Woody Creek and monitoring of tidal inundation levels across Coxs Swamp and The Horseshoe. Acquisition of affected properties. Land reshaping to improve surface drainage and low-height levees to prevent inundation. Landholder engagement and negotiations to encourage change in land management practice. Continued promotion of the long-term objective of restoring the wider Everlasting Swamp National Park to encourage public interest and awareness.

4.6 Option 5: Full opening or complete removal of Sportsmans Creek Weir (Management Areas 1, 3, 4, 5, 6, 9)

4.6.1 Description

This option details a partial restoration scenario to reinstate the natural, full tidal variation within Sportsmans Creek, and floodplain connectivity with the natural creeks. This option was previously recommended in Smith (1999), and more recently in Gordos (2012). The characteristics of this option, include:

- No change to existing land management practices, or the design, operation and maintenance of the existing floodplain drainage network or infrastructure, outside of the Everlasting Swamp National Park, except for full opening (i.e. floodgates only removed) or complete removal of Sportsmans Creek Weir;
- Shifting the management of tidal/saline ingress from Sportsmans Creek Weir to the internal floodgates across Sportsmans Creek and its associated tributaries; and
- Active floodgate management and regular opening of all floodgates within the Everlasting Swamp National Park, particularly at Reedy and Woody Creeks, to maximise regular tidal exchange and enhance floodplain connectivity.

Note that boating access to Sportsmans Creek would depend on whether the entire weir structure was removed or not. Furthermore, removal of the weir would trigger several legislative considerations as outlined in Gordos (2012).

4.6.2 Rationale

At present, the NPWS manage over 80% of the Everlasting Swamp wetland complex, with the Everlasting Swamp National Park mostly surrounded by private landholdings, some of which have areas that are mapped as SEPP 14 (Coastal Wetlands). While past and present landholders on the floodplain have cooperated with Clarence Valley Council since 1998 to examine options and investigate ways to better integrate agriculture and environmental management (Wilkinson, 2003b), achieving the optimal management strategy has been met with strong opposition, due to the potential risks associated with water management on these adjoining properties. Of particular concern via community feedback was the flooding of properties with tidal waters, or muted tidal waters that currently penetrate upstream of the weir, where existing drainage must be maintained. Other concerns related to the inundation of upstream properties from manipulation or removal of the Sportsmans Creek Weir, or uncontrolled inundation on the NPWS land resulting in undesirable environmental outcomes (e.g. poor water quality, poor ecosystem management, mosquitoes, etc.) for the whole area.

To date, the Sportsmans Creek Weir remains the dominant structure controlling surface and groundwater hydrology across the Everlasting Swamp wetland complex. However, the Sportsmans Creek Weir is now over 90 years old, and is slowly deteriorating and at risk of failure. While the community sees value in the weir, recent community feedback (Appendix G, Table G.1, P3) suggested that the risks (e.g. failure, litigation) outweigh the benefits (e.g. prevents powerboats, maintains water levels, allows freshwater fish to breed), associated with a 'do-nothing' option (Option 1). As such, the status and operation of the Sportsmans Creek Weir must be a primary consideration for the possible restoration of the Everlasting Swamp wetland complex.

4.6.3 Implications – Changes from Baseline Conditions

This option considers the most likely scenario for the future operation of the Sportsmans Creek Weir, such that in the short-to-medium term, the most feasible solution to resolve the issue of the deteriorating weir would be to remove its floodgates. This interim management approach would effectively provide the same hydraulic conditions in Sportsmans Creek, that would be achieved by the complete removal of the weir, without the additional capital costs. Note that complete removal of the Sportsmans Creek Weir was not modelled in this study.

For this option, the results from numerical model scenarios 10, 16, 17, 18 and 19 were assessed to determine the hydrologic impacts of the proposed changes in Management Areas 1, 3, 4, 5, 6 and 9. Further information on these scenarios is also provided in Appendix F. The results from the analysed scenarios are discussed here, in terms of the changes to the predicted mean inundation extents and hydroperiods, when compared to baseline conditions (Option 1). Following the removal of the floodgates on the Sportsmans Creek Weir and all internal floodgates are removed (Scenario 13), the modelling results indicated that:

- Water levels in Sportsmans Creek, at a location approximately 9 km upstream of the weir, would increase by up to 0.5 m, and show a much stronger tidal signal compared to the previous conditions with the weir in-place (Figure 4.6);
- Teal Lagoon, Reedy Creek and Coxs Swamp are the key areas experiencing frequent tidal inundation, remaining wet for 80-100% of the time. It was noted that the wetting-drying patterns of these areas are noticeably different; the Reedy Creek/Teal Lagoon area has a tidal response, whereas Coxs Swamp tends to infill like a basin on higher spring tides and is more susceptible to losses due to evaporation. On higher spring tides, tidal inundation extends further towards the NPWS boundary with the maximum inundation extent shown in Figure 4.8; and
- The maximum inundation extents and corresponding hydroperiods highlight areas of the swamp that appear to have poor connectivity and drainage due to the underlying site topography.

Following the removal of the floodgates on the Sportsmans Creek Weir and all internal floodgates are operational, tidal inundation was predicted in the low-lying areas in the upstream reaches of Sportsmans Creek. Note that despite several efforts to obtain adequate field data in the low-lying areas in the upper reaches of Sportsmans Creek, some areas were inaccessible and were left as 2-D features (based on LiDAR) in the model floodplain bathymetry. A stage-volume analysis showed that below 1.5 m AHD, these inaccessible low-lying areas in the upper reaches of Sportsmans Creek were less than 1% of the total volume of the Everlasting Swamp floodplain. Further site investigations would be required to ground-truth these areas should the removal of the Sportsmans Creek Weir be the preferred option for the future management of Everlasting Swamp.

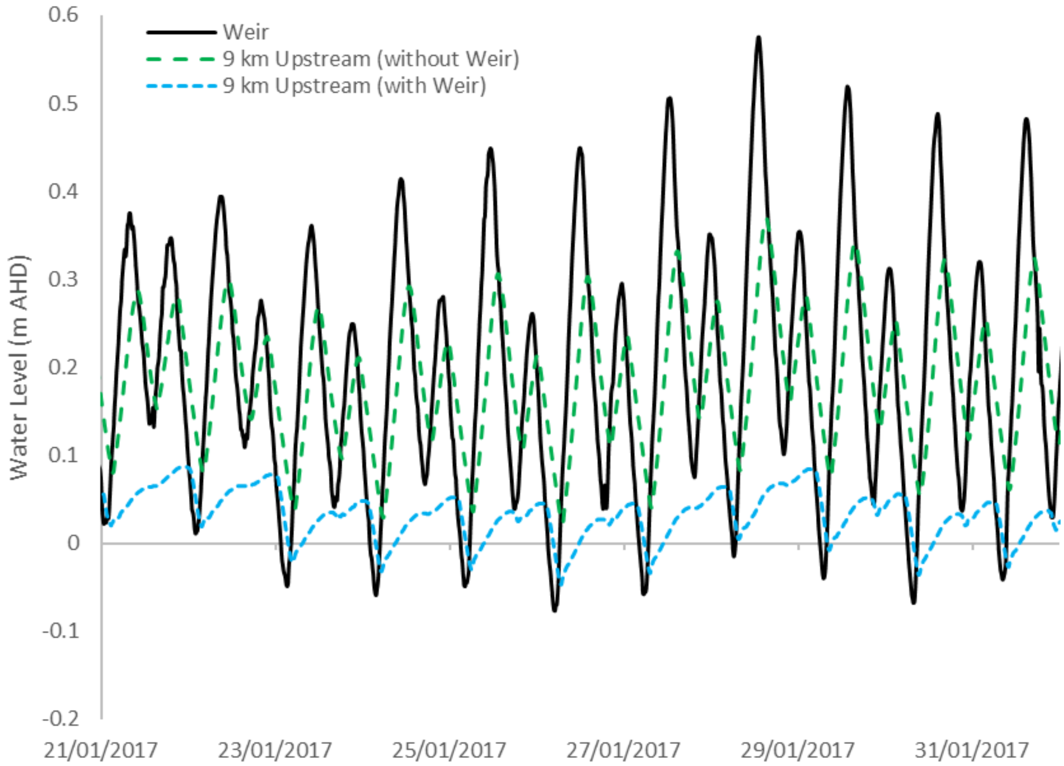


Figure 4.6: Predicted Water Levels in Sportsmans Creek Following Removal of Sportsmans Creek Weir

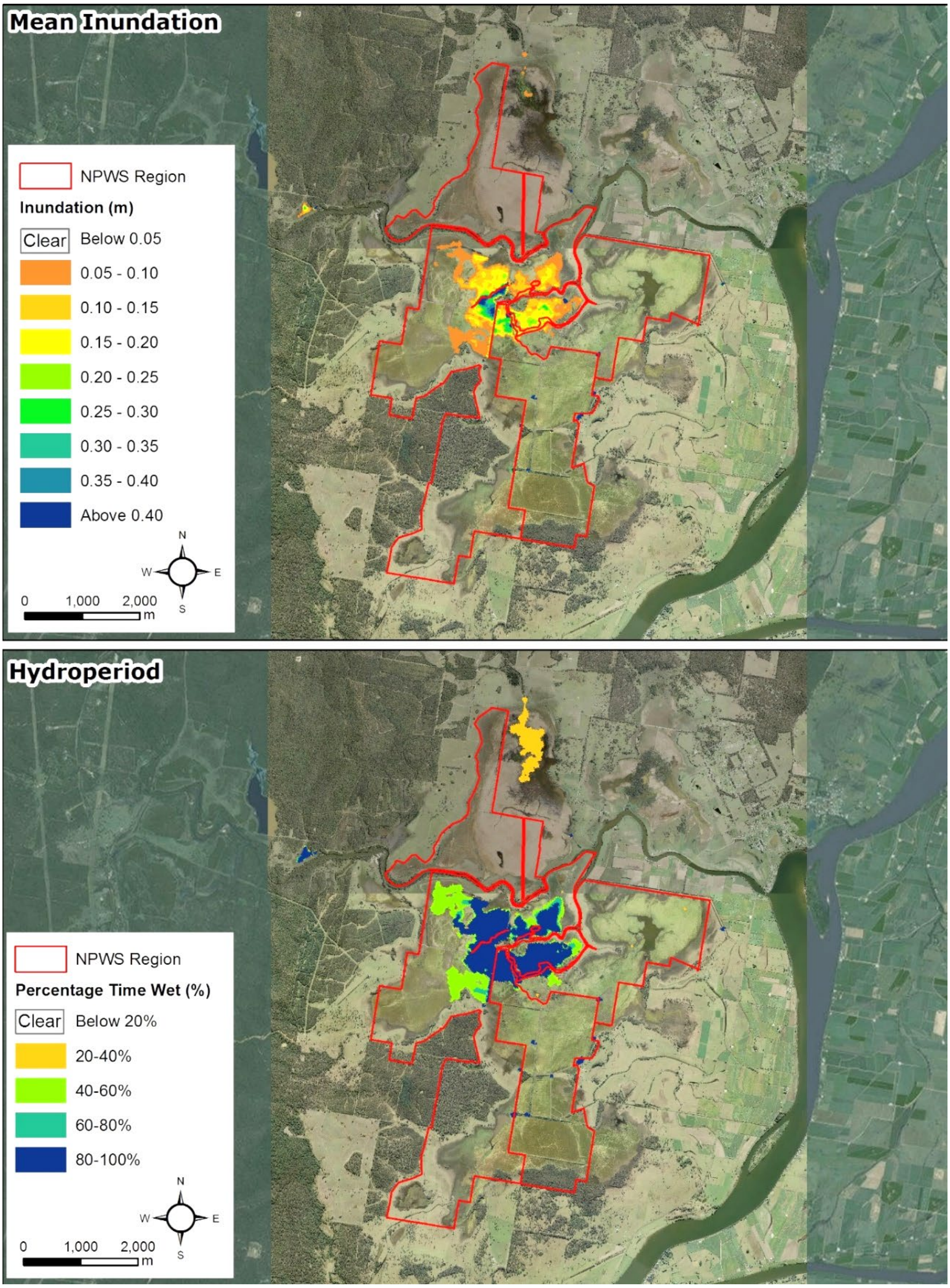


Figure 4.7: Scenario 10 – Sportsmans Creek Weir (Floodgates Removed), with Internal Floodgates Closed, and Reedy Creek Auto-Tidal Gate Open – 1 January to 22 February 2017

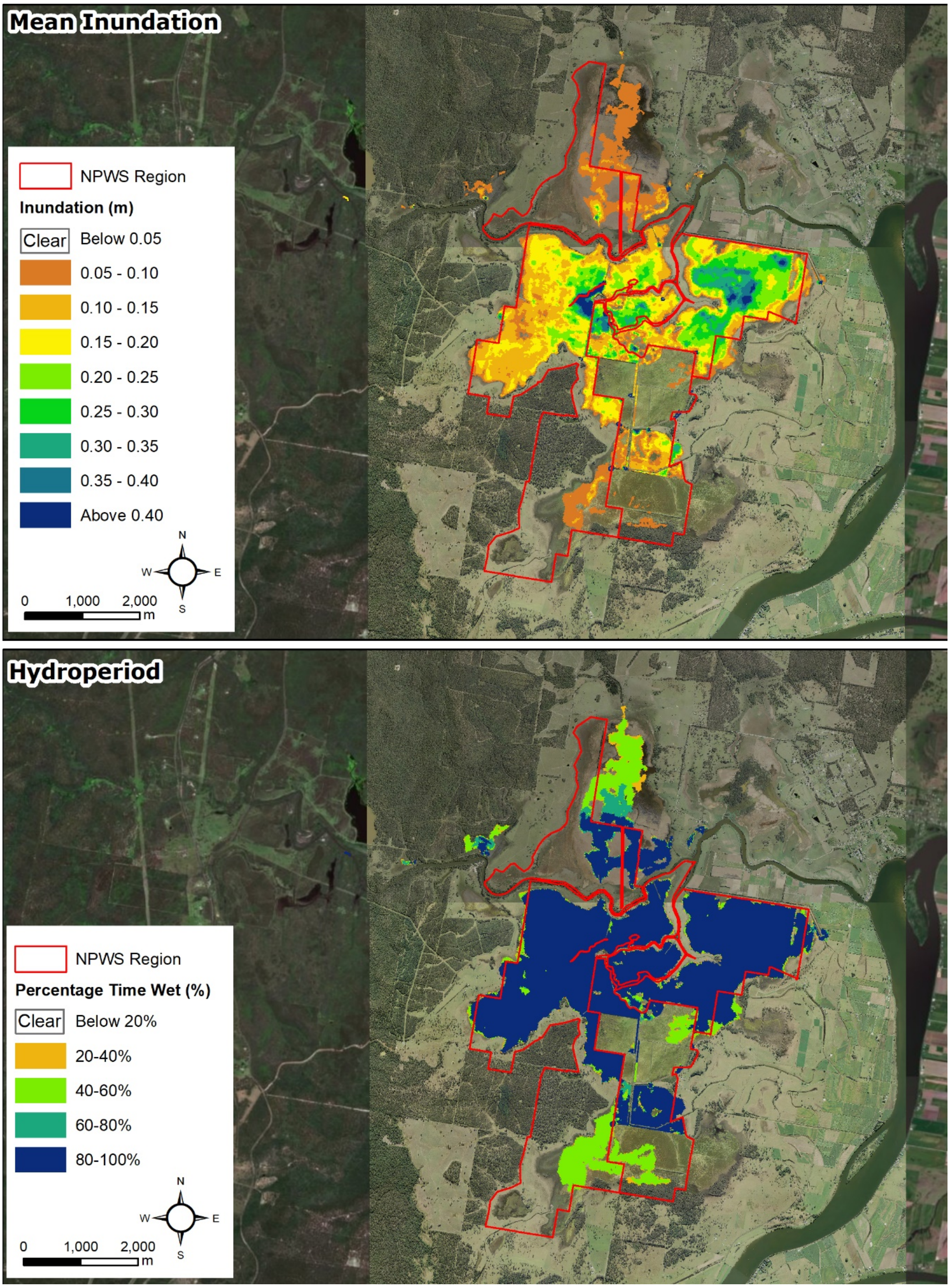
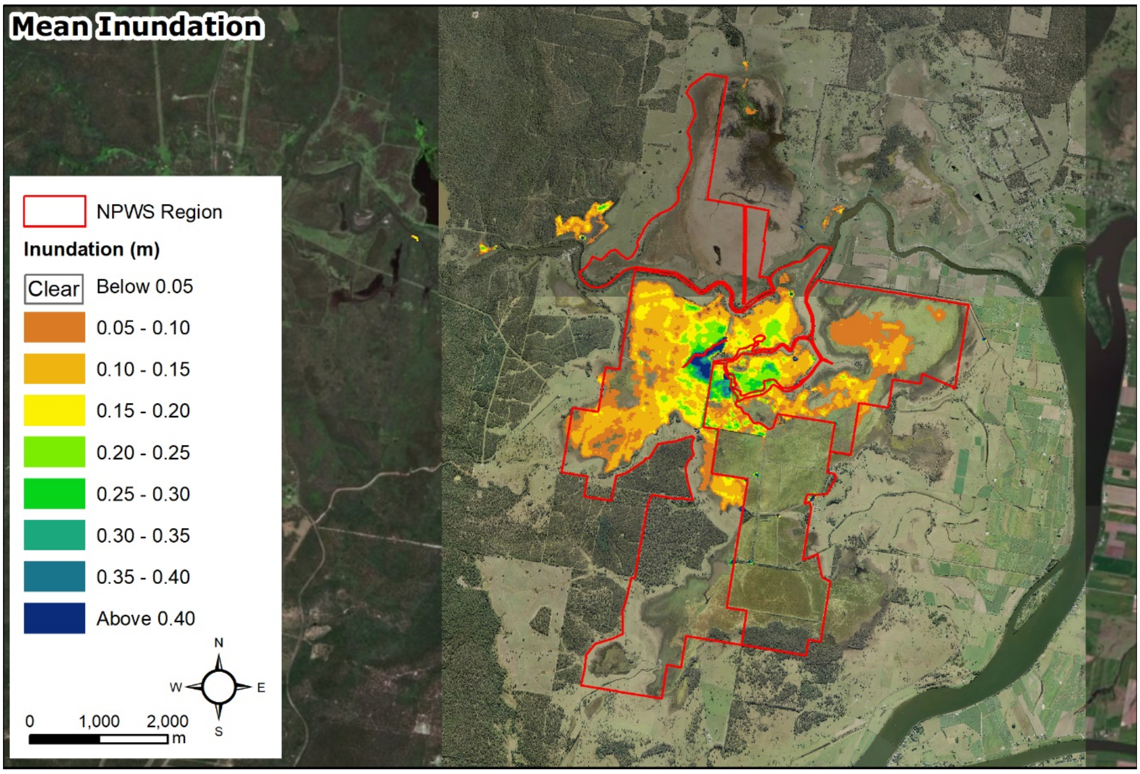


Figure 4.8: Scenario 17 – Sportsmans Creek Weir (Floodgates Removed), with all Internal Floodgates Removed – 1 January to 22 February 2017



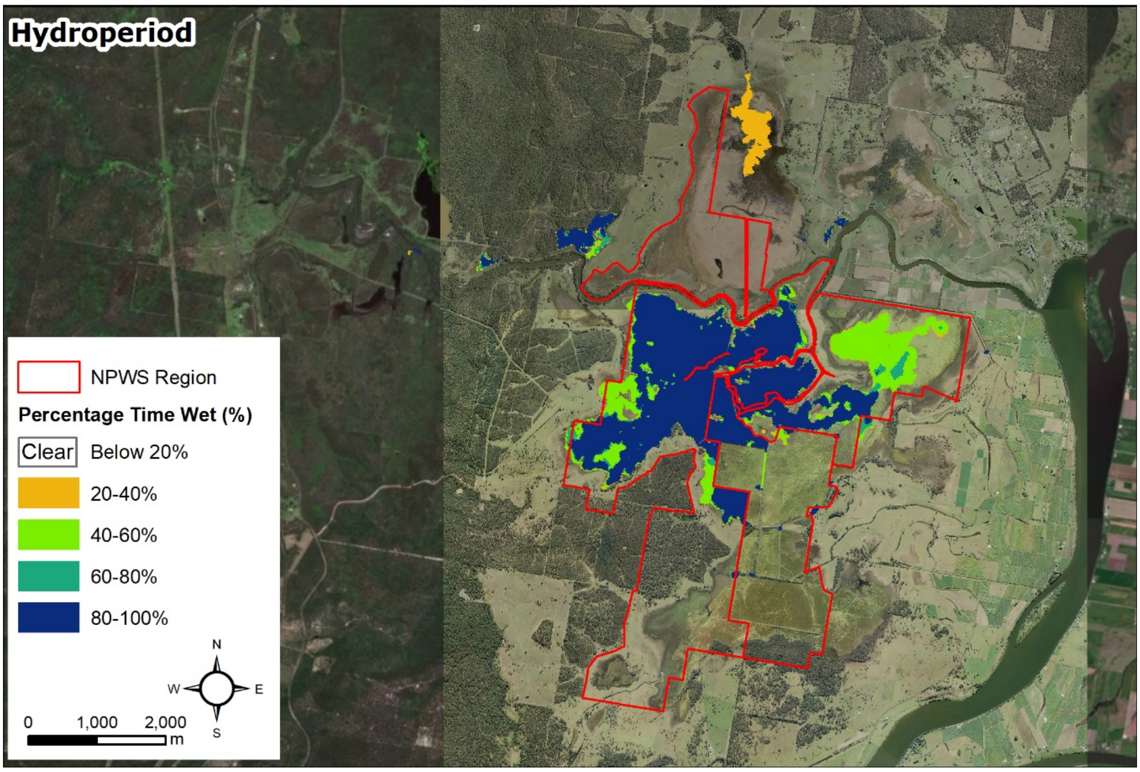


Figure 4.9: Scenario 19 – Reedy Creek, Sportsmans 35/1 and Sportsmans Creek Weir Open Only – Mean Inundation Extent and Hydroperiod Analysis – 1 January to 22 February 2017

4.6.4 Potential Benefits/Advantages for Option 5

For this option, the potential benefits were assessed, in terms of ecological, economic, and social/cultural considerations at the site, and are provided in Table 4.9.

Table 4.9: Potential Benefits or Advantages for Management Option 5

Considerations	Potential Benefits or Advantages
Ecological	Improved floodplain connectivity, and surface and groundwater exchange. Over 20 kms of unimpeded fish passage in natural creek system. Increased foraging and waterbird habitat, particularly during prolonged inundation. Reduced impacts of onsite ASS from inundation and buffering/dilution of acidity. Reduced impacts from blackwater due to improved surface drainage. Increased river health via flushing of natural creeks and side channels. Increased salt-water tolerate vegetation.
Economic	Relatively low-cost on-ground solutions, potential funding provided by Government environmental restoration and fisheries grants. Use of existing floodgate lifting devices.
Social/Cultural	Drainage of floodwaters would be improved with the removal of the weir. Improved community or public value of the Everlasting Swamp National Park. Public access to Sportsmans Creek would be improved by the removal of the weir. Improved landholder perception and understanding of the hydrologic conditions across the Everlasting Swamp National Park. Greater ecotourism (e.g. bird watching opportunities).

4.6.5 Potential Risks/Disadvantages and Risk Mitigation Measures for Option 5

For this option, the potential risks and mitigation measures were assessed, in terms of ecological, economic, and social/cultural considerations at the site, and are provided in Table 4.10.

Table 4.10: Potential Risks and Mitigation Measures for Management Option 5

Considerations	Potential Risks or Disadvantages	Possible Mitigation Measures
Ecological	Freshwater drought refuges in Sportsmans Creek may be lost for terrestrial fauna. Die-off of existing freshwater vegetation. Removal of the Sportsmans Creek Weir could lower water tables across the wider Everlasting Swamp. Complete removal of the Sportsmans Creek Weir could lead to increased scouring of Sportsmans Creek causing it to become more hydraulically efficient. Feral pig populations and straying livestock within the National Park. Infestations of exotic weeds and vegetation.	In-drain weirs/drop-boards to manage drain and wetland water levels. Management of onsite ASS at a property scale using techniques recommended in the ASS Management Manual. Land reshaping to create shallow, swale drains. Ongoing land management programs by NPWS.
Economic	Medium to high cost option associated with removal of weir floodgates or structure. Ongoing maintenance costs for flow control infrastructure. Costs of levee construction, modifying existing or construction of new flow control structures.	Application for Government environmental and floodplain restoration grants.
Social/Cultural	Impacts from unwanted inundation of adjacent private landholdings. Levee construction may be impractical in some locations, thereby posing a potential impact/cost to affected landholders.	Raising existing levees or constructing new levees to ensure that these are at least at, or potentially above, the height of the existing weir (0.583 m AHD). Modifying existing structures or constructing new in-drain structures, as required. Acquisition of remaining affected properties. Trial opening of the floodgates in natural creeks and monitoring of tidal inundation levels across Coxs Swamp and The Horseshoe. Land reshaping to improve surface drainage and low-height levees to prevent inundation. Landholder engagement and negotiations to encourage change in land management practice. Continued promotion of the long-term objective of restoring the wider Everlasting Swamp National Park to encourage public interest and awareness.

4.7 Option 6: Fully re-create the natural flow regimes across the wider ESNP (Management Areas 1, 3, 4, 5, 6, 7, 9)

4.7.1 Description

This option details a full restoration scenario to re-create the natural flow regimes across the wider Everlasting Swamp National Park. The characteristics of this option, include:

- No change to existing land management practices, or the design, operation and maintenance of the existing floodplain drainage network or infrastructure, outside of the Everlasting Swamp National Park, except for full opening (i.e. floodgates only removed) or complete removal of Sportsmans Creek Weir (Option 5);
- Acquisition of all remaining low-lying private land surrounding Sportsmans Creek, specifically land within the Everlasting Swamp wetland complex, to remove any future risk of inundation;
- Removal of all artificial impedances (e.g. levees, redundant structures, etc.), to restore natural flow paths and improve floodplain connectivity with natural creeks;
- Land re-shaping, to create wide, shallow swale drains (above the PASS layer) that maintains surface drainage and encourages tidal flushing of acid scalds; and
- Ongoing monitoring of the study area to quantify the outcomes of the on-ground works and changes to the hydrologic regimes across the site.

Once under complete NPWS ownership, a management plan would need to be developed to determine how the Everlasting Swamp wetland complex would be best managed, and where the reinstatement of tidal inundation into the wetland would be permitted and to what extent. Note that any change to the current situation depends on the agreement of adjacent landholders, other stakeholders and Clarence Valley Council.

4.7.2 Rationale

As previously mentioned, the return of natural flow regimes across the Everlasting Swamp National Park is the primary long-term management objective for the NPWS (OEH, 2016). A major concern among landholders raised via community feedback was the effect of the introduction of water of higher salinity into the Everlasting Swamp, including potential impacts on existing waterbird populations and freshwater pastures used for grazing. The perception among landholders was that a previous attempt to restore tidal flushing to the neighbouring Little Broadwater was unsuccessful, and the same management approach was not desirable for the Everlasting Swamp and Imesons Swamp areas. As such, the possibility of restoration by hydrological manipulation across the whole site is still limited by the reluctance of some landholders to retain water on their land to suitable salinities, depths and durations, to achieve full re-creation of the site’s wetlands values. Therefore, further acquisition of low-lying land adjacent to the existing National Park is required to secure the return of natural flow regimes across the ESNP and achieve long-term management objectives of the site.

The Everlasting Swamp wetland complex is one of the largest remaining coastal floodplain wetlands in NSW and is recognised by the State and Federal Governments as a site of ecological significance. For similar sites of biodiversity importance, private land has also been purchased by the State government to protect and enhance the biological attributes of the site (Gordos, 2012). A successful acquisition of the wider Everlasting Swamp wetland complex would mean the whole wetland would be designated for conservation purposes, including conservation of waterbirds. Smith (2010) suggested that with the maintenance of higher water levels, combined with a mosaic of freshwater and tidal water wetlands across the Everlasting Swamp National Park, its habitat qualities for foraging waterbirds would be expected to increase quickly. Indeed, marsh vegetation and many waterbird species were observed to appear in the Little Broadwater wetland soon after the introduction of water after being dry (White, 2009), although monitoring was not undertaken to quantify the differences. In this manner, ongoing monitoring of the study area is recommended to quantify the outcomes of the on-ground works and re-creation of the natural floodplain dynamics.

4.7.3 Implications – Changes from Baseline Conditions

The outcomes of the numerical modelling presented in this study, combined with the ecology assessment of the site under a range of hydrologic conditions, provides suitable guidance on options to successfully return the natural flow regimes to the Everlasting Swamp National Park. Note that options 5 and 6 are not mutually exclusive, with both options requiring further detailed site investigations and monitoring once Sportsmans Creek Weir is removed. However, the modelling results provided in this section and Appendix F, have highlighted the highest immediate priority for NPWS is to put in place sufficient provisions to allow Sportsmans Creek Weir to be removed. Ultimately, the modelling results provided support a staged-approach towards fully re-creating a natural flow-regime across the Everlasting Swamp National Park.

4.7.4 Potential Benefits/Advantages for Option 6

For this option, the potential benefits were assessed, in terms of ecological, economic, and social/cultural considerations at the site, and are provided in Table 4.11.

Table 4.11: Potential Benefits or Advantages for Management Option 6

Considerations	Potential Benefits or Advantages
Ecological	Improved floodplain connectivity, and surface and groundwater exchange. Over 20 kms of unimpeded fish passage in natural creek system. Increased foraging and waterbird habitat, particularly during prolonged inundation. Reduced impacts of onsite ASS from inundation and buffering/dilution of acidity. Reduced impacts from blackwater due to improved surface drainage. Increased river health via flushing of natural creeks and side channels. Increased salt-water tolerant vegetation.
Economic	Relatively low-cost on-ground solutions, potential funding provided by Government environmental restoration and fisheries grants.
Social/Cultural	Drainage of floodwaters would be improved with the removal of the weir. Improved community or public value of the Everlasting Swamp National Park. Public access to Sportsmans Creek would be improved by the removal of the weir. Greater ecotourism (e.g. bird watching opportunities) and options to create riparian parks, walkways, bird viewing areas, and water access points. Large-scale wetland re-creation demonstration site. No apparent impacts or inconvenience to landholders outside of the restoration area.

4.7.5 Potential Risks/Disadvantages and Risk Mitigation Measures for Option 6

For this option, the potential risks and mitigation measures were assessed, in terms of ecological, economic, and social/cultural considerations at the site, and are provided in Table 4.12.

Table 4.12: Potential Risks and Mitigation Measures for Management Option 6

Considerations	Potential Risks or Disadvantages	Possible Mitigation Measures
Ecological	Freshwater drought refuges in Sportsmans Creek may be lost for terrestrial fauna. Die-off of existing freshwater vegetation. Complete removal of the Sportsmans Creek Weir could lead to increased scouring of Sportsmans Creek causing it to become more hydraulically efficient. Feral pig populations and straying livestock within the National Park. Infestations of exotic weeds and vegetation.	Management of onsite ASS at a property scale using techniques recommended in the ASS Management Manual. Land reshaping to create shallow, swale drains. Ongoing land management programs by NPWS.
Economic	Higher cost option associated with removal of weir floodgates or structure, and land acquisitions. No ongoing maintenance costs for removed flow control infrastructure.	Application for Government environmental and floodplain restoration grants.
Social/Cultural	Displacement of landholders with long history of family heritage in the area and loss of income.	Landholder engagement and negotiations to encourage change in land management practice. Continued promotion of the long-term objective of restoring the wider Everlasting Swamp National Park to encourage public interest and awareness.

5. Summary

This report details the previous studies, community feedback, identified concerns and potential engineered management options for improving hydrologic conditions at the Everlasting Swamp National Park.

In summary, the findings of this study indicate that:

- The Everlasting Swamp region has undergone extensive drainage and hydrologic manipulation since 1926, including the installation of agricultural drains, levees and tidal floodgates. Significant floodplain drainage works throughout the latter part of the 20th century were primarily undertaken for flood mitigation, as well as to promote dry land agriculture, and to prevent saline intrusion onto the backswamp areas of the floodplain.

- The management issues of the Everlasting Swamp wetland complex are well established and the legacy issues of flood mitigation, the construction of the Sportsmans Creek Weir and acid sulfate soils remain prevalent today. Without significant improvements to current management practices, the current drainage program would continue to have detrimental consequences, including (but not limited to) exposure of ASS, encroachment of native tree species into swamp areas (thereby reducing suitable habitat for waterbirds), and impacts of poor water quality across the whole area.

- To date, the Sportsmans Creek Weir remains a dominant feature controlling surface and groundwater hydrology across the Everlasting Swamp wetland complex. However, the Sportsmans Creek Weir is now over 90 years old, and is slowly deteriorating and at risk of failure. Community feedback highlighted the Sportsmans Creek Weir as one of the top priority concerns for landholders and the future management of the site. While the community sees value in the weir, recent community feedback suggested that the risks (e.g. failure, litigation) outweigh the benefits (e.g. prevents powerboats, maintains water levels, allows freshwater fish to breed), associated with a 'do-nothing' option.

- Several engineered management options were proposed for investigation and further community and stakeholder discussion, include:

    1. Do-Nothing;
    2. Restoration of natural flow paths for Duck Creek and Warragai Creek;
    3. Maximise in-drain tidal flushing of Blanches Drain;
    4. Restoration of natural creeks to encourage flushing of Teal Lagoon and Coxs Swamp;
    5. Full opening or removal of Sportsmans Creek Weir; and
    6. Fully re-create a natural flow regime across the wider Everlasting Swamp National Park.

- The modelling results have highlighted the highest priority for NPWS is to put in place sufficient provisions to allow Sportsmans Creek Weir to be removed. Additional priorities include re-creating suitable habitat for waterbird conservation and further land acquisitions of low-lying land to expand the existing Everlasting Swamp National Park. The outcomes of the numerical hydrodynamic modelling presented in this study, combined with the ecology assessment of the site under a range of hydrologic conditions, provides suitable guidance on a future management pathway to restoration. Ultimately, the modelling results support a staged-approach towards fully re-creating the natural flow-regimes of the Everlasting Swamp National Park.

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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 are 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 are 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).

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 10ºC.

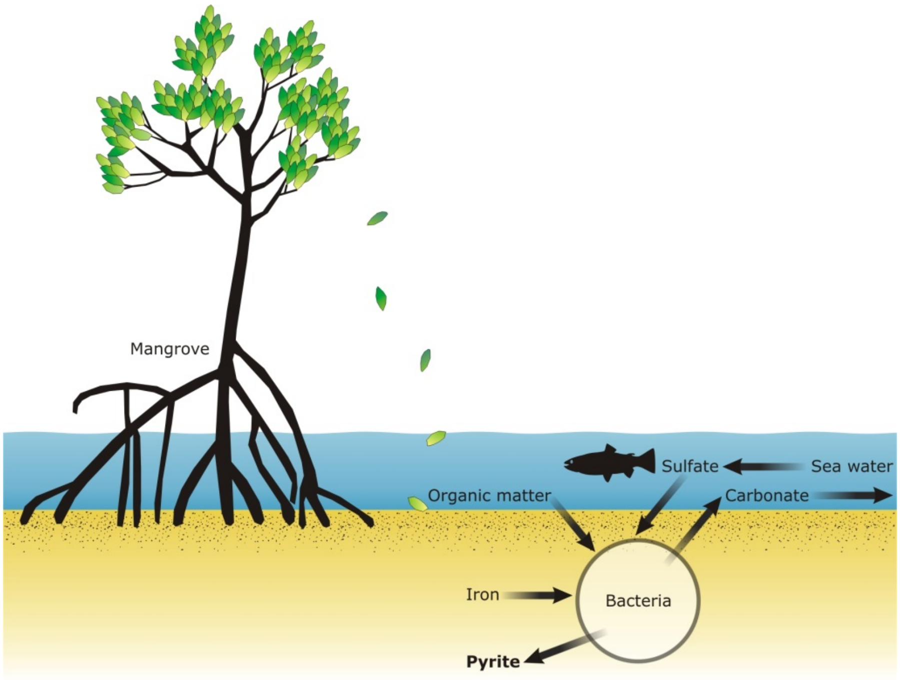


Figure A.1: Pyrite Formation (NRM, 2011)

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).

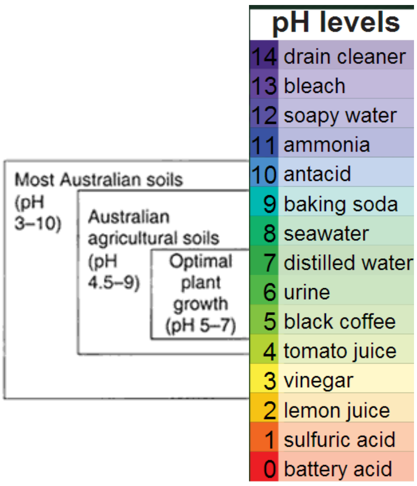


Figure A.2: pH Scale (NRM, 2011)

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.

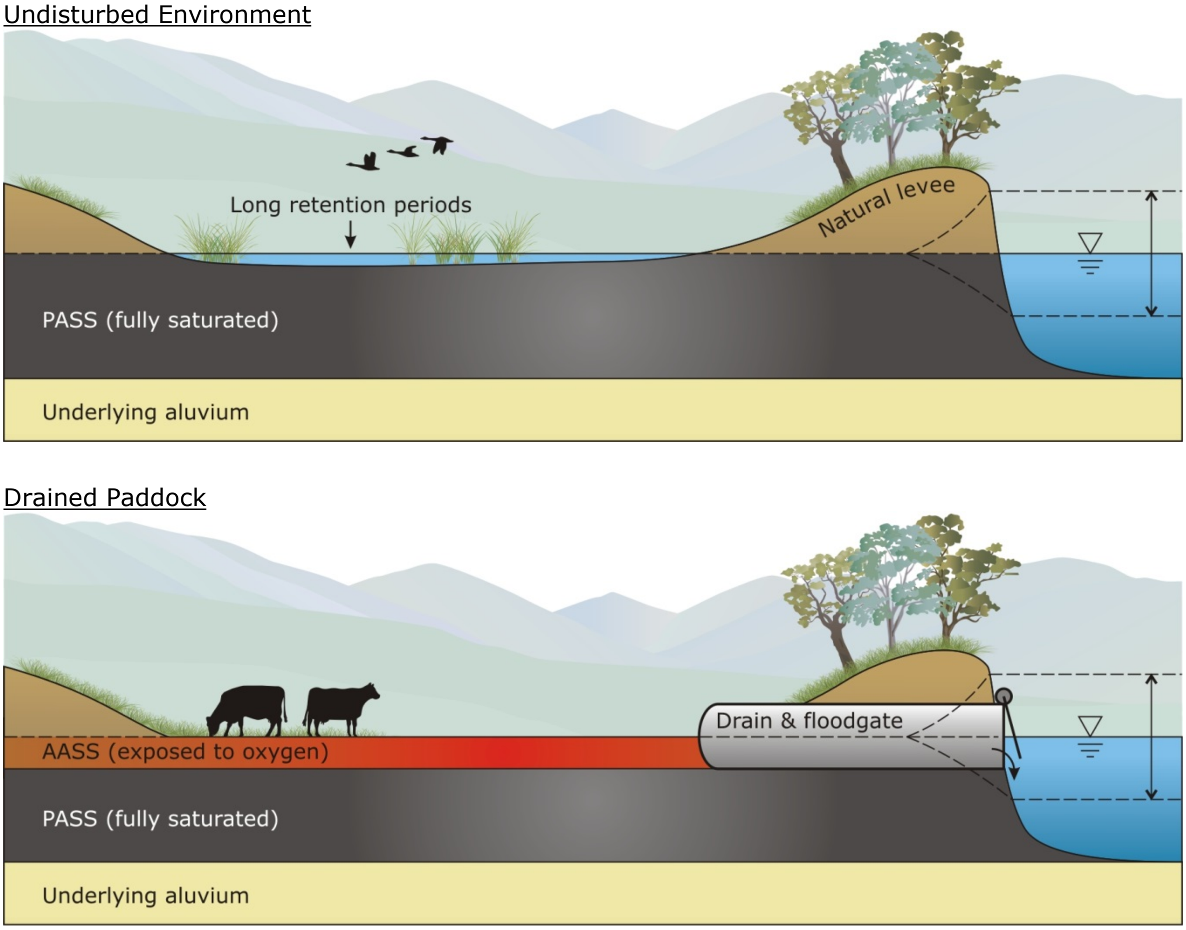


Figure A.3: Soil Acidification by Lowering of Groundwater Levels

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).

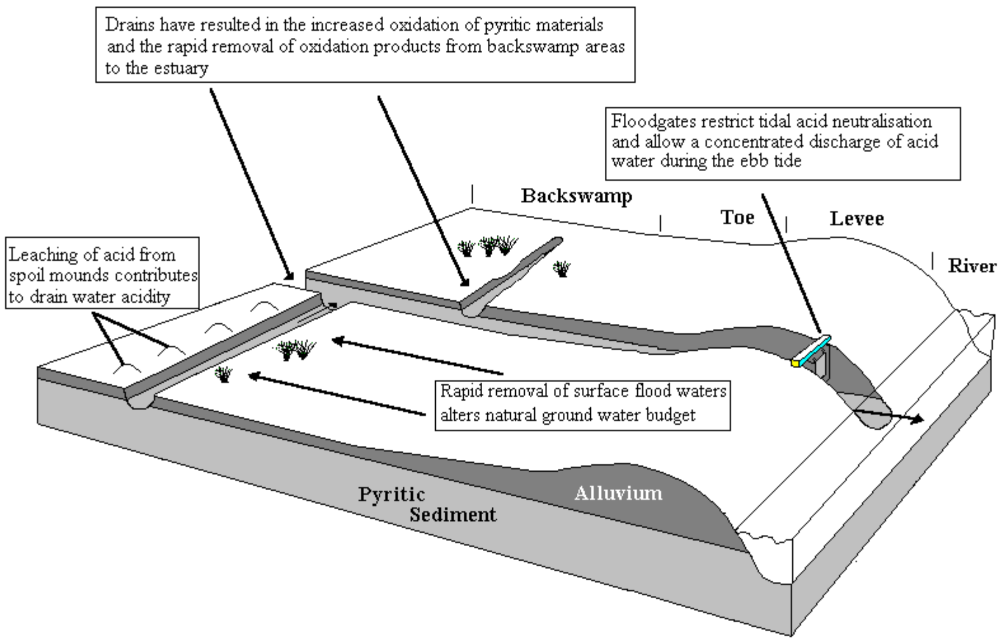


Figure A.4: Schematic of a Backswamp Drainage and Floodgate Network (Naylor et al., 1995)

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 would 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. The Clarence River estuary is an example of this type of estuary (Digby, 1999). 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, salt water 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.

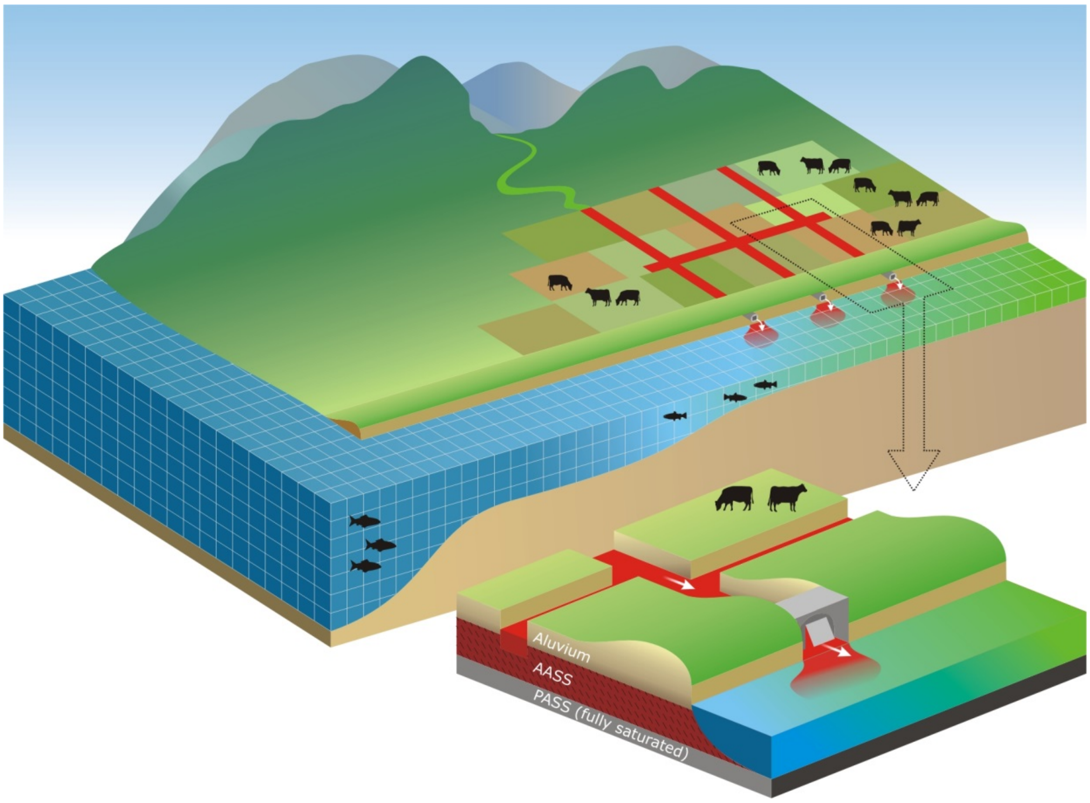


Figure A.5: Period of Tidal Buffering and Low Acid Risk

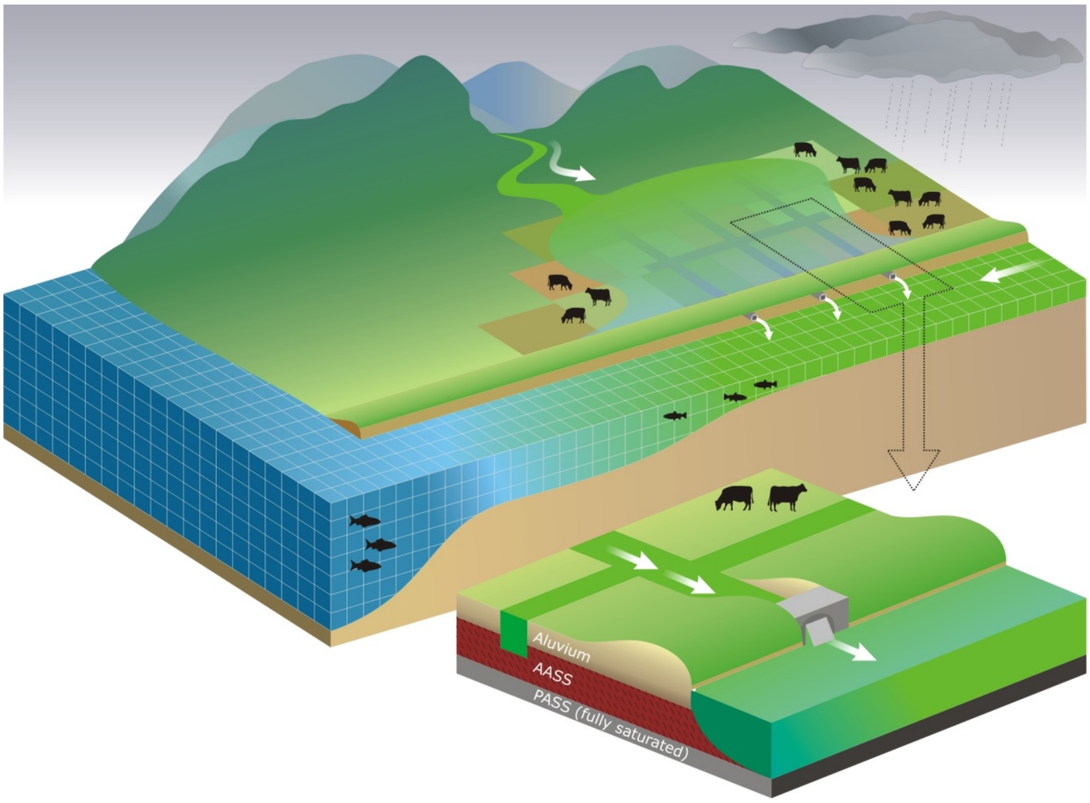


Figure A.6: Flow Dilution Period as a Result of a Large Rainfall Event

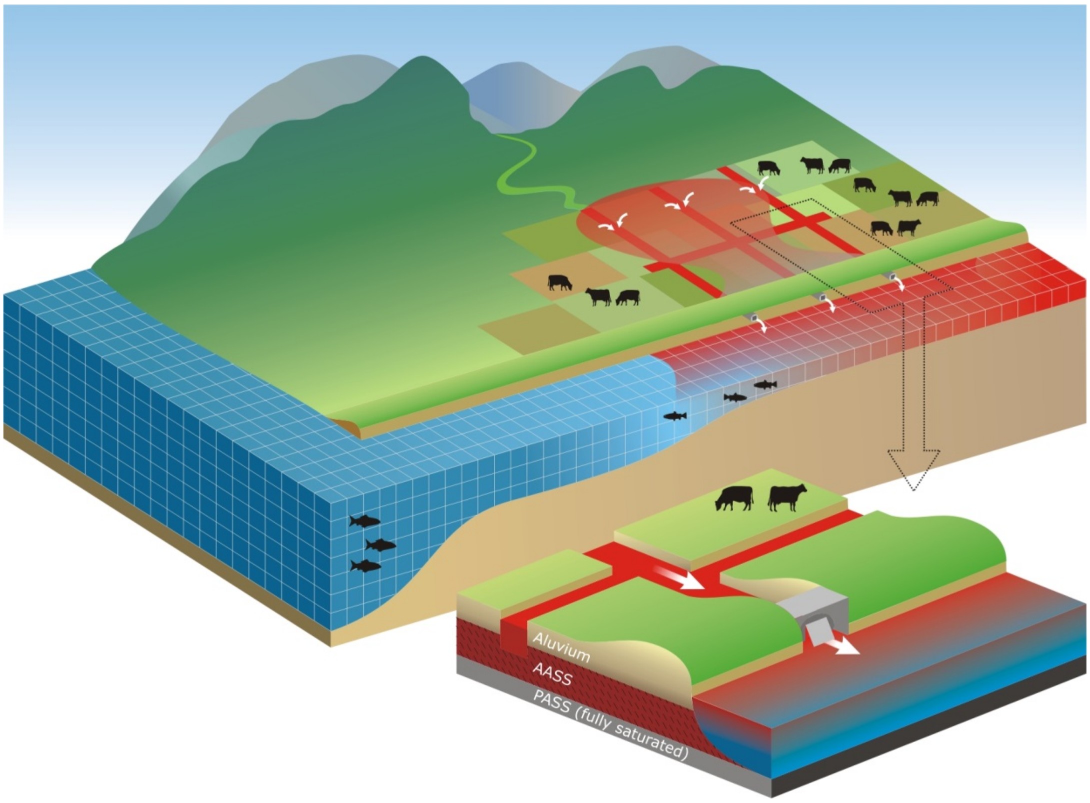


Figure A.7: Period of Acid Impact Following Rainfall Event

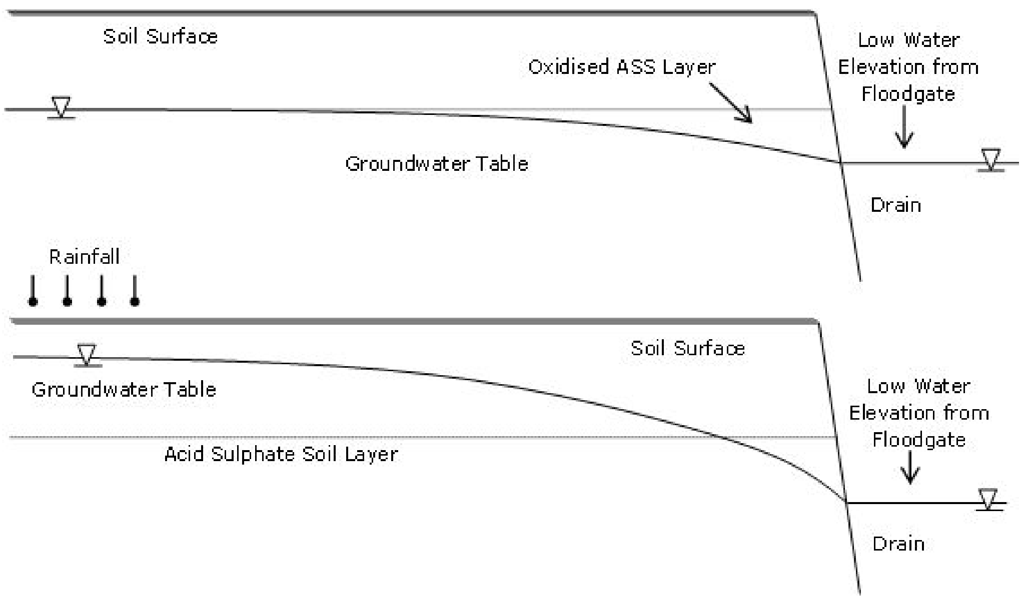


Figure A.8: Influence of One-way Floodgates on Groundwater Elevation under Normal (top) and Flood (bottom) Conditions (Glamore, 2003)

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 section provides details of the available data for the study area prior to undertaking this study. LiDAR survey data (flown in March 2010) of the wider catchment was used to create a preliminary Digital Elevation Model (DEM) of the study area. For the purpose of this study, the catchment area below 2 m AHD was used to determine the floodplain area for investigation.

B.2 LiDAR

WRL received LiDAR survey data from Clarence Valley Council of the Everlasting Swamp wetland complex to AHD at a 1 m horizontal resolution. LiDAR surveys are taken using an airborne laser scanner providing a vertical accuracy of ±0.15 m and a horizontal accuracy of ±0.3 m. LiDAR surveys are an efficient technique to obtain broad-acre topographic data, providing significant special coverage in comparison to conventional, labour-intensive ground surveys. However, the remote sensing approach can be hindered by dense vegetation and water on the ground surface. For example, the ground surface in areas featuring dense stands of grasses or phragmites are misrepresented, with the elevation of the top of the vegetation measured rather than the ground surface. As such, care must be taken when utilising LiDAR survey datasets in swamp and wetland environments. GIS techniques were used to produce a preliminary DEM of the study area below 2 m AHD at a 1 m horizontal resolution as shown in Figure B.1.

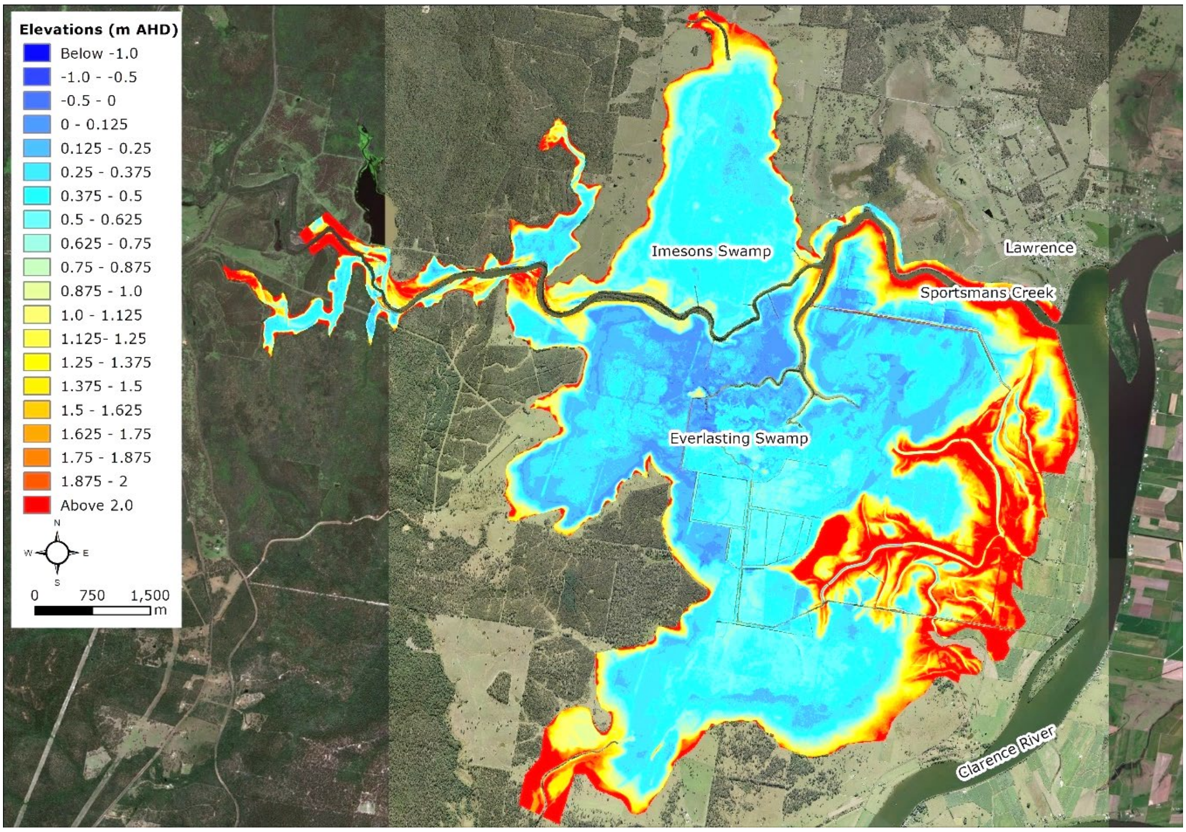


Figure B.1: Preliminary DEM of the Everlasting Swamp wetland complex

B.3 Ground Survey

In 2002/03, Council completed two (2) detailed ground surveys across Everlasting Swamp wetland complex. These ground surveys covered large areas of the floodplain, as well as the tops of levees along Sportsmans, Reedy and Woody Creeks. WRL completed an additional ground survey of the study area in 2016, as part of the Teal Lagoon Hydrologic Investigation (Rayner et al., 2016). WRL measured ground surface elevations using a Trimble 5800/R10 RTK-GPS (Real-Time Kinematic Global Positioning System) mounted on a quad bike, with the elevation data offset to AHD using the NSW CorsNET network, to an accuracy of ± 20 mm vertically and horizontally. The location of ground survey points are shown in Figure B.2

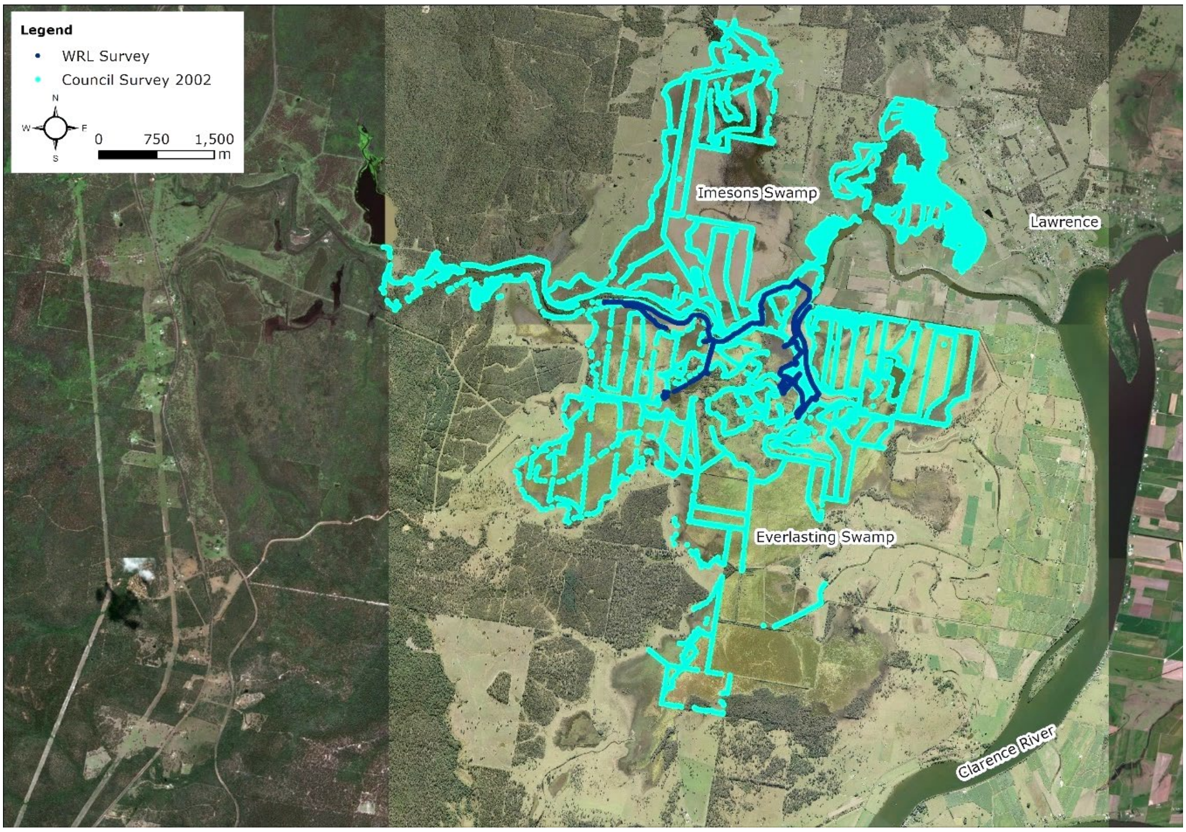


Figure B.2: Previous Ground Survey of the Everlasting Swamp Wetland Complex

During the 2016 field investigation, WRL also surveyed Teal Lagoon using a canoe and a Trimble RTK-GPS. Bed elevations ranged from -0.4 m to -0.6 m AHD measured along a transect in Teal Lagoon, as shown in Figure B.3. The water level of Teal Lagoon during the survey was measured to be approximately 0.0 m AHD.

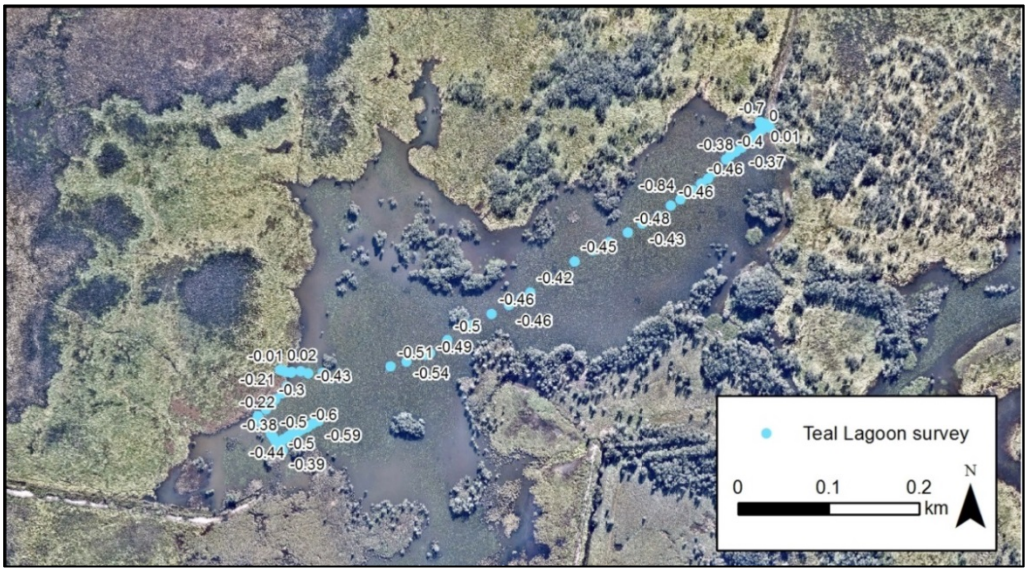


Figure B.3: WRL Survey of Teal Lagoon in 2016 (Elevations in m AHD)

B.4 Structures

The Everlasting Swamp study area has 12 main flood mitigation structures (not counting the Sportsmans Creek Weir) that discharge into Sportsmans Creek and the Clarence River. These structures consist of 10 man-made flood mitigation drains with floodgates and two (2) flood-gated natural watercourses being Reedy and Woody Creeks. The structures located at Everlasting Swamp and Imesons Swamp are managed and maintained by Council. Wilkinson (2003b) reported on these structures, including type, number of gates, pipe size and invert, as provided in Table B.1. WRL re-surveyed a number of these structures in 2016 (Figure B.4), including the structure inverts using a Trimble RTK-GPS, as shown in Table B.2.

Table B.1: Flood Mitigation Structures Located within Study Area (Wilkinson, 2003b)

Drain Name/ID	Floodgates and Pipes		
	Type of Structure	No./ Size (m)	Invert (m AHD)
Sportsmans Ck. 33	Pipe/Flap	1/1.5	-0.77
Woody Creek	Pipe/Flaps	2/1.5	-0.96
Sportsmans Ck. 34	Pipe/Flap	1/1.5	-0.94
Reedy Creek	Pipe/Flaps	2/1.5	-1.05
Sportsmans Ck. 35	Pipe/Flaps	2/1.5	-0.84
Sportsmans Ck. 35/1	Pipe/Flap	1/1.25	-0.92
South Levee 32	Pipe/Flaps	2/1.5	No data
Blanches Drain	Pipe/Flaps	2/2.1	-1.26
Lawrence No. 3	Pipe/Flap	1/1.5	No data
Lawrence No. 2	Pipe/Flap	1/0.9	No data
Lawrence No. 1	Pipe/Flap	1/1.5	No data
Blanches	Box Culvert/Flap	2/2.1	-1.26

Table B.2: WRL 2016 Survey of Flood Mitigation Structures (Rayner et al., 2016)

Drain Name/ID		Floodgates and Pipes		
WRL Ref.	Wilkinson (2003)	Type of Structure	No./ Size (m)	Upstream Invert (m AHD)
1	Sportsmans Ck. 33	Pipe/Flap	1/1.5	-0.77
2	Woody Creek	Pipe/Flaps[1]	2/1.5	-1.09
3	Sportsmans Ck. 34	Pipe/Flap	1/1.5	-0.85
4	Reedy Creek	Pipe/Flaps[1]	2/1.5	-1.11
5	Sportsmans Ck. 35	Pipe/Flaps[2]	2/1.5	-0.84
6	Sportsmans Ck. 35/1	Pipe/Flap	1/1.25	-0.83
7	South Levee 32	Pipe/Flaps	2/1.5	-0.45

[1] Manual opening on one and modified auto-tidal buoyancy gate (500 x 800 mm) with flap on other.
[2] Manual opening gates.

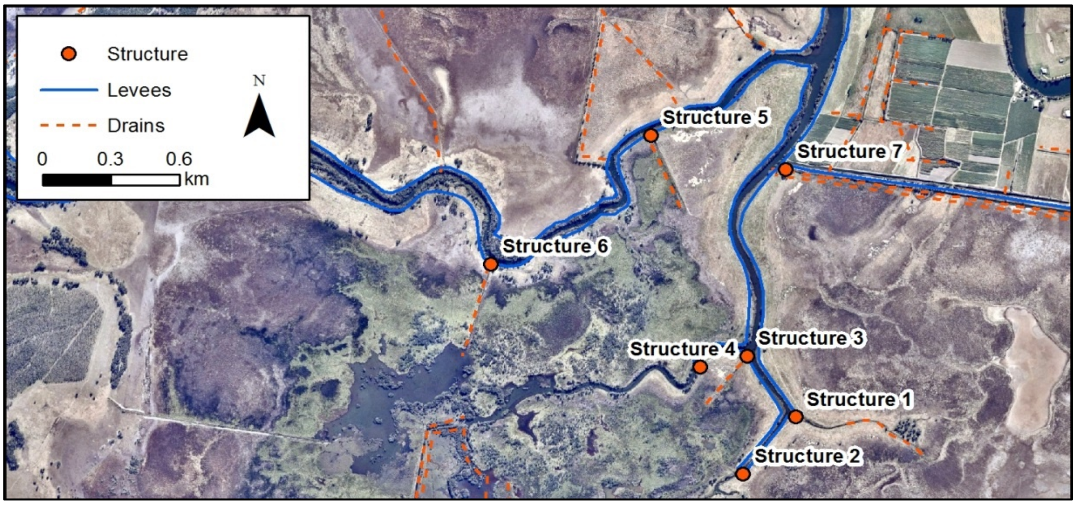


Figure B.4: WRL Structure Survey (Rayner et al., 2016)

B.5 Cross-Sections

Historical bathymetry data of Sportsmans Creek was available in FMA (1972). The 1972 report by Clarence Valley Council (formerly the Clarence River County Council – Flood Mitigation Authority) was a feasibility study of the proposed Sportsmans Creek flood mitigation scheme. As part of the 1972 study, 13 cross-sections were surveyed along Sportsmans Creek at the locations (chainages) provided in Figure B.5. This cross-section data (Figure B.5) was digitised and Arc GIS was used to estimate the geographical locations of each cross-section, based on the chainages provided.

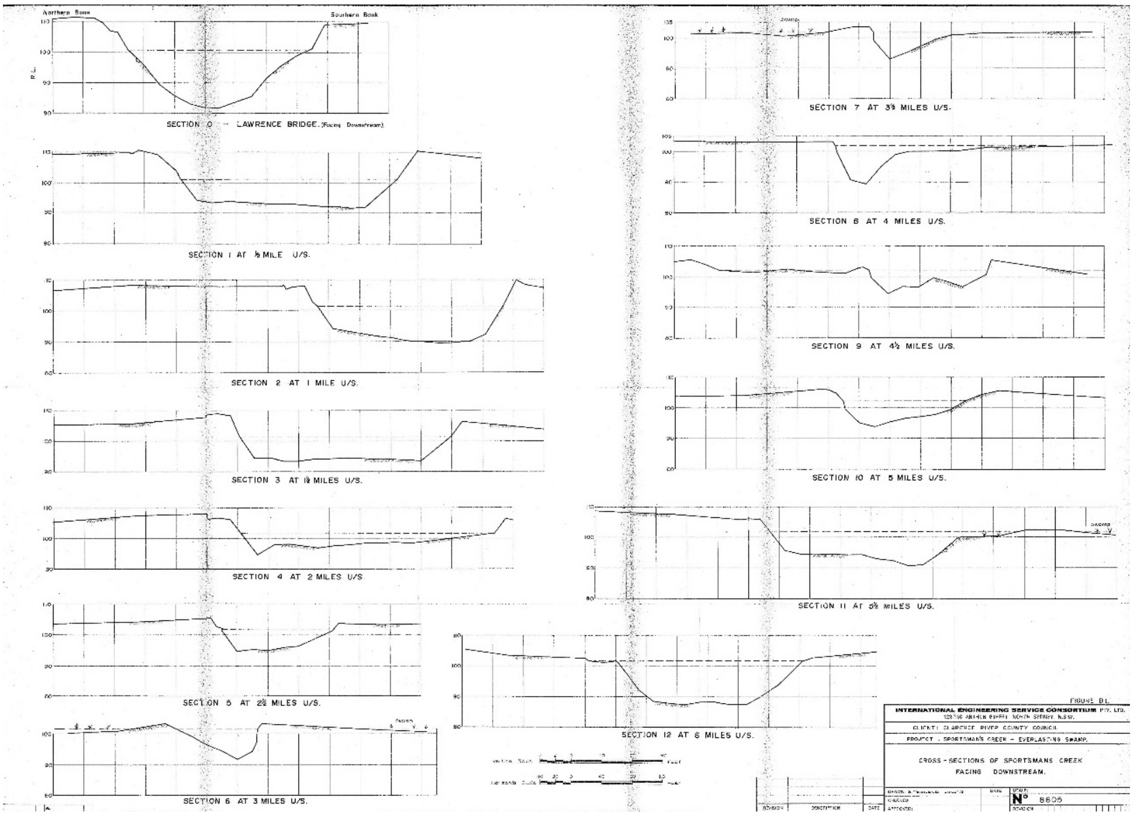


Figure B.5: Historical Cross-Sections of Sportsmans Creek (FMA, 1972)

B.6 Cadastre

The number, size, shape and location of cadastral portions in relation to floodplain backswamps, and the consistency of cadastral boundaries with physical boundaries meaningful to management, are key parameters in both the process of environmental degradation of backswamps, and in providing opportunities and constraints to remediation options. The current subdivisions of the floodplain are shown in Figure B.6. The cadastre was also used to provide information on privately owned properties for access permission during the field investigations completed during this study.

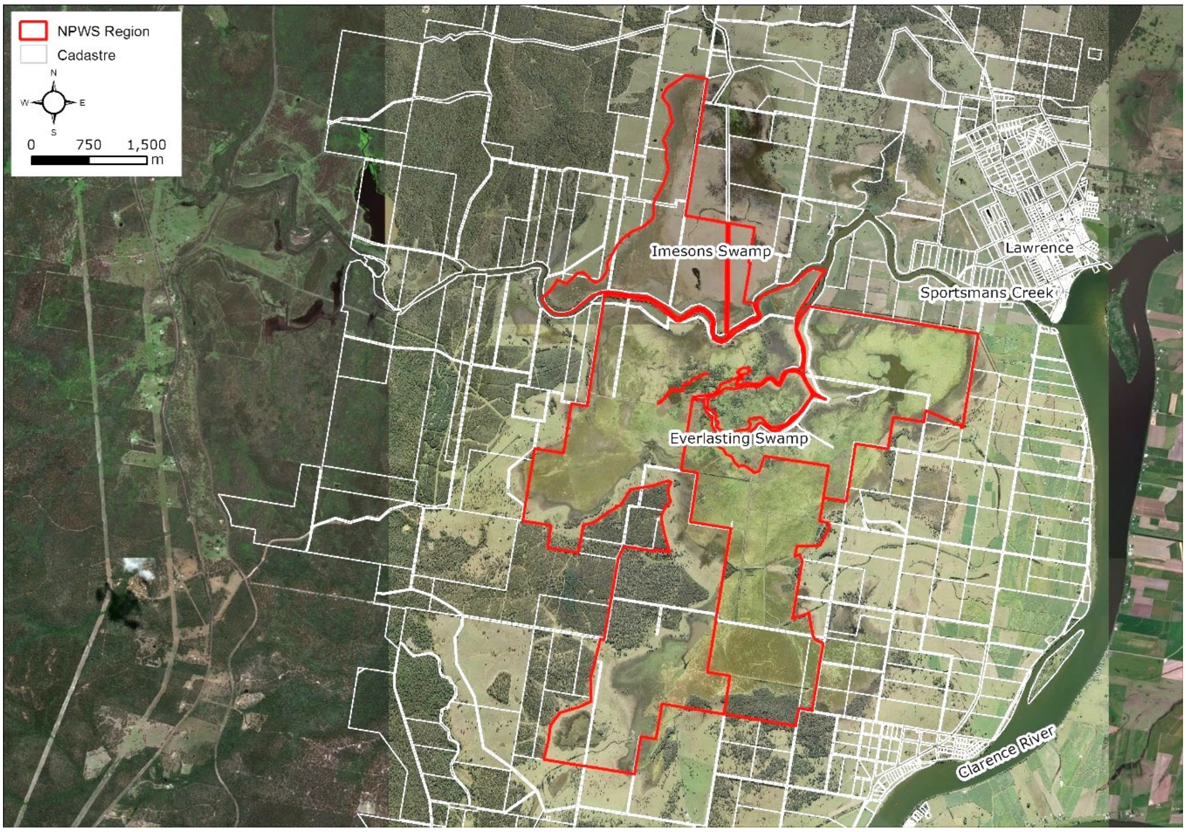


Figure B.6: Current Everlasting Swamp Cadastre (Source: Clarence Valley Council)

B.7 Acid Sulfate Soils

Previous soil profile data collected at Everlasting Swamp and Imesons Swamp was sourced from:

- eSPADE Database (OEH, 2018);
- WRL (Rayner et al., 2016);
- Johnston et al. (2004);
- Morand (2002);
- Morand (2001); and
- Beveridge (1998).

eSPADE 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. eSPADE contains extensive soil profile data for the study area, as provided in Figure B.7. The soil profile data contained within eSPADE was collected through various investigations, including:

- Morand (1998/00/01/02);
- Tulau (1998);
- Eddie (1998);
- Gibbons (1995); and
- Milford (1994).

WRL completed a field investigation in March 2016 to quantify the ASS risk at key locations adjacent to drainage channels feeding Teal Lagoon. Three (3) soil profiles (Figure B.7) were excavated to depths of 2.0 to 3.0 m below the ground surface (approximately -1.9 to -2.9 m AHD). Acidic soils were measured at all sampling locations, with a soil pH ranging from 3.5 to 4.0 at elevations of -0.5 to -1.0 m AHD. Note that these acidic soils were found at similar bed elevation to that of Teal Lagoon. Surface soil pH was measured to be below pH 5.0 at all locations. Furthermore, the soil profiles reflected typical acid backswamp sediments, with a thin layer of organic matter overlaying a horizon of grey-brown clay, with iron and jarosite mottling. The AASS layer was observed to overlay the PASS layer, where the field acidity measurements were near neutral. Note the PASS layer sediments reacted strongly to field oxidation tests, indicating the presence of un-oxidised ASS.

Johnston et al. (2004) completed several investigations around Blanches Drain to quantify the acid flux dynamics from the ASS backswamp. Soil profiles (n = 10) were hand augured to a depth of approximately 0.16 m and sampled every 0.01 to 0.02 m for analysis. Johnston et al. (2004) reported that beneath an organic rich surface layer was a sulfuric horizon with iron (III) mineral and jarosite mottles extending to a depth of approximately 0.6 to 1.0 m. Located immediately below this soil layer was reduced sulfidic material. The export flux rate of acidity at Blanches Drain was reported as equivalent to 25 tonne H_2SO_4/ha (as reported in Wilkinson (2003a)). While this number was relatively small compared to other acidic sites in NSW, there was considerable AASS stored in the soil and groundwater due to oxidation of underlying sulfidic material, and this remains a prevalent issue at this site today.

The Everlasting Swamp Hotspot area occurs across the Maclean and Tyndale Acid Sulfate Soil Risk maps and was mapped as high-risk (Milford, 1995, Morand, 1995). As part of ASS risk mapping program, Morand (2001) completed several soil profile surveys at Everlasting Swamp, and described the typical soil profile below the ground surface, as follows: brownish-black, fibrous peat from 0 to 0.05 m, with a field pH of 3.5; overlaying mottled, sticky dark brown clay from 0.05 to 0.2 m, with a field pH of 6.0; overlaying unripe, grey clay containing jarosite mottles from 0.2 to 0.6 m, with a field pH of 4.5; and overlaying unripe, dark clay containing iron mottles from 0.6 to 0.8 m, with a field pH of 6.0.

Morand (2002) completed additional soil profiles, as part of the ASS Hotspot program during 2001/02, to determine the depth of sulfuric/sulfidic material, and to characterise soil types across the Everlasting Swamp floodplain. Morand (2002) reported that soils throughout the hotspot area showed little variation and were classified as predominantly sulfuric/sulfidic oxyaquic or redoxic hydrosols (or Humic Gleys). All soils examined were shown to display the physical characteristics of PASS/AASS, and the depth to potential or actual acid sulfate material was generally 0.2 – 0.5 m below the ground surface. Further information on the soils report can be found in Morand (2002) and Wilkinson (2003b).

As part of a review into the drainage of ASS at Everlasting Swamp, Beveridge (1998) completed five (5) soil profiles, also shown in Figure B.7. The results of the soil investigation showed uniformity in their characteristics and confirmed the presence of ASS, as confirmed in later studies. Soil pH was reported to range from 4.2 to 5.0 along the levee banks, and 3.8 to 4.5 across the low-lying floodplain areas.

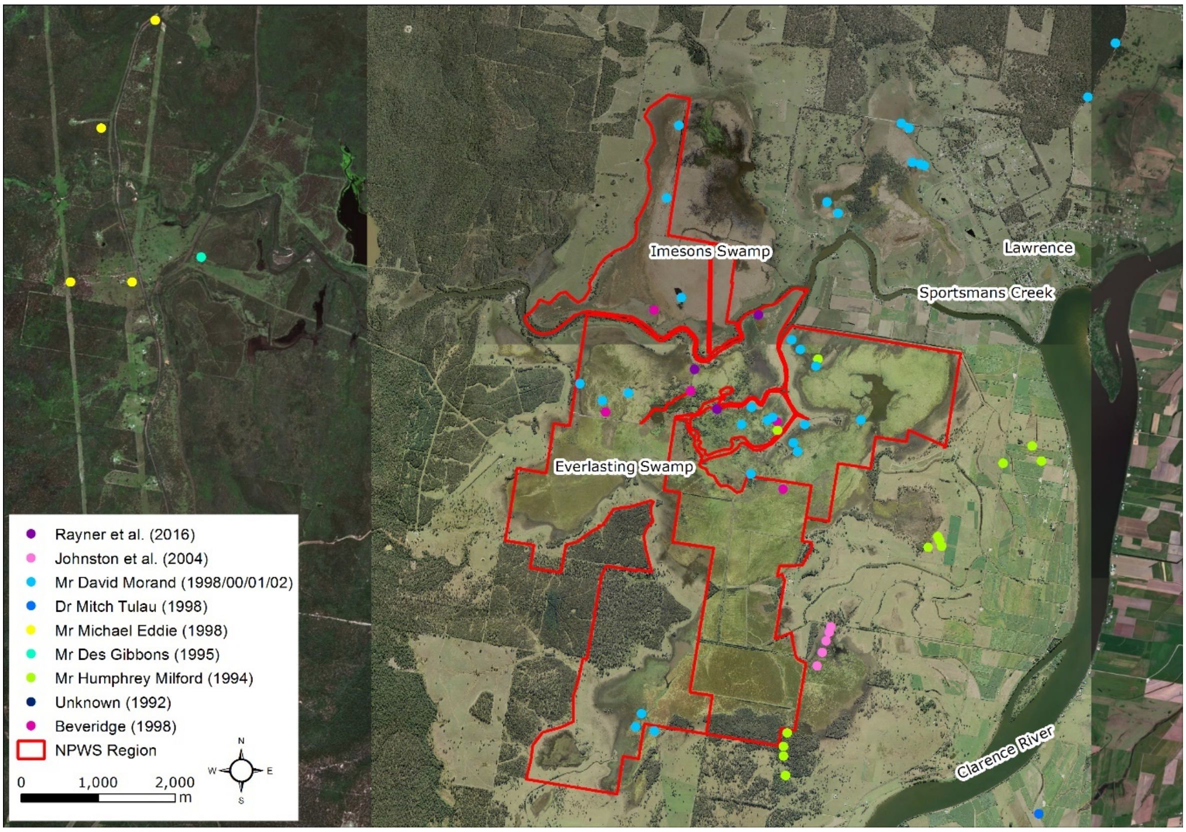


Figure B.7: Soil Profile Data at the Everlasting Swamp wetland complex

B.8 Water Levels and Quality

Water quality datasets in the Clarence River and across the Everlasting Swamp wetland complex have been extensively monitored. A good historical overview of water quality in the Clarence River and its tributaries was provided in Tulau (1999). More specifically and over the past two (2) decades, water quality monitoring of the Everlasting Swamp wetland complex has typically focused on spot checks of dry weather pH and salinity of surface and ground waters, or a range of other water quality indicators, as part of the ASS hotspot program. Most recently, monitoring of the Teal Lagoon area and adjacent surface water was undertaken as part of the Teal Lagoon Hydrologic Study (Rayner et al., 2016). Ultimately, these studies confirm the undesirable outcomes of the site's legacy issues resulting in widespread poor water quality in the area and support the need for a management plan to restore the natural flushing of the site.

Key water quality studies of the study area, include:

- Beveridge (1998);
- Smith (1999);
- MHL (2001);
- Wilkinson (2003b);
- Johnston et al. (2004);
- Wilkinson (2004);
- White (2009);
- Gordos (2012); and
- WRL (Rayner et al., 2016).

A brief description and the main findings from these studies, in terms of water quality, is provided below.

Beveridge (1998) investigated the potential impacts of disturbed ASS across the Everlasting Swamp floodplain. Water quality sampling sites were located within natural waterbodies (n=18) and artificial drainage systems (n=14). Water quality measurement were taken weekly from 2 April to 30 August 1998. This data showed a consistently high pH that ranged from 6 to 7 throughout the waterways at Everlasting Swamp, with the exception of low pH readings from drains in the vicinity of Round Mountain. The minimum pH recorded was 2.68. Laboratory analysis of water quality samples was completed for six (6) sites on 30 August 1998, which was considered to be a dry period. A summary of the laboratory analysis of water quality data is provided in Table B.3. Note that no concurrent measurements of water levels were taken during the study.

Table B.3: Summary of Laboratory Analysis of Water Quality Beveridge (1998)

Site	pH	Salinity (mS/cm)	Cl^-:$SO4^{2-}$	Total Al (mg/L)	Total Fe (mg/L)
SW1	2.92	18.6	5.4	3.12	3.3
SW2	7.69	17.0	23.1	0.38	0.6
SW3	7.28	13.2	26.0	0.38	0.7
SW4	7.17	11.4	35.3	0.38	0.4
SW5	3.07	6.8	5.7	1.47	8.0
SW6	7.32	1.2	17.9	0.38	0.2

Smith (1999) conducted water quality sampling as part of an initial options assessment to modify structures and management practices to better manage surface and groundwater quality across the Everlasting Swamp wetland complex. The reported water quality data showed that pH ranged from 2.5 to 6.0, with the lowest measurements observed at acid surface scald areas in Coxs Swamp, Teal Lagoon, Sportsmans Creek and Round Mountain. Smith (1999) was the first to report that the Sportsmans Creek Weir was no longer working as an effective tidal barrier, and the freshwater pool upstream of the weir was seasonally brackish.

MHL (2001) provided time-series water quality and water level data from April 2000 to June 2001 at a gauge installed in Sportsmans Creek, located immediately downstream of Sportsmans Creek Weir. The monitoring program included measurements of water levels, electrical conductivity, pH, water temperature, and dissolved oxygen. Water quality profiles were also completed during the study period. A statistical summary of water quality data is provided in Table B.4. The data showed fairly consistent values for all water quality parameters over monitoring period, except for a large freshwater flow event in February 2001, which flushed salinity in Sportsmans Creek and reduced the surface water pH to 5.7.

Table B.4: Sportsmans Creek Summary of Data MHL (2001)

Site	Parameter	Unit	Min	Median	Max
SW7	Level	m[1]	0.81	1.52	6.05[2]
	EC	mS/cm	0.04	1.10	9.99
	pH	-	5.72	7.09	8.54
	Temperature	C	22.13	22.56	32.64
	DO	mg/L	0.10	4.93	14.62
	DO	% Sat	1.00	57.00	139.00

In 2001/02, as part of the Everlasting Swamp ASS hotspot program, Wilkinson (2003b) reported on monitored surface and ground water levels and quality at several locations across the study area, including upstream/downstream in Sportsmans Creek, Sportsmans Creek Weir, an ASS ponding trial site near Sportsmans 35, Coxs Swamp, and the Reedy/Woody Creeks area. Continuous monitoring of the in-situ properties of the drain water at these sites was conducted using a Greenspan integrated discharge and water quality monitoring system, installed and maintained by Greenspan and Clarence Valley Council. Note that water level measurements at sites upstream of the Sportsmans Creek Weir were not referenced to AHD during the study and could not be used to compare with more recent water level data. A summary of the average concentrations of key ASS indicators measured in the groundwater samples during the hotspot program is provided Table B.5.

Table B.5: Average Concentrations of Groundwater Samples (Wilkinson, 2003b)

Site	Location	pH	Salinity (ppm)	$Cl^{-}:SO4^{2-}$	Dissolved Fe (mg/L)
GW1	Ponding Trial Site (Sportsmans 35)	5.48	10,241	2.6	398.9
GW2	Coxs Swamp	3.33	10,758	1.23	High
GW3	Reedy/Woody Creek	5.62	13,178	2.71	289
GW4	Round Mountain/Blanches Drain[1]	4.07	7,500	0.5	n.a.

[1]Data collected by Prof. Scott Johnson

Johnston et al. (2004) assessed groundwater acidity and hydraulic conductivity of soils located near Blanches Drain. Blanches Drain drains an ASS backswamp area of approximately 600 ha, plus a proportion of the upland Warragai catchment. For a single acid discharge event in 2001, a mean pH of 4.1 was reported in Blanches Drain. This study showed that dilute surface run-off was determined to be the main pathway via which acidity was transported to the drain. The study found that acid export was likely to be concentrated within a relatively narrow water level elevation range, and was likely to be most significant when the groundwater was near the surface and the soil profile saturated (i.e. following a rainfall event). Any changes which decreased low-tide level in the drain (i.e. drain vegetation cleaning or estuarine dredging/entrance modifications), were expected to enhance acid flux by increasing the effective range over which groundwater seepage could occur.

Later, Wilkinson (2004) reported on additional water quality data collected during the Everlasting Swamp ASS hotspot project, that was not previously included in Wilkinson (2003b). The monitoring station at Reedy Creek indicated that acidic discharges were event based and occurred after periods of heavy rainfall. There were two (2) significant rainfall events during the monitoring period, with the first in February 2003, where 220 mm of rainfall fell in a 24-hour period, and the second in early-February 2004, where 230 mm of rainfall fell in a 24-hour period. A Greenspan water quality monitoring station recorded acidic discharges from Reedy Creek for several months after the rainfall event in February 2003 (Wilkinson, 2004). The discharging water was reported to have had an approximate pH of 3.9 during both events.

White (2009) investigated the hydrology and changes in water quality characteristics during the re-establishment of tidal exchange at Little Broadwater, an isolated hydrologic unit in the northern portion of the Everlasting Swamp wetland complex. While the Little Broadwater itself is outside the scope of this study, White (2009) also measured water levels and quality, upstream of the Reedy Creek floodgates, and downstream of the Sportsmans Creek Weir in Sportsmans Creek. Drain water quality at Reedy Creek was monitored continuously from March 2002 to mid-July 2005, while bi-monthly monitoring at Site 20 commenced in April 2005 and continued to February

2007. The data loggers were programmed to record electrical conductivity (EC), pH, dissolved oxygen (DO), water temperature, water levels (corrected to m AHD), and velocities at one-hour intervals.

White (2009) reported that EC and DO measurements exhibited a strong seasonal pattern at Reedy Creek. These parameters generally increased during winter and spring, and rapidly decreased in late-summer and early-autumn, in response to increased rainfall. For the entire monitoring period, mean daily measurements of EC ranged from approximately 0 to 32 mS/cm, while mean daily measurements of DO was generally below 8 mg/L. Furthermore, a strong acidic discharge (average pH of 4.0) was recorded in late-February 2003 at Reedy Creek in response to a large rainfall event. Note that it was reported that the pH of the discharge water at Reedy Creek did not return to near-neutral until mid-August 2003. After this time there were four (4) more acid discharge events recorded at Reedy Creek. It was reported that Reedy Creek had a pH of less than 6.0 (and a minimum of 4.5) for at least four (4) months during the monitoring period.

Gordos (2012) provided a summary of EC data recorded at Reedy Creek, using the Greenspan data loggers that were operated and maintained by Manly Hydraulics Laboratory (MHL), as part of the ASS hotspot program. Electrical conductivity data was recorded over a three (3) year period from 2002 to 2005, as provided in Figure B.8. The dataset showed few EC values below 5,000 µS/cm, with the majority greater than 10,000 µS/cm. As an indication, seawater has an EC of approximately 54,000 µS/cm. Therefore, the data indicated that surface waters at Reedy Creek were approximately 50% seawater during dry periods, while the existing auto-tidal floodgates were operational. The data also showed that significant rainfall events flushed the system of residual salinity, resulting in a freshwater pool upstream of the Sportsmans Creek Weir for a short period before becoming brackish again. This data supported the previous findings of Smith (1999), and indicated that the weir was no longer operating as an effective barrier to tidal (saline) intrusion.

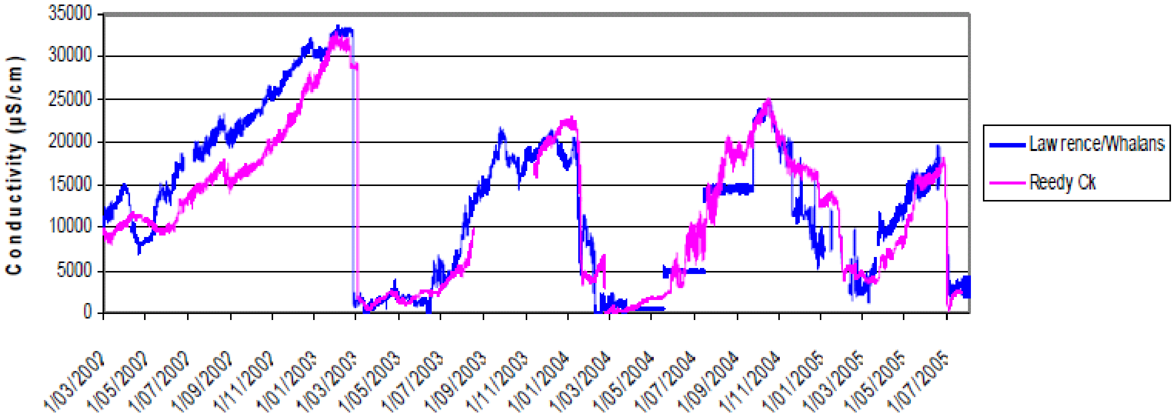


Figure B.8: Electrical conductivity measured above (Sportsmans/Reedy Creek) and below (Little Broadwater) Sportsmans Creek Weir between 2002 and 2005 (Manly Hydraulics Laboratory; Acid Sulphate Soil Hotspot Monitoring Project) (Source: Gordos (2012))

The most recent surface water quality monitoring data of Teal Lagoon and the surrounding surface waters was reported in Rayner et al. (2016). A summary of the surface water quality data collected during the field investigation is provided in Table B.6. Surface water quality parameters measured in Woody Creek and Sportsmans Creek were observed to be above ANZECC (2000) water quality guideline trigger values for aquatic ecosystems, whereas Reedy Creek and Sportsmans 35/1 drain had low DO concentrations that were below ANZECC trigger values. Note that DO concentrations below 2 mg/L are hypoxic for aquatic fauna. Furthermore, groundwater pH from the soil profiles completed during the field investigation showed peak soil acidity ranging from 3.5 to 4.0, at elevations of -0.5 m to -1.0 m AHD. These acid concentrations were reported as occurring as a result of extended dry conditions observed onsite, limiting any potential gradient/flow between acidic groundwater sources and surface water channels.

Table B.6: Surface Water Quality at Everlasting Swamp (9 – 11 March 2016) Rayner et al. (2016)

Location	Temperature (°C)	EC (µS/cm)	pH	DO (mg/L)
Sportsmans Creek	29.2	9,114	8.0	6.8
Reedy Creek	27.1	8,660	7.5	1.8
Woody Creek	29.0	8,392	7.9	6.3
Sportsmans 35	25.5	8,302	7.3	2.2
Sportsmans 35/1	23.8	8,976	7.6	2.7

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 and Slavich (2003), can produce varying results depending on the presence of macropores in the pit. The presence of macropores 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.

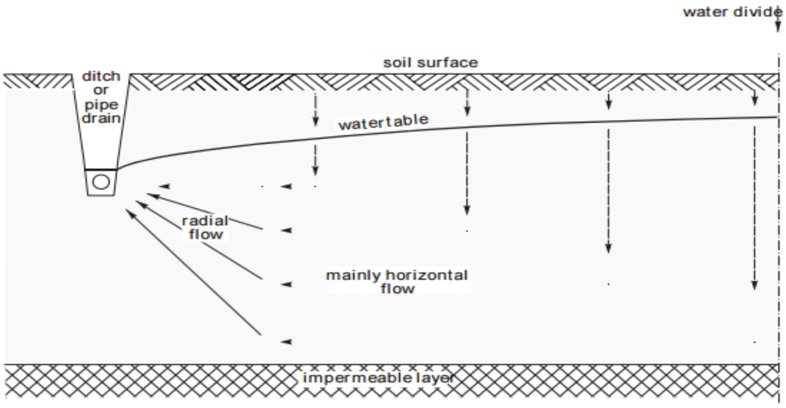


Figure B.9: Groundwater Flow to Subsurface Drains in Unconfined Aquifers of Intermediate Depth

Reviewed sources of insitu saturated hydraulic conductivity data across the Everlasting Swamp wetland complex, included:

- Johnston et al. (2004)
- Johnston et al. (2009); and
- Rayner et al. (2016).

All three (3) studies measured hydraulic conductivity using the methodology outlined by Bouwer and Rice (1983). This method provides a rapid, semi-quantitative assessment of saturated hydraulic conductivity (K_{sat}) and can be used to assess the relative groundwater flux, including acid transport risks, across the study area. The field tests involved the excavation of a shallow pit, extraction of standing groundwater, and measurements of the rate of infilling of the pit which is indicative of the hydraulic conductivity of the soil.

While there was limited available data on hydraulic conductivity across the Everlasting Swamp wetland complex, the variability in the available data was low. Johnston et al. (2004) investigated the hydraulic conductivity in the south-eastern section of Everlasting Swamp, near Blanches Drain, and reported a mean K_{sat} of the sulfuric horizons of 17.9 m/day (σ = 12.9) using three (3) test pits. Johnston et al. (2009) later reported a mean K_{sat} of 19.42 m/day (σ = 16.76). Furthermore, Rayner et al. (2016) reported a moderate to high hydraulic conductivity of approximately 10-20 m/day measured at two (2) locations near Teal Lagoon. The hydraulic conductivity rates measured are consistent with other nearby locations (i.e. Arndilly and Farlows) as measured by Hirst et al. (2009). These results indicate that transport of acidic groundwater in this area of the floodplain is relatively efficient, and supports previous studies (Johnston et al., 2005) linking surface water quality to extensive ASS found across the floodplain.

Appendix C – Field Investigation

C.1 Preamble

Following a review of the available data provided in Appendix B, data gaps were identified and targeted during field investigations of the study site. WRL staff completed several detailed field investigations at the study site, including 8 to 11 November 2016, 8 to 9 February 2017, and 15 to 16 August 2017. The field investigations included detailed surveys of floodplain topography, drainage infrastructure and bathymetry, water levels and water quality monitoring, and an additional soil profile near Blanches Drain. The field investigations were undertaken to provide further information on how the site functions, including hydrodynamic processes, and were used to develop and calibrate a numerical hydrodynamic model of the site. Further information on the model development and calibration is provided in Appendices D and E.

C.2 Additional Ground Survey

During the LiDAR survey of March 2010, vegetation was noted to be dense, with some surface water present at low-lying areas of the floodplain (pers. comms. P Wilson, Clarence Valley Council, 7 July 2016). As such, the accuracy of the LiDAR data needed to be checked against detailed ground survey data, since the Everlasting Swamp wetland complex contains vast areas of dense vegetation and substantial areas of permanent open water. For this study, a large amount of additional ground survey data was collected during the field investigation. WRL used a combination of handheld and quad bike mounted Trimble RTK-GPS survey equipment to gather survey points to an accuracy of ±0.2 m (±0.1 m for the handheld technique) in the vertical and horizontal. Figure C.1 outlines the coverage of WRL's latest on-ground survey in relation to previous surveys completed at Everlasting Swamp wetland complex.

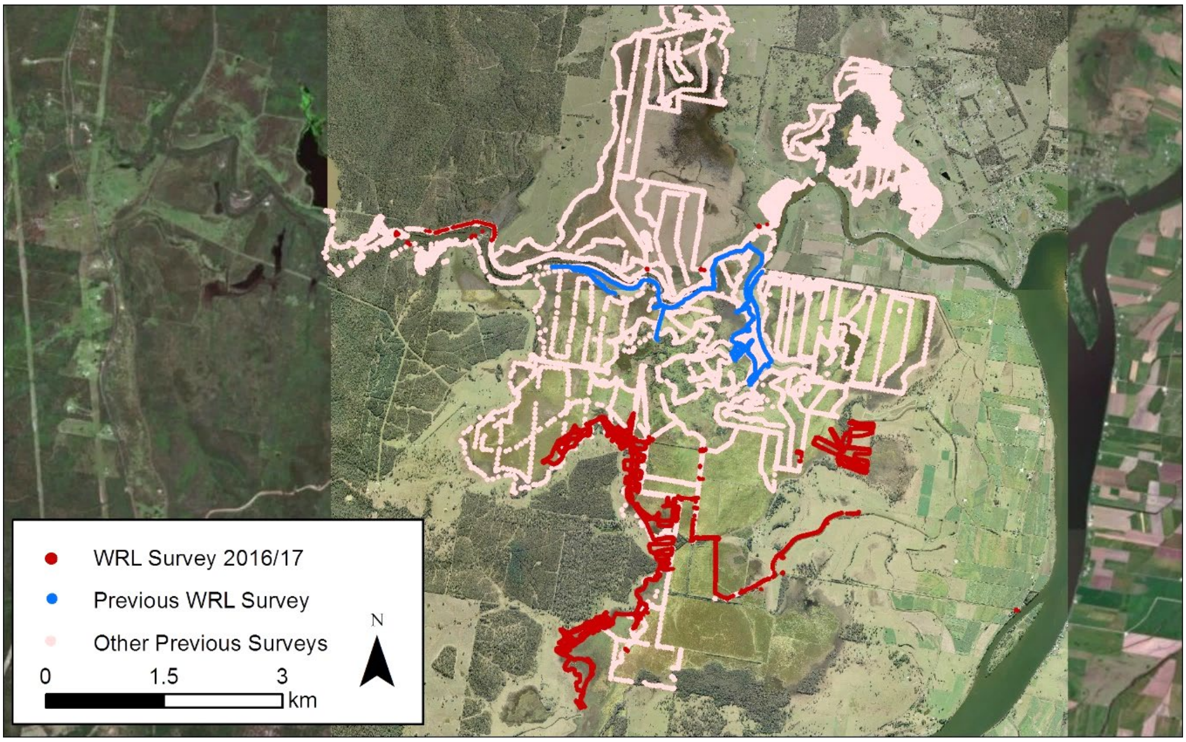


Figure C.1: Additional Ground Survey Locations at Everlasting Swamp wetland complex

C.3 Structures

For this study, 11 main structures, including the Sportsmans Creek Weir, were surveyed and catalogued. Figure C.2 provides the locations of the culverts, auto-tidal gates and weir structures that were surveyed during 2016/17 field investigations. A summary of the structural properties of the existing weirs and culverts across the study area, including type, number of gates, pipe size and invert, are provided in Table C.1.

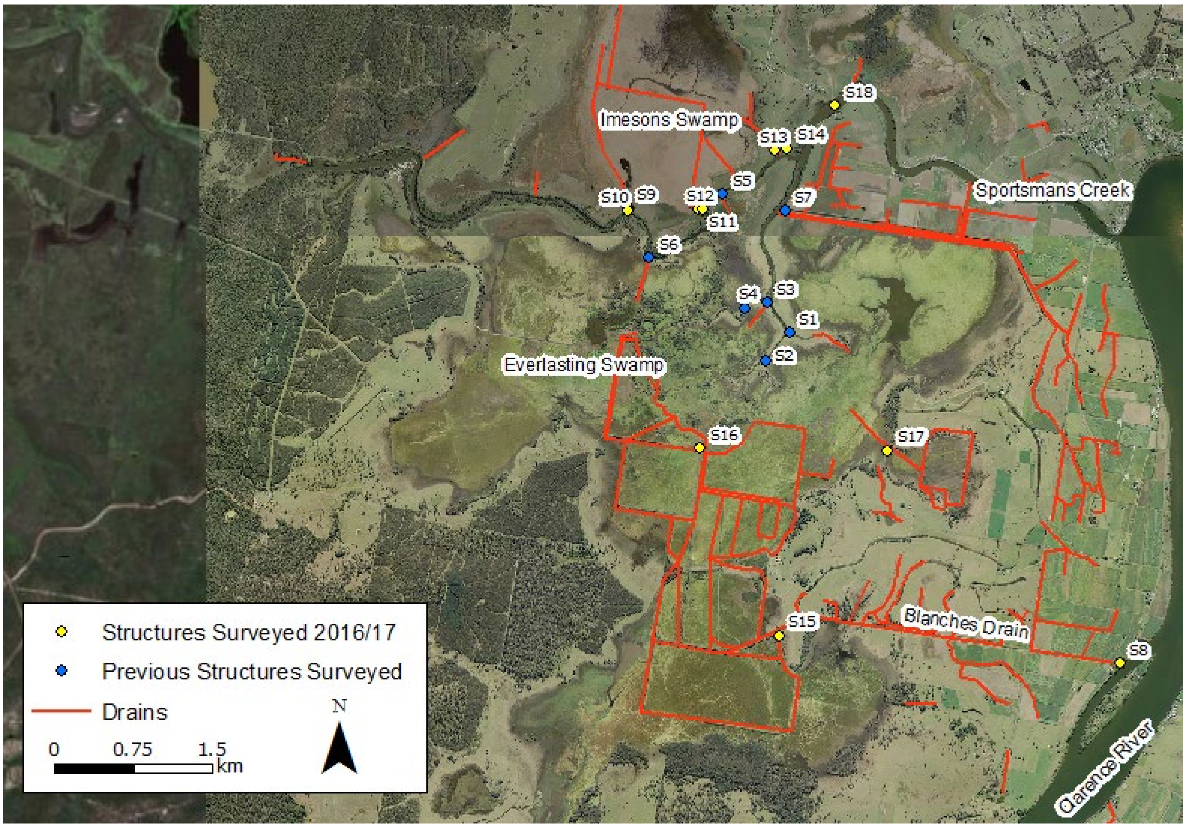


Figure C.2: Flow Control Structures Surveyed at Everlasting Swamp in 2016/17

Table C.1: Summary of Flow Control Structures Surveyed by WRL in 2016/17 (MGA 56)

ID	Description	Easting (m)	Northing (m)	Opening Device	Internal Diameter (m)	Invert Elevation (m AHD)
S1	Single pipe culvert with one-way floodgate on D/S side, well-sealed.	506557.544	6735261.938	N	1.5	-0.77 (U/S) -0.54 (D/S)
S2	Double culvert, manual lifting device on one flap and modified auto-tidal buoyancy floodgate (500x800 mm) on the other flap.	506328.101	6734996.931	Y	1.5	-1.09 (U/S)
S3	Single culvert with floodgate.	506345.494	6735546.375	N	1.5	-0.85 (U/S)
S4	Double culvert, manual lifting device on one flap and modified auto-tidal buoyancy floodgate (500x800 mm) on the other flap.	506138.412	6735494.962	Y	1.5	-1.11 (U/S)
S5	Double culverts with one-way floodgates, incl. manual lifting device.	505924.101	6736575.500	Y	1.5	-0.95 (U/S)
S6	Single culvert with one-way floodgate on D/S.	505222.413	6735974.903	N	1.25	-0.83 (U/S)
S7	Double pipes with one-way floodgates.	506515.607	6736416.980	N	1.5	-0.45 (U/S)
S8	Double rectangular culvert, one auto-tidal gate, the other a penstock gate, one-way floodgate on D/S side of penstock gate.	509693.830	6732122.075	Y	2.3 wide	-1.03(U/S) -1.21(D/S)
S9	Double pipe culvert with weir on top, one side with an open drop-board. Weir crest invert 0.078 m AHD, ~4 m wide.	505015.294	6736443.788	N	0.6	-0.48(U/S) -0.32(D/S)
S10	Single pipe culvert with one-way floodgate on D/S, well-sealed.	505016.824	6736418.043	N	1.5	1.16(D/S)
S11	Double pipe culvert with weir on top, both sides had open drop-boards. Weir crest invert 0.069 m AHD, ~4 m wide.	505691.676	6736436.709	N	0.8	-0.52(U/S) -0.56(D/S)
S12	Single pipe culvert with one-way floodgate on D/S, well-sealed.	505730.444	6736430.966	N	0.95	-0.75(U/S) -1.28(D/S)
S13	Single pipe culvert with one-way floodgate.	506425.461	6736983.347	N	1.5	-1.27(U/S) -1.23(D/S)
S14	Single pipe culvert, no floodgate.	506535.890	6737006.123	N	0.4	0.54(U/S) 0.53(D/S)
S15	Rectangular drop-board culvert with weir on top. Weir crest invert 0.396 m AHD, ~6 m wide.	506457.945	6732386.849	N	-	-0.53(US)
S16	Triple culvert, closed one-way floodgate on right most culvert.	505705.754	6734158.970	N	1.5	-1.59(U/S) -1.66(D/S)
S17	Single pipe culvert, no floodgate.	507492.486	6734141.508	N	1	-0.55(U/S) -0.58(D/S)
S18	Sportsmans Creek Weir with 40 concrete floodgates. Weir crest invert 0.586 m AHD, ~73 m wide.	506989.534	6737418.156	Y	-	-0.62

C.4 Cross-sections

For this study, a total of 52 cross-sectional surveys were completed across Everlasting Swamp. Each of the cross-sectional surveys were completed using an echo sounder and Trimble RTK-GPS survey gear, except where it was possible to walk the cross-sections with survey gear. The locations of these cross-sections, included:

- Upper Sportsmans Creek;
- Everlasting Swamp at Gospers Point;
- Everlasting Swamp;
- Blanches Drain and Harrison Creek;
- Warragai Creek;
- Imesons Swamp; and
- Woody Creek.

A summary of the eastings and northings for the start and end of each cross-section is provided in Table C.2. Further information and plots of each cross-section are provided in Sections C.4.1 to C.4.7.

Table C.2: Summary of Culvert Structures Surveyed by WRL in 2016/17 (MGA 56)

ID	Start Easting (m)	Start Northing (m)	End Easting (m)	End Northing (m)
SC_CS01	502829.17	6736936.8	502855.68	6736899
SC_CS02	501959.17	6736858.1	501980.57	6736805.9
SC_CS03	501476.3	6736607.6	501484.58	6736576
SC_CS04	502146.98	6736861.4	502121.27	6736826.6
SC_CS05	502464.39	6736897.4	502446.12	6736831
SC_CS06	503031.2	6736939.4	502981.6	6736929.8
SC_CS07	502783.11	6736848.2	502836.08	6736866.3
SC_CS08	501972.65	6736786.3	502000.18	6736754.1
SC_CS09	501858.53	6736894.2	501857.48	6736887.4
SC_CS10	501833.88	6736912.6	501824.16	6736873.6
ID_CS01	505701.79	6736435.1	505701.41	6736430.6
ID_CS02	506436.96	6736987.2	506425.11	6736976.1
ID_CS03	506423.64	6736992.6	506417.28	6736983
ES_CS01	505608.44	6733425.3	505644.04	6733419.8
ES_CS02	505622.41	6733546.3	505658.02	6733544
ES_CS03	505588.89	6733521	505591.98	6733537.9
ES_CS04	505432.49	6733525.7	505452.89	6733522.8
ES_CS05	505400.23	6733547.4	505403.3	6733566.9
ES_CS06	505711.31	6733783.5	505711.68	6733786.8
ES_CS07	505683.25	6733782.4	505685.14	6733782.3
ES_CS08	505688.07	6734140	505722.88	6734136.7
ES_CS09	505742.39	6734143.5	505746.48	6734161.7
ES_CS10	505684.66	6734153.4	505685.29	6734159.5
ES_CS11	505702.3	6734148.7	505709.4	6734148.4
ES_CS12	507452.97	6733982.3	507480.38	6733984.8
ES_CS13	507445.85	6734038.4	507472.13	6734040.2
ES_CS14	507442.81	6734110.5	507465.49	6734094.5
ES_CS15	507476.61	6734148.1	507496.95	6734129

ID	Start Easting (m)	Start Northing (m)	End Easting (m)	End Northing (m)
ES_CS16	507476.61	6734148.1	507486.52	6734158
ES_CS17	507506.64	6734142.8	507486.52	6734158
ES_CS18	507499.89	6734129.7	507507.83	6734139.4
ES_CS19	507528.55	6734170.8	507509.03	6734187.4
ES_CS20	506959.04	6734011.9	506938.55	6734015.8
HC_CS1	506215.12	6732372	506227.78	6732346.6
BD_CS1	506731.64	6732603.6	506729.43	6732587.8
GP_CS1	504789.36	6734315.9	504837.42	6734313.7
GP_CS2	504837.42	6734313.7	504830.33	6734286.5
GP_CS3	505037.8	6734318.3	505052.71	6734293
GP_CS4	505053.5	6734295.4	505058.69	6734288.2
GP_CS5	505058.66	6734295.9	505069.12	6734286.2
GP_CS6	505036.64	6734244.8	505039.02	6734259.1
GP_CS7	505005.89	6734250.1	505036.64	6734244.8
WAC_CS1	503021.79	6729906.5	503058.68	6729894.5
WAC_CS3	502997.78	6729874	503032.14	6729858.2
WAC_CS2	503009.47	6729894.2	503035.9	6729863.5
HC_CS2	507267.16	6733243.5	507292.27	6733223
ID_CS04	506417.43	6736990.5	506416.88	6736989.2
HC_CS3	506454.73	6732387.8	506463.38	6732390
WC_CS1	503020.52	6729906.27	503058.66	6729893.98
WC_CS2	503008.88	6729893.98	503036.68	6729863.60
WC_CS3	502995.951	6729873.94	503031.51	6729858.43

C.4.1 Upper Sportsmans Creek

The locations of six (6) cross-sections surveyed in the upper section of Sportsmans Creek, as well as at four (4) locations in smaller side channels, are provided in Figure C.3. The elevations of each cross-section are provided in Figure C.4 and Figure C.5.

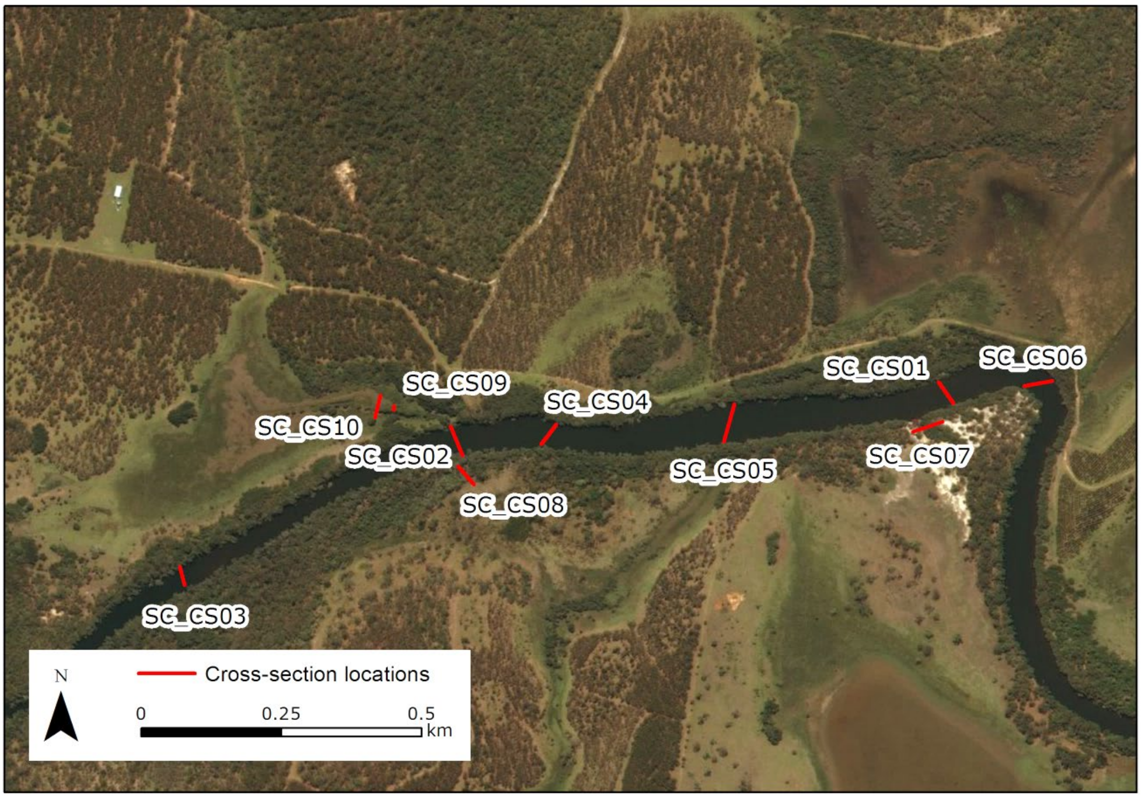
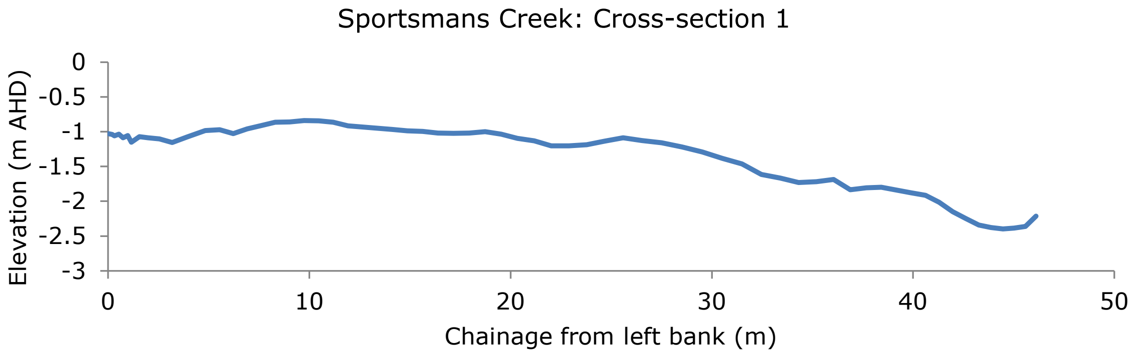
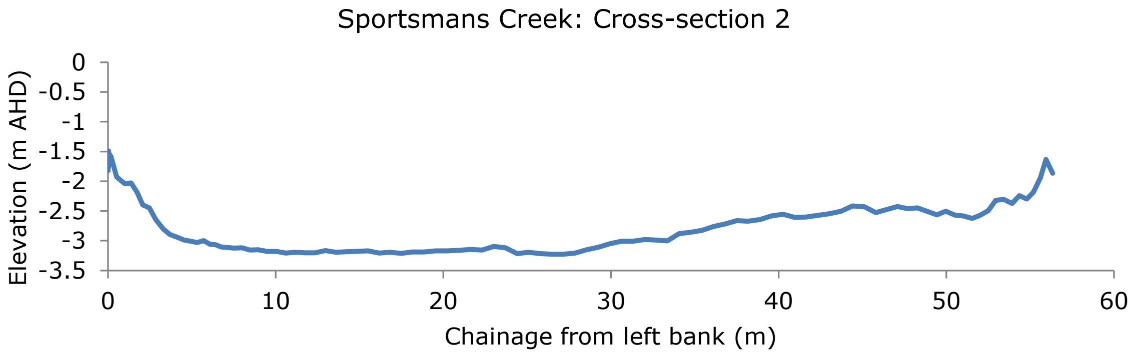
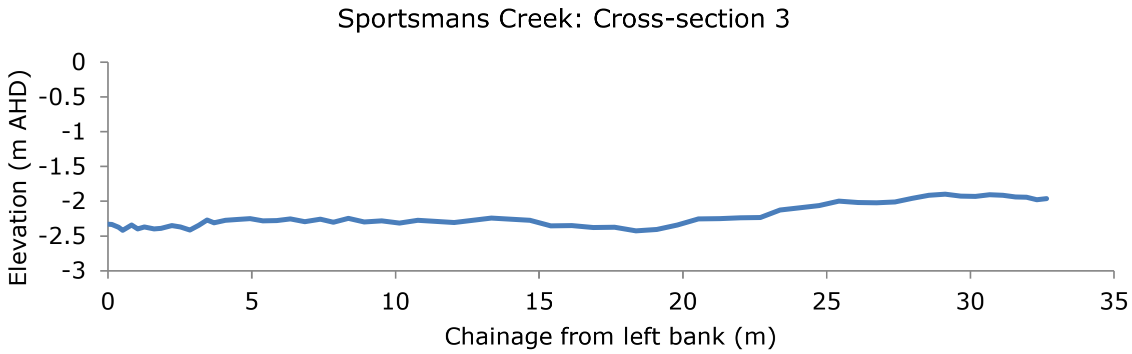
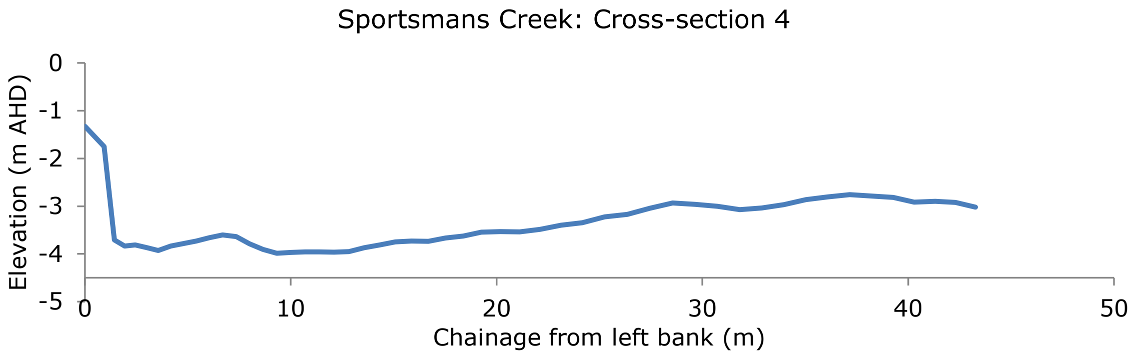


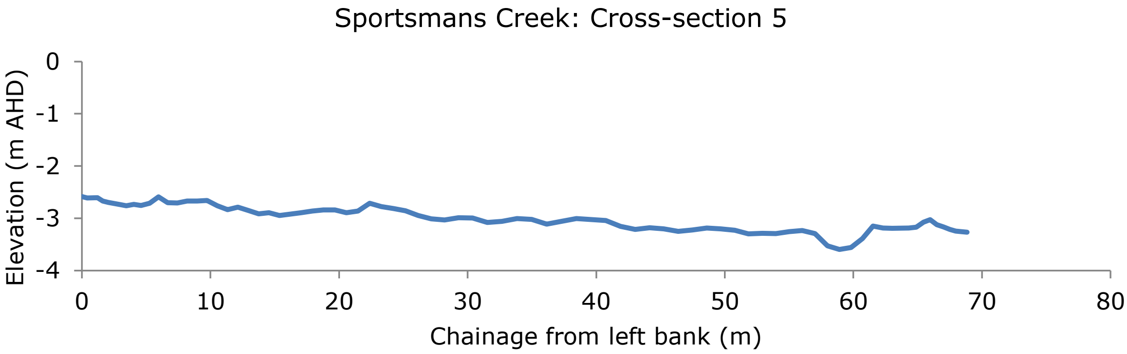
Figure C.3: Locations of Cross-Sections Surveyed at Upper Sportsmans Creek


Sportsmans Creek: Cross-section 1
Elevation (m AHD)
0
-0.5
-1
-1.5
-2
-2.5
-3
0
10
20
30
40
50
Chainage from left bank (m)


Sportsmans Creek: Cross-section 2
Elevation (m AHD)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
0
10
20
30
40
50
60
Chainage from left bank (m)


Sportsmans Creek: Cross-section 3
Elevation (m AHD)
0
-0.5
-1
-1.5
-2
-2.5
-3
0
5
10
15
20
25
30
35
Chainage from left bank (m)


Sportsmans Creek: Cross-section 4
Elevation (m AHD)
0
-1
-2
-3
-4
-5
0
10
20
30
40
50
Chainage from left bank (m)



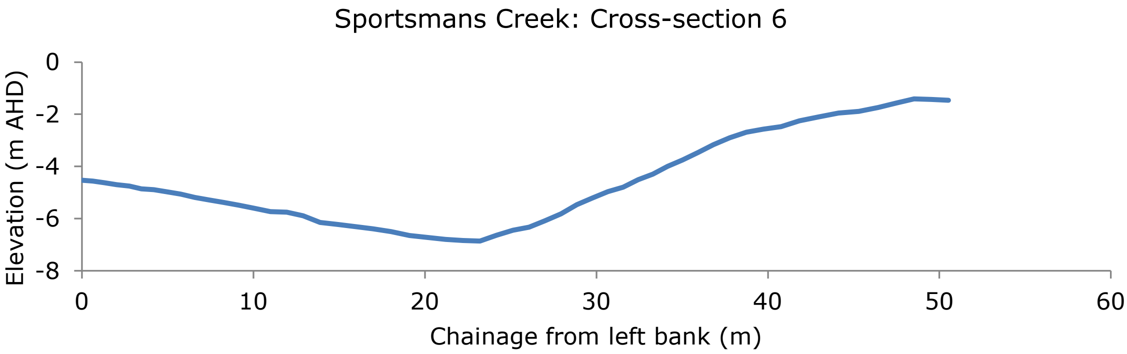
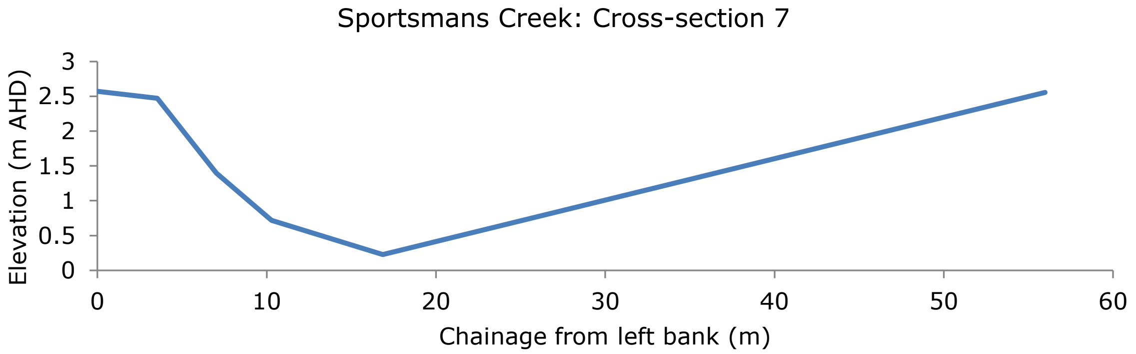
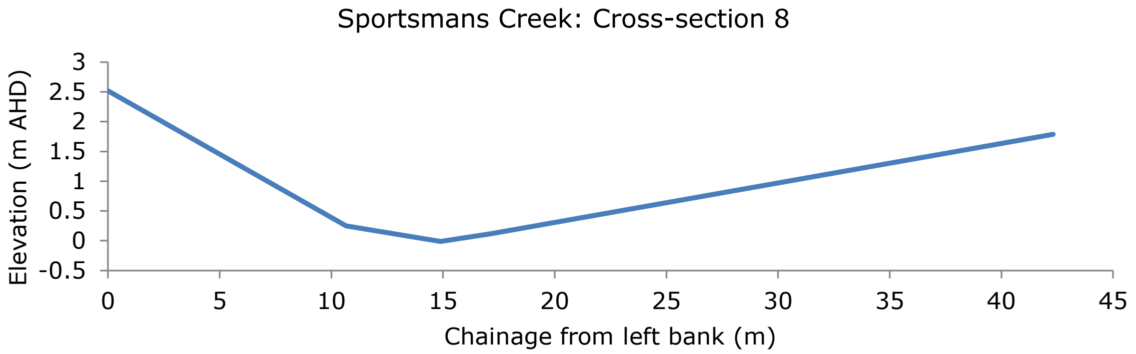
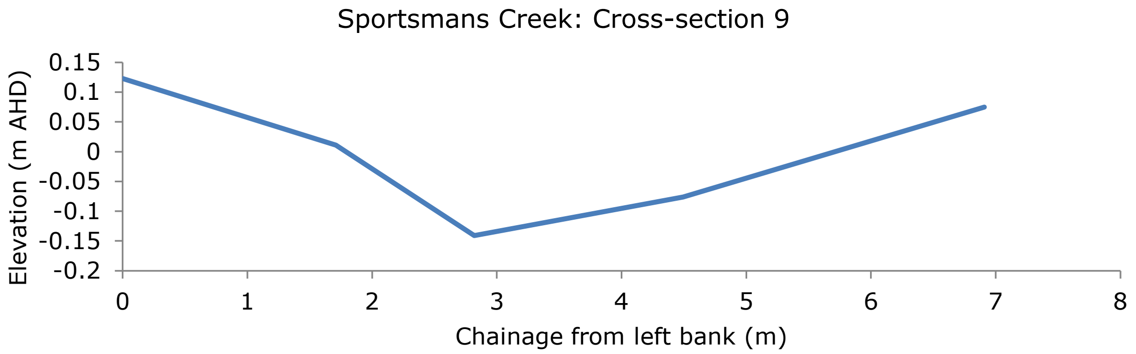


Figure C.4: Elevations of Cross-sections (1-6) Surveyed at Upper Sportsmans Creek







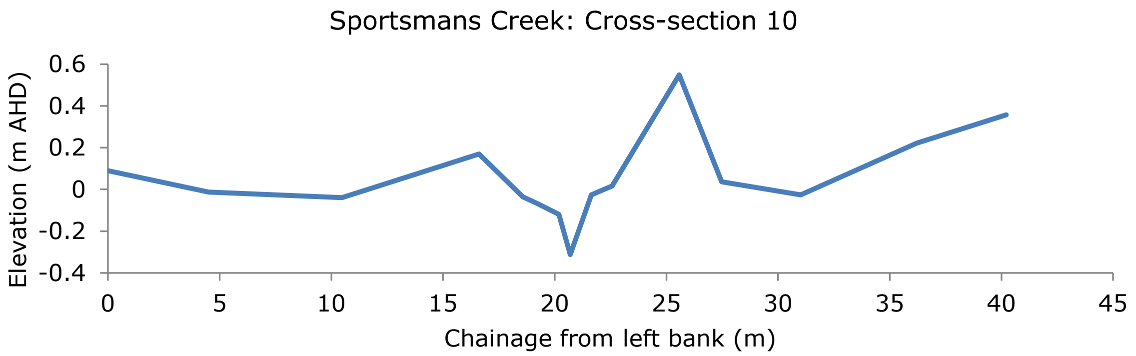


Figure C.5: Elevations of Cross-sections (7-10) Surveyed of Creeks Flowing into Sportsmans Creek

C.4.2 Gospers Point and Central Everlasting Swamp

The locations of 19 cross-sections surveyed at Everlasting Swamp near Gospers Point and through the Everlasting Swamp SCA are provided in Figure C.6. Cross-sections at this location were taken using Trimble RTK-GPS survey gear. In some locations, survey data could not be obtained due to tree coverage blocking the GPS signal or drains that could not be crossed or accessed via canoe. In each case, channel banks were interpolated from available LiDAR data. The elevations of the cross-sections taken at Gospers Point and the central portion of Everlasting Swamp are provided in Figure C.7 and Figure C.8, respectively.

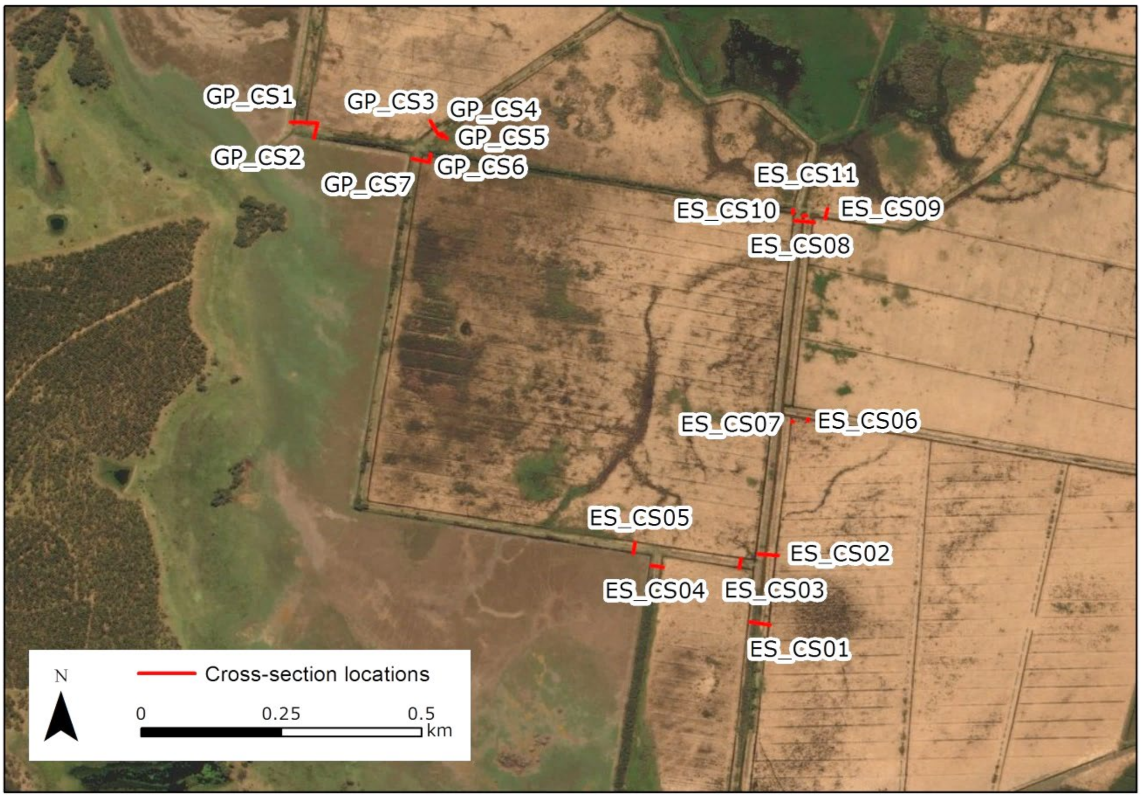
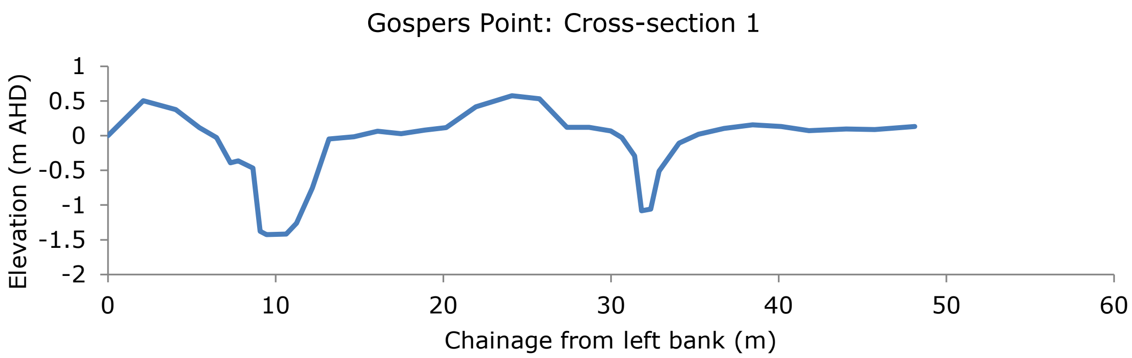
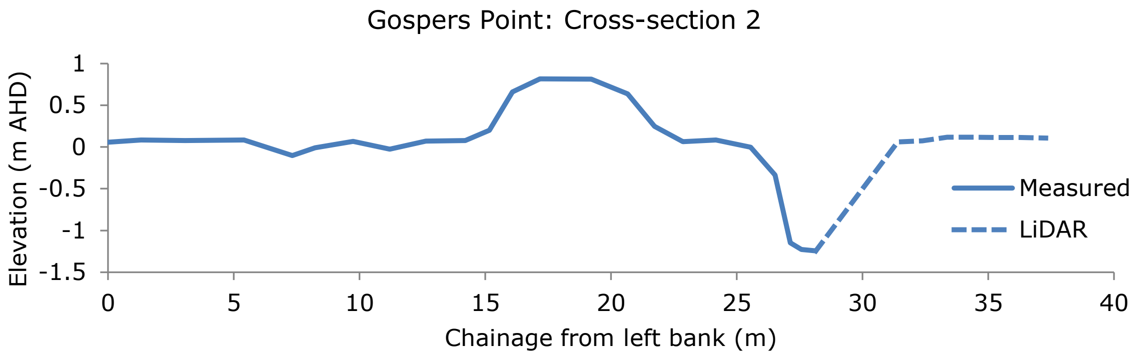
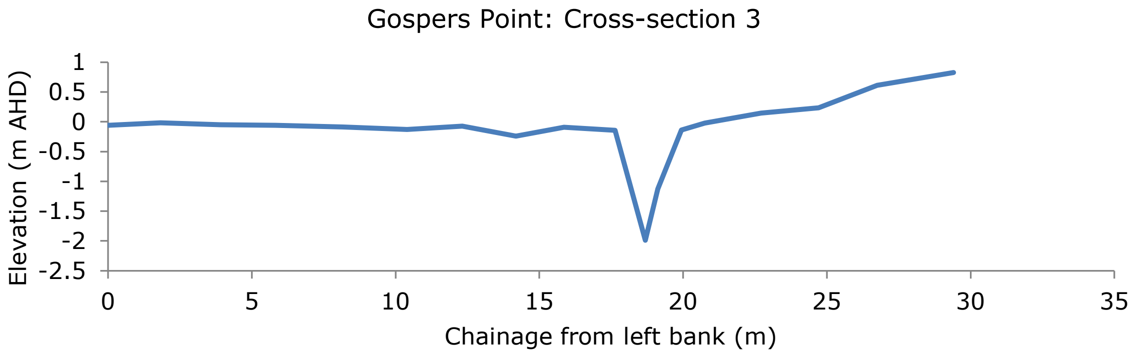
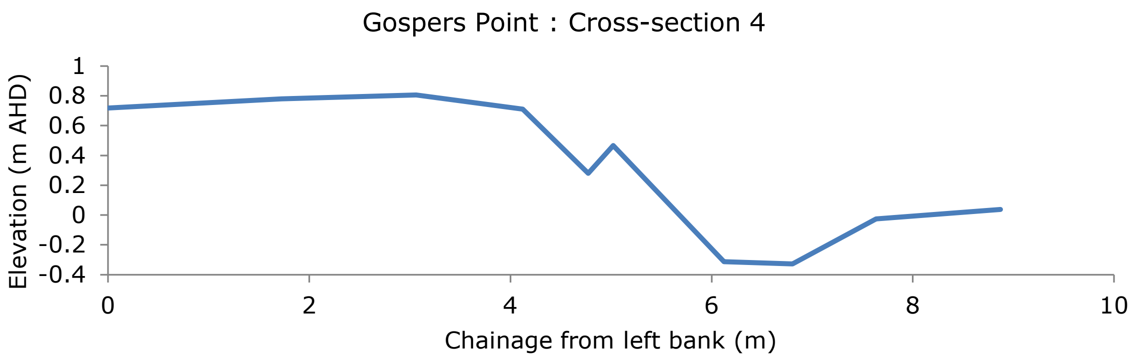


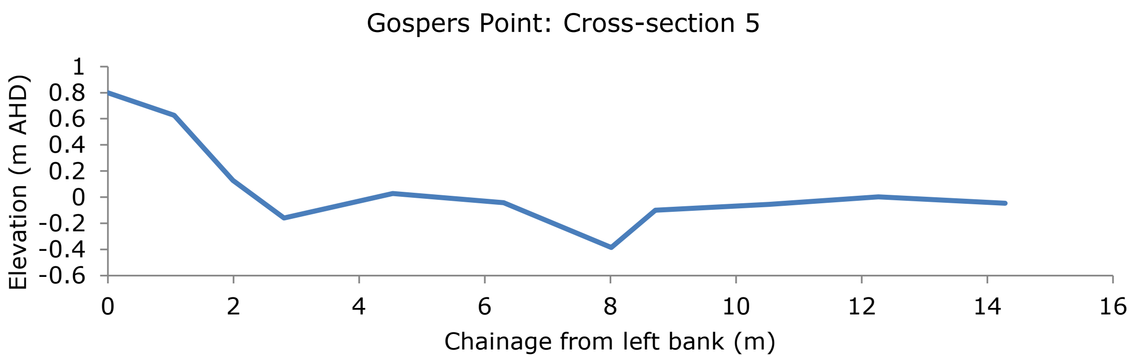
Figure C.6: Locations of Cross-Sections Surveyed at Gospers Creek and Central Everlasting Swamp

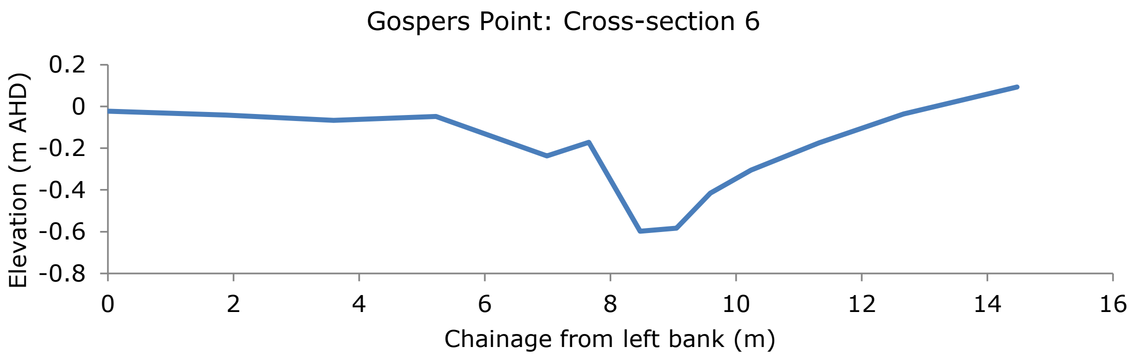

Gospers Point: Cross-section 1
Elevation (m AHD)
1
0.5
0
-0.5
-1
-1.5
-2
0
10
20
30
40
50
60
Chainage from left bank (m)


Gospers Point: Cross-section 2
Elevation (m AHD)
1
0.5
0
-0.5
-1
-1.5
0
5
10
15
20
25
30
35
40
Chainage from left bank (m)
Measured
LiDAR


Gospers Point: Cross-section 3
Elevation (m AHD)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
0
5
10
15
20
25
30
35
Chainage from left bank (m)


Gospers Point : Cross-section 4
Elevation (m AHD)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
2
4
6
8
10
Chainage from left bank (m)





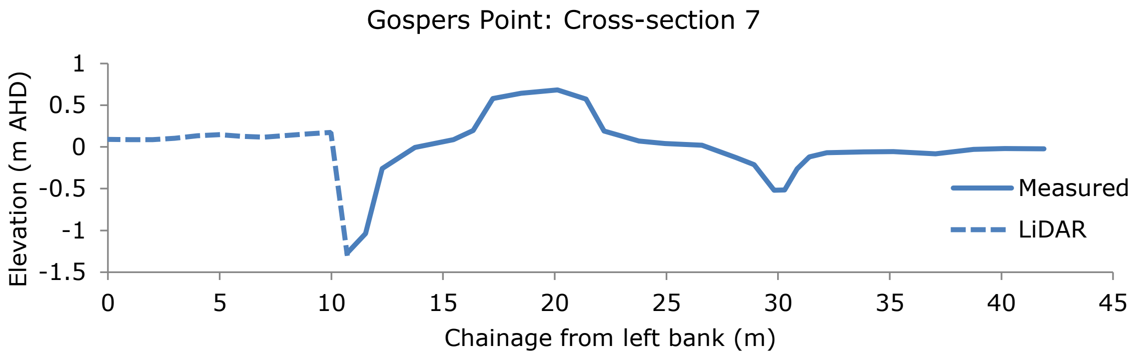
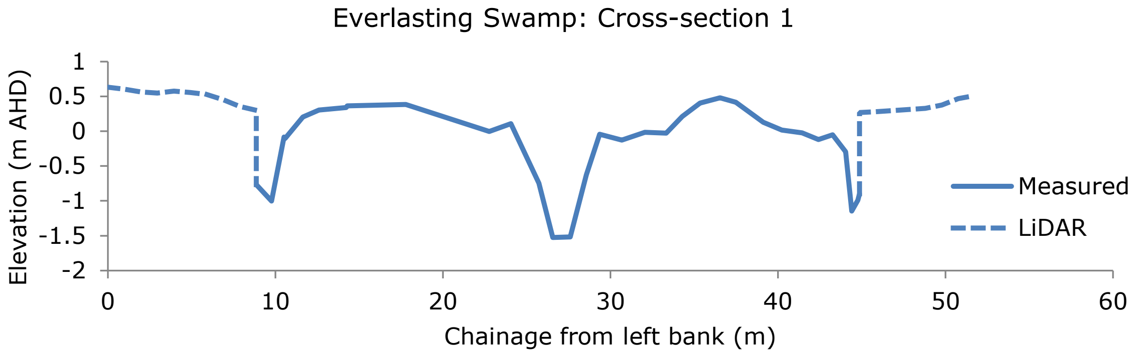
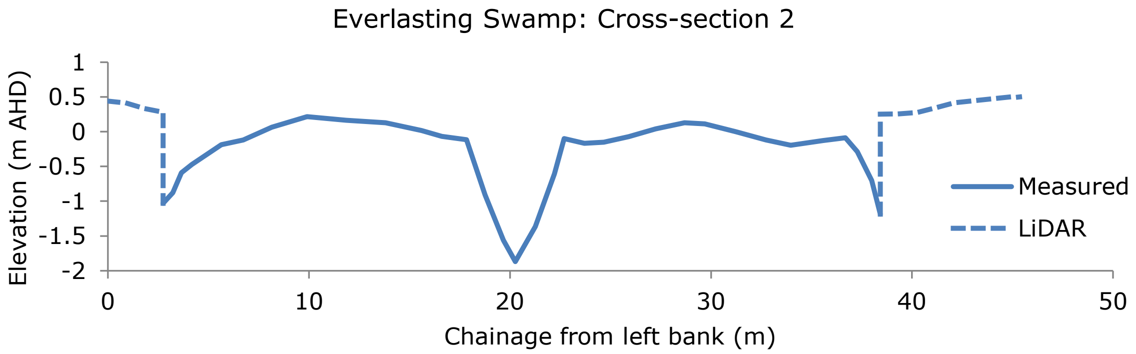
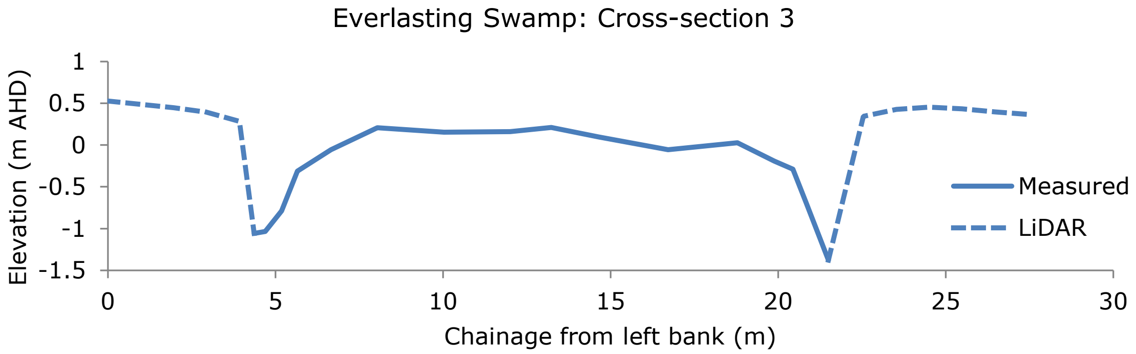
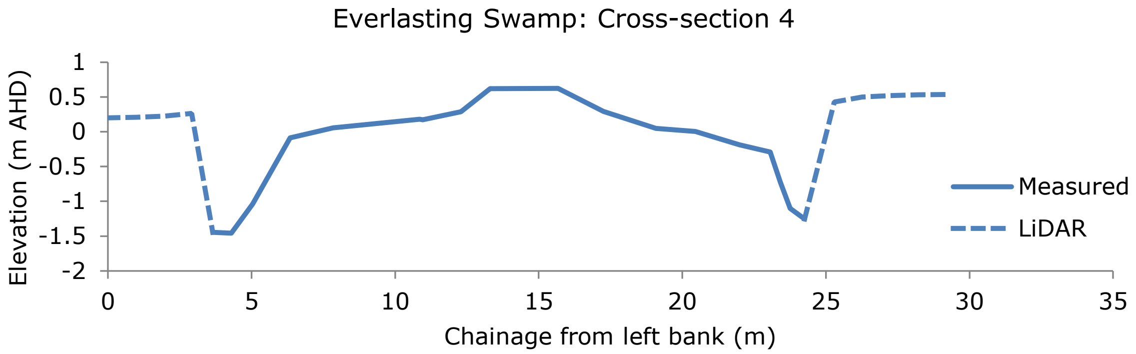


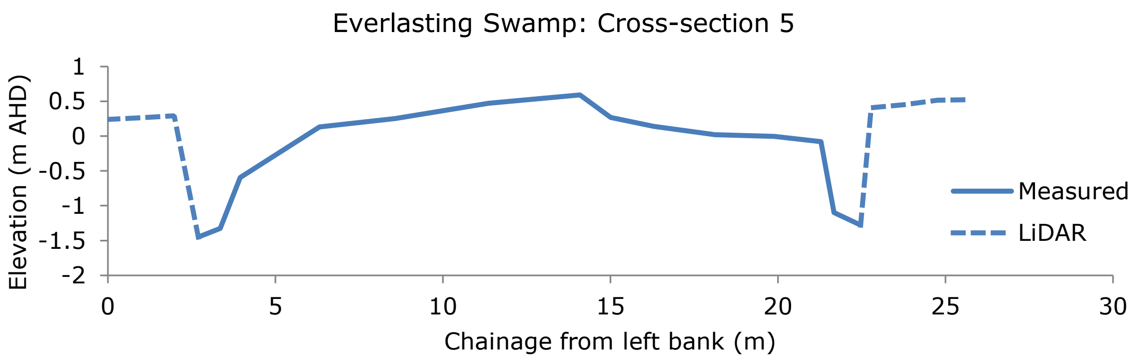
Figure C.7: Elevations of Cross-sections (1-7) Surveyed at Gospers Point on the Edge of Everlasting Swamp


Everlasting Swamp: Cross-section 1
Elevation (m AHD)
1
0.5
0
-0.5
-1
-1.5
-2
0
10
20
30
40
50
60
Chainage from left bank (m)
Measured
LiDAR

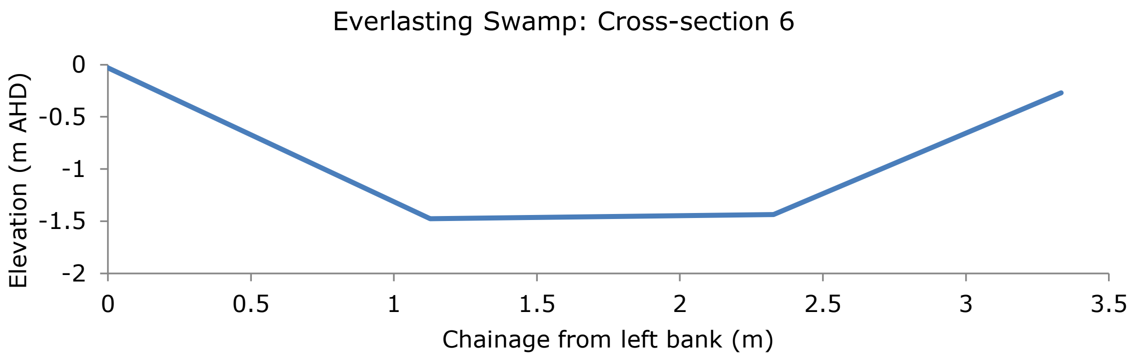

Everlasting Swamp: Cross-section 2
Elevation (m AHD)
1
0.5
0
-0.5
-1
-1.5
-2
0
10
20
30
40
50
Chainage from left bank (m)
Measured
LiDAR


Everlasting Swamp: Cross-section 3
Elevation (m AHD)
1
0.5
0
-0.5
-1
-1.5
0
5
10
15
20
25
30
Chainage from left bank (m)
Measured
LiDAR

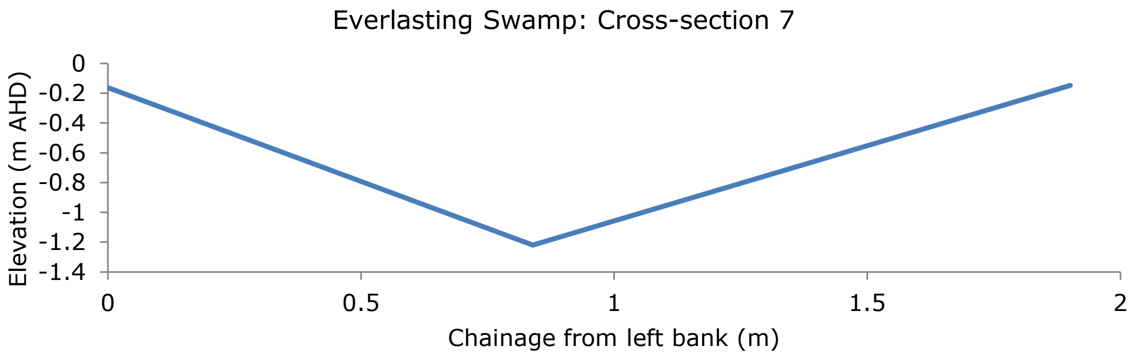

Everlasting Swamp: Cross-section 4
Elevation (m AHD)
1
0.5
0
-0.5
-1
-1.5
-2
0
5
10
15
20
25
30
35
Chainage from left bank (m)
Measured
LiDAR



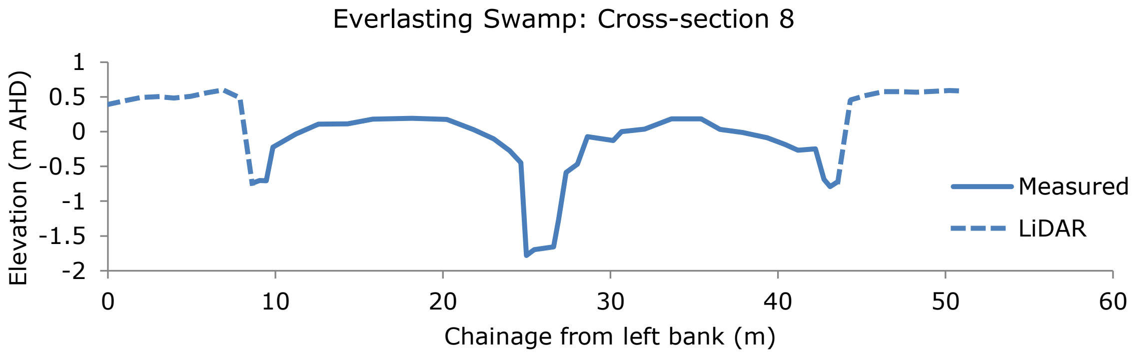
Everlasting Swamp: Cross-section 5
Elevation (m AHD)
1
0.5
0
-0.5
-1
-1.5
-2
0
5
10
15
20
25
30
Chainage from left bank (m)
Measured
LiDAR



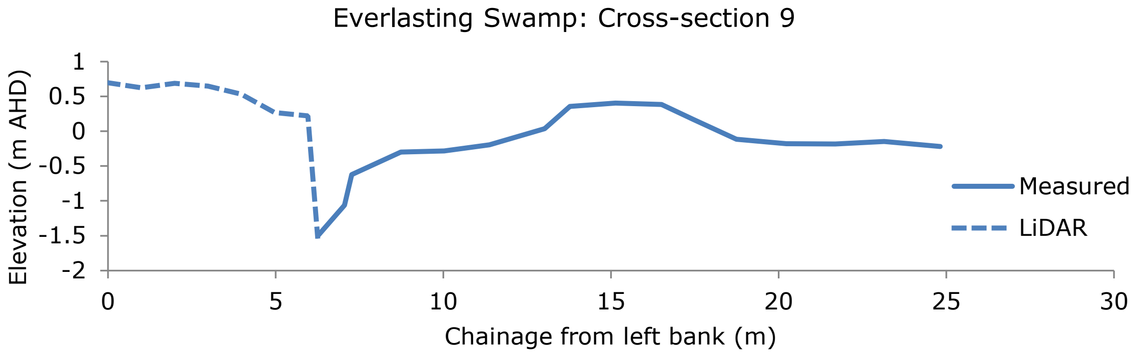
Everlasting Swamp: Cross-section 6
Elevation (m AHD)
0
-0.5
-1
-1.5
-2
0
0.5
1
1.5
2
2.5
3
3.5
Chainage from left bank (m)

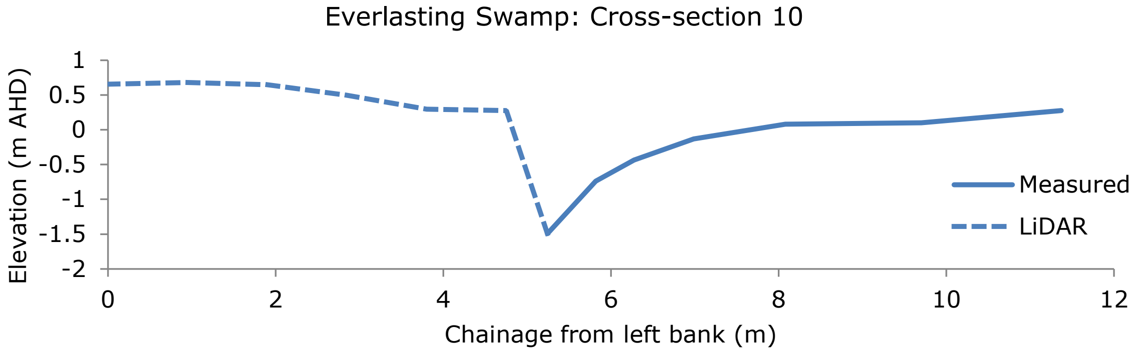


Everlasting Swamp: Cross-section 7
Elevation (m AHD)
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
0
0.5
1
1.5
2
Chainage from left bank (m)



Everlasting Swamp: Cross-section 8
Elevation (m AHD)
1
0.5
0
-0.5
-1
-1.5
-2
0
10
20
30
40
50
60
Chainage from left bank (m)
Measured
LiDAR





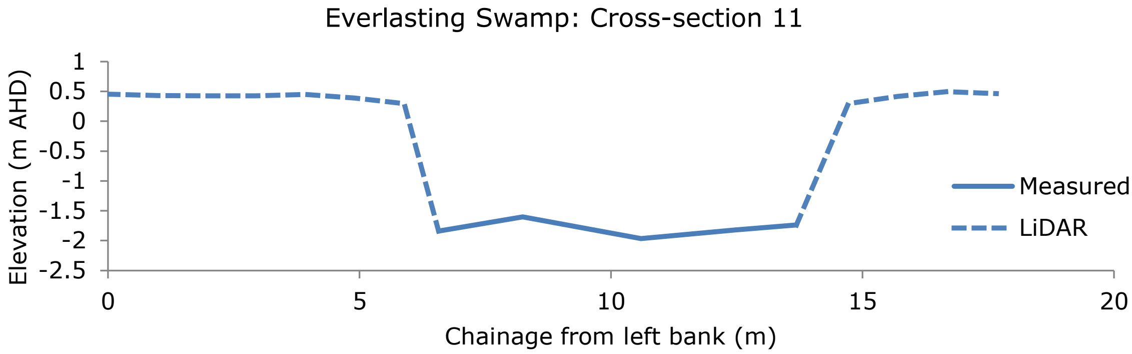


Figure C.8: Elevations of Cross-sections (1-11) Surveyed in Central Everlasting Swamp

C.4.3 Everlasting Swamp and The Horseshoe

The locations of nine (9) cross-sections surveyed at the eastern side of Everlasting Swamp and The Horseshoe area are provided in Figure C.9. The elevations of each cross-section are provided in Figure C.10 and Figure C.11.

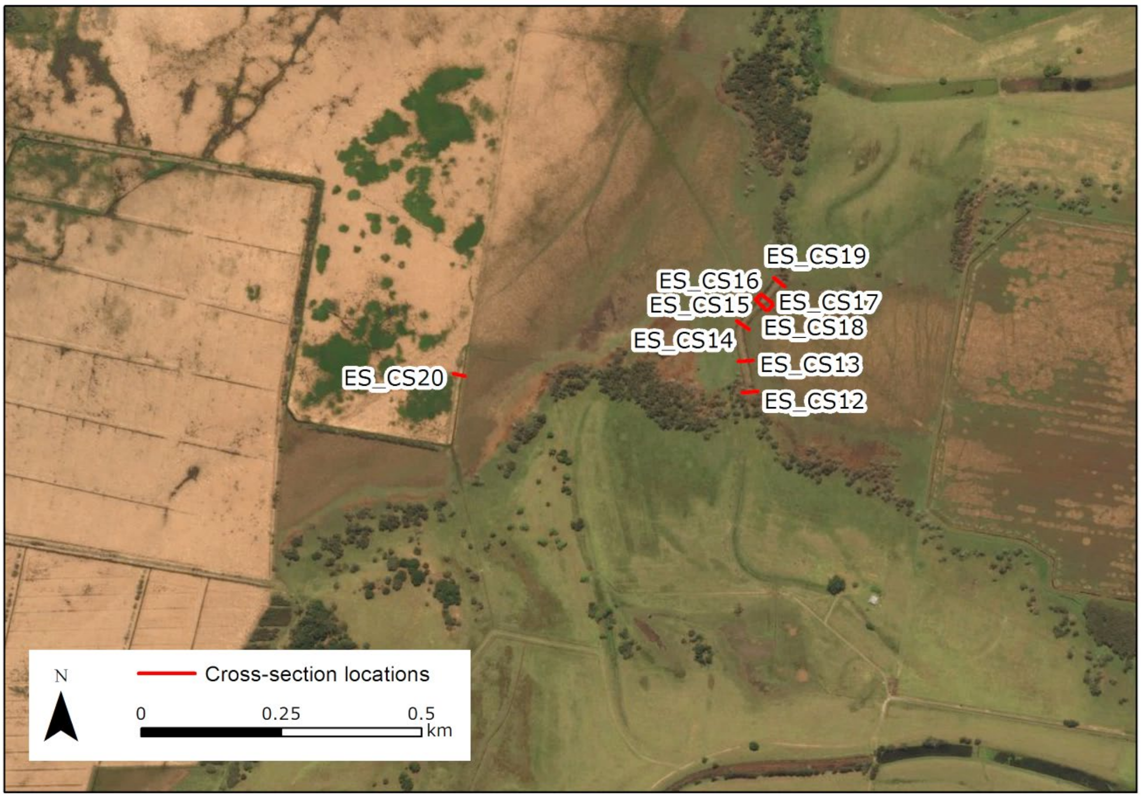
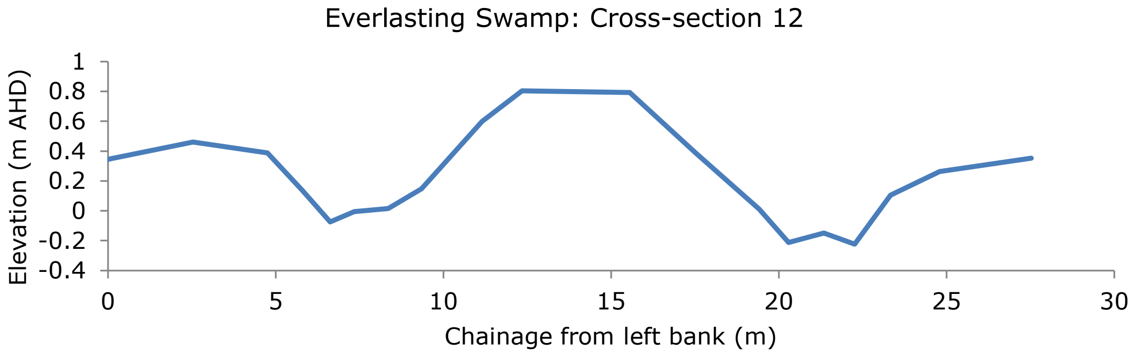
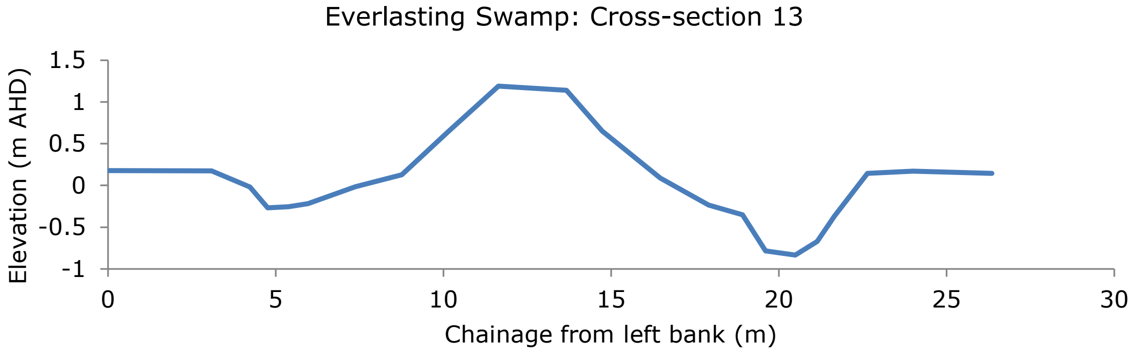
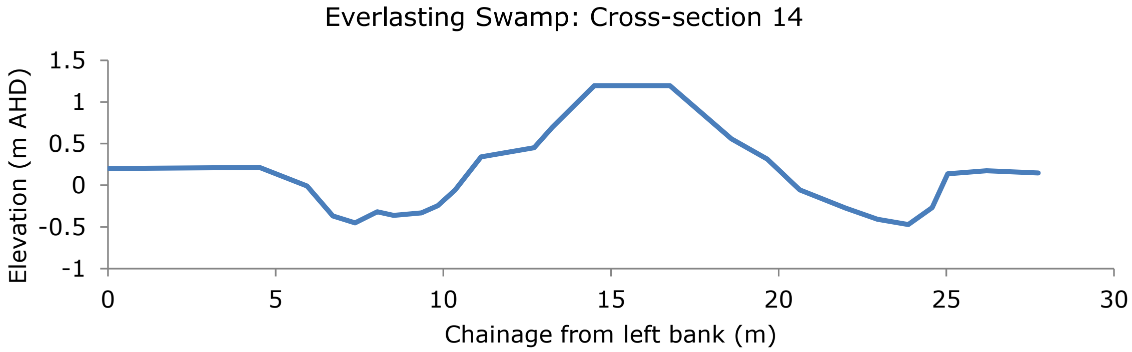
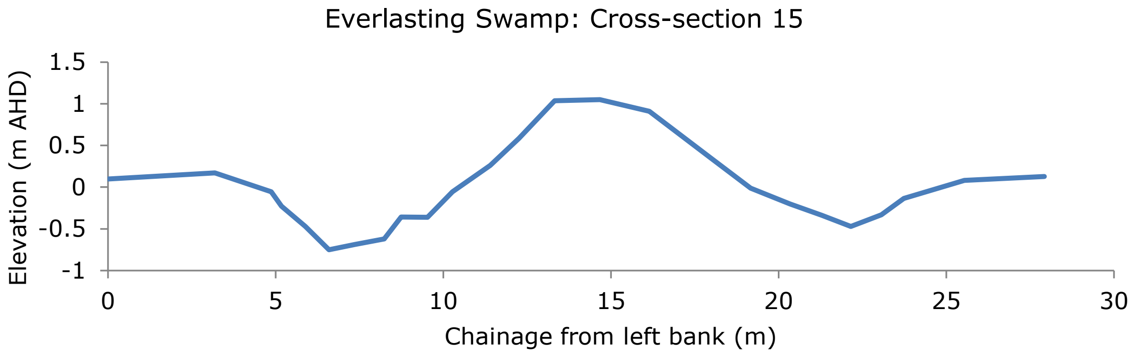


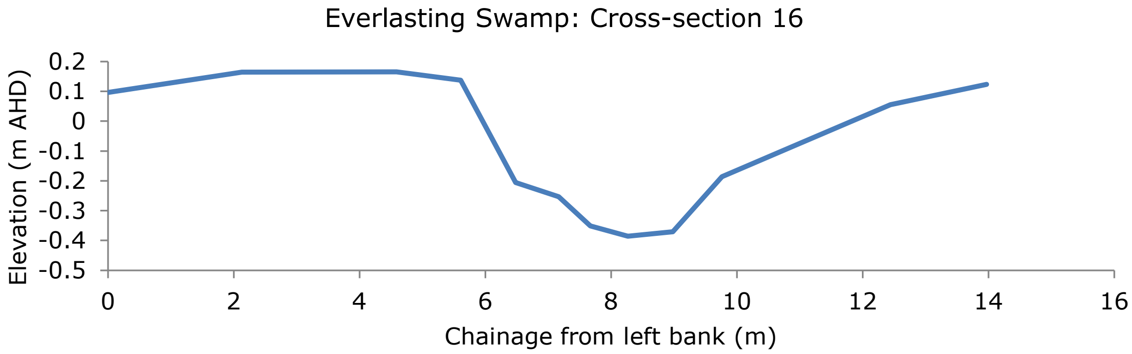
Figure C.9: Locations of Cross-Sections Surveyed on the Eastern Side of Everlasting Swamp and The Horseshoe

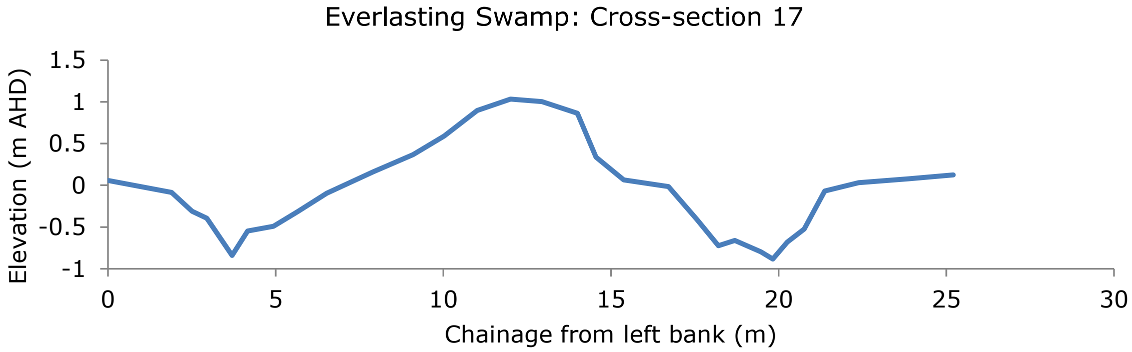

Everlasting Swamp: Cross-section 12
Elevation (m AHD)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
5
10
15
20
25
30
Chainage from left bank (m)

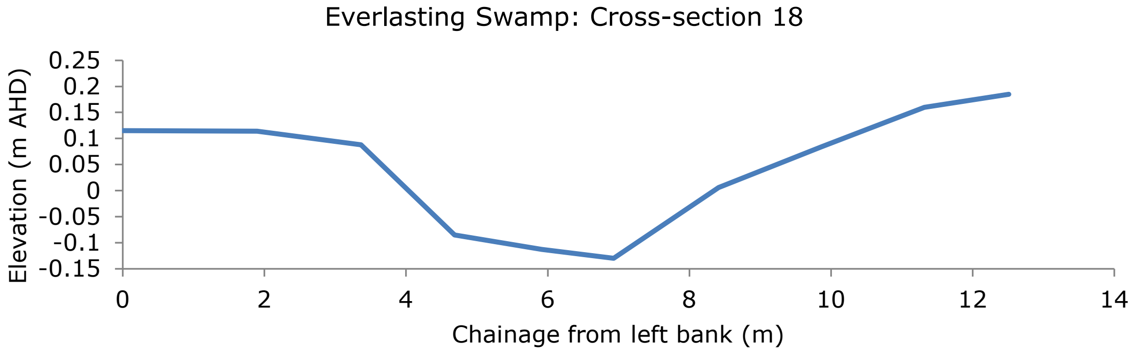

Everlasting Swamp: Cross-section 13
Elevation (m AHD)
1.5
1
0.5
0
-0.5
-1
0
5
10
15
20
25
30
Chainage from left bank (m)


Everlasting Swamp: Cross-section 14
Elevation (m AHD)
1.5
1
0.5
0
-0.5
-1
0
5
10
15
20
25
30
Chainage from left bank (m)


Everlasting Swamp: Cross-section 15
Elevation (m AHD)
1.5
1
0.5
0
-0.5
-1
0
5
10
15
20
25
30
Chainage from left bank (m)







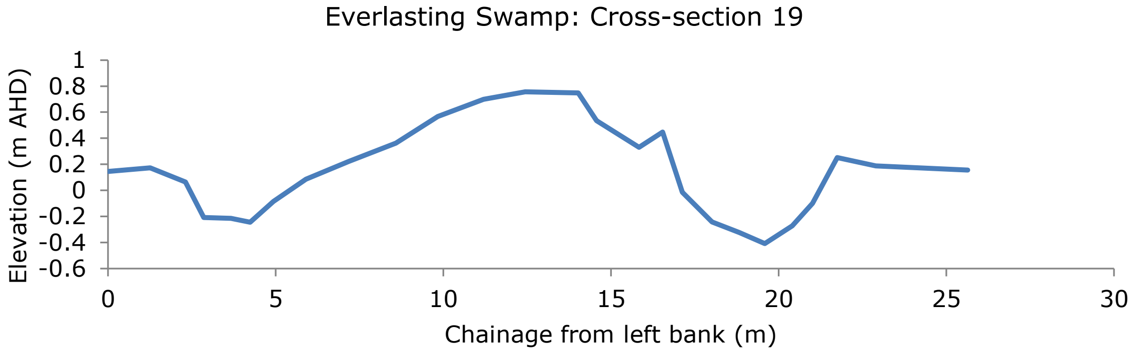


Figure C.10: Elevations of Cross-sections (12-19) Surveyed on the Eastern Side of Everlasting Swamp and The Horseshoe

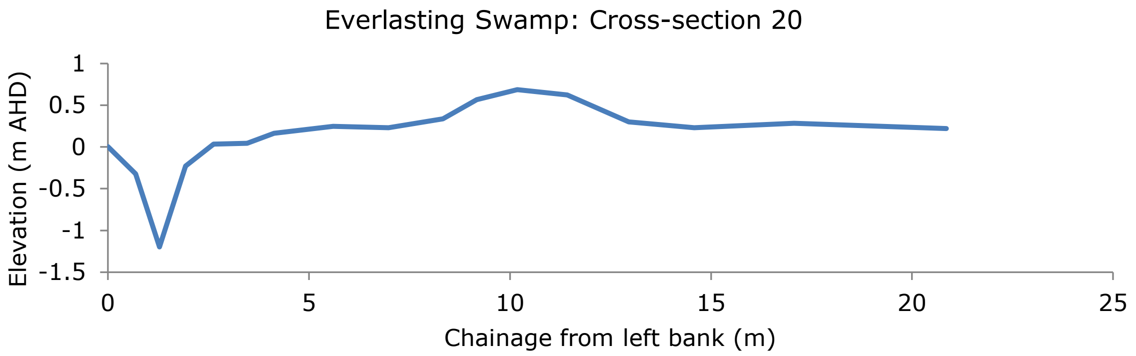
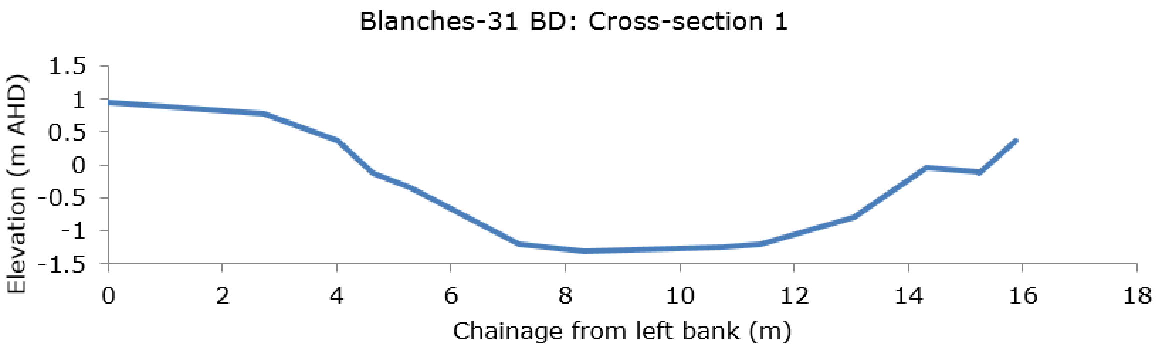


Figure C.11: Elevations of Cross-section 20 Surveyed on the Eastern Side of Everlasting Swamp

C.4.4 Blanches Drain and Harrison Creek

The locations of four (4) cross-sections surveyed at Blanches Drain and Harrison Creek are provided in Figure C.12. Cross-section HC_CS2 was taken on the upstream side of a drop-board weir located in the drain, named Harrisons Creek Weir for the purpose of this study. Further information on Harrisons Creek Weir is provided in Appendix C.3. The elevations of the cross-sections surveyed in Blanches Drain and Harrison Creek are provided in Figure C.13 and Figure C.14.

Figure C.12: Locations of Cross-Sections Surveyed at Blanches Drain and Harrison Creek



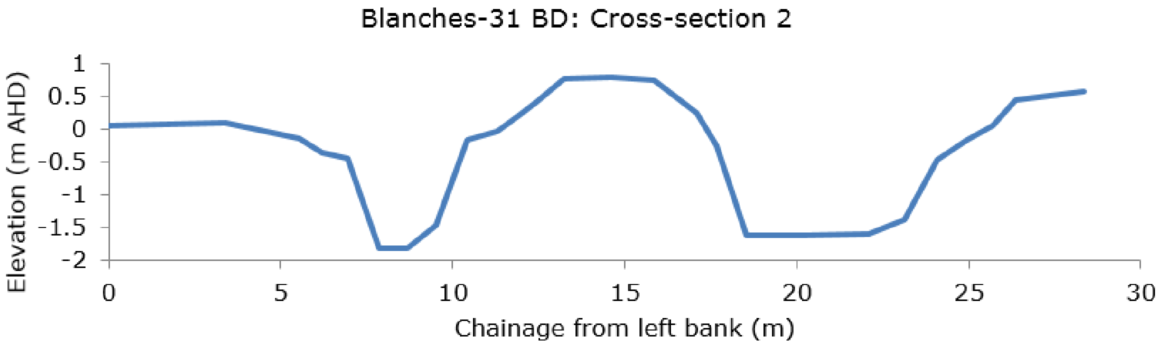


Figure C.13: Elevations of Cross-sections 1 and 2 Surveyed at Blanches Drain

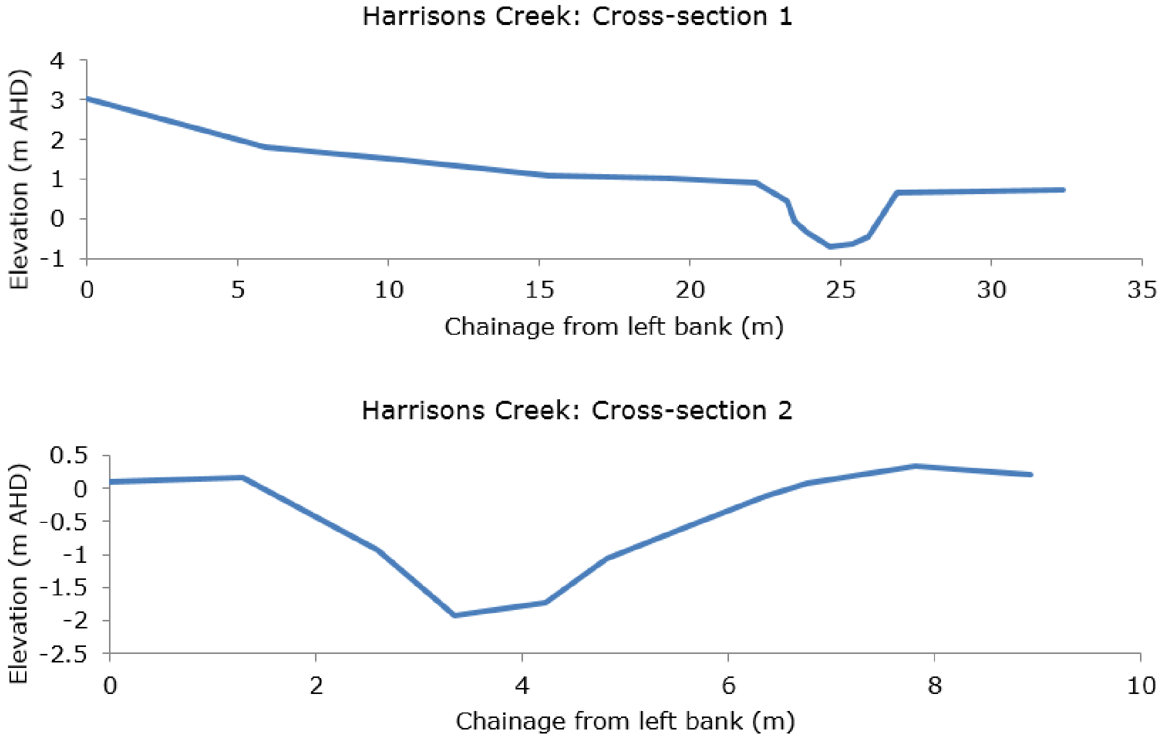


Figure C.14: Elevations of Cross-sections (1-2) Surveyed at Harrison Creek

C.4.5 Warragai Creek

The locations of three (3) cross-sections surveyed at Warragai Creek are provided in Figure C.15. A rocky crossing which dams the lower section of Warragai Creek would act like a weir during low flows and was located at WAC_CS2. The elevations of cross-sections surveyed at Warragai Creek are provided in Figure C.16.

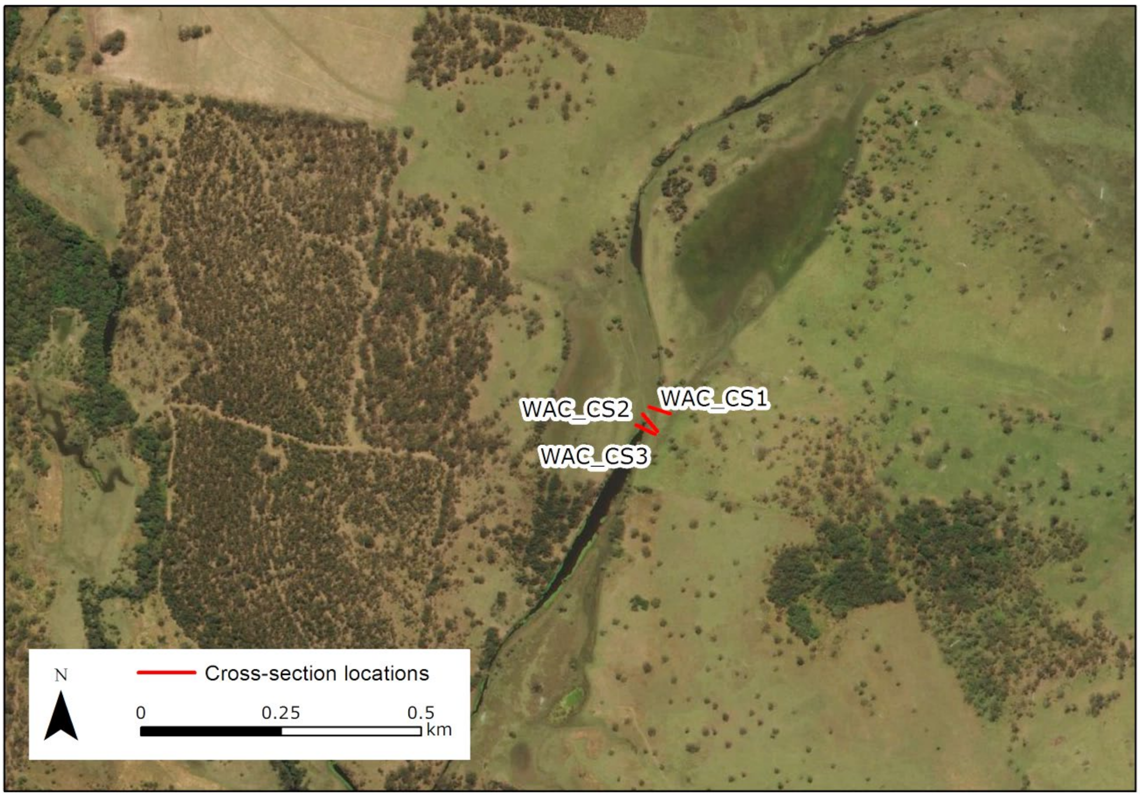


Figure C.15: Locations of Cross-Sections Surveyed at Warragai Creek

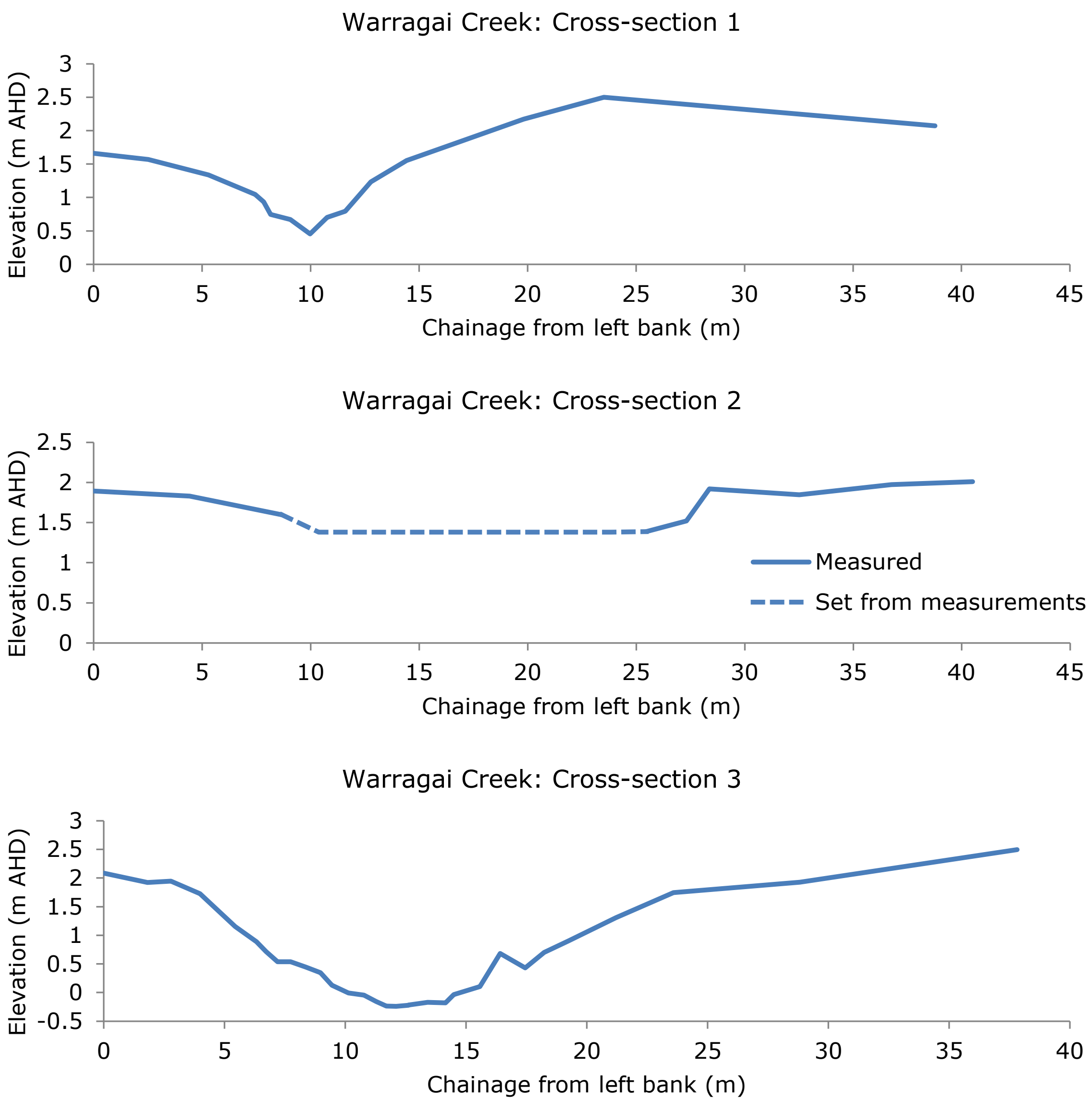


Figure C.16: Elevations of Cross-sections (1-3) Surveyed at Warragai Creek

C.4.6 Imesons Swamp

The locations of four (4) cross-sections surveyed at Imesons Swamp are provided in Figure C.17. At locations where the GPS signal was limited due to vegetation cover or where the drain was inaccessible, existing LIDAR data was used to interpolate the remainder of the cross-section. The elevations of cross-sections surveyed at Imesons Swamp are provided in Figure C.18 and Figure C.19.

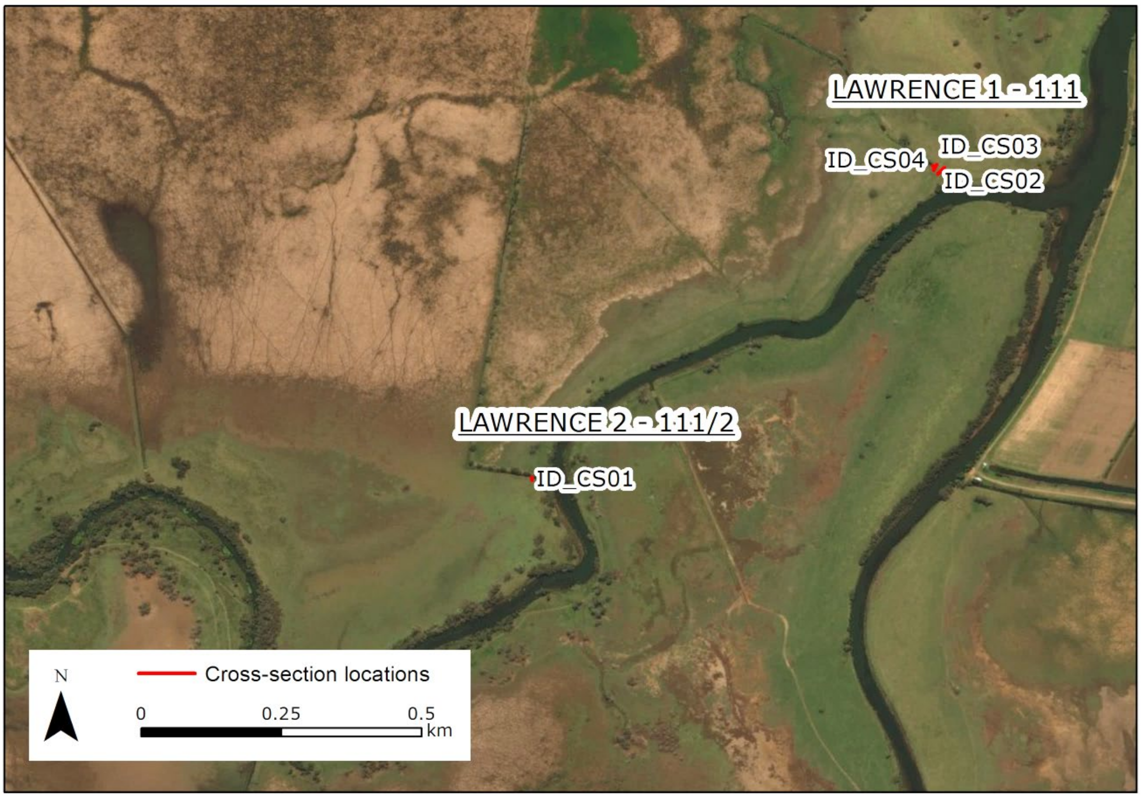


Figure C.17: Locations of Cross-Sections Surveyed at Imesons Swamp

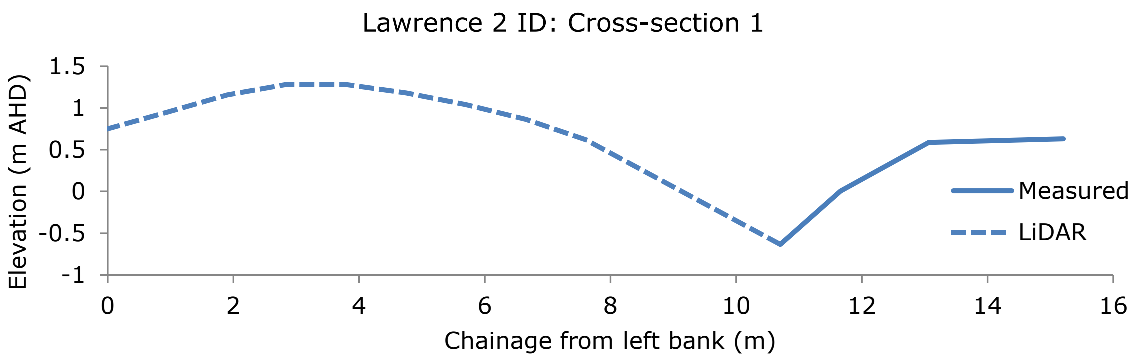


Figure C.18: Cross-section (1) surveyed at Imesons Swamp (Council ID: Lawrence 2-111/1)

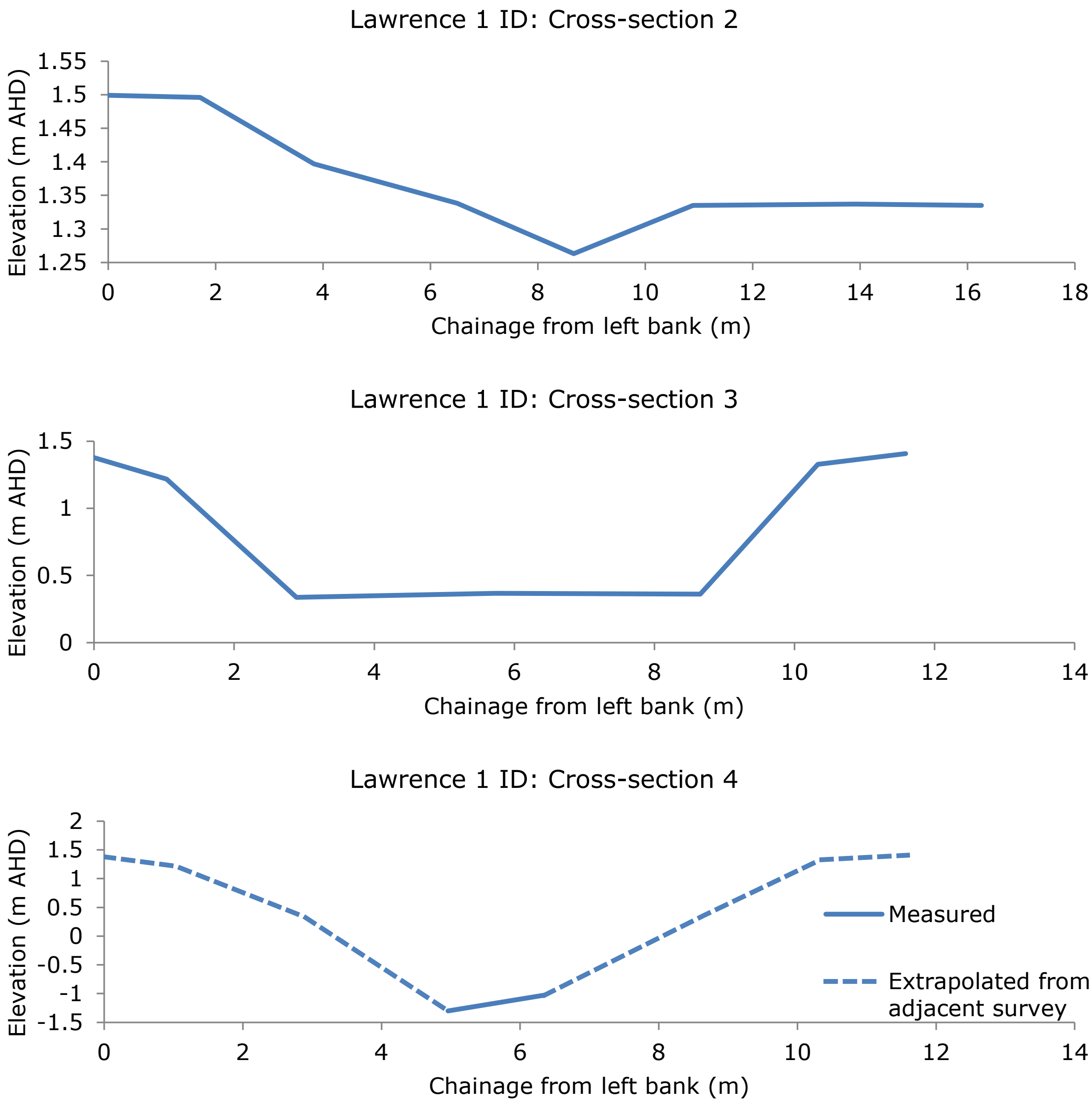


Figure C.19: Cross-sections (2-3) surveyed at Imesons Swamp (Council ID: Lawrence 1-111)

C.4.7 Woody Creek

The locations of four (4) cross-sections surveyed in Woody Creek are provided in Figure C.20. The elevations of the cross-sections at Woody Creek are provided in Figure C.21.

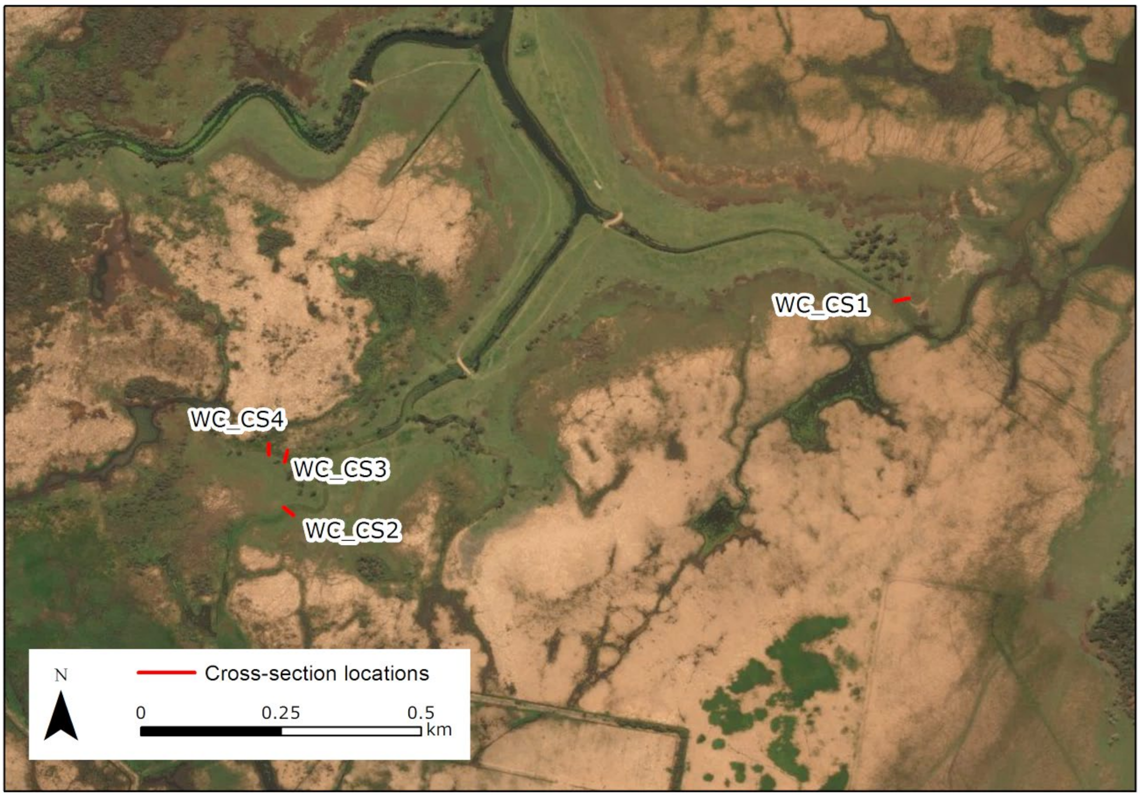


Figure C.20: Locations of Cross-Sections Surveyed at Woody Creek

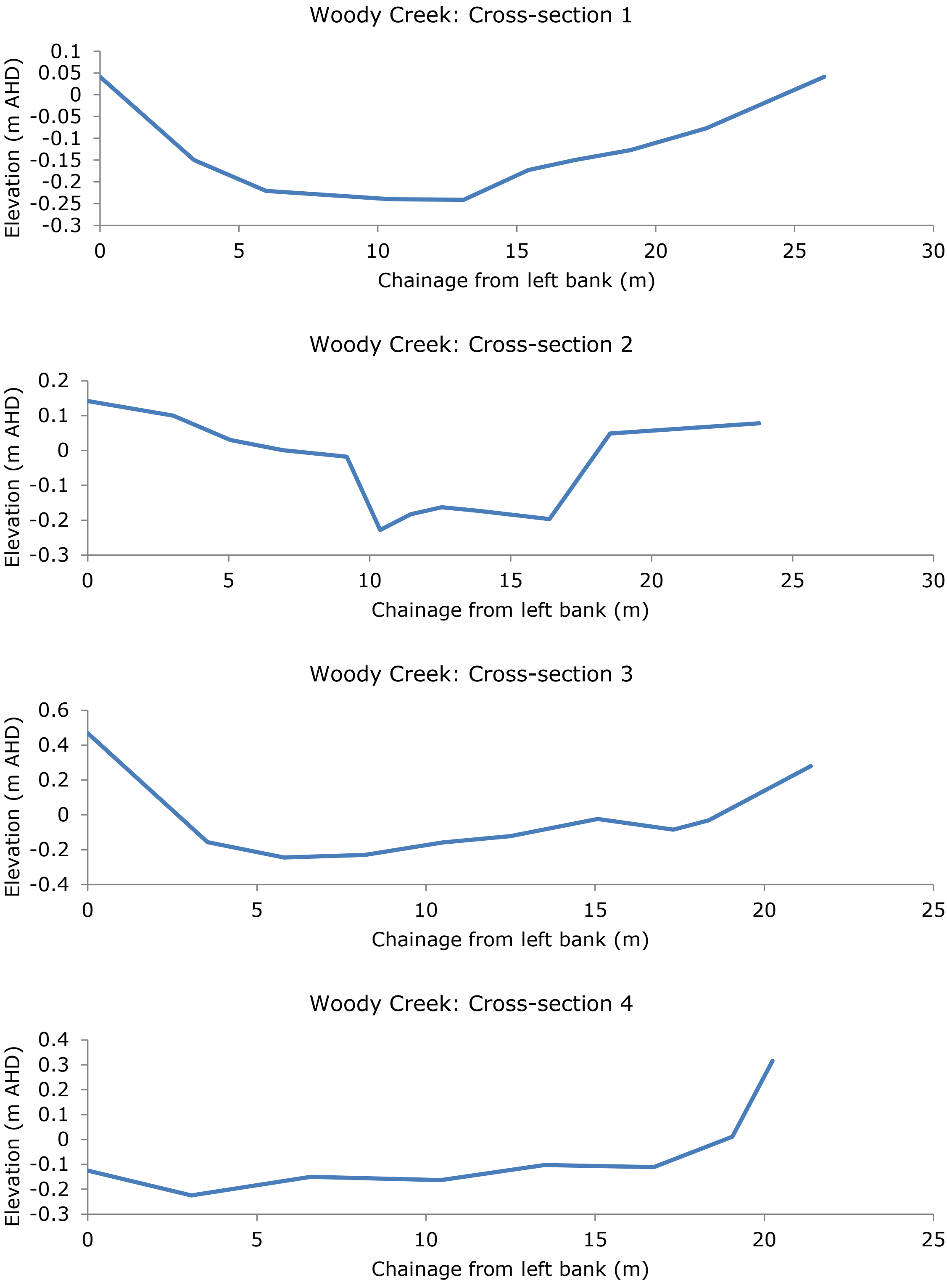


Figure C.21: Elevations of Cross-sections at Woody Creek

C.5 Water Levels

Water levels were recorded at 11 locations across the study area as provided in Figure C.22. The monitoring periods for each station is provided in Table C.3. At each of these locations the data loggers recorded absolute pressure, which was adjusted locally for barometric pressure using a Solinst Barologger. Following the barometric corrections, water levels were referenced to AHD. Adjusting water levels to AHD typically involves taking a water level measurement near the data logger using an RTK-GPS to provide a vertical correction that can be applied to the timeseries data.

Table C.4 summarises the survey point elevations used to correct the water levels at each of the monitoring stations, including the vertical precision of each point. Note that an RTK-GPS generally has a vertical precision of ±0.05 m, which is dependent on the satellite coverage. Furthermore, when the vertical corrections from the RTK-GPS were applied to the water level timeseries data, head (or energy) losses of approximately 3 – 4 cm were calculated between Site 2 and Sites 3 – 6. However, desktop estimates of head loss in the channels between these sites were calculated to be approximately 0.5 – 5 cm/km. In other words, peak water levels in the channels could be expected to decrease by up to 0.5 cm for every 1 km travelled upstream from Sportsmans Creek Weir. Furthermore, noting that the calculated head losses were within the RTK-GPS precisions, the timeseries data was further corrected to minimise these losses, and so they aligned with the desktop estimates. Additional corrections to the water levels is also provided in Table C.4.

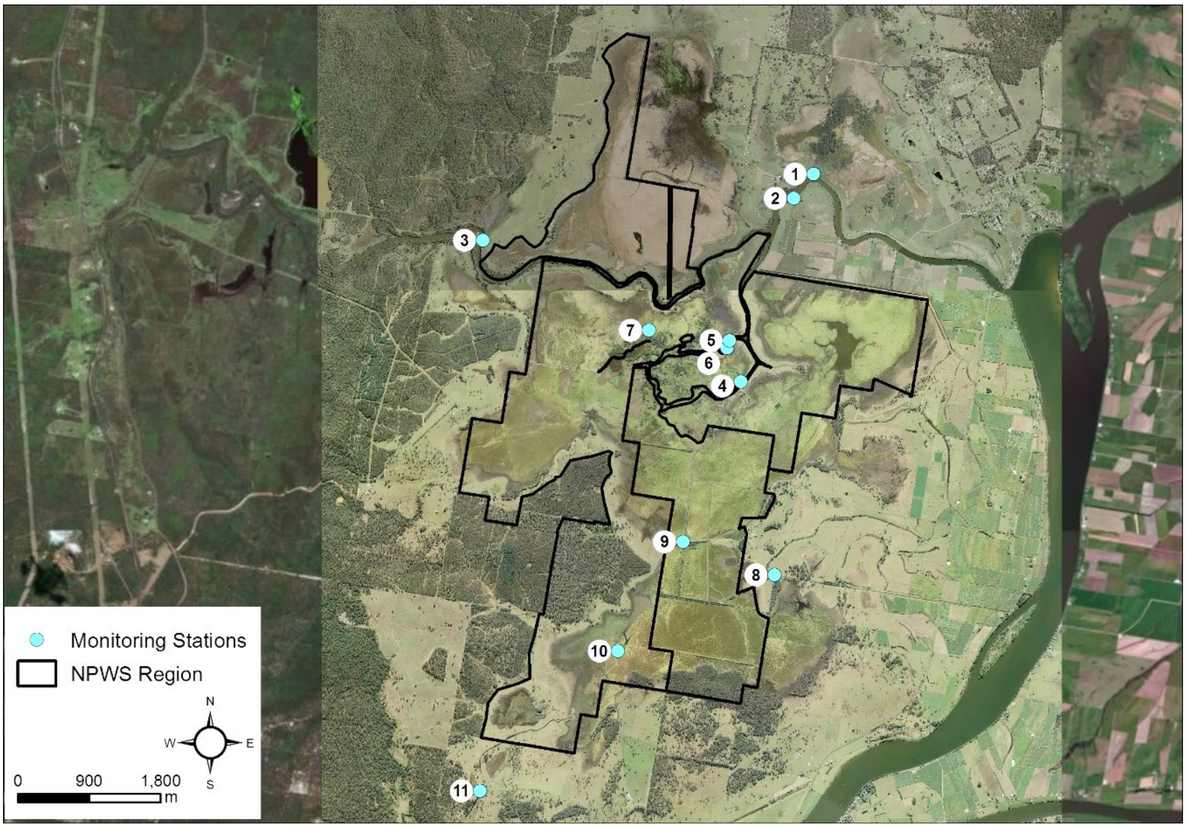


Figure C.22: Water Level Data Locations

Table C.3: Recorded Water Level Data

Site No.	Station Name	Easting (m)	Northing (m)	Start Date	End Date
1	Sportsmans Weir D/S	507208.843	6737650.579	18/11/16	16/08/17
2	Sportsmans Weir U/S	506962.109	6737345.789	18/11/16	16/08/17
3	Upper Sportsmans Creek	503038.169	6736815.111	11/11/16	15/08/17
4	Woody Creek Gates D/S	506296.580	6735031.310	23/12/16	16/08/17
5	Reedy Creek Gates D/S	506151.531	6735551.657	18/11/16	16/08/17
6	Reedy Creek Gates U/S	506121.223	6735453.157	18/11/16	16/08/17
7	Sportsmans 35/1	505134.456	6735679.266	08/02/17	16/08/17
8	Blanches Drain	506720.770	6732592.279	10/11/16	16/08/17
9	SCA Pump Station	505566.136	6733014.441	08/11/16	16/08/17
10	SCA Warragai	504740.494	6731632.558	09/11/16	02/04/17
11	Warragai Creek Crossing	503005.717	6729870.821	09/11/16	15/08/17

Table C.4: Water Levels Used for Sensor Corrections to AHD

Site No.	Date Time	Water Level (m AHD)	RTK-GPS Vertical Precision (±m)	Additional Corrections (m)
1	8/02/2017 8:49	0.314	0.032	-
2	9/02/2017 6:52	-0.117	0.038	-
3	11/11/2016 12:23	-0.048	0.054*	0.09*
4	8/02/2017 10:26	-0.085	0.036	-0.03
5	8/02/2017 11:31	-0.127	0.023	0.04
6	8/02/2017 11:49	-0.115	0.056	0.03
7	15/08/2017 17:18	0.014	0.02	-
8	16/08/2017 11:33	0.007	0.027	-
9	8/02/2017 16:25	-0.077	0.024	-
10	9/11/2016 15:45	0.179	0.053	-
11	9/11/2016 18:21	1.055	0.024	-

*Note - several measurements were taken in the same place with a vertical accuracy of at least ±0.1 m.

A summary of the water surface elevation data at Everlasting Swamp is provided in Figure C.23. Figure C.23 shows the range of water levels that were observed at Everlasting Swamp from December 2016 to August 2017. This data shows that the site experienced typical dry weather conditions during the summer months from December 2016 to early March 2017, where downstream water levels in Sportsmans Creek ranged approximately from -0.2 to 0.7 m AHD. This dry weather period preceded two (2) large catchment inflow events in March and April 2017, that completely inundated the Everlasting Swamp wetland complex. The recorded data shows that water surface elevations for both inflow events exceeded 1.5 m AHD across the site. The recorded data clearly depicts that the site experienced flooding from local catchment inflows, in addition to backwater flooding from the Clarence River. A third smaller inflow event was observed in June 2017, however, the site response was mainly driven by local catchment inflows as shown by the increase in water levels measured at the Upper Sportsmans Creek and Warragai Creek Crossing monitoring locations.

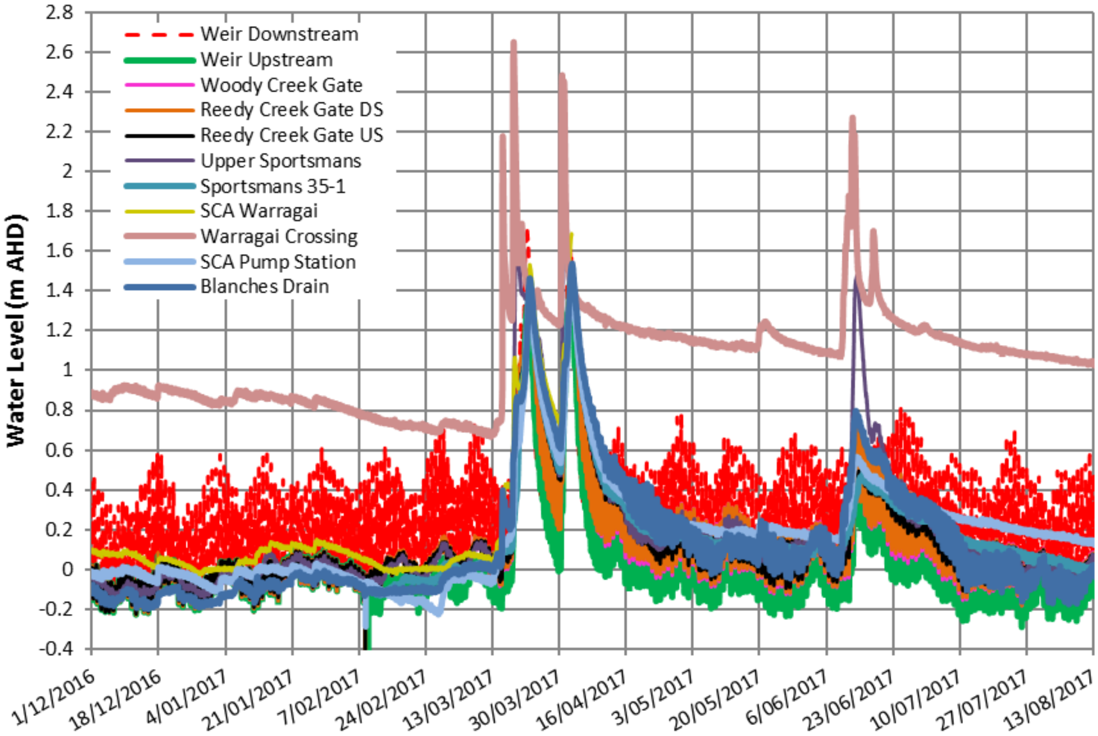


Figure C.23: Recorded Water Levels at Everlasting Swamp from December 2016 to August 2017

C.6 Acid Sulfate Soils

The location of a soil profile taken during the field investigation is provided in Figure C.24. The soil profile was excavated to approximately 1.0 m below the ground surface, equivalent to an elevation of 0.9 m AHD. Acidic soils were measured at the location with a pH ranging from 4.02 to 4.31. Sulfidic material was observed immediately below a layer of organic matter that was found at the surface. The soil profile was consistent with the ASS characteristics previously observed (Section B.7) across the Everlasting Swamp wetland complex and comprised of grey-brown Humic clays with iron and jarosite mottling. The soil profile log, along with sediment descriptions and reactivity test results, is provided in Figure C.25.

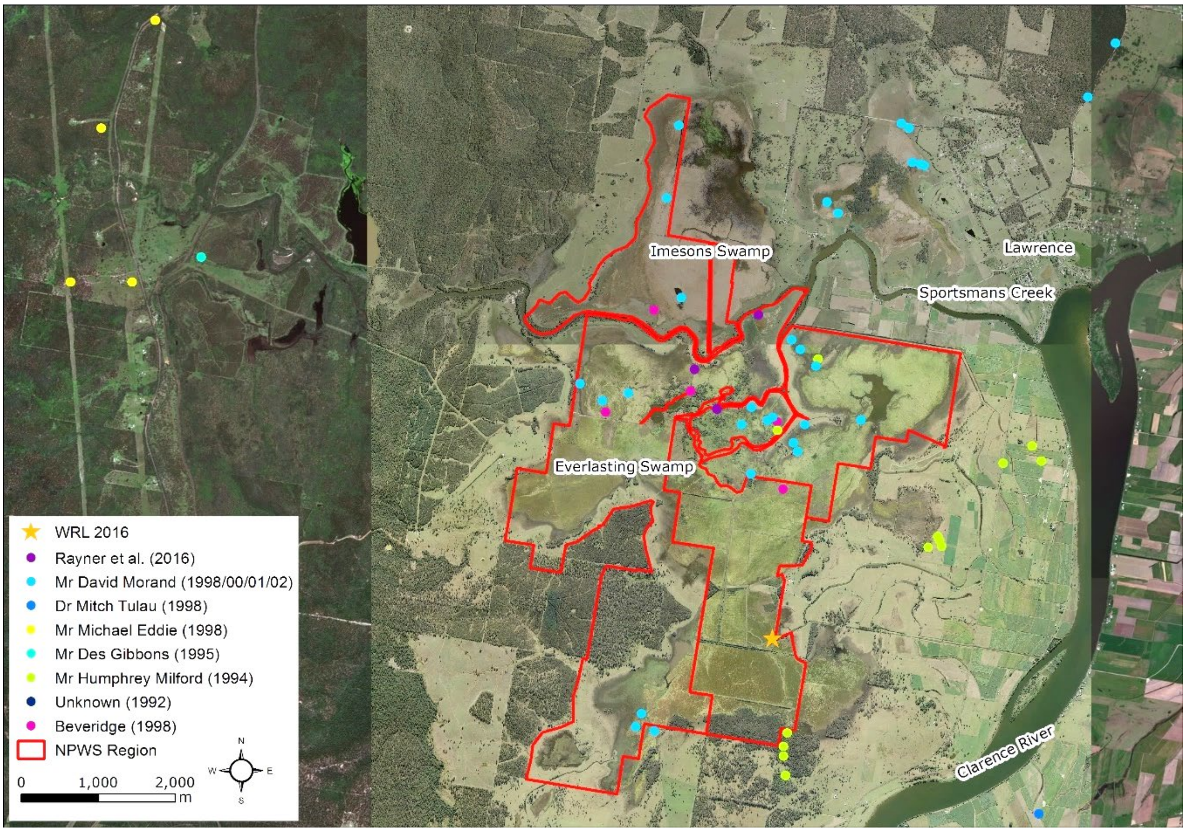


Figure C.24: Location of Additional Soil Profile During Field Survey

Water Research Laboratory

Location	P4
Date	10/11/16
Easting (m)	506209.157
Northing (m)	6732372.891
Elevation (m AHD)	0.119
Groundwater table (m depth)	0.259
Groundwater EC (μS/cm)	~700

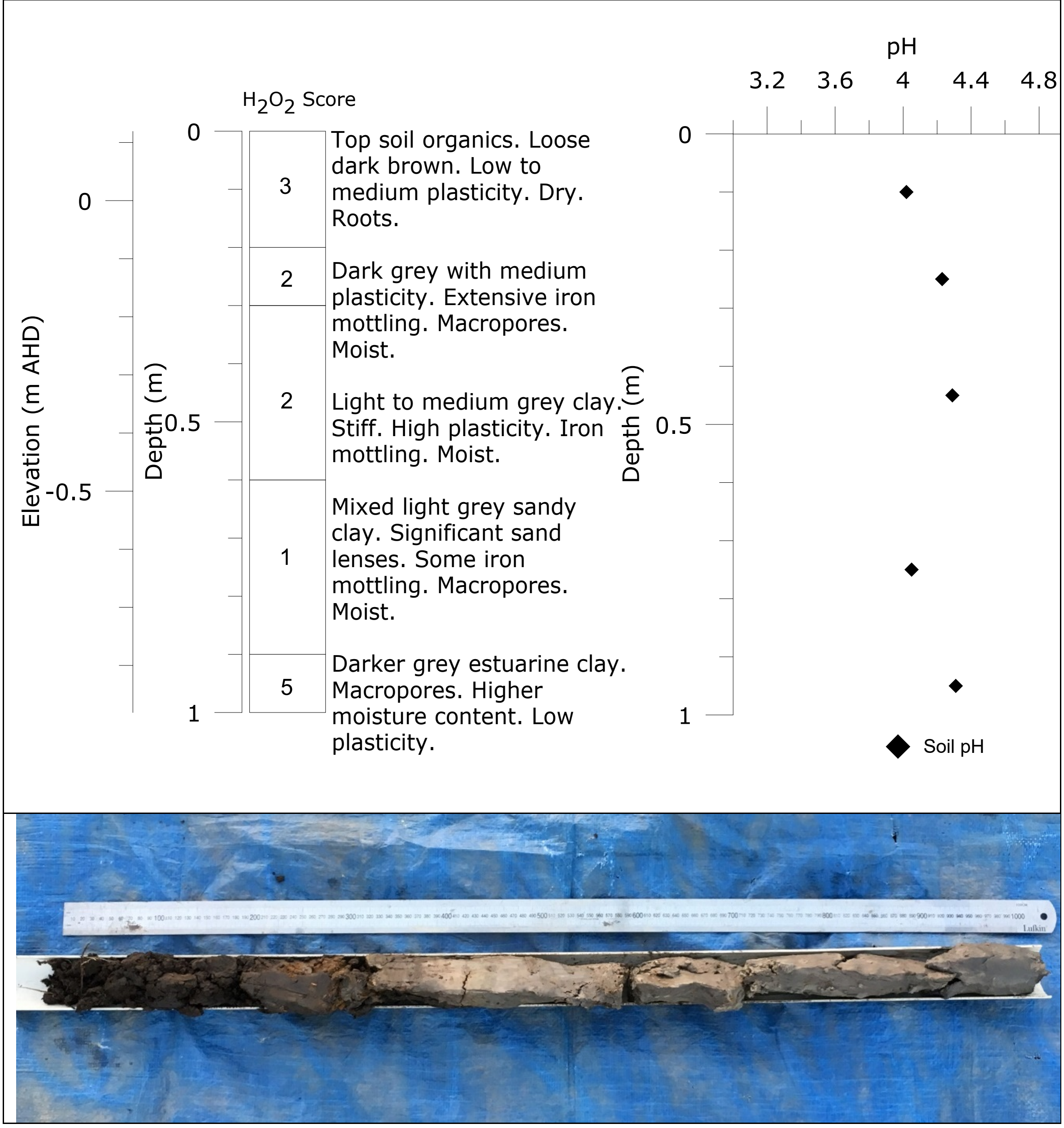


Figure C.25: Soil Profile During Field Survey

C.7 Water Quality

Surface water quality monitoring of the open areas of the wetland and across the floodplain drainage network was completed during the field investigations. Water quality parameters were measured during the ground survey using a calibrated YSI EXO-2 multi-parameter sonde, and included values pH and EC. The median value of surface water acidity observed in the eastern portion of Everlasting Swamp was a pH of 6.95, while EC in this area was observed to be 7,306 µS/cm (or ~4 ppt). However, the surface waters in Blanches Drain were measured to be more acidic, with a pH of 4.0. These observations were similar to previous surface water quality measurements taken by WRL and others across the study area (Sections B.8 and B.9).

A continuous timeseries of electrical conductivity data was also observed between November 2016 and August 2017, at three (3) of water level monitoring locations at the study site, as provided in Figure C.26. The locations of these data, included:

- Upstream of Sportsmans Creek Weir;
- Downstream of Woody Creek 33/1 floodgates; and
- Upper Sportsmans Creek.

This data showed that the salinity in Sportsmans and Woody Creeks were approximately the same concentrations during the monitoring period. This supports the premise that EC in the drainage channels of Everlasting Swamp would likely be the same salinity concentration found in Sportsmans Creek. Furthermore, salinity levels appeared to be lower in the upper section of Sportsmans Creek, where the system becomes more like a tidal freshwater pool. The observed data at these locations was based on the current operation of the Sportsmans Creek Weir.

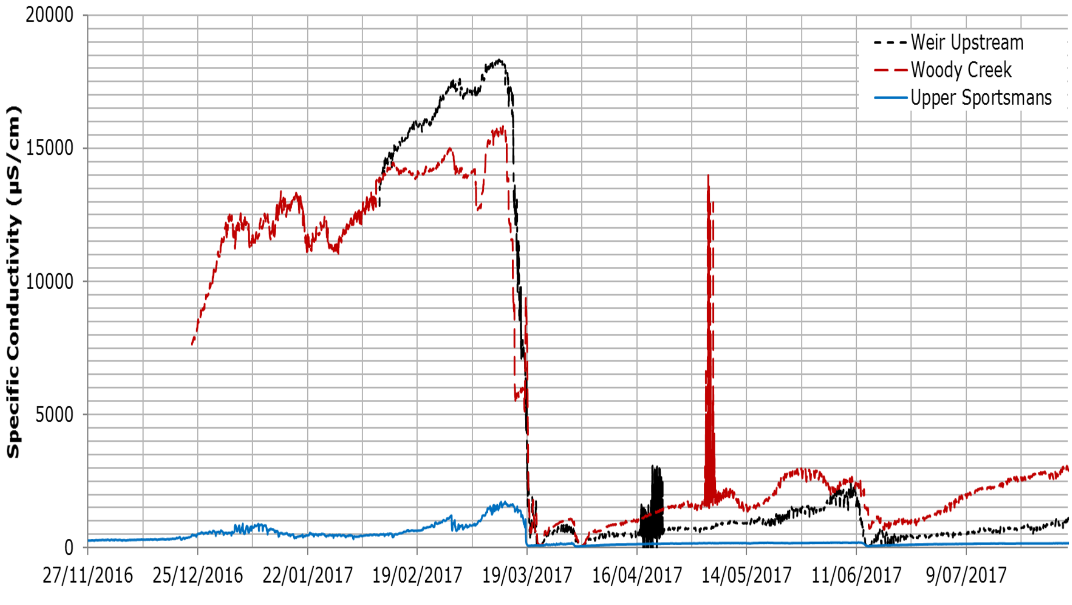


Figure C.26: Observed Electrical Conductivity Data at Everlasting Swamp

Appendix D – Model Development

D.1 Preamble

The management issues of the Everlasting Swamp wetland complex are well established. As per the project brief, a thorough understanding of the dynamics of water flows on properties upstream of the Sportsmans Creek Weir is essential to guide onsite management actions. In wetland projects, hydrodynamic modelling is used to simulate different on-ground strategies and quantify potential impacts and risks in terms of inundation areas, flooded depths, flow distributions and velocities, and hydro-period. These models can also be used to qualitatively assess associated ecological outcomes following on-ground works.

The modelling approach was formulated based on WRL's assessment of the overall objectives of the study. MIKE Flood was used to establish a dynamically linked 1-D/2-D hydrodynamic numerical model of the Everlasting Swamp wetland complex. LiDAR data at Everlasting Swamp and Imesons Swamp was ground-truthed and adopted as the topography of the numerical model. The model geometry and boundary conditions were based on field observations and measurements, catchment modelling results and the current understanding of how the site functions. The boundary conditions applied in model, included forcing the model with local catchment inflows and representative tides at Lawrence.

Note that irrespective of the model size and complexity, a hydrodynamic model is a predictive tool that incorporates site characteristics and field data into a mathematical approximation of reality. This is achieved by dividing the study area into discrete pieces (or grid cells) and applying mathematical equations within each grid cell to simulate real world systems. A mathematical algorithm (or model) is then used to solve the mathematical equations in each grid cell at each model time step. Once the model has been developed and calibrated to real world observations (e.g. water levels, flow etc.), it can be used as a predictive tool to test "what if" scenarios.

D.2 Bathymetry Data

D.2.1 Ground-truthed LiDAR

Extensive ground elevation survey data collected in 2002/03/16/17 was used to ground-truth available LiDAR survey data (flown in March 2010) of the Everlasting Swamp wetland complex. Onsite ground survey measurements (see Section C.2) were plotted against interpolated LiDAR returns at the same locations, as provided in Figure D.1. Figure D.1 shows that the LiDAR returns are approximately 0.15 m higher in elevation than the ground survey points. This was likely due to open water areas, ground cover and dense vegetation at the time of the LiDAR survey. Based on the ground-truthing exercise, the areas of the floodplain that were likely underwater or densely vegetated at the time of the LiDAR survey, were corrected using the ground survey data to create a revised DEM of the site. GIS techniques were used to create the final DEM of the study area, as provided in Figure D.2. A comparison between the ground survey measurements and the corrected DEM at the same locations, is provided in Figure D.3. Note the final DEM was used to create the bathymetry for the 2D model domain.

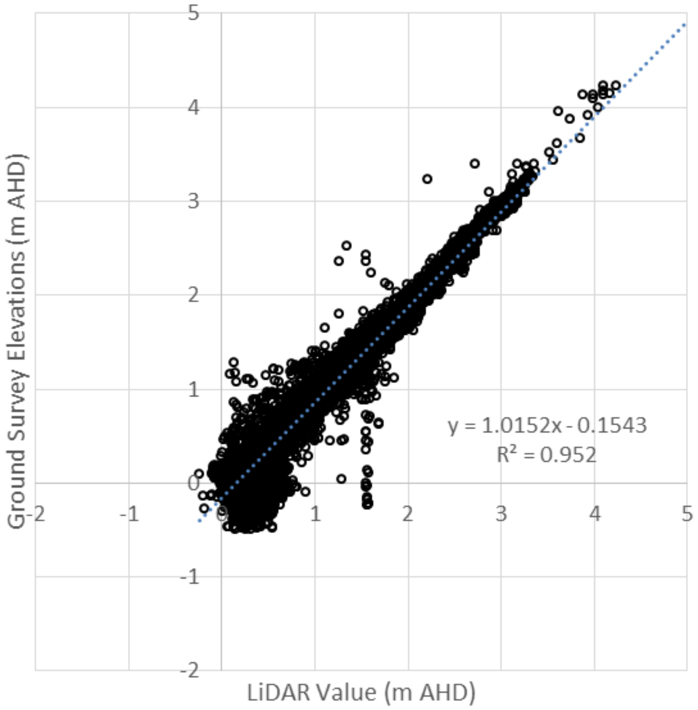


Figure D.1: Comparison of LiDAR and Ground Survey Elevations

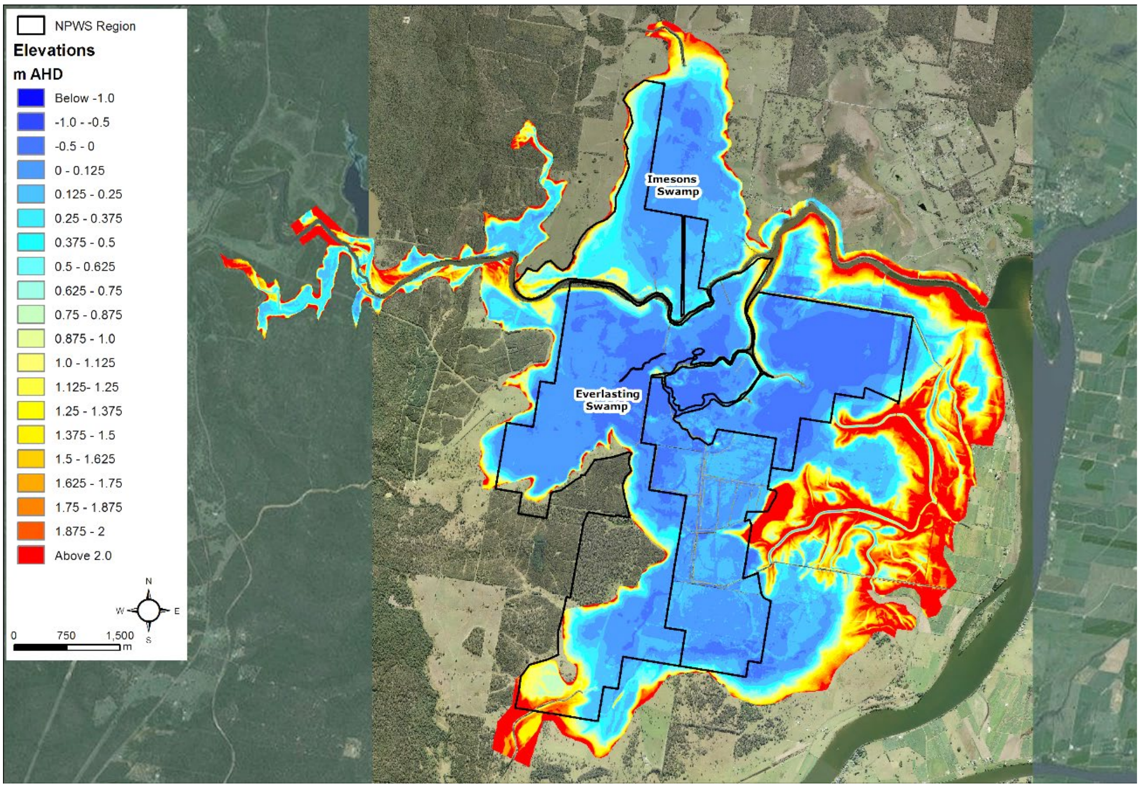


Figure D.2: Model Extent and 2D Bathymetry

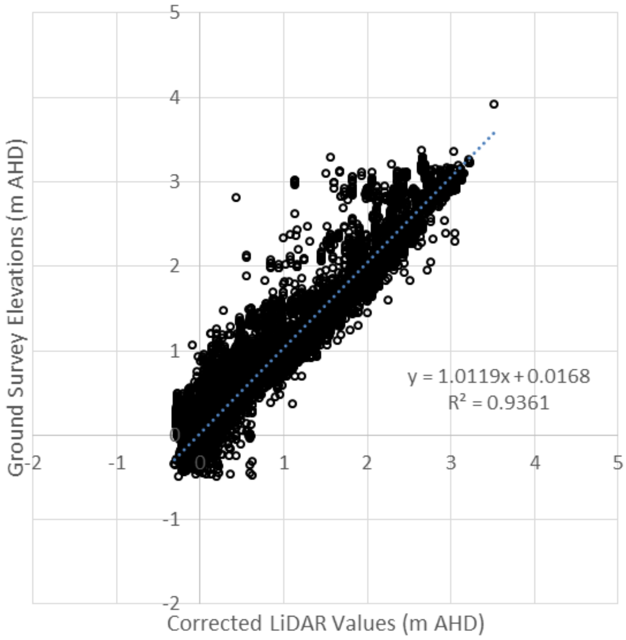


Figure D.3: Comparison of Corrected LiDAR Values and Ground Survey Elevations

D.2.2 Stage-Volume Relationship

A key step in assessing the potential inundation response of the site was to develop a stage-storage relationship from the site topography. The stage-volume relationship indicates the volume of water below a certain elevation in the DEM. Volume data was extracted for the site using the DEM at a range of water levels as provided in Figure D.4. The stage-volume relationship for the site indicated that the storage capacity of the study area upstream of the Sportsmans Creek Weir, below mean high water, is approximately 6,000,000 m^3. Further, the volume of water entering Sportsmans Creek over a single tidal cycle (~6.2 hours) was estimated to be 500,000 m^3. Therefore, by removing the Sportsmans Creek Weir it could be expected that the whole site would be flushed in 12 average tidal cycles, or approximately six (6) days.

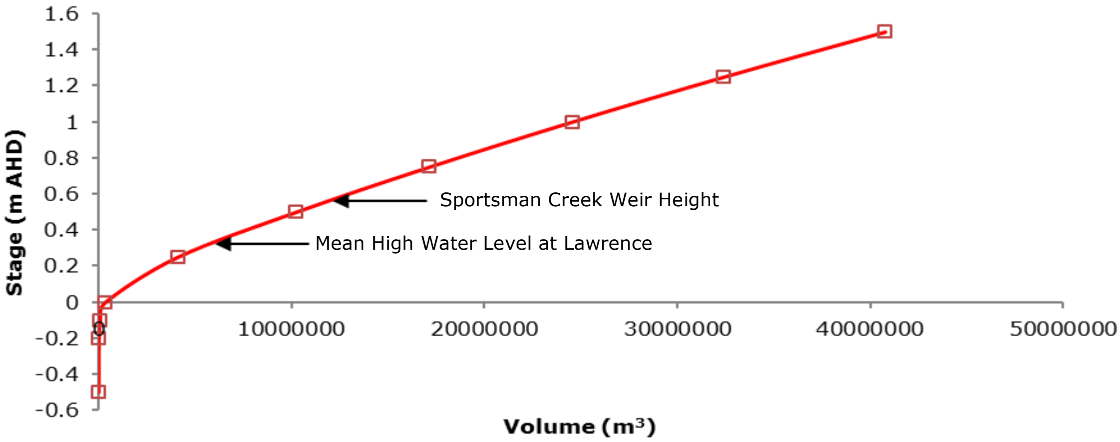


Figure D.4: Everlasting Swamp Wetland Complex Stage-Volume Relationship for the Final DEM

D.2.3 Model Domain

A MIKE 21 Flexible Mesh (FM) was selected for the model grid representing the 2-D model domain of the study area. A MIKE 21 FM was selected for the 2-D model domain due to the computational advantages of an unstructured grid and stability in dealing with shallow water depths across floodplains. For this study, the model grid contained approximately 133,000 triangular computational elements ranging in size from approximately 10 m^2 to 500 m^2, with a median area of approximately 300 m^2. The model grid was auto-generated using the MIKE Flood Mesh Generator which provided greater resolution in areas around the channel drainage network and reduced resolution across open floodplain areas.

A 1-D model of the floodplain drainage channels was also developed. Channel geometry and hydraulic control structures were used to represent the 1-D channel drainage network. The 1-D model extent and structures included in the model are provided in Figure D.5. Available channel survey data used to build the 1-D model (Section C.4). Note that where channel survey data was unavailable, channel geometry was interpolated or extrapolated from the nearest survey data or available historical bathymetry (Section B.5).

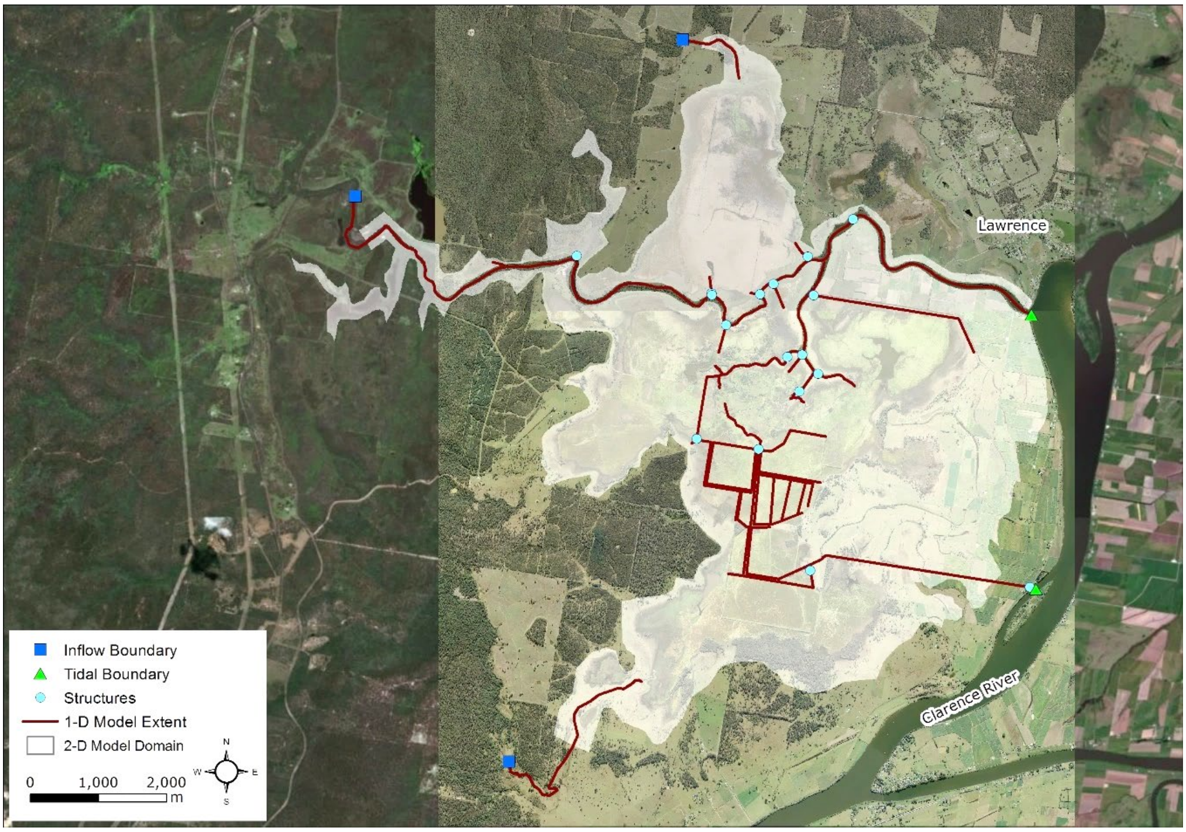


Figure D.5: 1-D Model Extent and Flow Control Structures Included in the MIKE Model

D.3 Boundary Data

The inflow boundaries of the 1-D model are provided as local catchment inflows from Sportsmans, Warragai and Duck Creeks, and tidal water levels at the confluence of Sportsmans Creek and the Clarence River. Each of these conditions are briefly discussed in the following sub-sections.

Note that salinity was not modelled in this study. Recall that previous studies indicated the surface waters at Reedy Creek reached salinities of approximately 50% seawater during dry periods, while all floodgates were operational. As such, it was assumed conservatively that under a restoration scenario, the salinities of tidal waters inundating different areas of the floodplain are equivalent to the salinities of the incoming tide in Sportsmans Creek. However, further modelling investigations would be required to determine predicted salinity distributions and concentrations in different areas of the floodplain under a restoration scenario.

D.3.1 Sportsmans Creek Inflows

Daily measured flow data for Sportsmans Creek from 28 February 1972 to present day was provided by the NSW Office of Water (NOW) at the Gurranang discharge gauging station (NOW station ID 204055). No data gaps existed within the measured record for the 2016-17 model simulation period.

Note that although this boundary condition was applied at the most upstream element on Sportsmans Creek (approximately 6.5 km upstream of the Lawrence Drain No.3), the NOW measurement station is located a further 5.5 km upstream at Gurranang. Due to the relatively coarse time step for inflows (daily), this assumption was considered reasonable, but it may result in the model "leading" the measured discharge data by a short period of time.

D.3.2 Catchment Modelling

An AWBM catchment model was developed to quantify ungauged catchment inflows for the Everlasting Swamp hydrodynamic model. AWBM is a catchment water balance model that calculates runoff from rainfall that has been extensively shown to be representative for Australian catchments.

Daily rainfall and evaporation data for the AWBM model was sourced from the Bureau of Metrology (BoM) at three (3) gauges within the study area. Information about the rainfall and evaporation data, as well as the gauging location, is provided in Figure D.6 and Table D.1. Rainfall and evaporation data for 2016-17 was assigned to each catchment by best matching the meteorological conditions of the site to the surrounding gauges. For this study, data obtained from the Lawrence Road (Pringles Way) station was used in preference to other rainfall gauges. Where data gaps or poor-quality data existed within the measured record, data from Grafton Research Station was used to fill the data gaps. Customised computer code was used to pre-process the BoM data into the format used by AWBM. Note that catchment boundaries were developed using ESRI ArcMap GIS software.

Table D.1: Rainfall and Evaporation Data for AWBM Model

Station Name	Station ID	Period	Rainfall Data Available	Evaporation Data Available
Lawrence Road (Pringles Way)	058068	2001-present	Yes	No
Grafton Research Station	058077	1917-present	Yes	Yes
Lawrence Post Office	058033	1884-2015	Yes	No

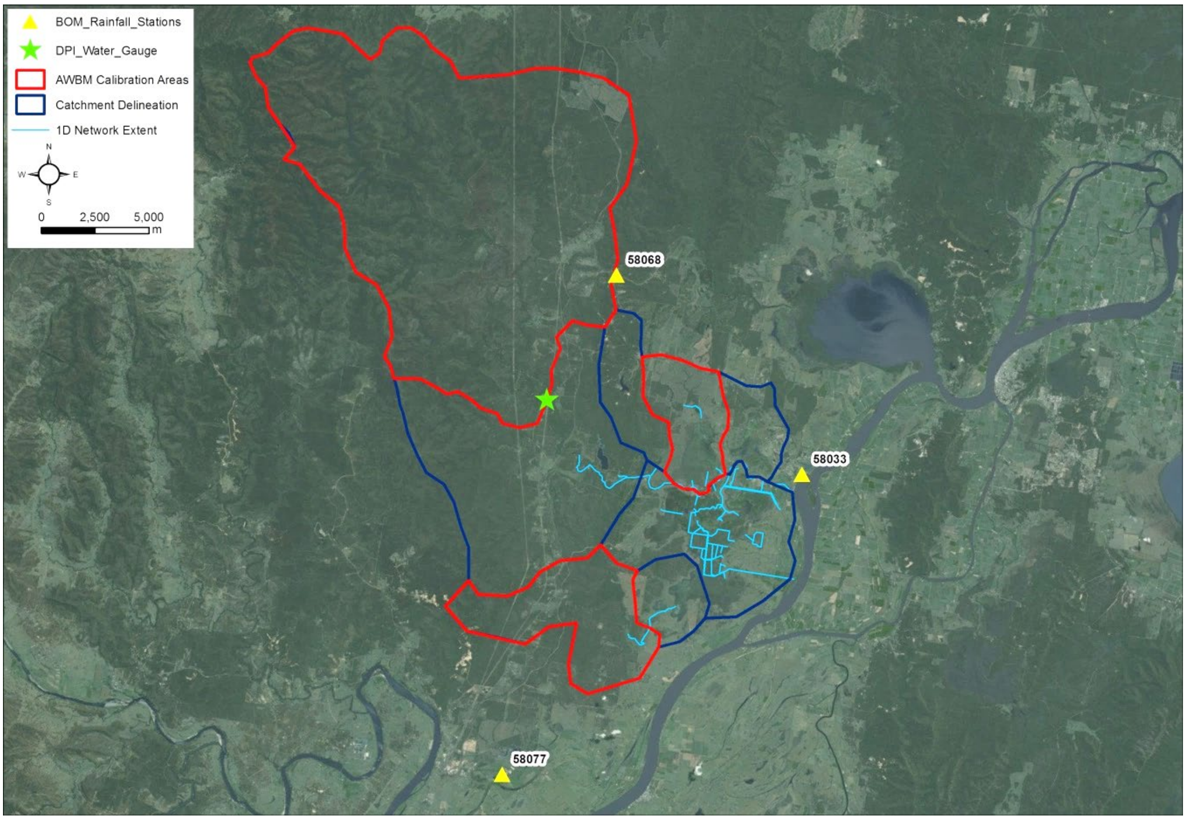


Figure D.6: Sub-Catchment Delineation of the Everlasting Swamp Region

A daily runoff record was generated for each catchment using AWBM and applying methods developed for ungauged catchments on the south-east coast of Australia (Boughton and Chiew, 2007). An annual time-series of streamflow data for 2016-17 from the Sportsmans Gurranang gauge was compared to the predicted runoff volumes from the contributing catchment for rainfall recorded in the same year. Figure D.7 shows the time-series of predicted and observed runoff from the NOW streamflow gauge at Sportsmans Gurranang. The predicted and observed runoff show reasonable agreement, in terms of flow timing and magnitudes, for the modelled period. Note that for this study, it was assumed that land-use type, vegetation, and the proportion of pervious and impervious surfaces, was the same for each of the AWBM calibration areas.

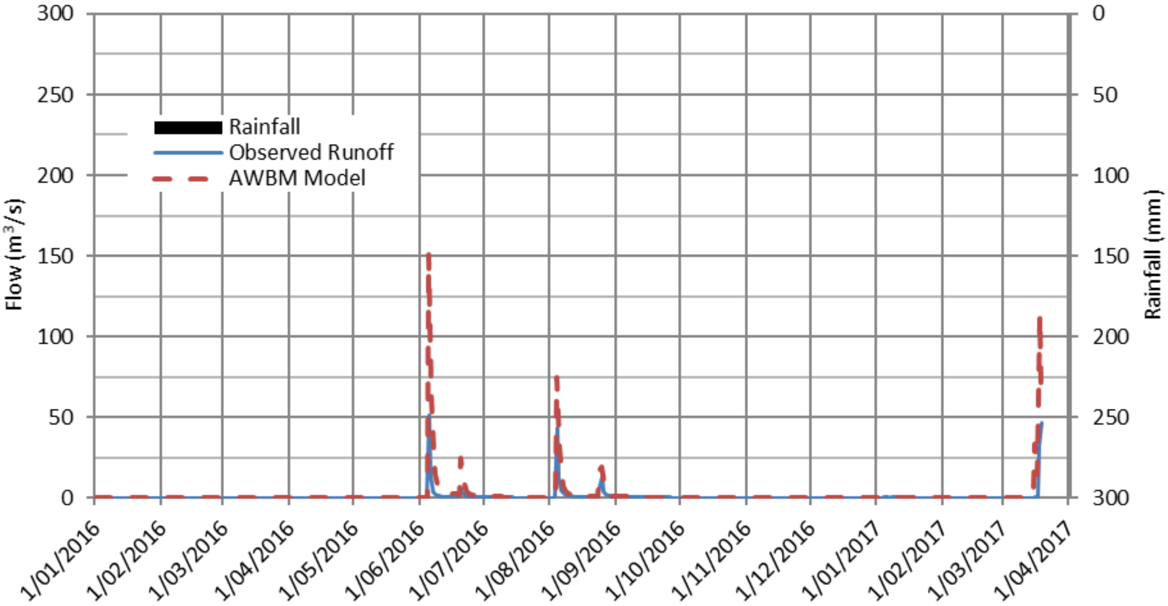


Figure D.7: Predicted and Observed Runoff for the Catchment Area Upstream of the NOW Gauging Location at Sportsmans Gurranang

D.3.3 Tides at Lawrence

Measured tide data from 11 November 2002 to present day at Lawrence (station ID 204453) on Clarence River, was provided by the Manly Hydraulics Laboratory (MHL). Data was recorded at 15-minute intervals in Australian Eastern Standard Time (AEST) and supplied with levels reported to AHD. The tidal boundary condition was applied in the model with a 15-minute time step that was offset (+1.0 hour) to account for the water level loggers installed at the site recording in Australian Eastern Standard Daylight (Savings) Time (AESDT).

Note that although this boundary condition was applied at the confluence of Sportsmans Creek and the Clarence River, the measurement station is located approximately 1.0 km downstream. Due to the close proximity of the gauge to the entrance of Sportsmans Creek, this application was considered appropriate and will not result in a phase shift of the tidal wave.

For the selected model simulation period from 27/11/2016 to 22/02/2017, a peak water level at Lawrence of 0.62 m AHD was observed on 28/01/2017. The exceedance probability of water levels at Lawrence is provided in Figure D.8. Figure D.8 shows that a peak water level at Lawrence of 0.62 m AHD on 28/01/2017 is exceeded <5% of the time for all recorded levels since November 2002. This confirms that the simulation period covered the full range of water levels expected at Everlasting Swamp.

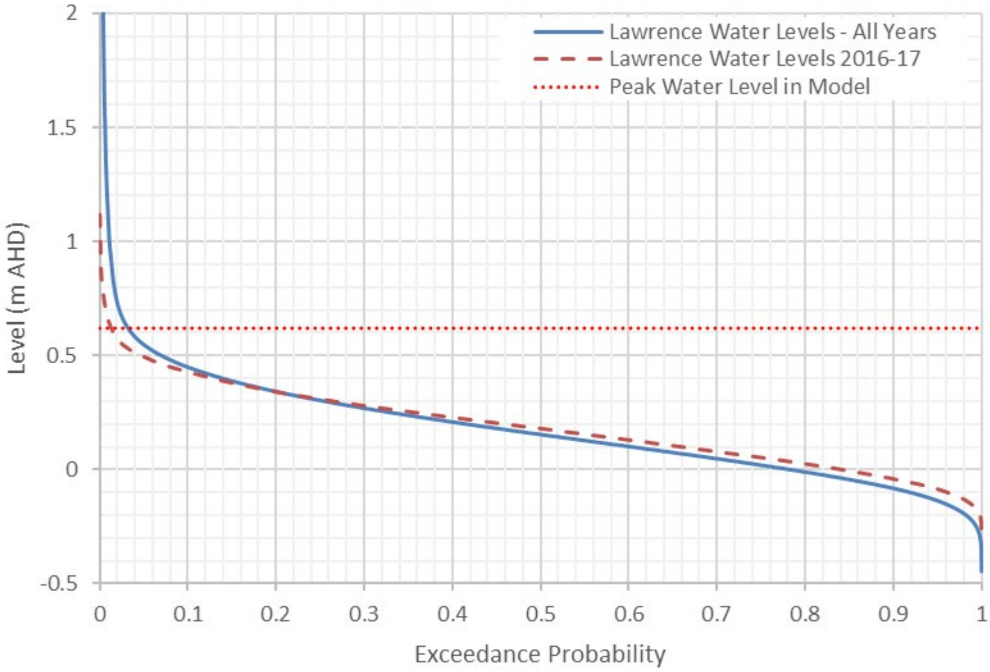


Figure D.8: Exceedance Probability of Water Levels at Lawrence Tide Gauge

Note that salinity data was also provided by MHL at the Lawrence gauge from 1 May 2014 to present day. Data was recorded at 15-minute intervals and supplied in practical salinity units (PSU). Note that 1 PSU = 1 ppt. For the observation period, the data ranged between 0 and 19.67 ppt, with a mean of 5.68 ppt and a median value of 5.53 ppt. Note that typical ocean salinities are approximately 35 ppt.

Appendix E – Model Calibration

E.1 Preamble

This section provides the results of the hydrodynamic model calibration. Model calibration involves adjusting model parameters so that when a known set of external boundary conditions are applied, the model reproduces field measurements made within the model domain. To determine if the model is 'fit for purpose' and capable of testing any proposed modifications to the existing drainage system, the model was run to simulate onsite conditions during January 2017, that were measured by installed water level loggers (Section C.5). The model geometry and boundary conditions were based on observations and measurements as discussed in Appendix D.

E.2 Model Calibration

E.2.1 Period of Calibration

The MIKE hydrodynamic model was simulated for the period from 27 November 2016 to 22 February 2017, using a 5-second timestep. The period from November 2016 to February 2017 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 in late January 2017, during high spring tides.

E.2.2 Internal Model Parameters

Model friction (Manning's "n") was adjusted to match the observed water levels and phasings throughout the model domain. This was essentially the only hydrodynamic model calibration parameter. The adopted Manning's "n" values selected for the calibrated model are shown in Table E.1. A roughness value of 0.03 was adopted for all elements throughout the 2-D model domain and most of the 1-D channel network. This roughness value is within the range of reported industry accepted values (Chow, 1959) for clean natural channels and floodplains, and was assumed to be a conservative estimate of the current onsite conditions at Everlasting Swamp and Imesons Swamp. For sections of Sportsmans Creek and Blanches Drain, different Manning's "n" values were applied to simulate the channel flow conditions observed during the field investigations (Table E.1).

Table E.1: MIKE Model Roughness Parameters

<table>
<tr><th>Model</th><th>Location</th><th>Chainage from upstream (m)</th><th>Manning's n</th></tr>
<tr><td>2-D</td><td>Floodplain</td><td>-</td><td>0.03</td></tr>
<tr><td rowspan="7">1-D</td><td>Channels</td><td>-</td><td>0.03</td></tr>
<tr><td rowspan="4">Sportsmans Creek</td><td>11,080</td><td rowspan="2">0.025</td></tr>
<tr><td>14,470</td></tr>
<tr><td>0</td><td rowspan="2">0.05</td></tr>
<tr><td>10,277</td></tr>
<tr><td rowspan="2">Blanches Drain</td><td>0</td><td rowspan="2">0.05</td></tr>
<tr><td>3,060</td></tr>
</table>

E.2.3 Water Surface Elevations

Water surface elevation data at nine (9) locations across the study area were used for model calibration (Figure C.22). Figure E.1 to Figure E.8 show the recorded (green line) and calibrated model predictions (dashed black line) for water levels from 20/01/2017 to 31/01/2017. Recorded and predicted water levels matched to within 0.1 m for all 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.

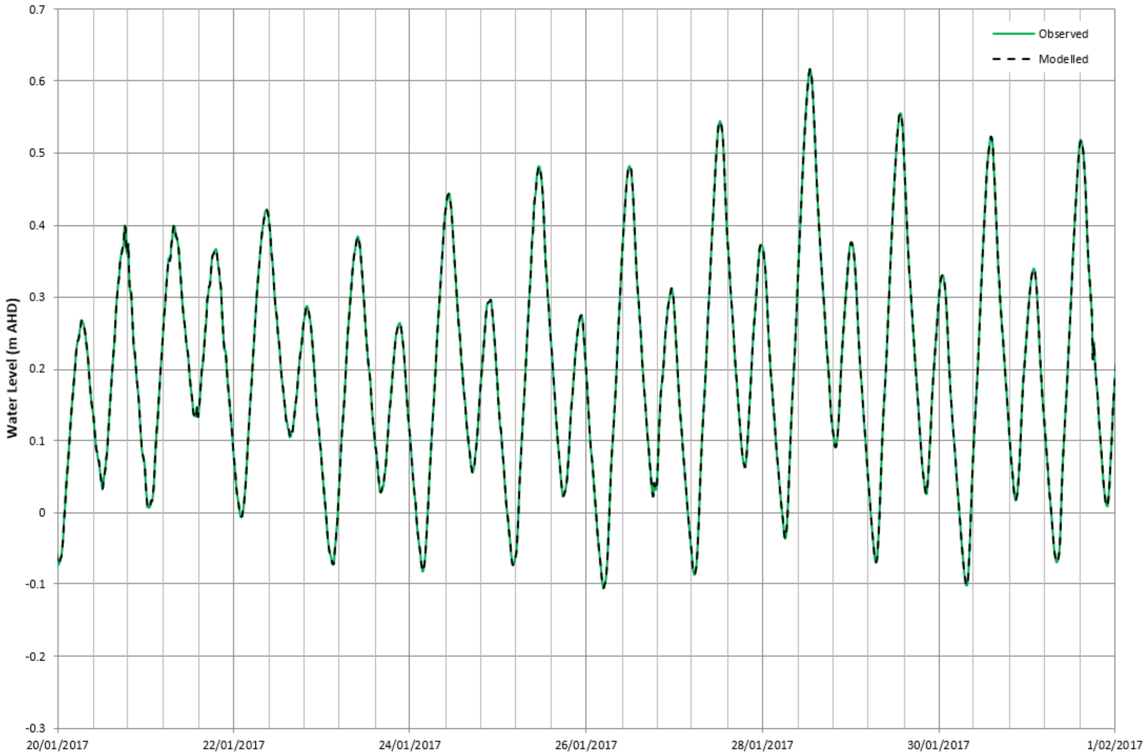


Figure E.1: Observed and Predicted Water Level – Sportsmans Creek Boundary – January 2017

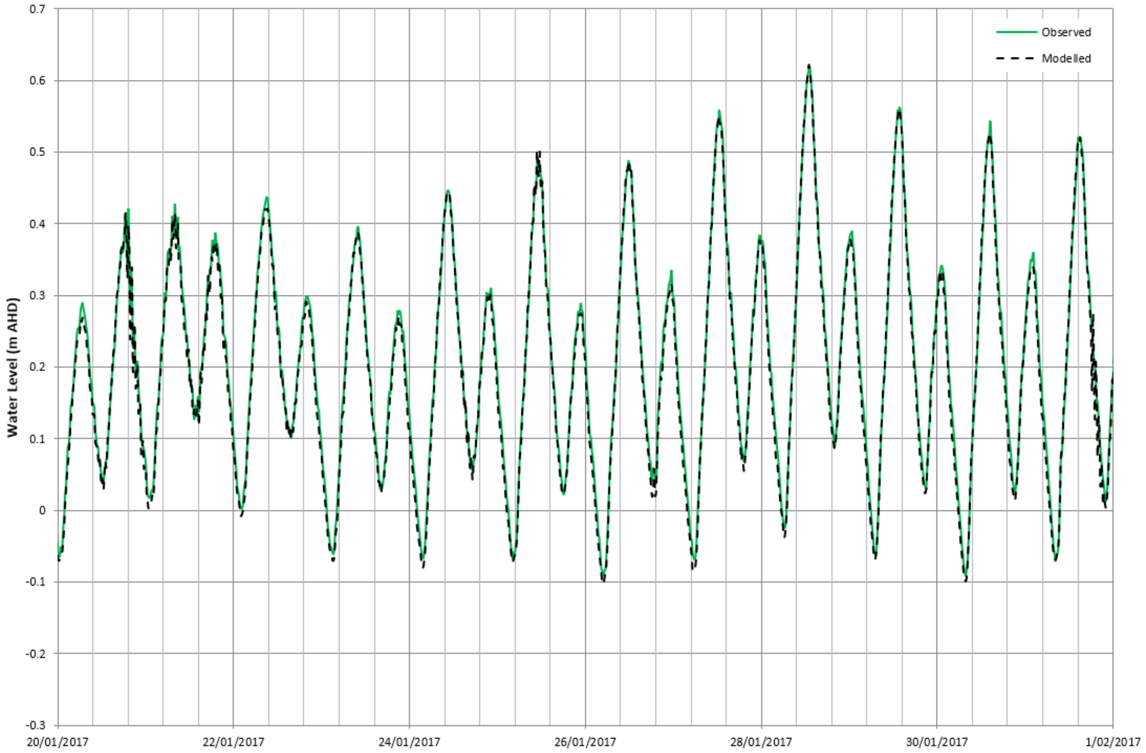


Figure E.2: Observed and Predicted Water Level – Downstream Sportsmans Weir – January 2017

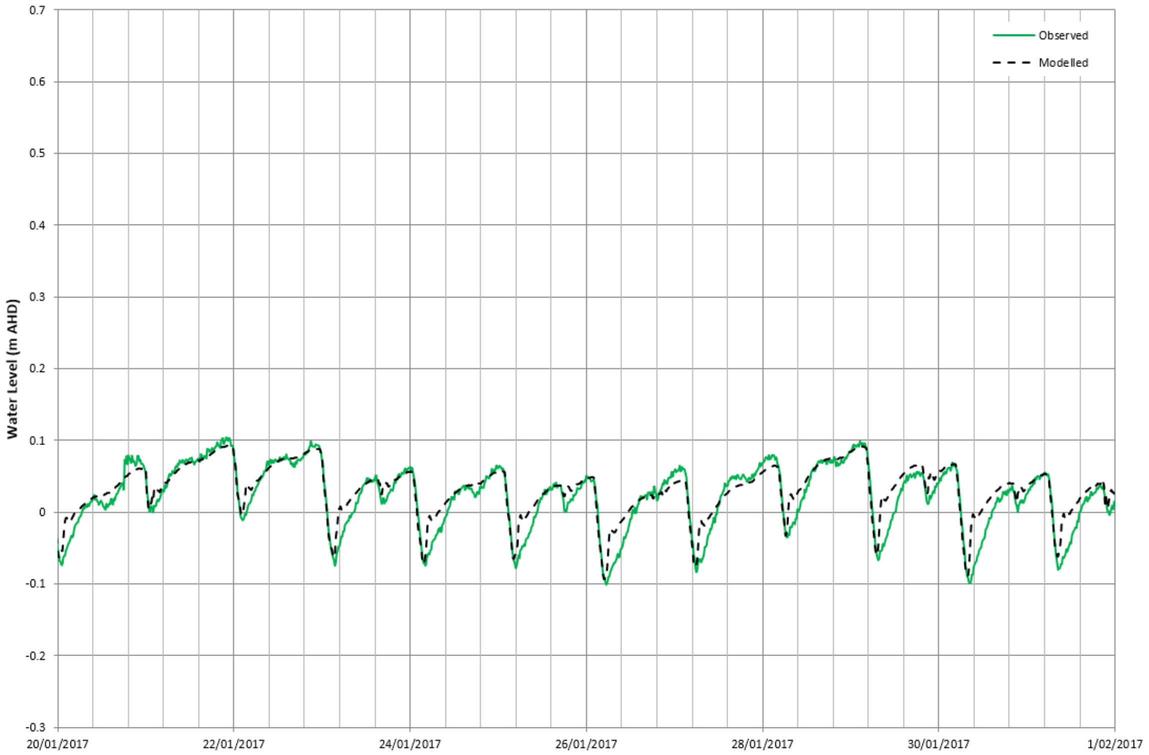


Figure E.3: Observed and Predicted Water Level – Upstream Sportsmans Weir – January 2017

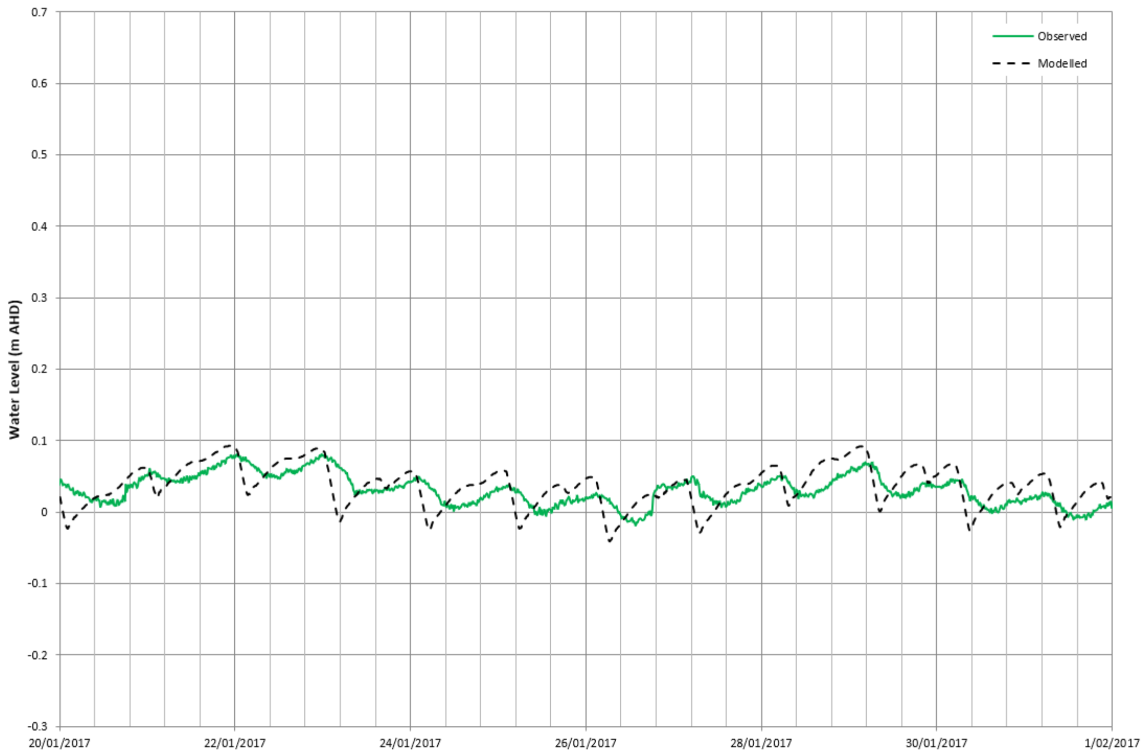


Figure E.4: Observed and Predicted Water Level – Upstream Sportsmans Creek – January 2017

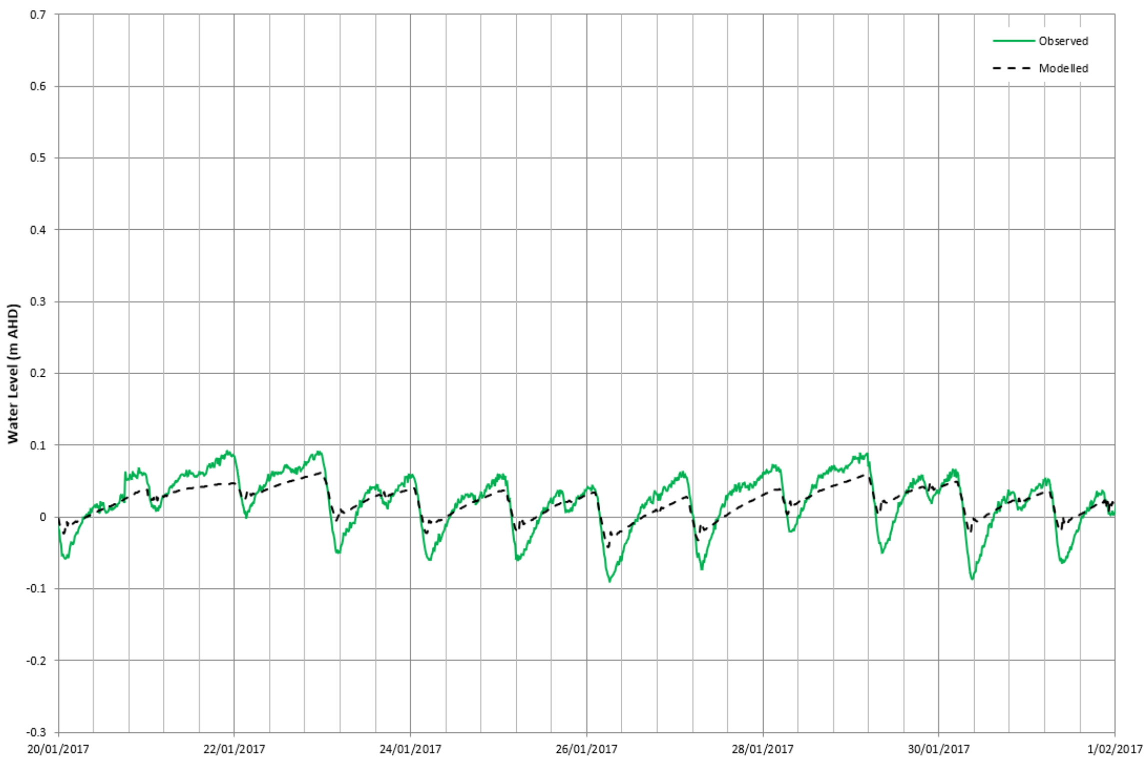


Figure E.5: Observed and Predicted Water Level – Upstream Reedy Creek Gates – January 2017

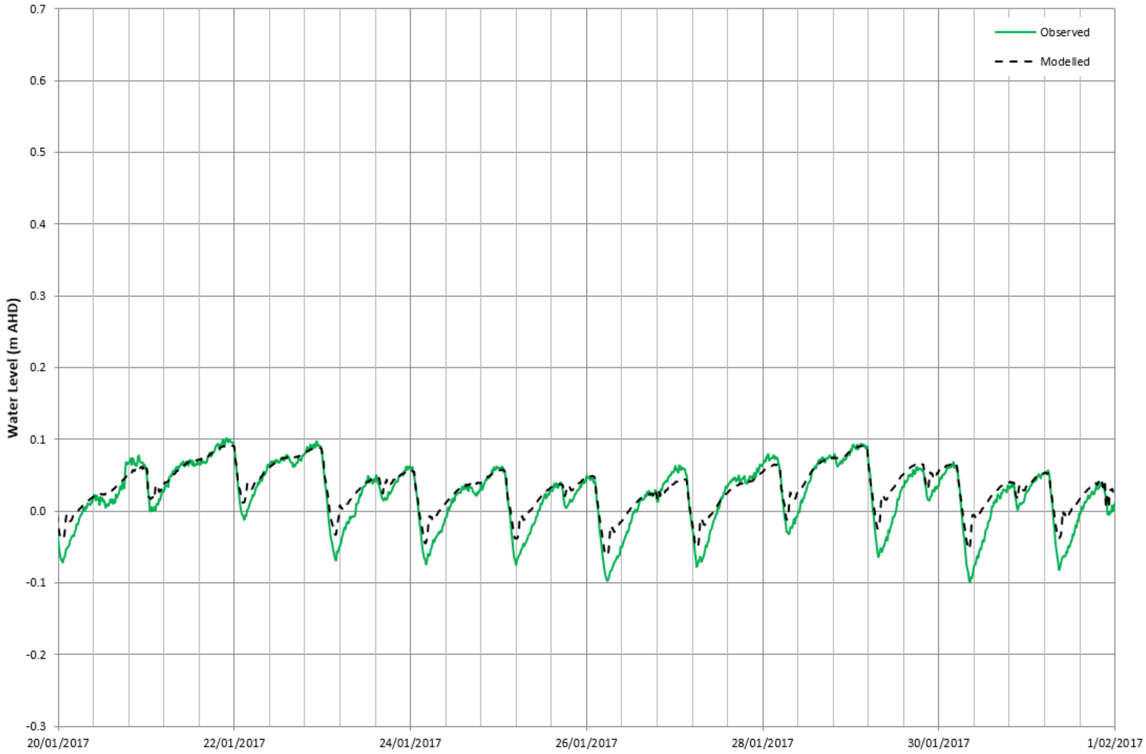


Figure E.6: Observed and Predicted Water Level – D/S Reedy Creek Gates – January 2017

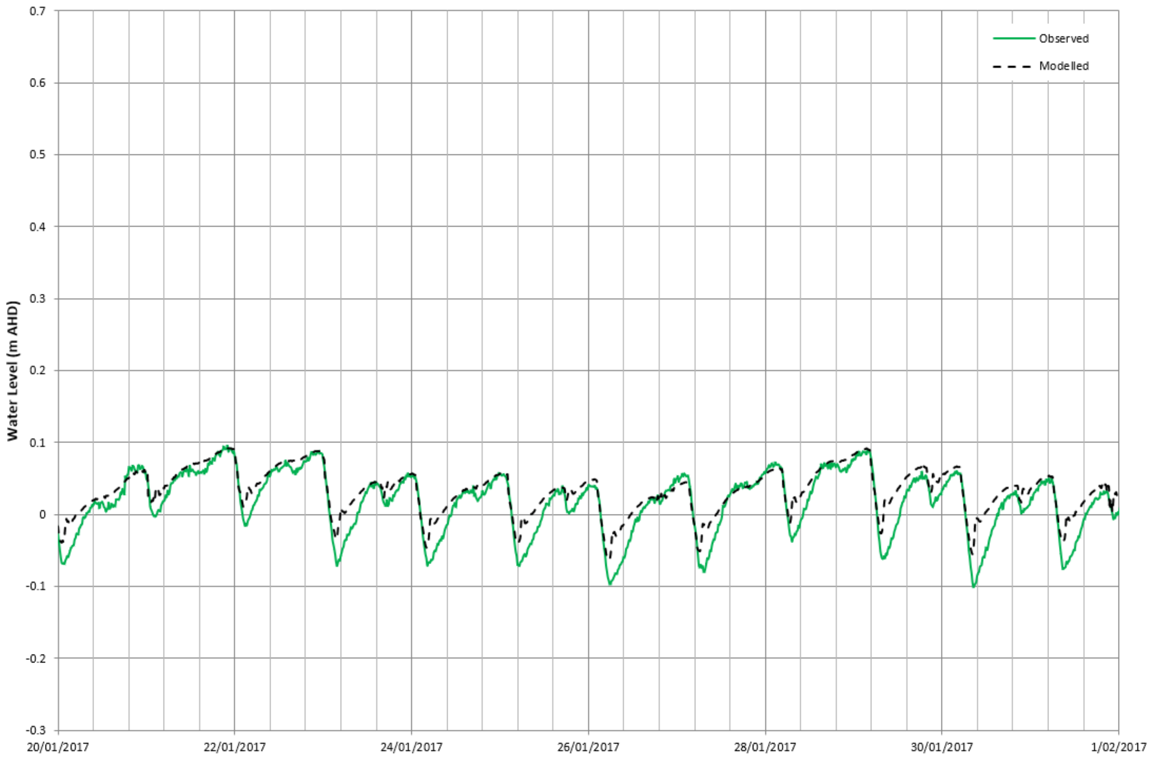


Figure E.7: Observed and Predicted Water Level – D/S Woody Creek Gates – January 2017

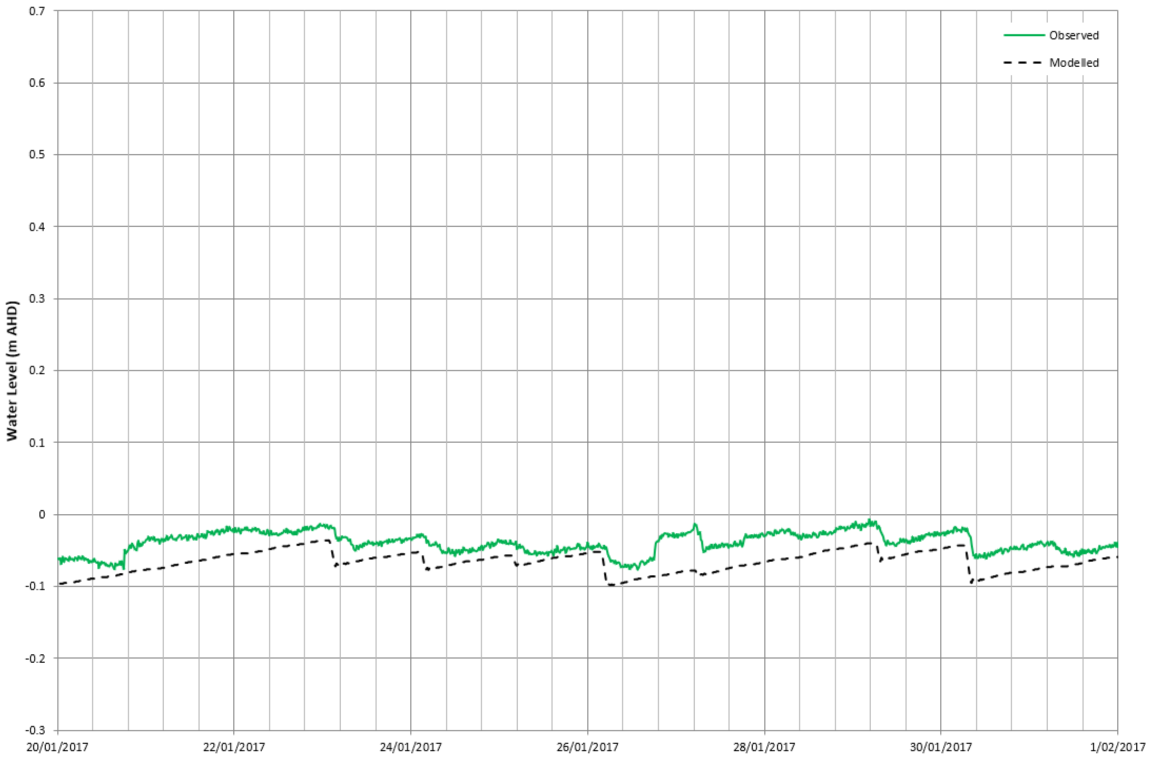


Figure E.8: Observed and Predicted Water Level – Blanches Drain – January 2017

Appendix F – Scenario Modelling

F.1 Preamble

The numerical hydrodynamic model was developed to compare the relative impacts of various proposed remediation options at Everlasting Swamp and Imesons Swamp, particularly in terms of the potential inundation of private properties adjacent to the NPWS management area. In developing a restoration plan for Everlasting Swamp, potential on-ground options were rationalised into a series of scenarios for model testing. The list of scenarios modelled were tested in three (3) stages, as provided in Table F.1. The stages were as follows:

- Stage 1: Scenarios 1 – 11 used a baseline model of the study domain;
- Stage 2: Scenarios 12 – 15 used an updated model of the study domain following additional field investigations completed in August 2017; and
- Stage 3: Scenarios 16 – 19 used an updated model of the study domain following refinements around Sportsmans Creek Weir and Round Mountain.

Each of the model scenarios were simulated for the period between 27/11/2016 and 22/02/2017, except for Scenarios 14 and 15, which were simulated for a 12-month period beginning from 01/01/2010. Scenarios 14 and 15 were modelled to assess the implications of wetting and drying patterns across the study area over a longer duration, compared to the shorter simulation period from 27/11/2016 to 22/02/2017. The longer duration model also provided an indication of the relative impacts of tidal restoration on localised flooding of private properties adjacent to the National Park.

Note that based on locally available rainfall data records and long-term rainfall data statistics obtained from the Bureau of Meteorology (BOM), 2010 was selected as a representative average rainfall year for the Everlasting Swamp area. However, like the large rainfall events that occurred in March and April 2017, a rainfall event of similar magnitude also occurred in October 2010 that completely inundated the Everlasting Swamp floodplain. For this study, the October 2017 rainfall event was excluded from the analysis of the model results to avoid bias in the statistical results.

For each tested scenario, the model results were analysed in terms of inundation extents (maximum, minimum, mean) and changes to wetting-drying patterns (hydroperiod), compared with the existing conditions. 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 model simulation periods. For this calculation, inundation areas were defined by water depths of greater than 0.05 m, 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 MIKE DataStatisticsFM. The hydroperiod was calculated using the following equation:

$$\%\ time\ wet = \left(\frac{E \times \bar{L} \times \Delta t}{T}\right) \times 100$$

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.

Analysis of the model results provided information on the relative influence of changes to hydrologic conditions across the study area as a function of time. Figures showing the maximum inundation extent provided an assessment of the risk that a given remediation option will impact adjacent landholders. Note that inundation results and statistics for Scenarios 1 – 13 and Scenarios 16 – 19 are shown for the period between 1 January to 22 February 2017 to provide representative baseline conditions for comparison between model scenarios. Whereas, inundation results and statistics for Scenarios 14 and 15 are shown for the period between 1 January to 30 September 2010, because this period was determined to be representative of long-term average wet and dry conditions at the site, and excluded large inflow events. Each of the scenarios model tested are discussed in more detail in Appendix F.2.

Table F.1: Summary of Modelled Scenarios

Stage	Scenario	Description
1	1	Existing Conditions – Measured Water Level Data (2016-2017)
	2	Full Restoration – Open Flow Control Structures (Gates Removed)
	3	Existing Conditions + 63.2% AEP[1] (1-year ARI[2]), 6-hour Storm Event in Early February 2017
	4	Full Restoration + 63.2% AEP (1-year ARI), 6-hour Storm Event in Early February 2017
	5	Open Flow Control Structures (Gates Removed), Blanches Drain (Auto-Tidal Gate Only)
	6	Open Flow Control Structures (Gates Removed), Sportsmans 35/1 Closed
	7	Open Flow Control Structures (Gates Removed), Reedy Creek Gates Closed
	8	Open Flow Control Structures (Gates Removed), Sportsmans 35/1 + Reedy Creek Gates Closed
	9	Site Open (Gates Removed), Sportsmans Creek Weir Gates existing conditions (with Leakage)
	10	Site Closed, Reedy Creek Modified Gates Open, Sportsmans Creek Weir Open (Gates Removed)
	11	Open Flow Control Structures (Gates Removed), Harrisons Weir Removed
2	12	Updated Model - Existing Conditions – Measured Water Level Data (2016-2017)
	13	Updated Model - Full Restoration – Open Flow Control Structures (Gates Removed)
	14	Updated Model - Longer Duration (Existing Conditions) – 12-month Scenario
	15	Updated Model - Longer Duration (Full Restoration) – 12-month Scenario
3	16	Updated Model - Existing Conditions – Measured Water Level Data (2016-2017)
	17	Updated Model - Full Restoration – Open Flow Control Structures (Gates Removed)
	18	Updated Model – Internal Floodgates Closed, Sportsmans Creek Weir Open
	19	Updated Model – Reedy Creek, Sportsmans 35/1 and Sportsmans Creek Weir Open Only

[1] AEP is the Annual Exceedance Probability.

[2] ARI is the Average Recurrence Interval.

F.2 Scenario Results and Discussion

F.2.1 Stage 1: Baseline Model Runs

Figure F.1 and Figure F.2 provide the existing conditions of the site for the baseline model simulation period. As expected during this relative dry period, Teal Lagoon and the adjacent water bodies fed by Reedy Creek are the main permanent water bodies at Everlasting Swamp. Note that a relatively small catchment rainfall event provided some inflow to model domain through Duck Creek on the northern boundary. However, this area of the site remained wet for between 20-40% of the model simulation period.

Figure F.3 and Figure F.4 provide the model results for the full restoration scenario. The full restoration scenario is indicative of the maximum inundation possible for the site and is achieved by the removal of all floodgates. It is worth noting that other flow control structures, levees and drainage channels across the site remain unchanged. That is, the existing invert of Sportsmans Weir would act like a weir when water levels approach low tide levels. Furthermore, boundary and input conditions to the model remain unchanged from Scenario 1.

In general, the model results for the open floodgates scenario indicate that Teal Lagoon, Reedy Creek and Coxs Swamp are the key areas experiencing frequent tidal inundation, remaining wet for 80-100% of the time. It is worth noting that the wetting-drying patterns of these areas are noticeably different; the Teal Lagoon/Reedy Creek area has a tidal response, whereas Coxs Swamp tends to infill like a basin on higher spring tides and is more susceptible to losses due to evaporation. On higher spring tides, tidal inundation extends further towards the NPWS boundary with the maximum inundation extent shown in Figure F.3. The maximum inundation extent and corresponding hydroperiods highlight areas of the swamp that appear to have poor connectivity and drainage due to the underlying site topography.

To assess the impact that a fully restored scenario has on drainage following a minor local catchment rainfall event, the model was run to simulate a 63.2% AEP, 6-hour rainfall event. Rainfall intensity-frequency-distribution (IFD) data for Everlasting Swamp was obtained from the Bureau of Meteorology (BOM) 2016 rainfall IFD data system. Rainfall was applied to the model by evenly distributing a rainfall intensity of 9 mm per hour across a 6-hour period starting on 1 February 2017 at midnight.

Inundation results for the existing conditions and open floodgates scenarios following the application of rainfall are provided in Figure F.5 to Figure F.8. Scenario testing for a minor local catchment rainfall event has shown that generally there is a low impact from the drainage of floodwaters for adjacent landholders, should a rainfall event occur following times of increased tidal inundation. Inundation results for the fully restored scenarios, with and without rainfall applied to the model, are comparable for all areas except the northern portion of Imesons Swamp, and along the NPWS boundary in Bullock Swamp and The Horseshoe. In these areas, water appears to be held back resulting in hydroperiods of up to 60%. It is worth noting that mean water depths in these areas are predicted to be less than 0.1 m.

The inundation results of the remaining model scenarios tested as part of Stage 1 are provided in Figure F.9 to Figure F.22. A summary of the key preliminary model predictions for these scenarios, includes:

- Scenario 5 highlighted that inundation of NPWS land to the south-east of the Round Mountain is controlled by Blanches Drain, and by closing the floodgates on Blanches drain, no overland inundation in this area occurs.

- Scenario 6 involved closing the floodgates on Sportsmans 35/1 and this was shown to: (i) increase mean inundation in the northern portion of Imesons Swamp, resulting in greater hydroperiods in some areas, particularly along the NPWS boundary; and (ii) decrease mean inundation in the Bullock Swamp area by approximately 0.1 m, with a corresponding reduction in hydroperiod of up to 50% in some areas along the NPWS boundary.
- Scenario 7 showed similar results to Scenario 6, with additional reductions in mean inundation (up to 0.1 m) and hydroperiods (up to 50%) in Coxs swamp mainly along the NPWS boundary.
- Scenario 8 involved closing the floodgates on Sportsmans 35/1 and Reedy Creek. The predicted results showed a combined effect of Scenarios 6 and 7, with additional reductions in mean inundation depths and extents, as well as hydroperiods in the areas of Bullock Swamp. These parameters were shown to increase in the northern portion of Imesons Swamp, outside of NPWS managed land.
- Scenario 9 involved opening the site by removing floodgates, while maintaining existing conditions at Sportsmans Creek Weir. The results of this scenario highlighted the influence of the weir on controlling floodplain water levels.
- Scenario 10 involved removing the floodgates on the Sportsmans Creek Weir and maintaining existing conditions at Reedy Creek (i.e. auto-tidal floodgate open), while the remainder of the site was closed. This scenario resulted in regular inundation (i.e. hydroperiods >80%) of the Teal Lagoon-Reedy Creek area. The maximum inundation extent was contained within the NPWS boundary, except for some low-lying areas in the upstream reaches Sportsmans Creek.
- Scenario 11 involved opening all floodgates across the site, while also removing Harrisons Creek Weir. Harrisons Creek Weir is directly influenced by water levels in Blanches Drain. This scenario highlighted the importance of Harrisons Creek Weir as an hydrologic control for floodplain water levels and inundation in the Warragai Creek area.

Results for each modelled scenario are also presented for representative locations across the study area as shown in Figure F.23. Several key locations across the 1-D/2-D model domain have been extracted for time-series water level data and can be compared to show the relative influence of changing inundation behaviour across the site. Timeseries data from the 1-D and the 2-D model outputs for each scenario are provided in Figure F.24 to Figure F.45.

As an example, Figure F.25 provides water level time series data from key locations within the drainage network for the fully restored scenario (Scenario 2). The timeseries data from the 1-D network shows the attenuation of tidal water levels across the site. Figure F.25 also highlights that the whole site will be impacted by saltwater intrusion following the removal of Sportsmans Creek Weir. This may have important implications for the future management of the site.

Figure F.36 provides water level timeseries data from key locations across the Everlasting Swamp floodplain for the fully restored scenario (Scenario 2). This time series data shows the wetting-drying patterns and relative influence of tidal inundation across the site. Figure F.36 is also useful to compare the attenuation that occurs as the tidal waters spread out across the floodplain.

Summary statistics of the timeseries data from the 2-D model outputs (Figure F.23) for each scenario are provided in Table F.2 to Table F.12. Note that the statistics are shown for the period from 1 January to 22 February 2017 to provide representative baseline conditions for comparison between model scenarios. Model outputs are analysed for 90th and 10th percentiles, maximum, minimum and median water levels (referenced to AHD) at each given location.

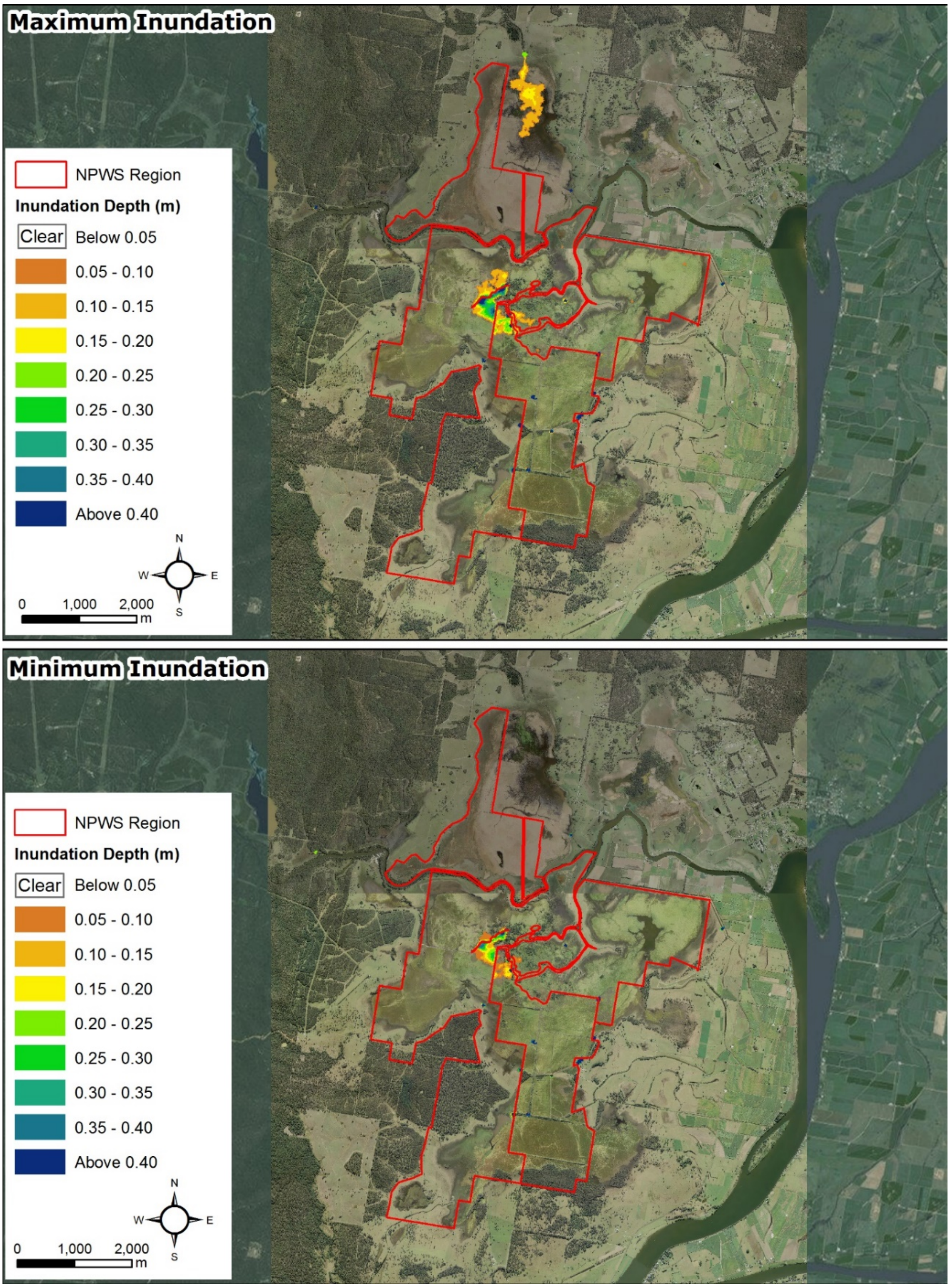
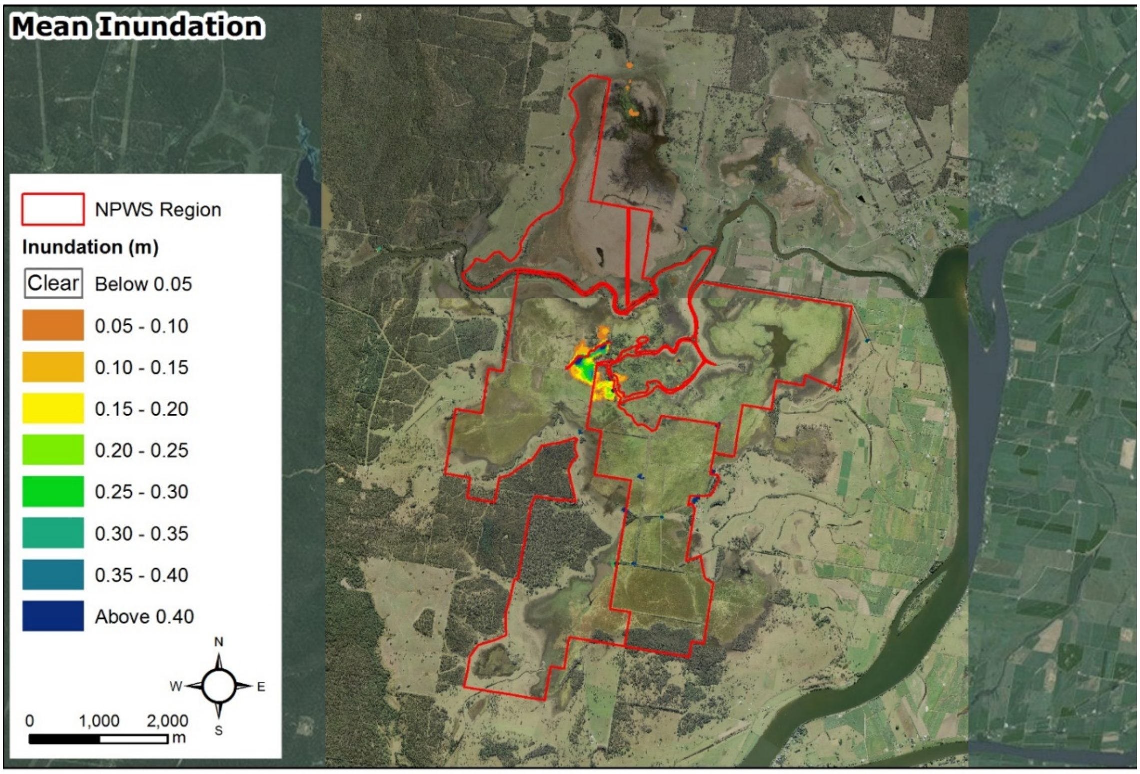


Figure F.1: Existing Conditions (Scenario 1) – Maximum and Minimum Inundation Extents – 1 January to 22 February 2017



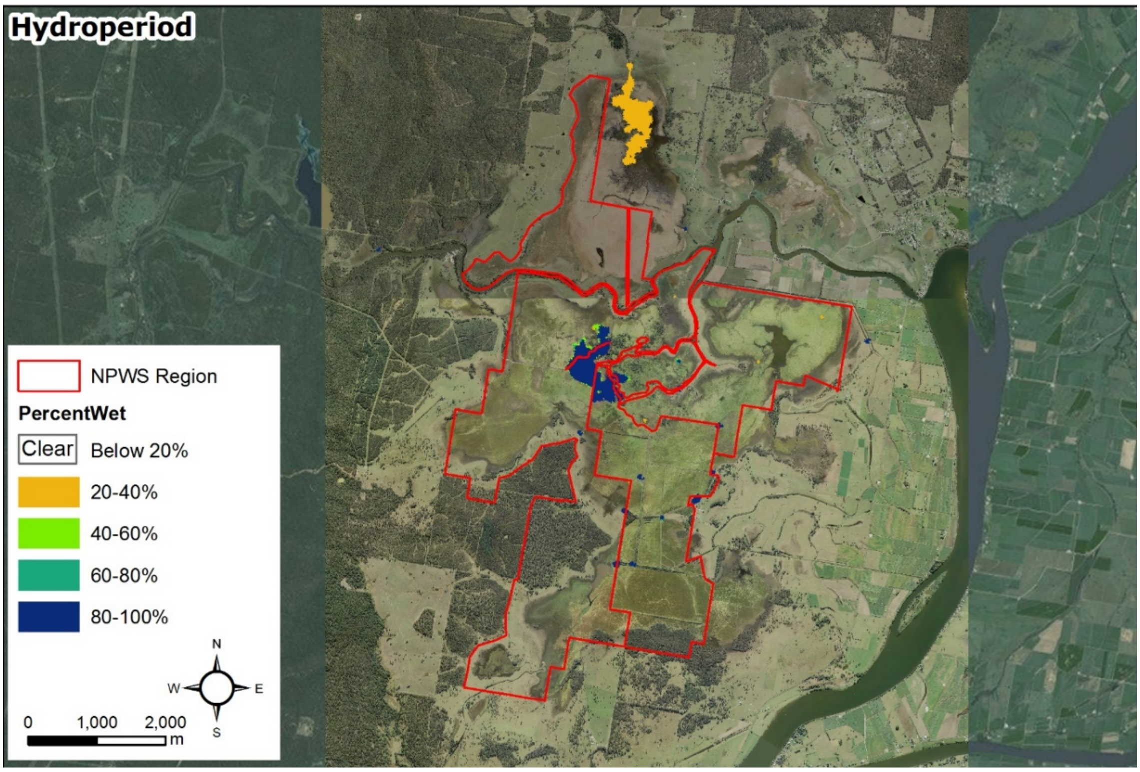


Figure F.2: Existing Conditions (Scenario 1) – Mean Inundation Extent and Hydroperiod Analysis – 1 January to 22 February 2017

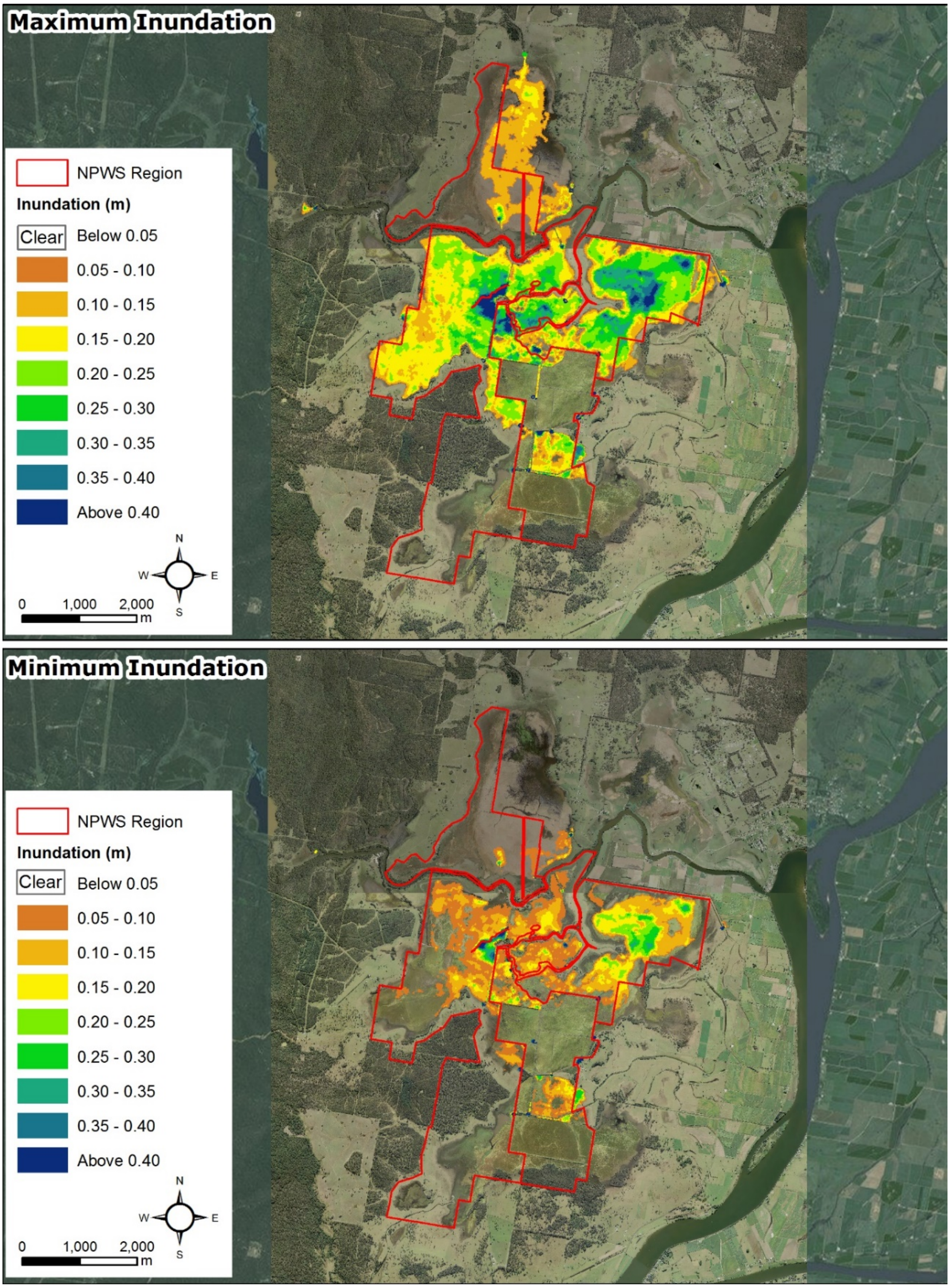


Figure F.3: Full Restoration (Scenario 2) – Maximum and Minimum Inundation Extents – 1 January to 22 February 2017

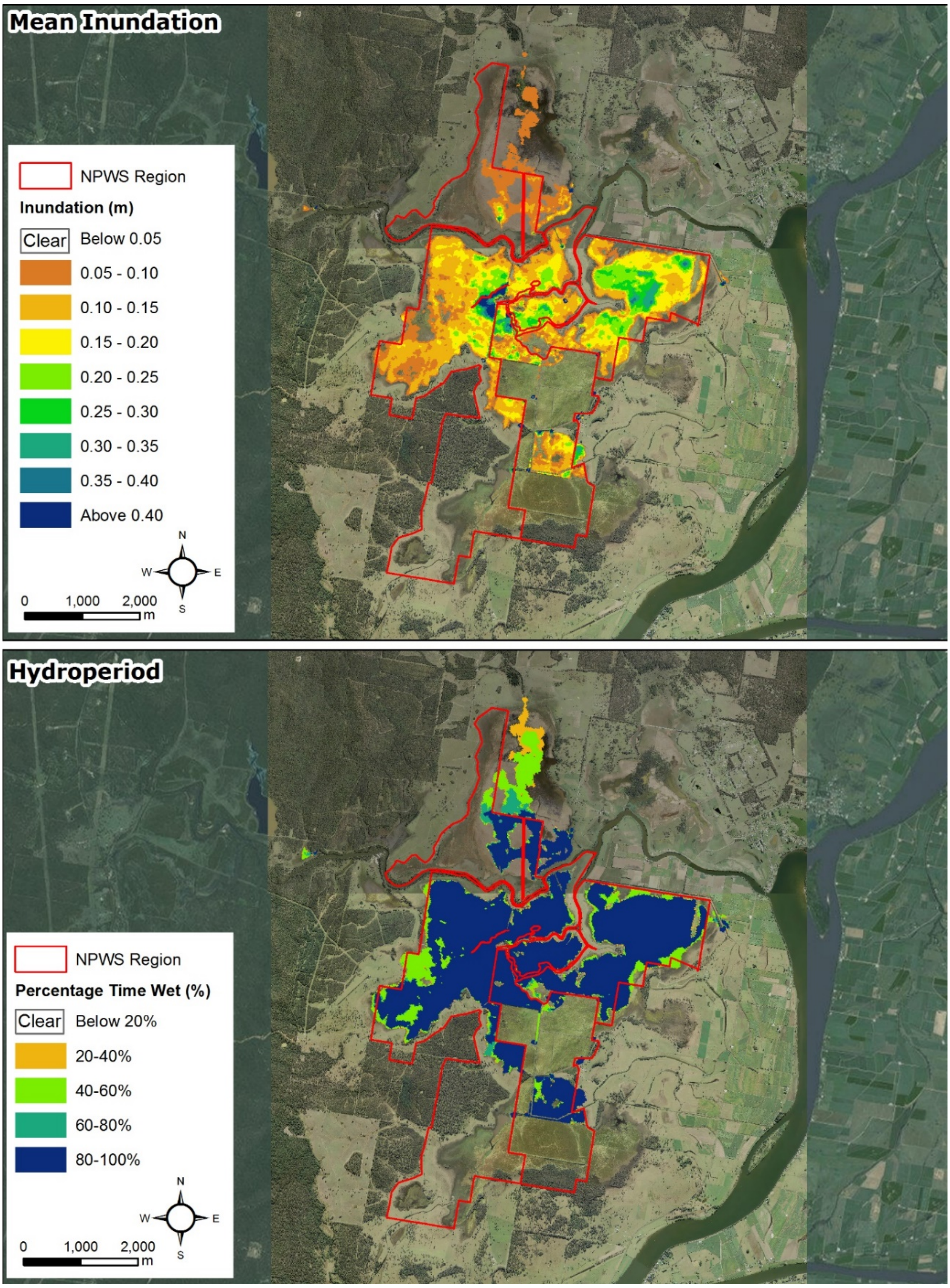


Figure F.4: Full Restoration (Scenario 2) – Mean Inundation Extent and Hydroperiod Analysis – 1 January to 22 February 2017

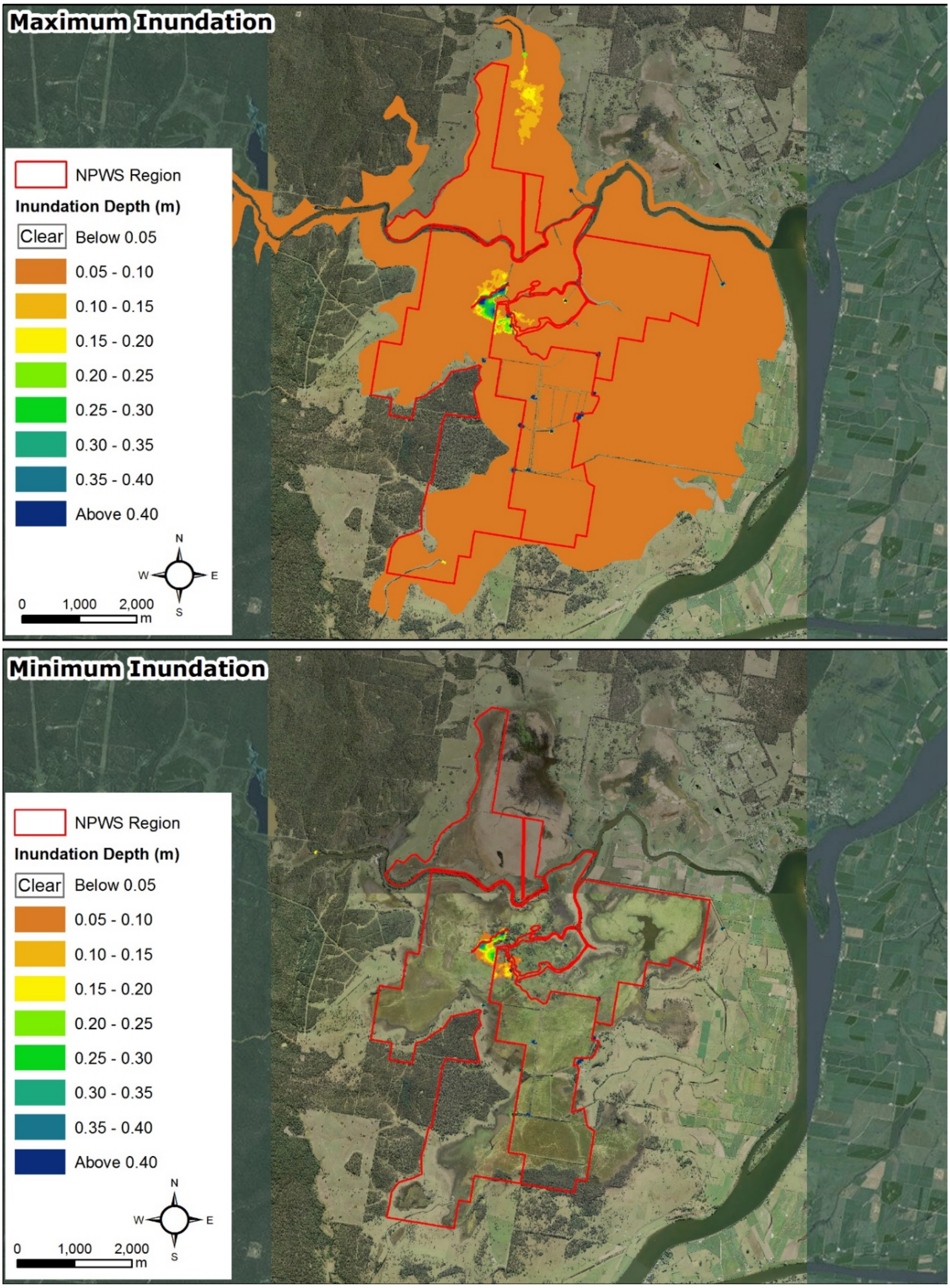


Figure F.5: Existing Conditions + 63.2% AEP, 6-hour Storm Event in Early February 2017 (Scenario 3) – Maximum and Minimum Inundation Extents – 1 January to 22 February 2017

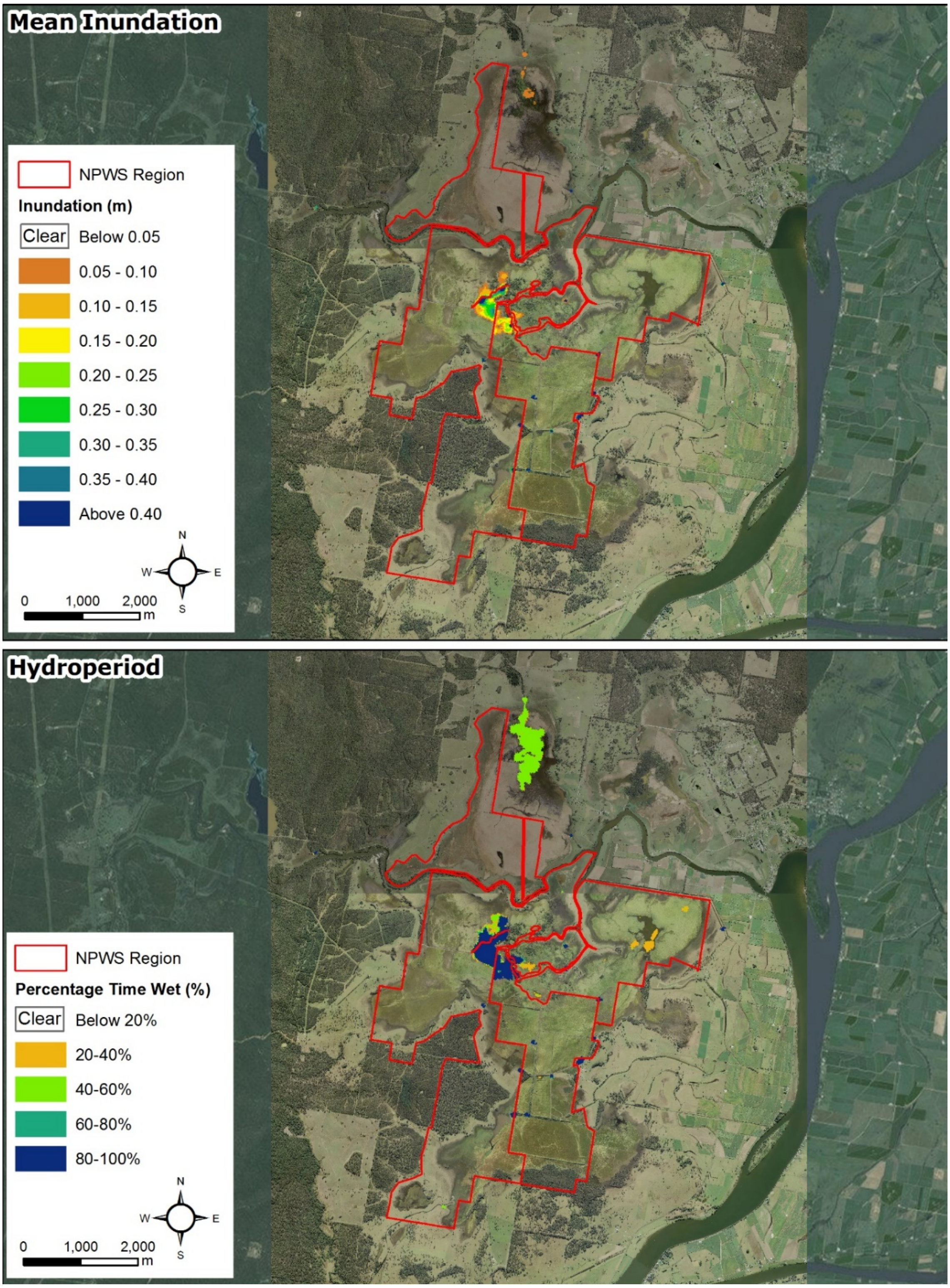


Figure F.6: Existing Conditions + 63.2% AEP, 6-hour Storm Event in Early February 2017 (Scenario 3) – Mean Inundation Extent and Hydroperiod Analysis – 1 January to 22 February 2017

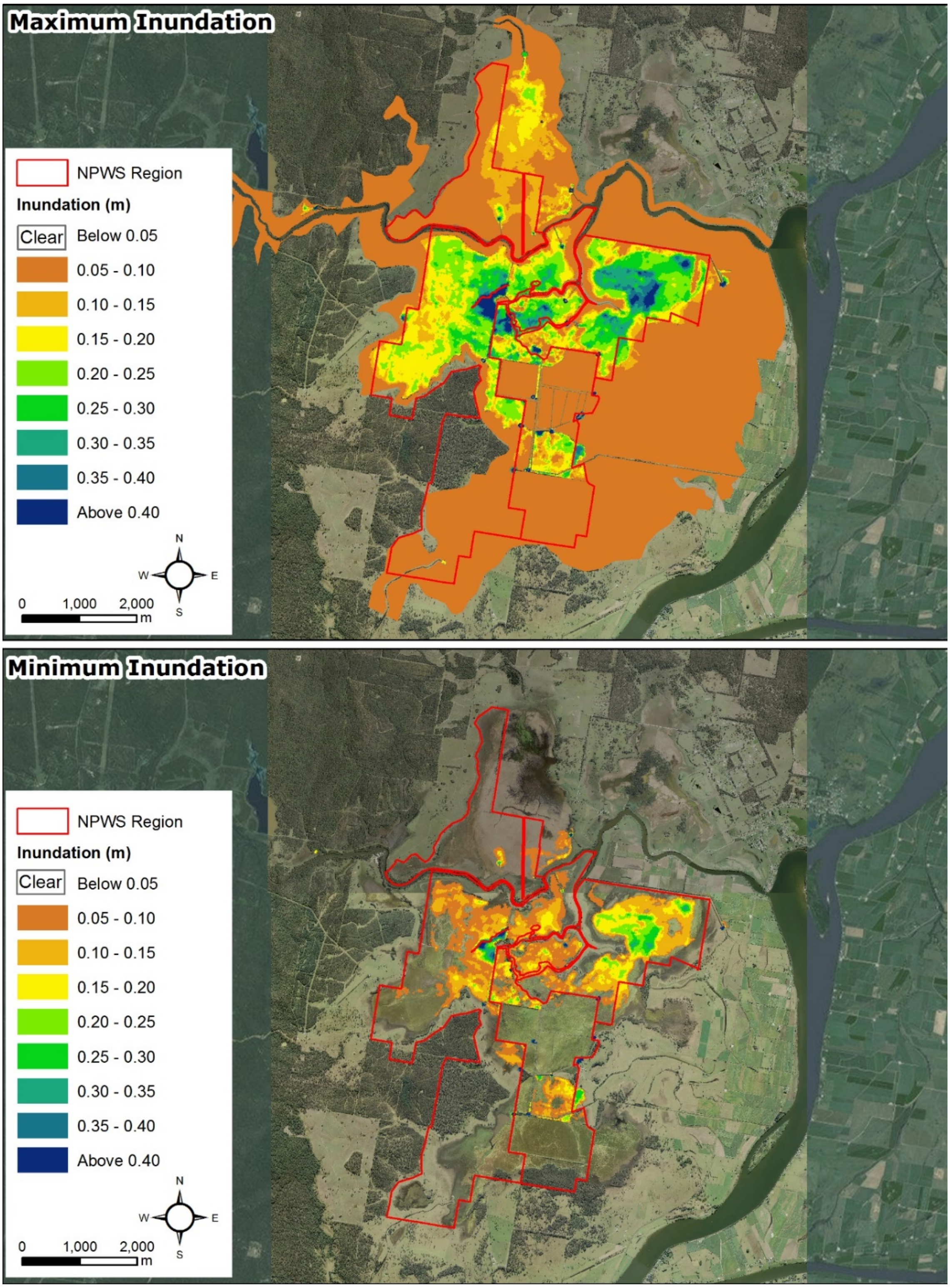


Figure F.7: Full Restoration + 63.2% AEP, 6-hour Storm Event in Early February 2017 (Scenario 4) – Maximum and Minimum Inundation Extents – 1 January to 22 February 2017

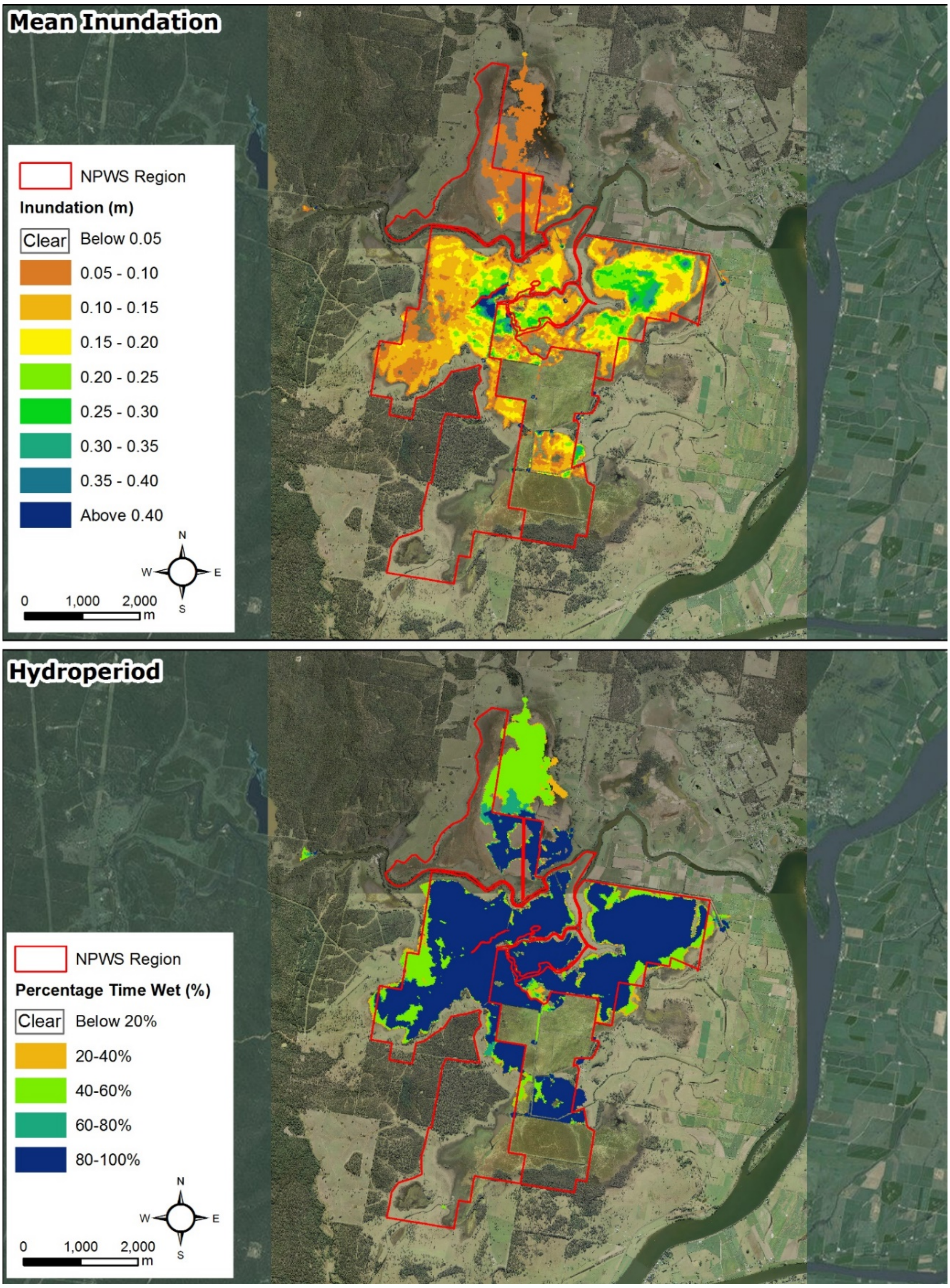


Figure F.8: Full Restoration + 63.2% AEP, 6-hour Storm Event in Early February 2017 (Scenario 4) – Mean Inundation Extent and Hydroperiod Analysis – 1 January to 22 February 2017

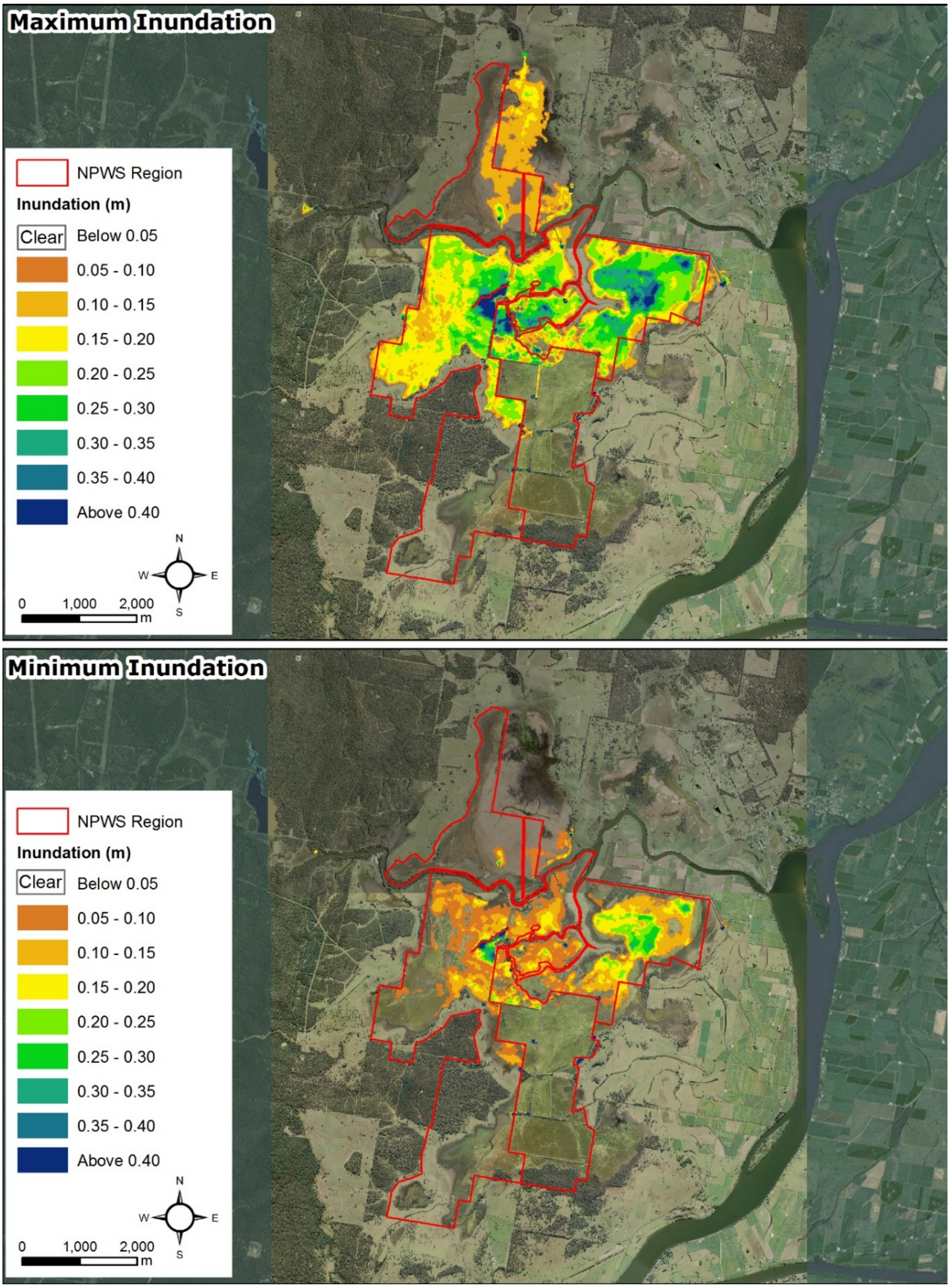


Figure F.9: Partial Restoration, Blanches Drain Closed (Scenario 5) – Maximum and Minimum Inundation Extents – 1 January to 22 February 2017

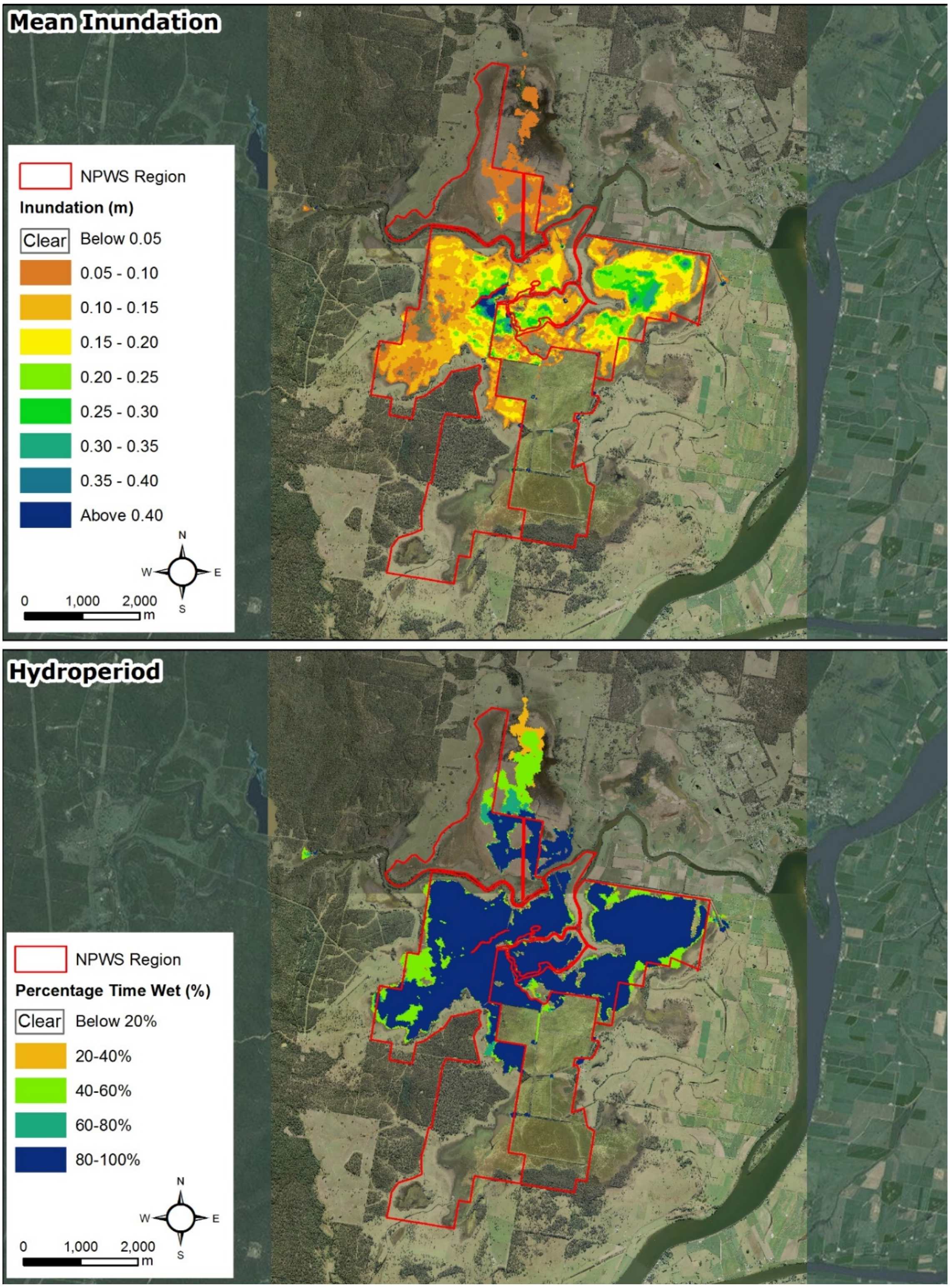


Figure F.10: Partial Restoration, Blanches Drain Closed (Scenario 5) – Mean Inundation Extent and Hydroperiod Analysis – 1 January to 22 February 2017

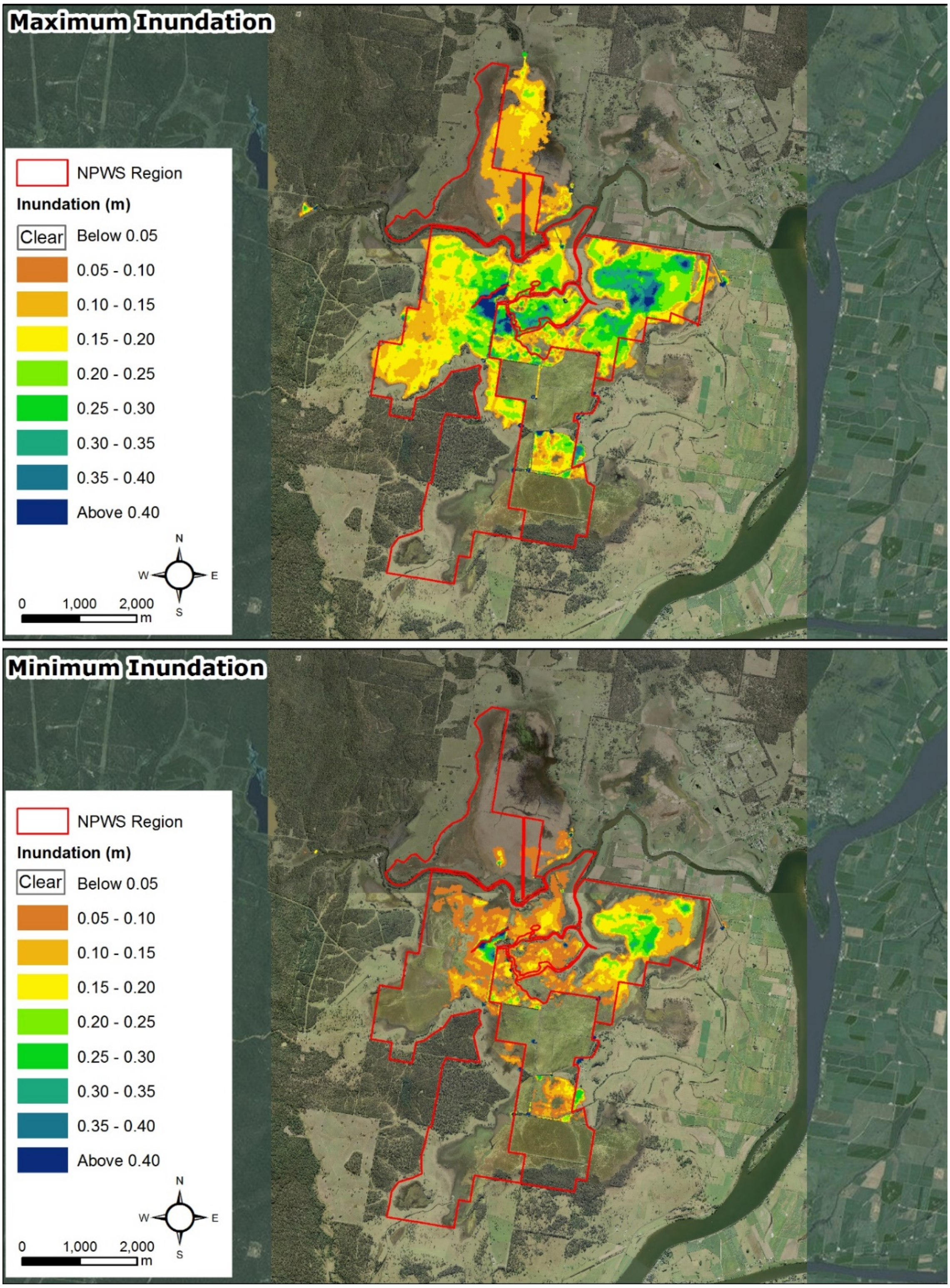


Figure F.11: Partial Restoration, Sportsmans 35/1 Closed (Scenario 6) – Maximum and Minimum Inundation Extents – 1 January to 22 February 2017

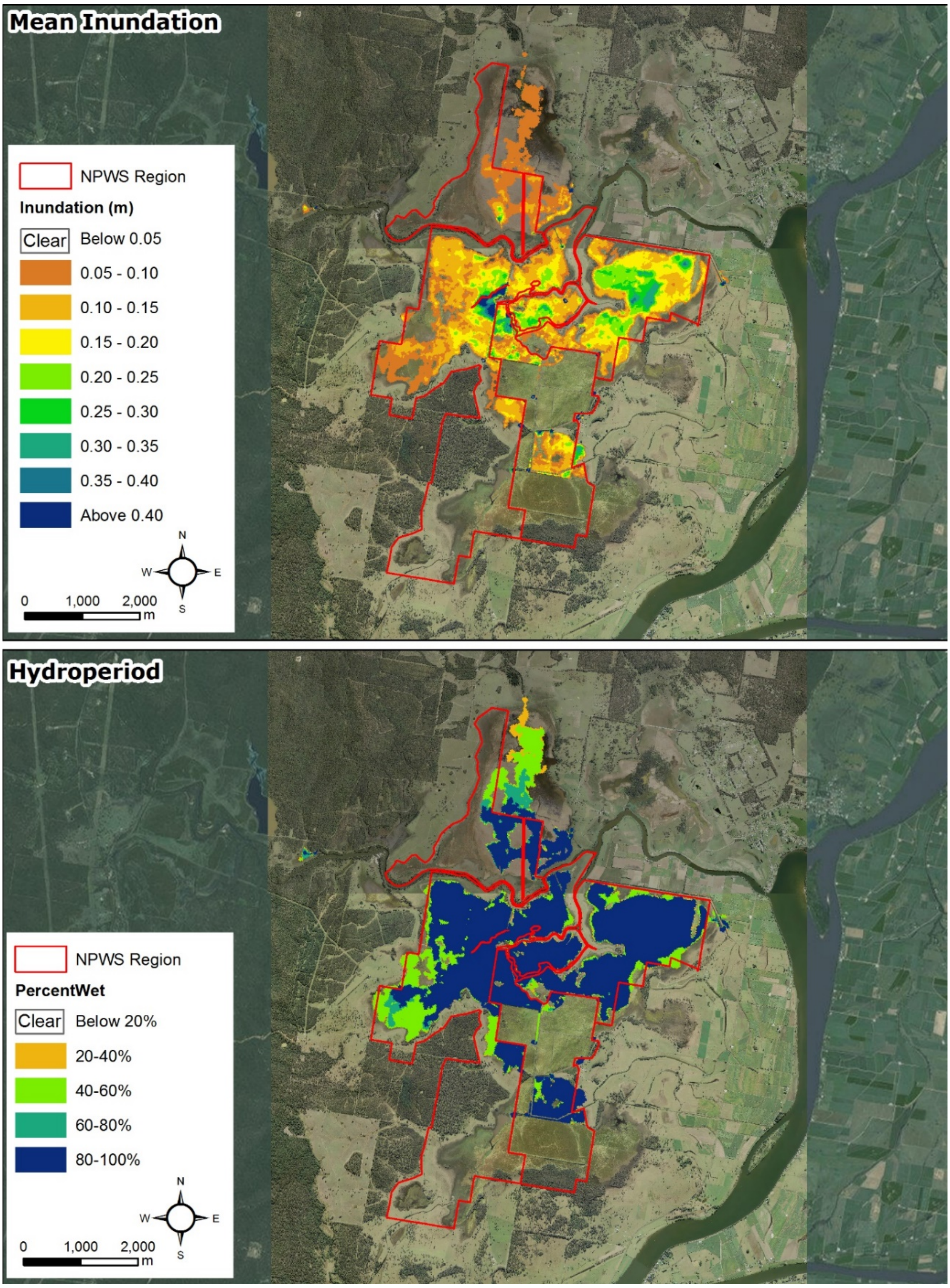


Figure F.12: Partial Restoration, Sportsmans 35/1 Closed (Scenario 6) – Mean Inundation Extent and Hydroperiod Analysis – 1 January to 22 February 2017

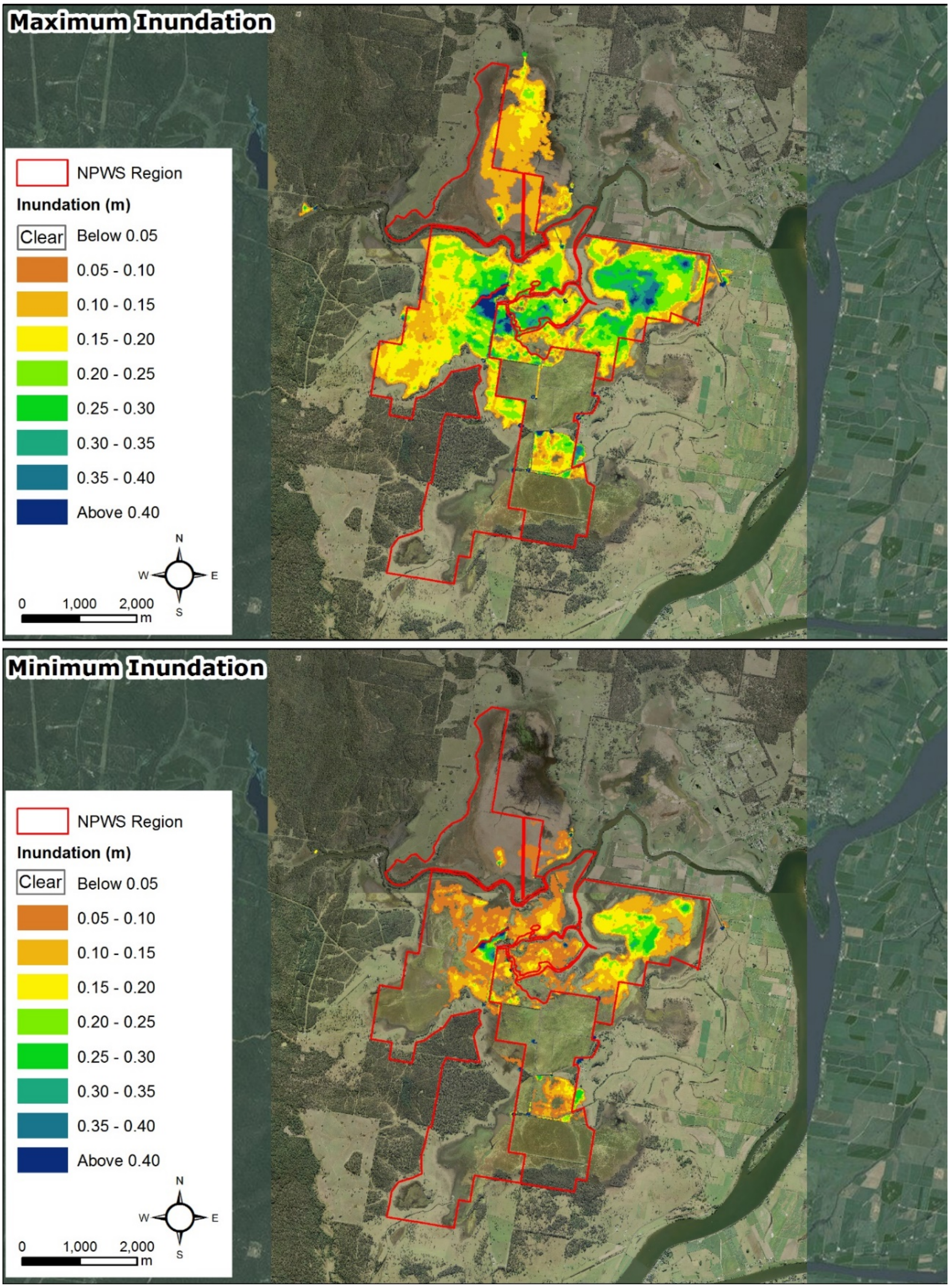


Figure F.13: Partial Restoration, Reedy Creek Gates Closed (Scenario 7) – Maximum and Minimum Inundation Extents – 1 January to 22 February 2017

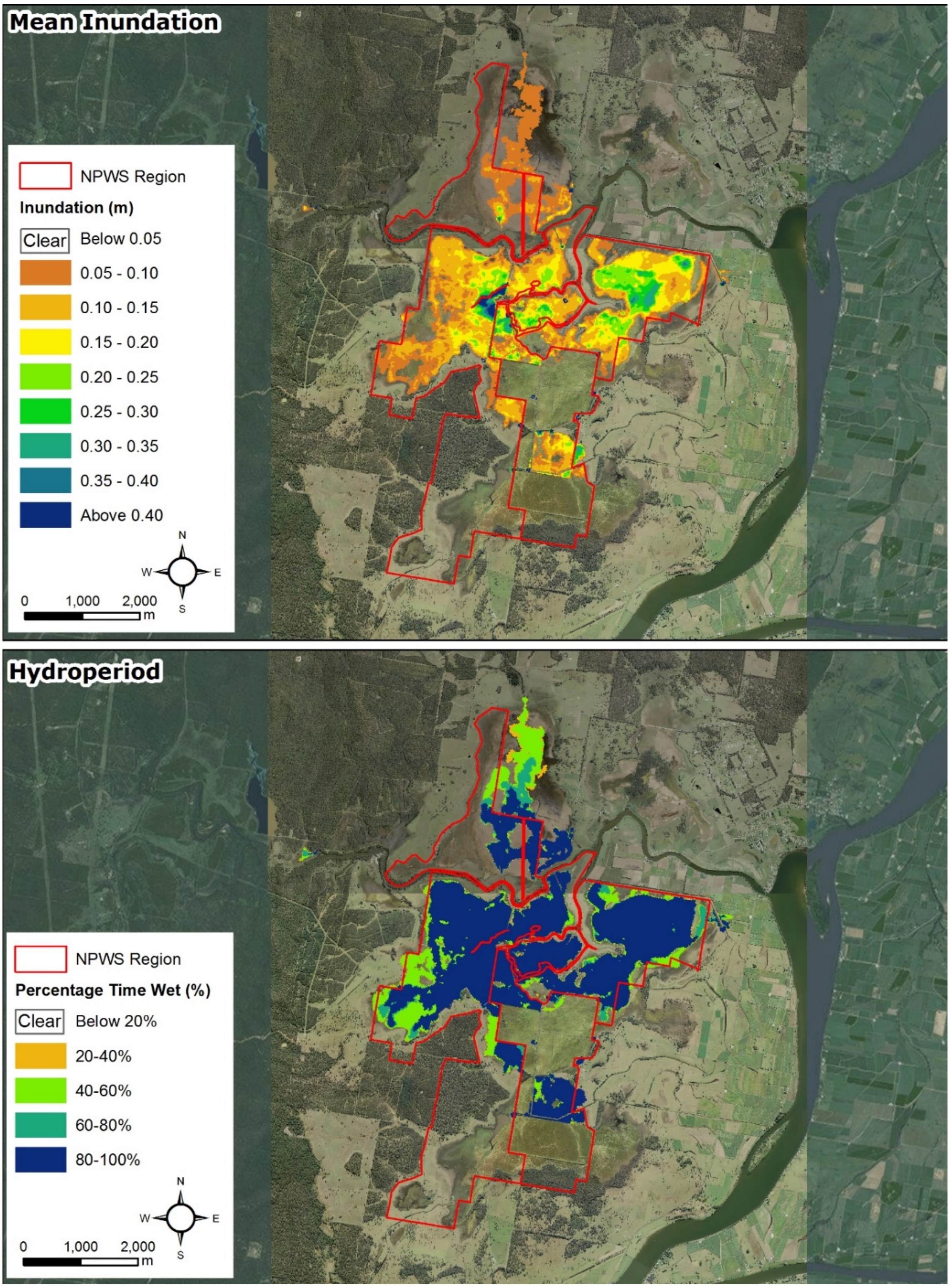


Figure F.14: Partial Restoration, Reedy Creek Gates Closed (Scenario 7) – Mean Inundation Extent and Hydroperiod Analysis – 1 January to 22 February 2017

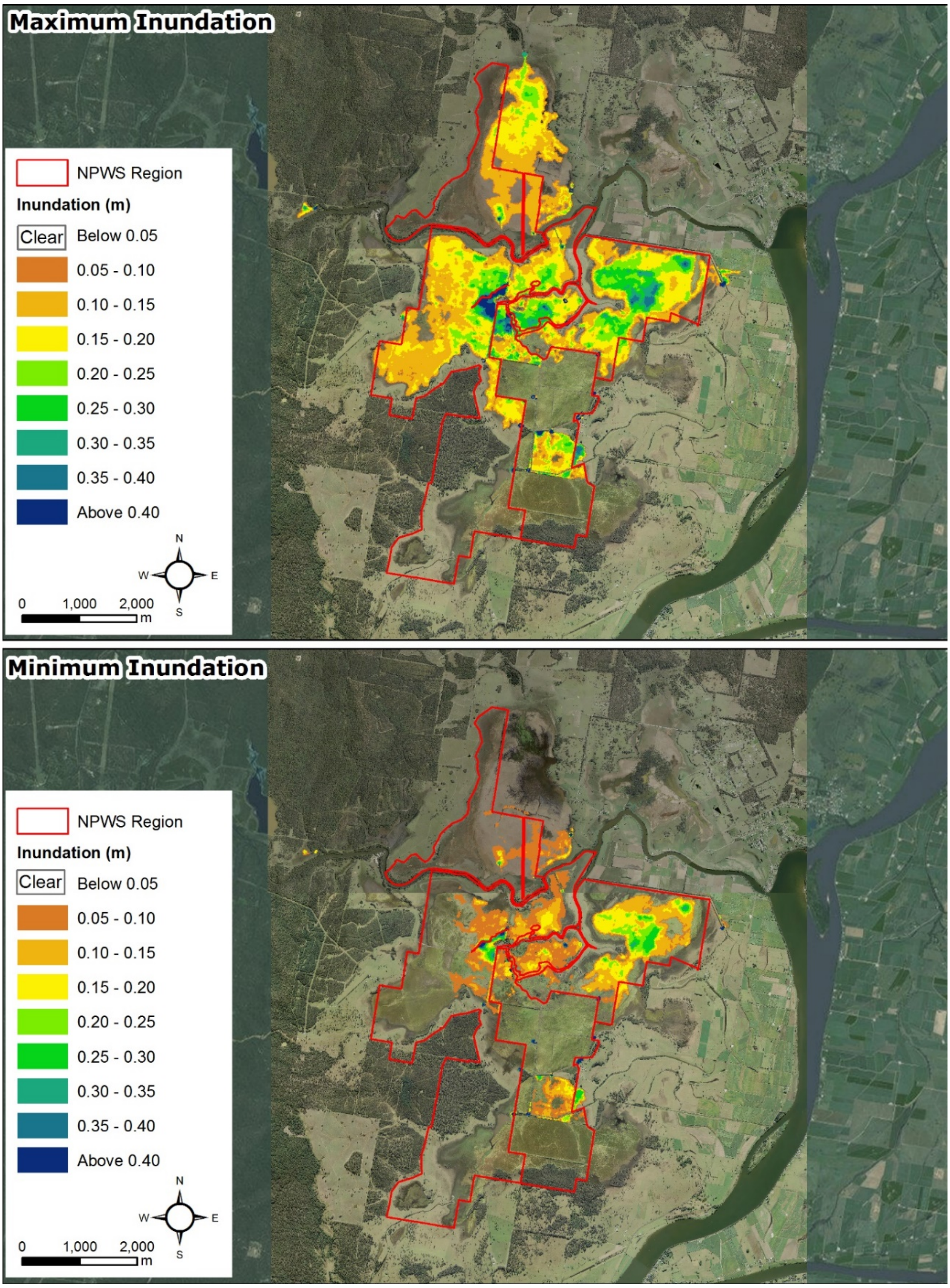


Figure F.15: Partial Restoration, Sportsmans 35/1 + Reedy Creek Gates Closed (Scenario 8) – Maximum and Minimum Inundation Extents – 1 January to 22 February 2017

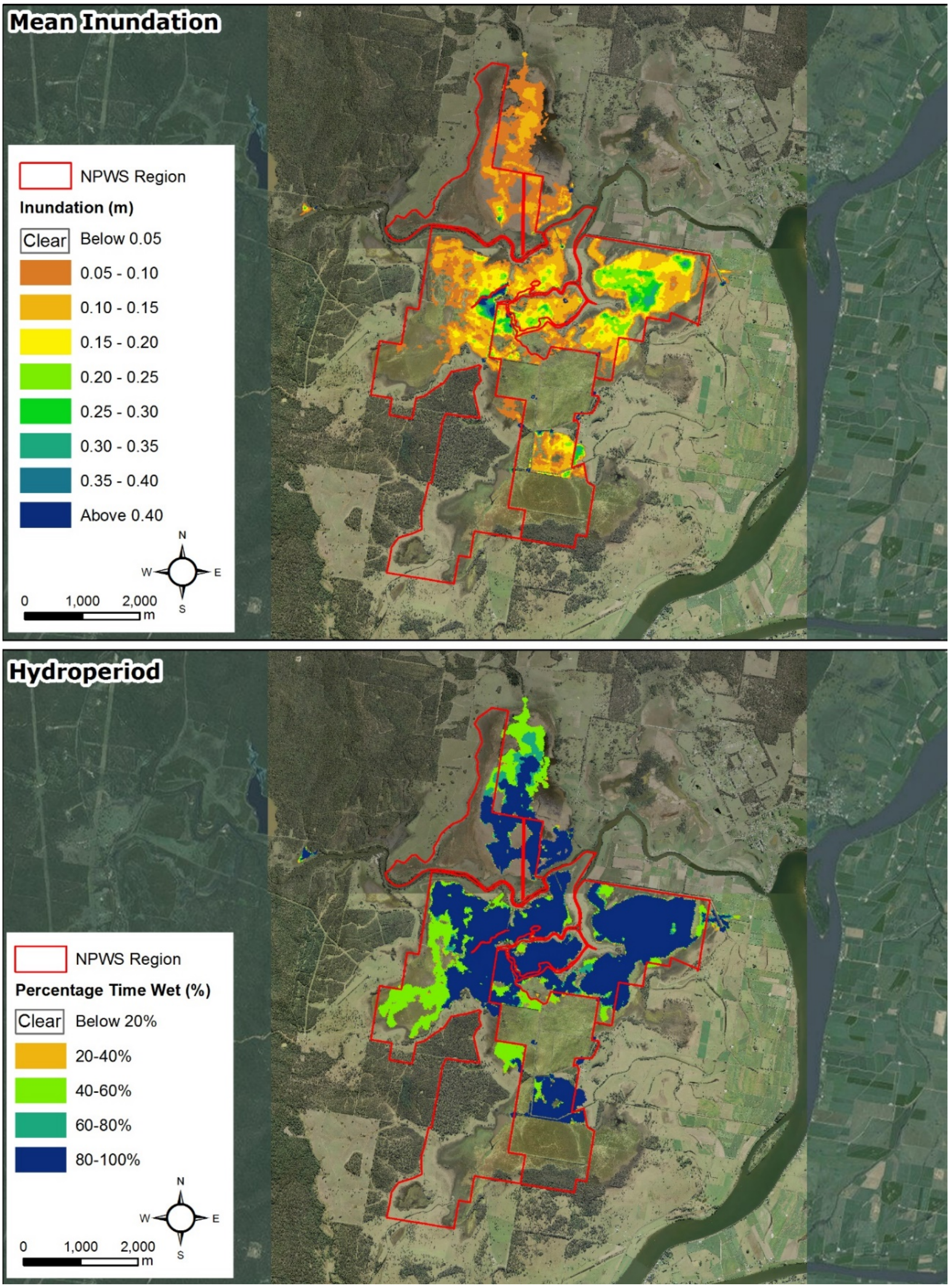


Figure F.16: Partial Restoration, Sportsmans 35/1 + Reedy Creek Gates Closed (Scenario 8) – Mean Inundation Extent and Hydroperiod Analysis – 1 January to 22 February 2017

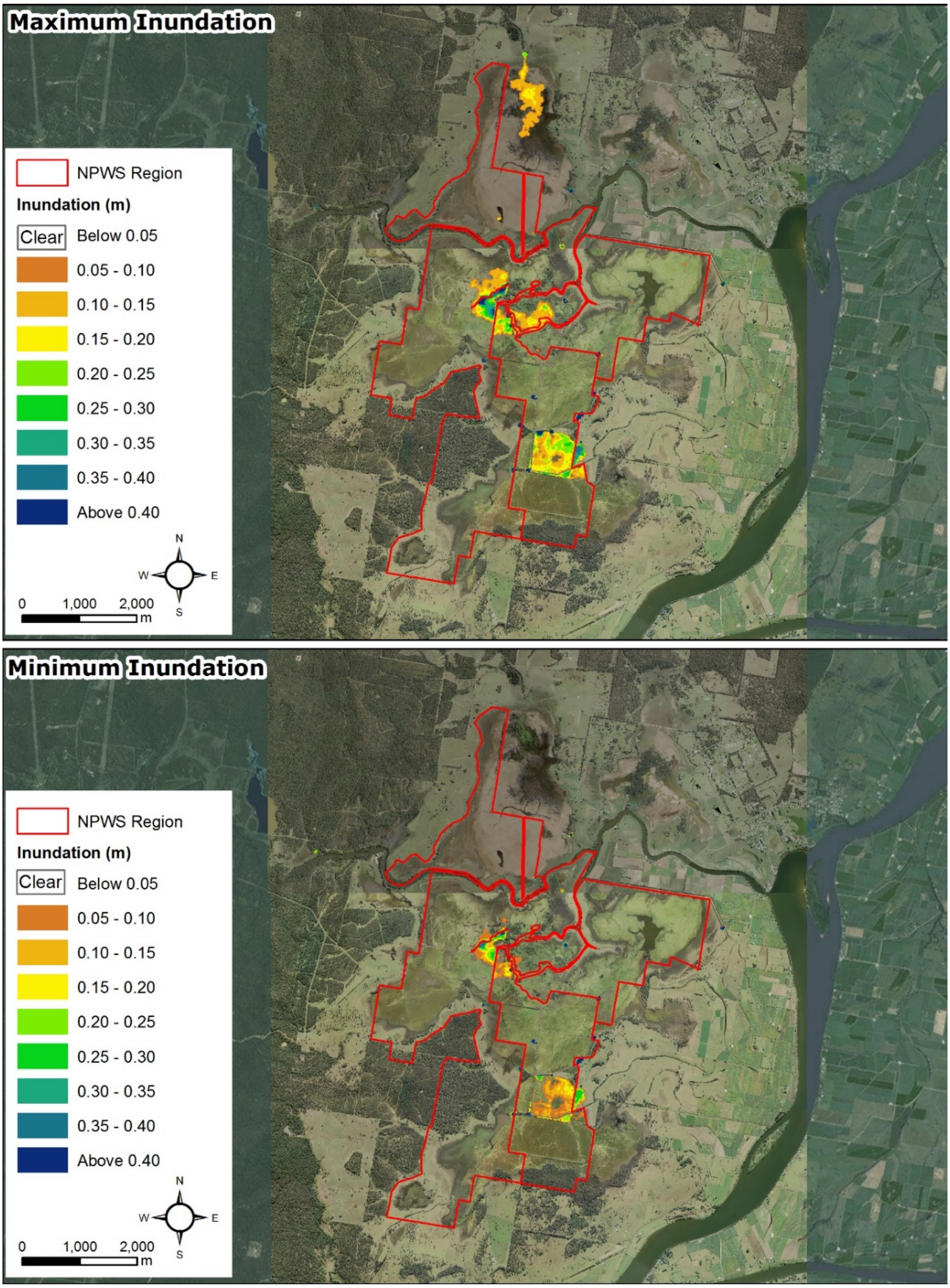


Figure F.17: Partial Restoration, Site Open (Gates Removed), Sportsmans Creek Weir Existing Conditions (Gates Closed with Leakage) (Scenario 9) – Maximum and Minimum Inundation Extents – 1 January to 22 February 2017

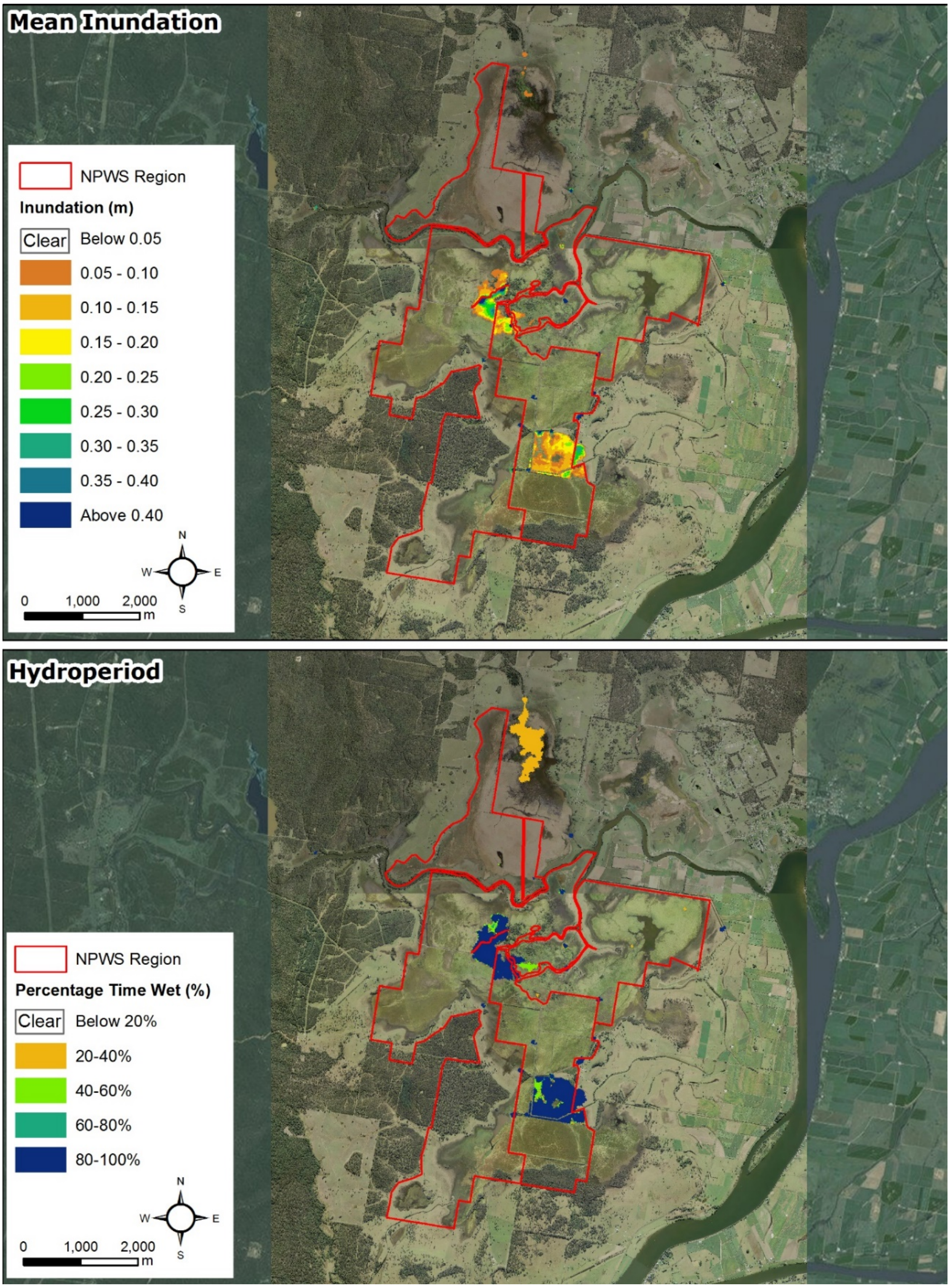


Figure F.18: Partial Restoration, Site Open (Gates Removed), Sportsmans Creek Weir Existing Conditions (Gates Closed with Leakage) (Scenario 9) – Mean Inundation Extent and Hydroperiod Analysis – 1 January to 22 February 2017

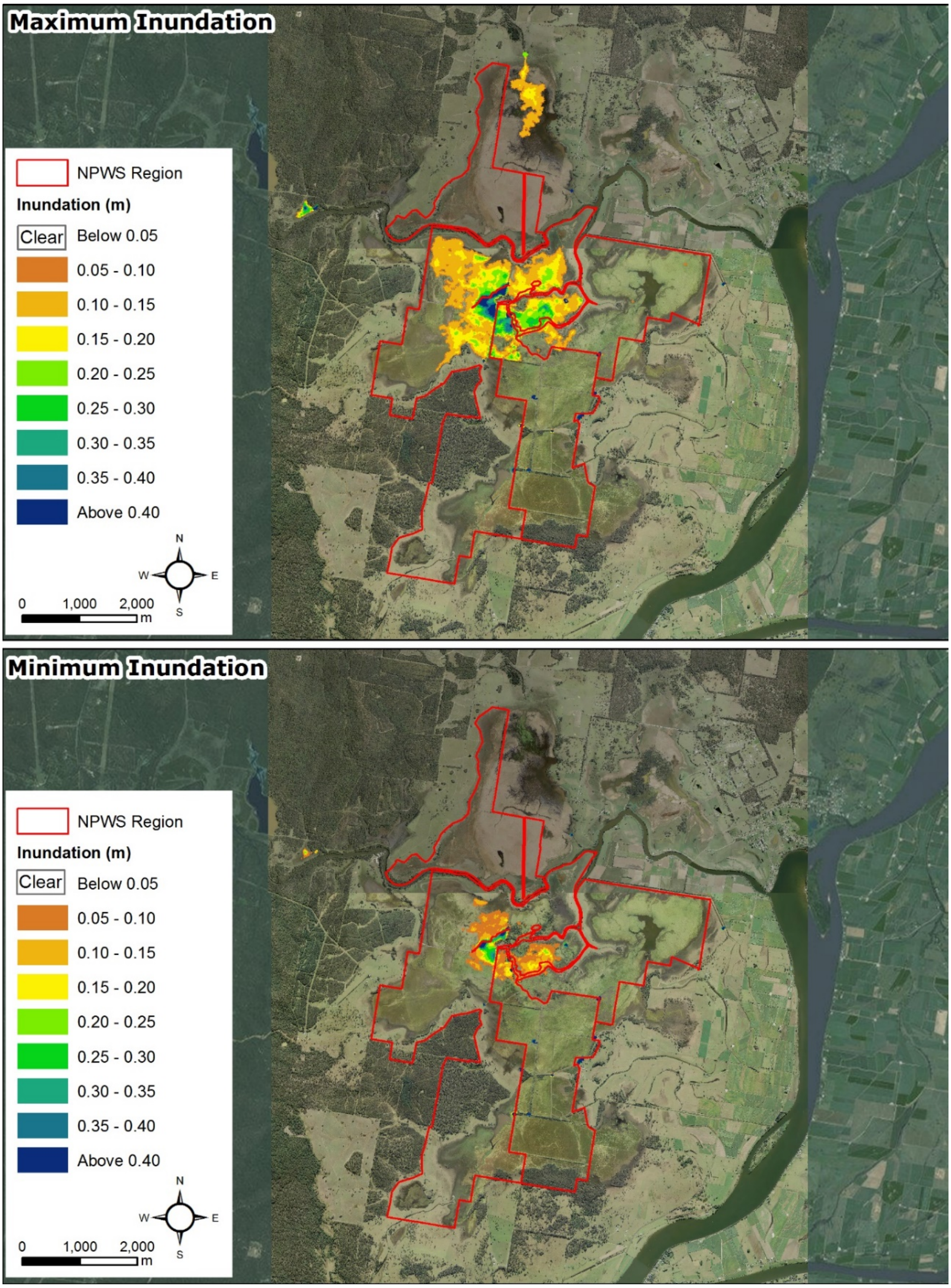


Figure F.19: Partial Restoration, Site Closed, Reedy Creek Gates (with Leakage), Sportsmans Creek Weir Open (Gates Only Removed) (Scenario 10) – Maximum and Minimum Inundation Extents – 1 January to 22 February 2017

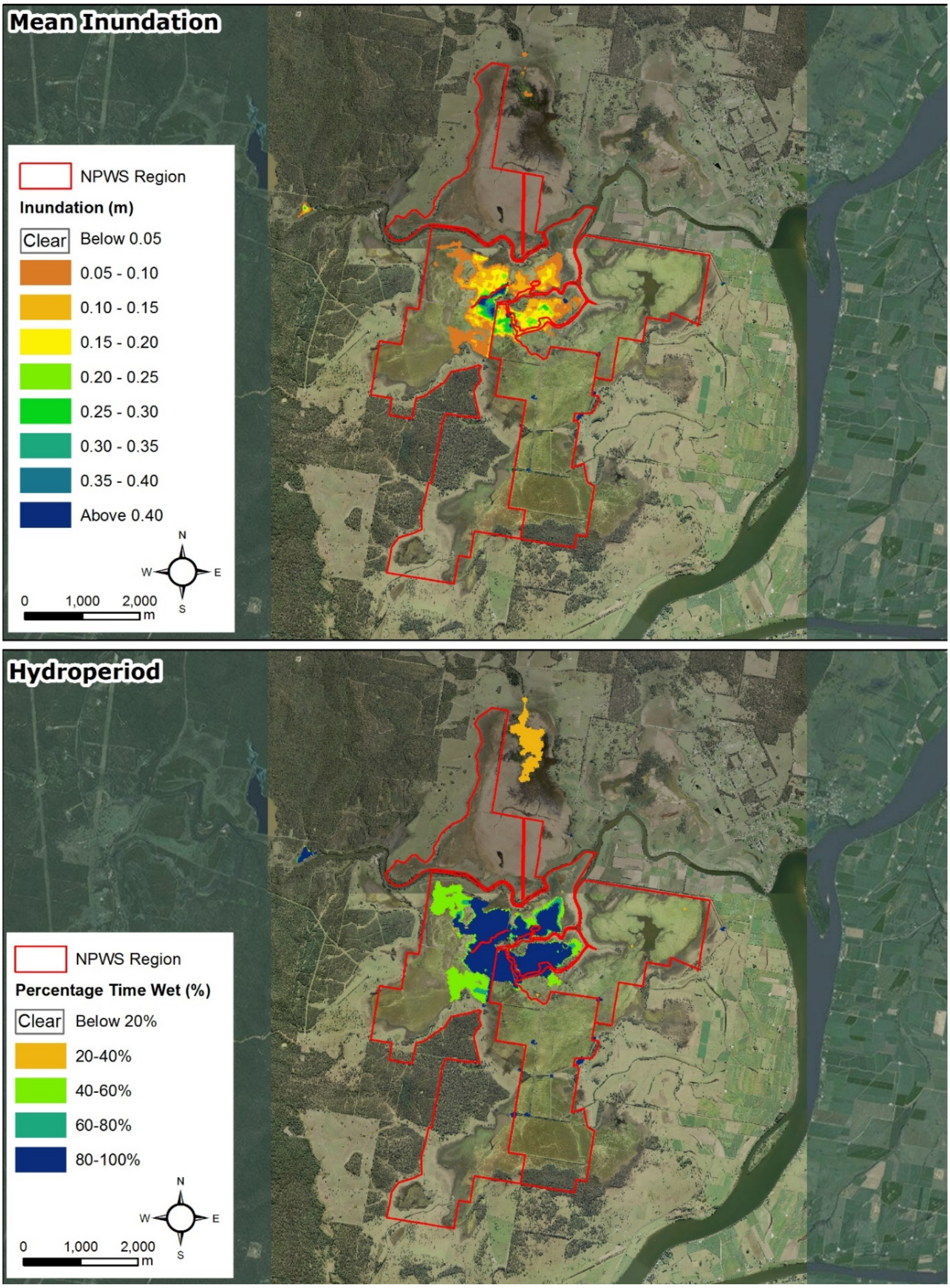


Figure F.20: Partial Restoration, Site Closed, Reedy Creek Gates (with Leakage), Sportsmans Creek Weir Open (Gates Only Removed) (Scenario 10) – Mean Inundation Extent and Hydroperiod Analysis – 1 January to 22 February 2017

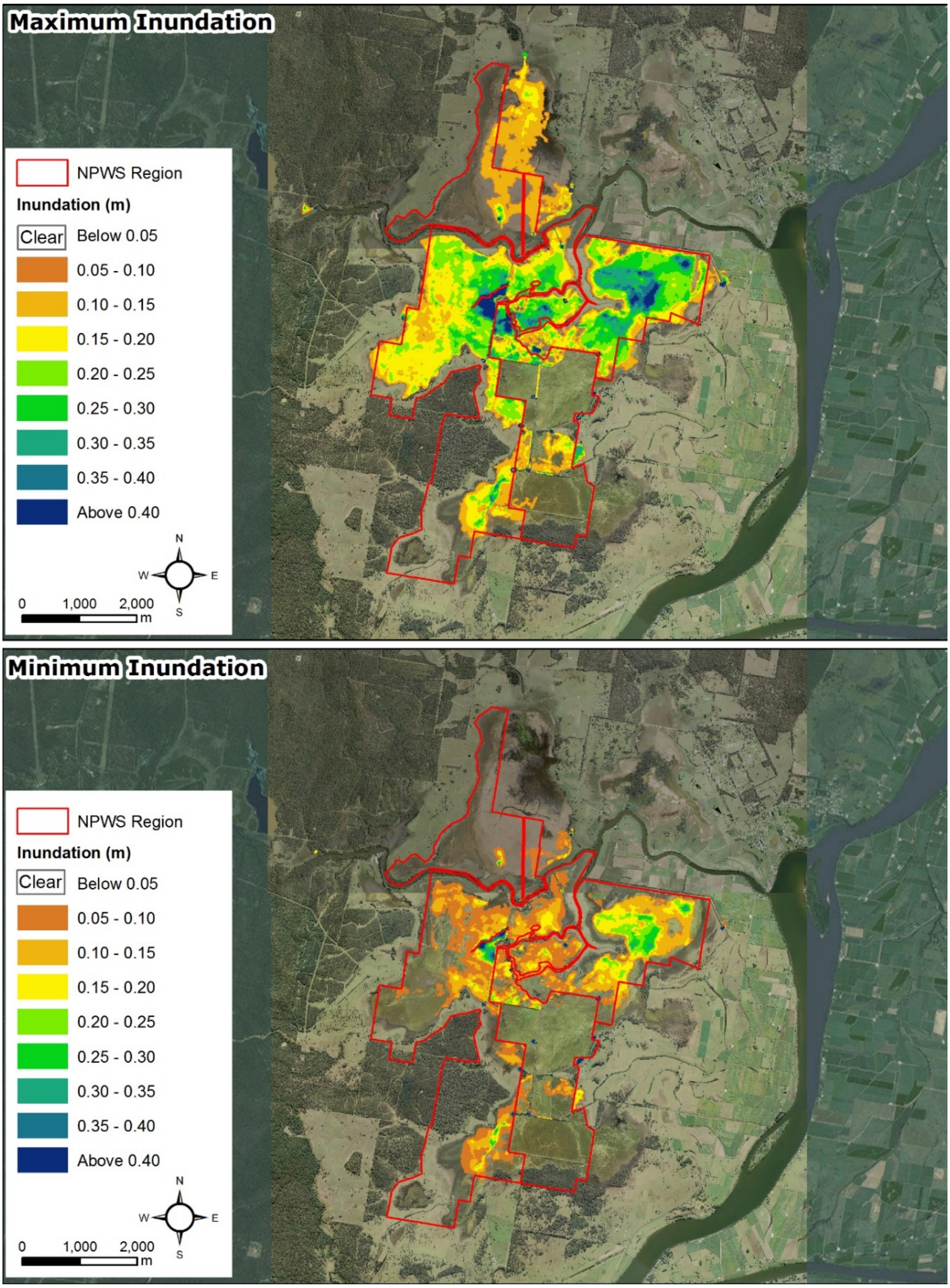


Figure F.21: Partial Restoration, Site Open, Harrisons Weir Removed (Scenario 11) – Maximum and Minimum Inundation Extents – 1 January to 22 February 2017

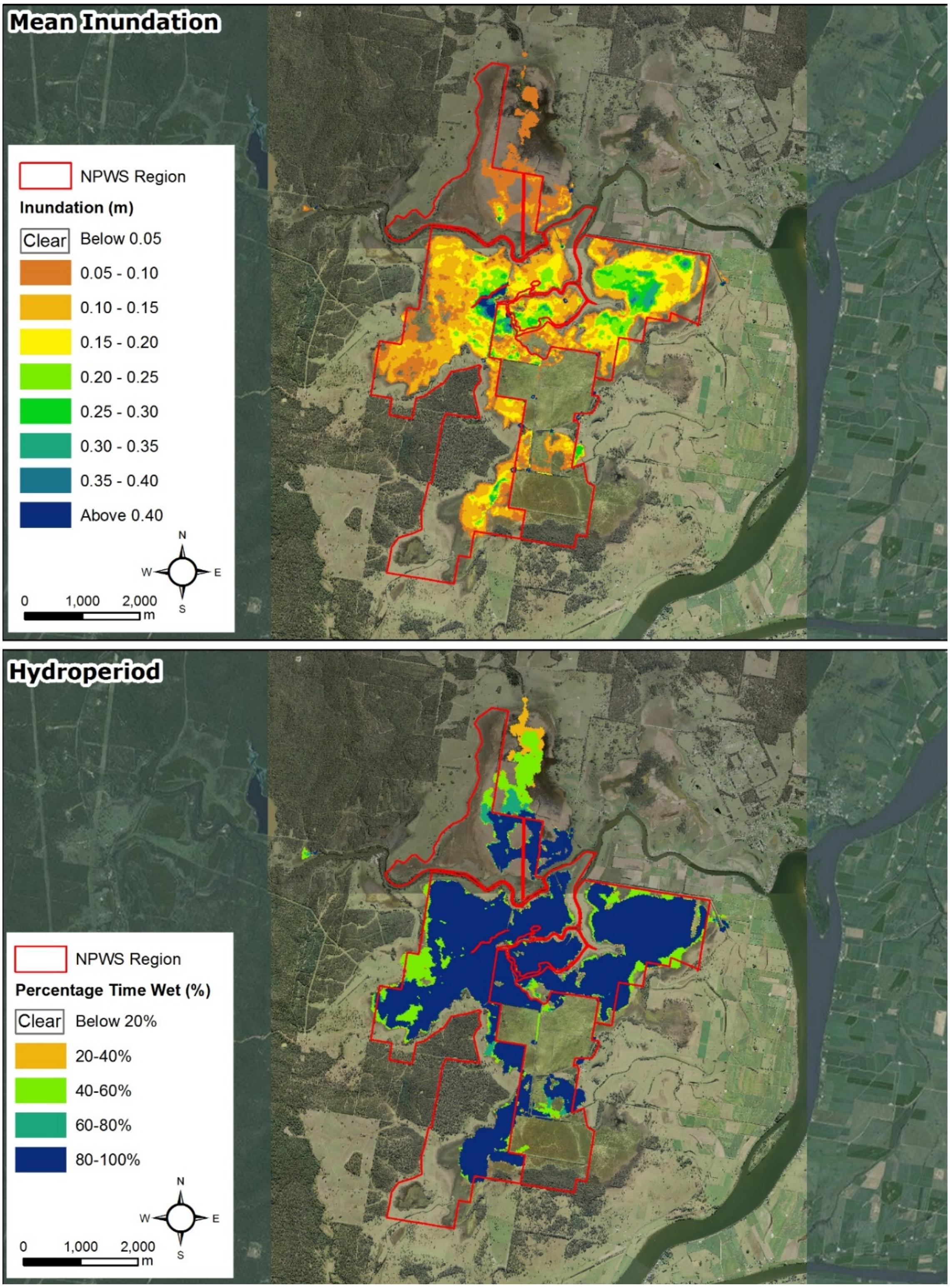


Figure F.22: Partial Restoration, Site Open, Harrisons Weir Removed (Scenario 11) – Mean Inundation Extent and Hydroperiod Analysis – 1 January to 22 February 2017

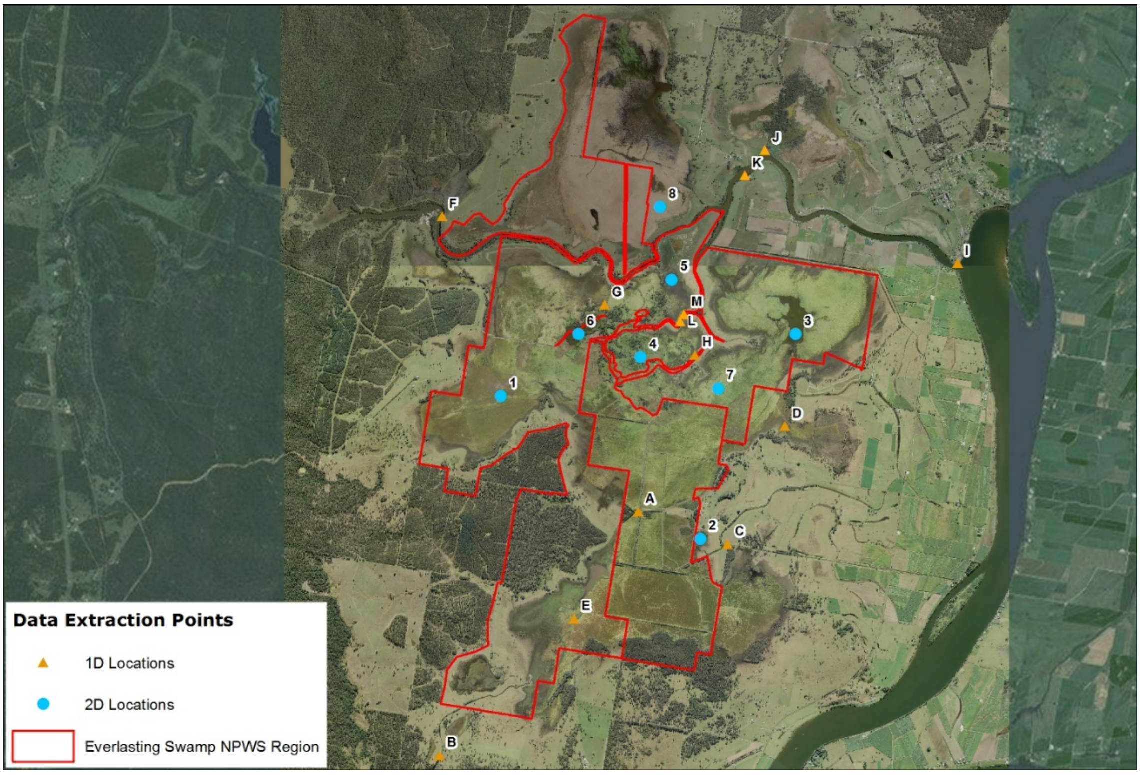


Figure F.23: Key Locations for Reporting

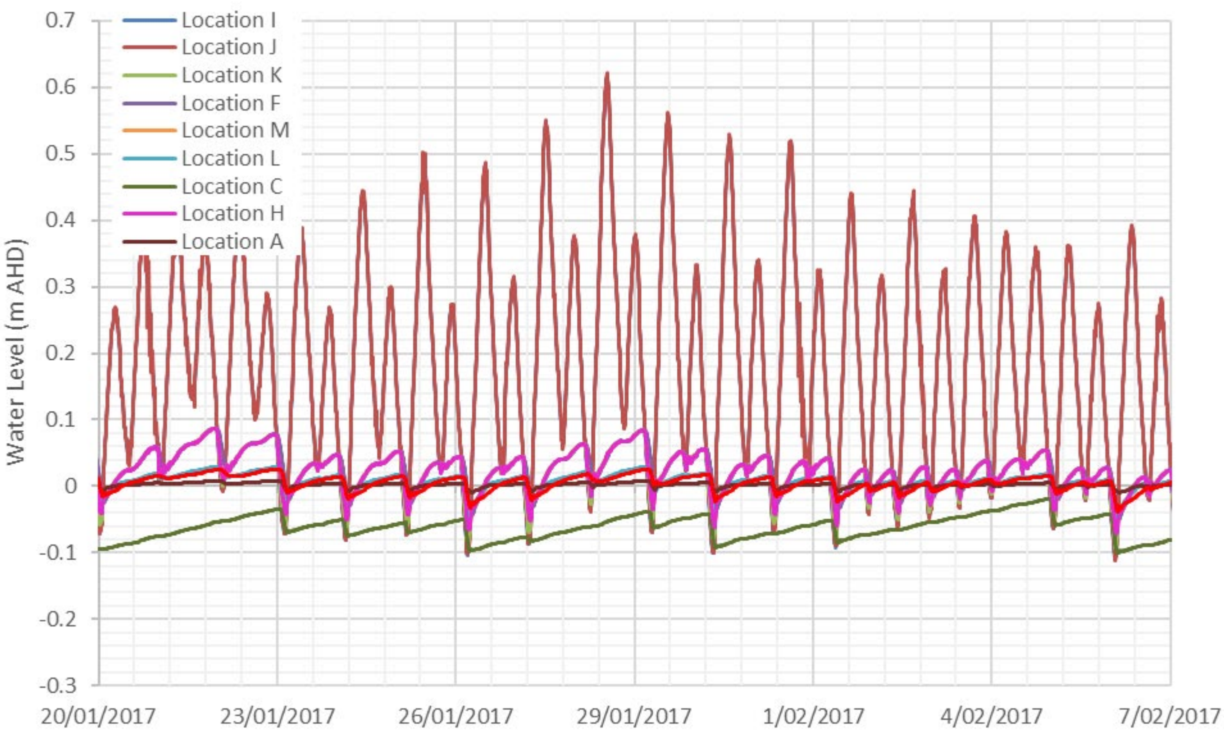


Figure F.24: 1D Drainage Channel Water Levels – Scenario 1

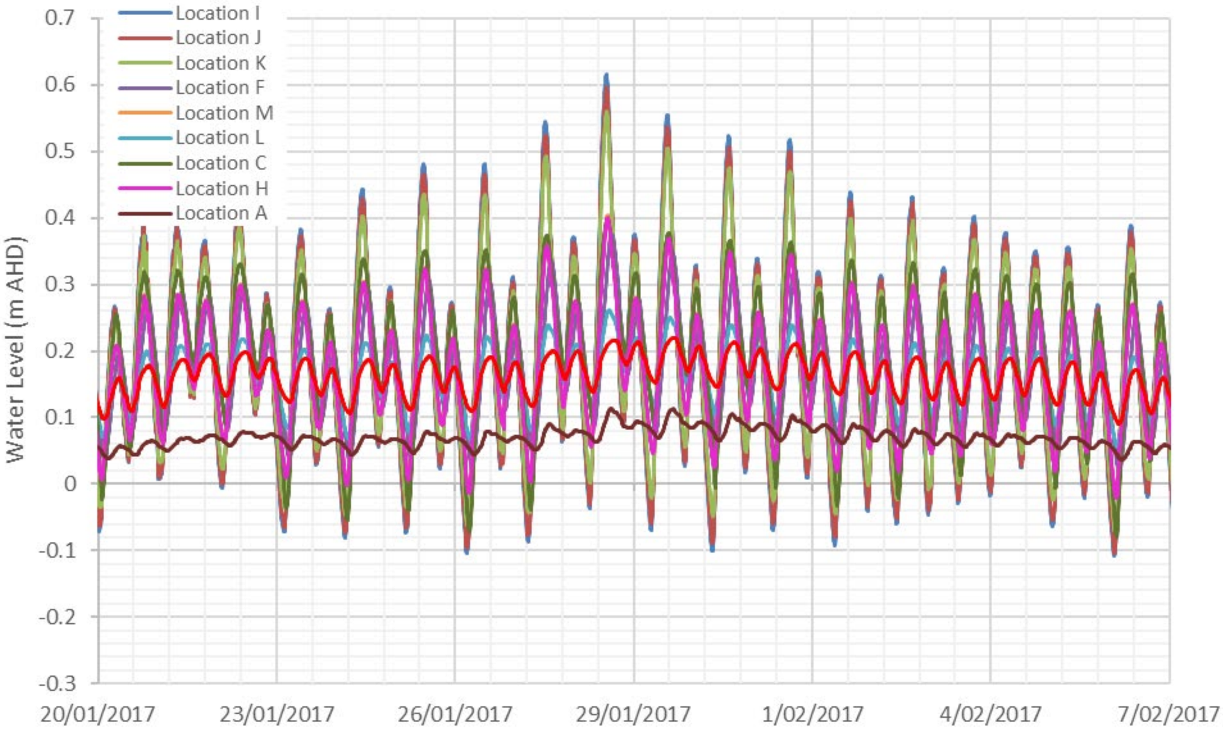


Figure F.25: 1D Drainage Channel Water Levels – Scenario 2

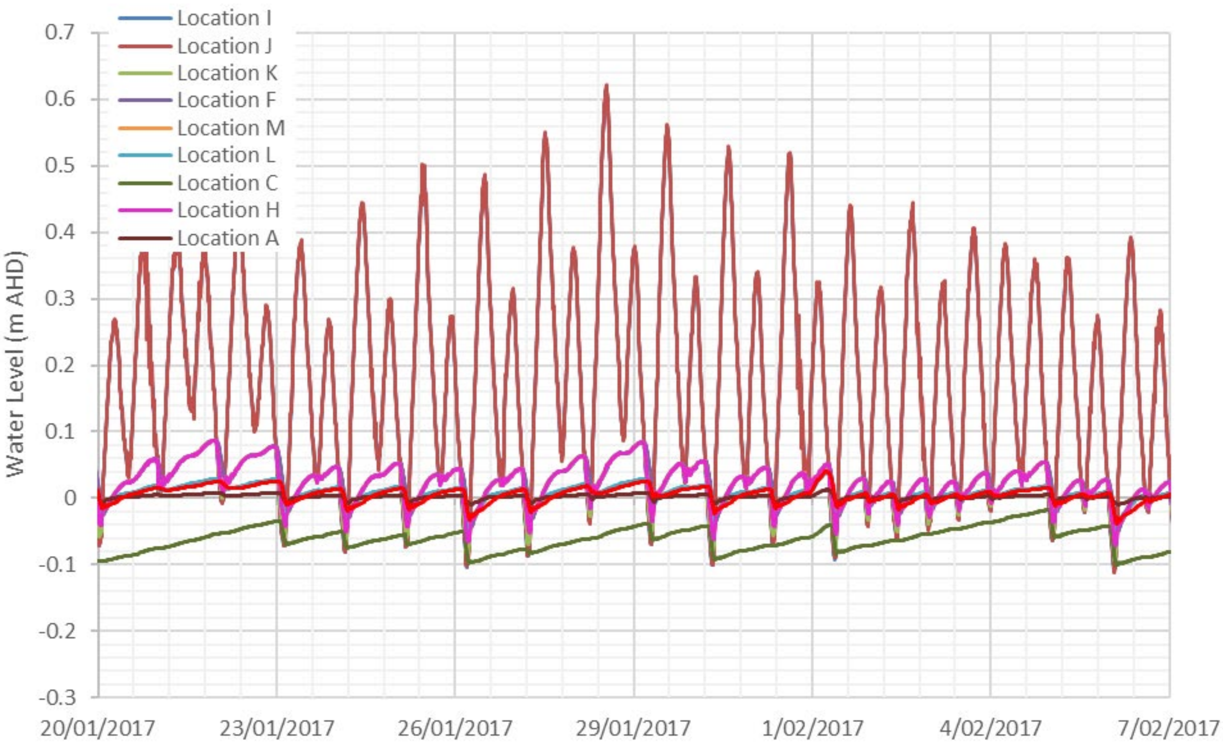


Figure F.26: 1D Drainage Channel Water Levels – Scenario 3

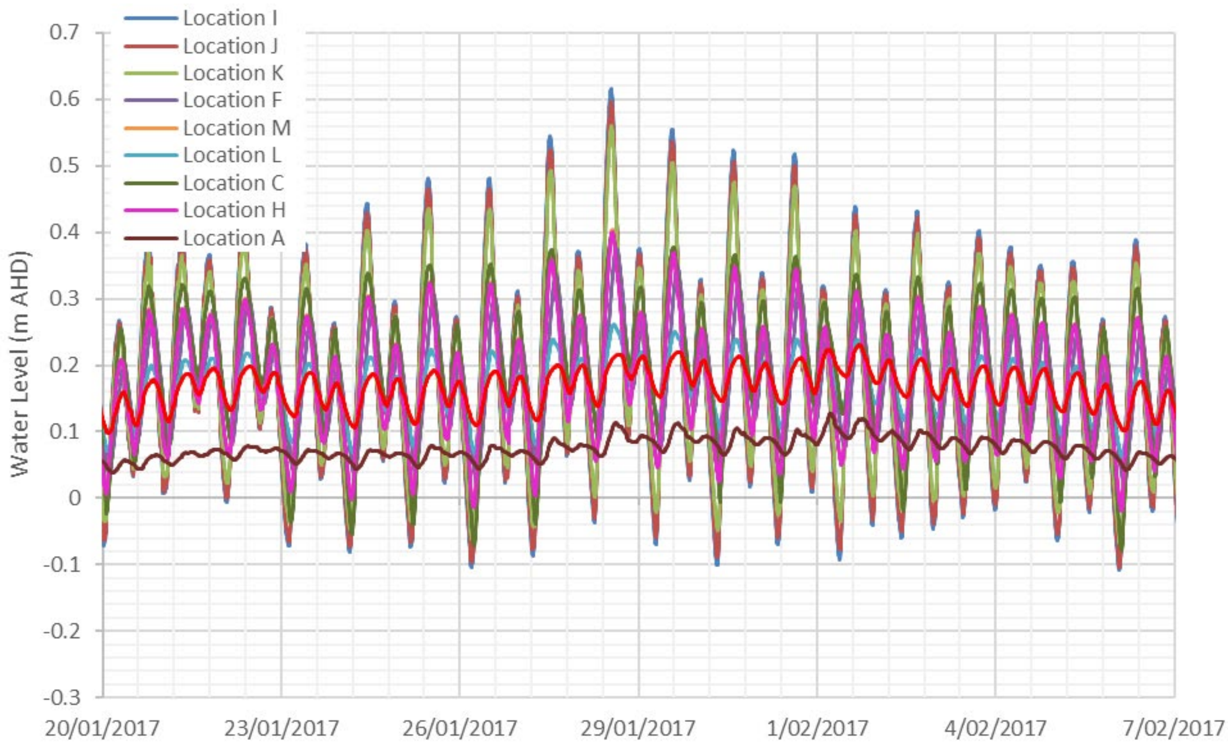


Figure F.27: 1D Drainage Channel Water Levels – Scenario 4

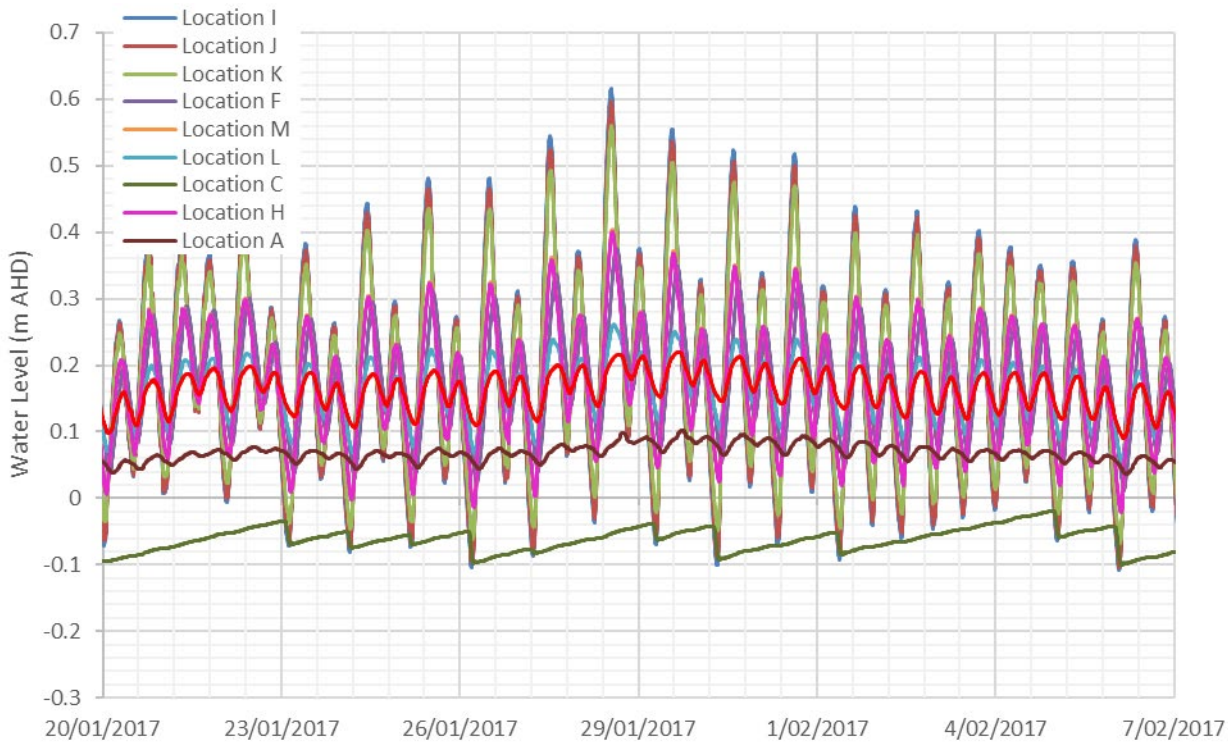


Figure F.28: 1D Drainage Channel Water Levels – Scenario 5

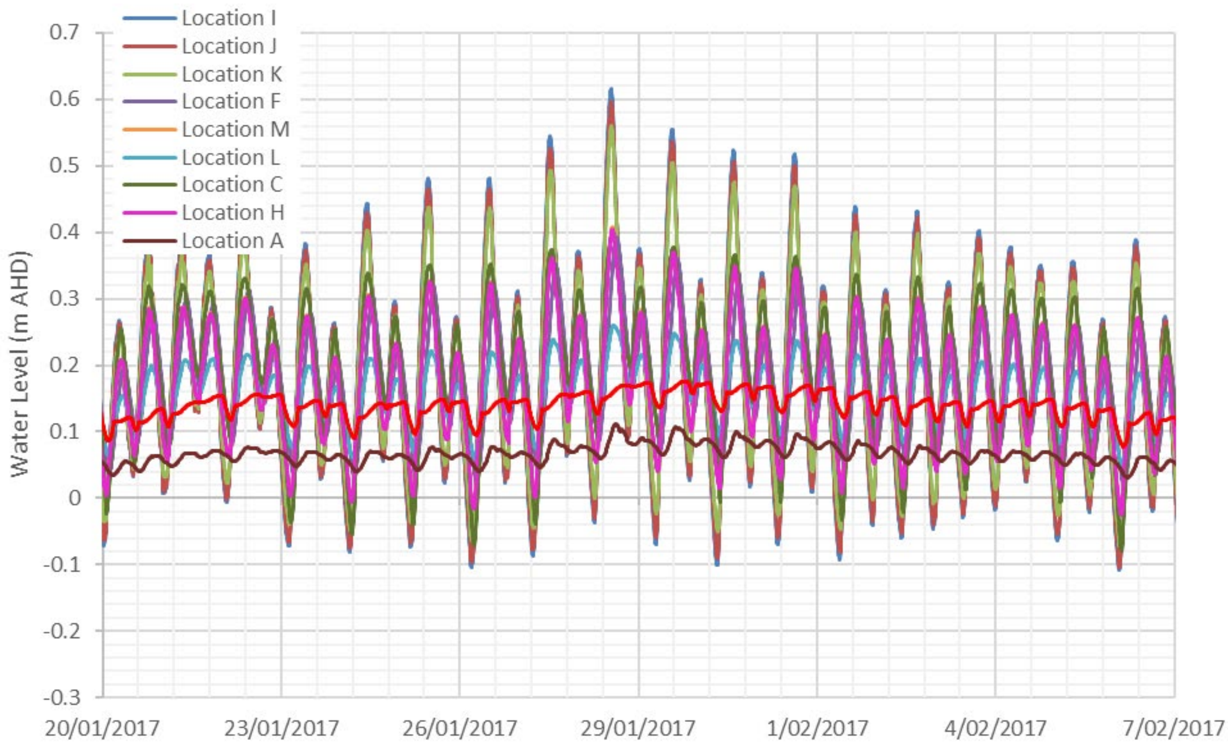


Figure F.29: 1D Drainage Channel Water Levels – Scenario 6

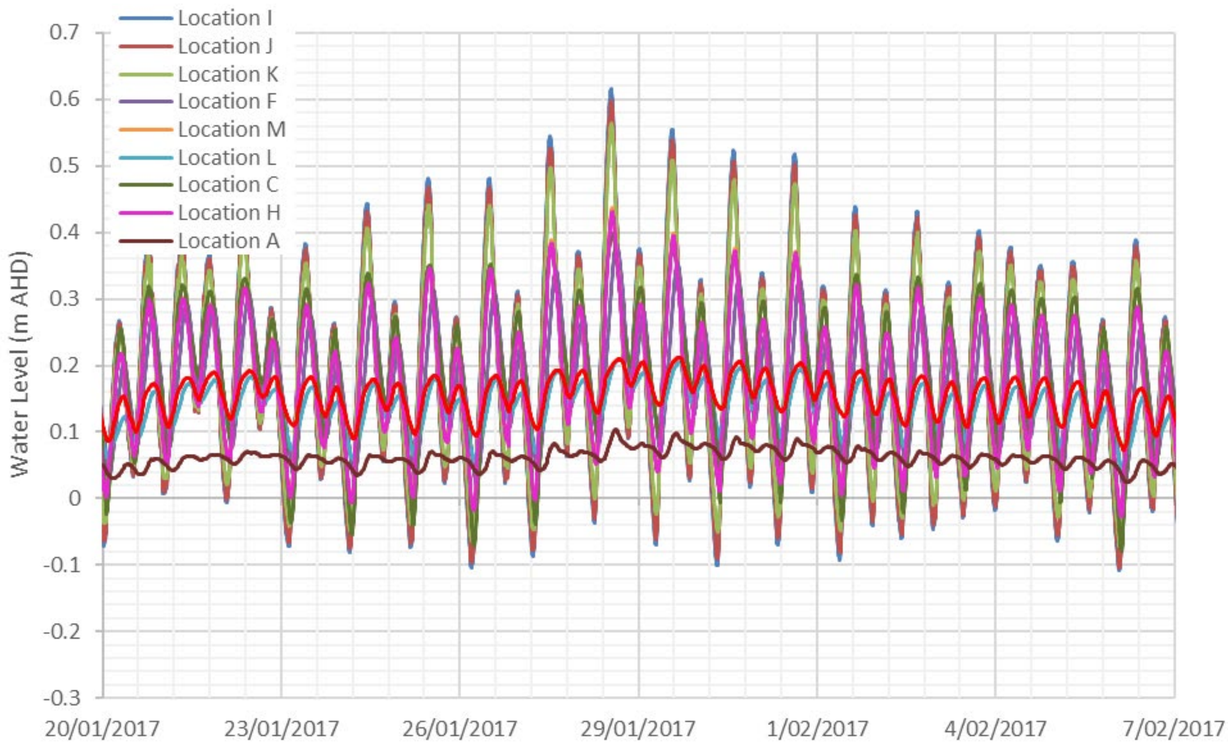


Figure F.30: 1D Drainage Channel Water Levels – Scenario 7

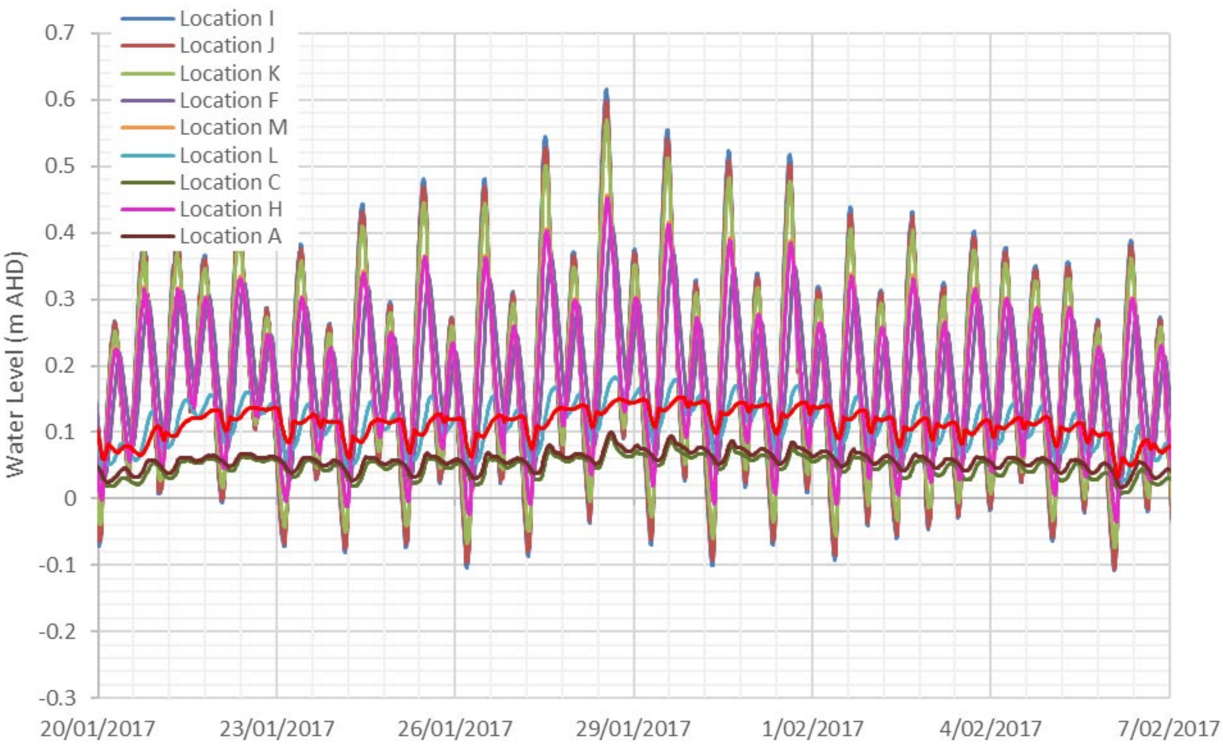


Figure F.31: 1D Drainage Channel Water Levels – Scenario 8

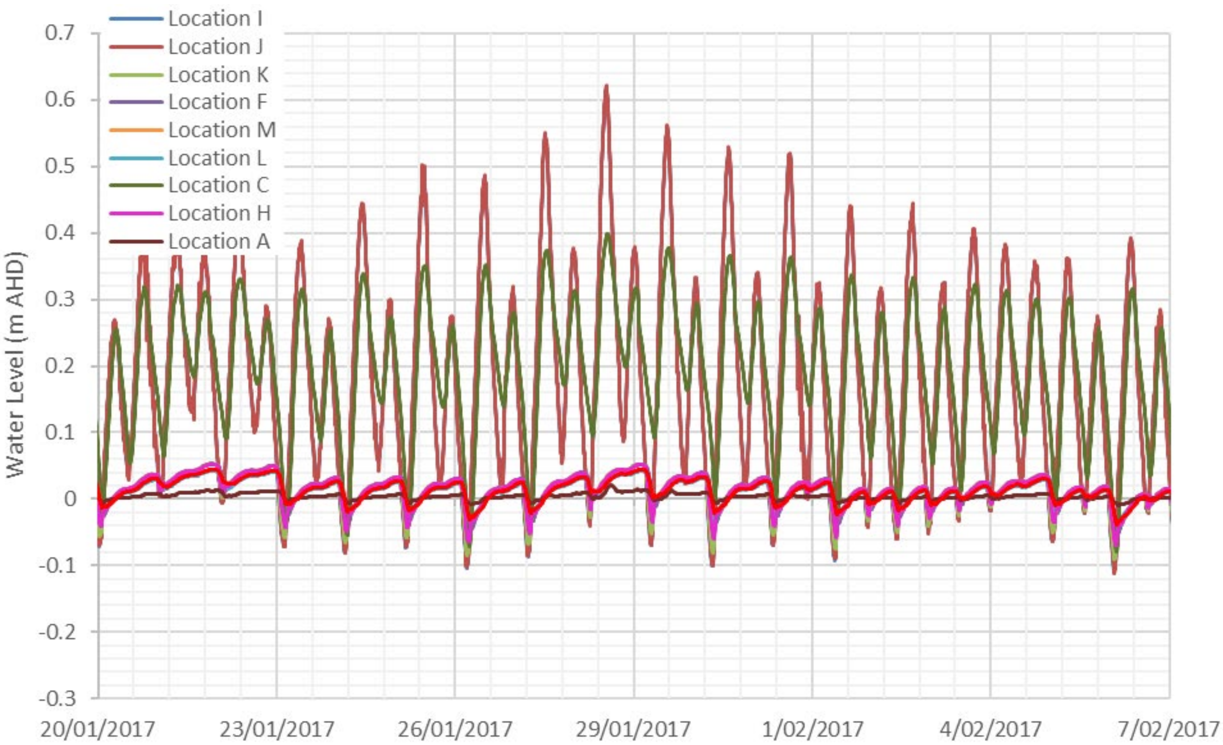


Figure F.32: 1D Drainage Channel Water Levels – Scenario 9

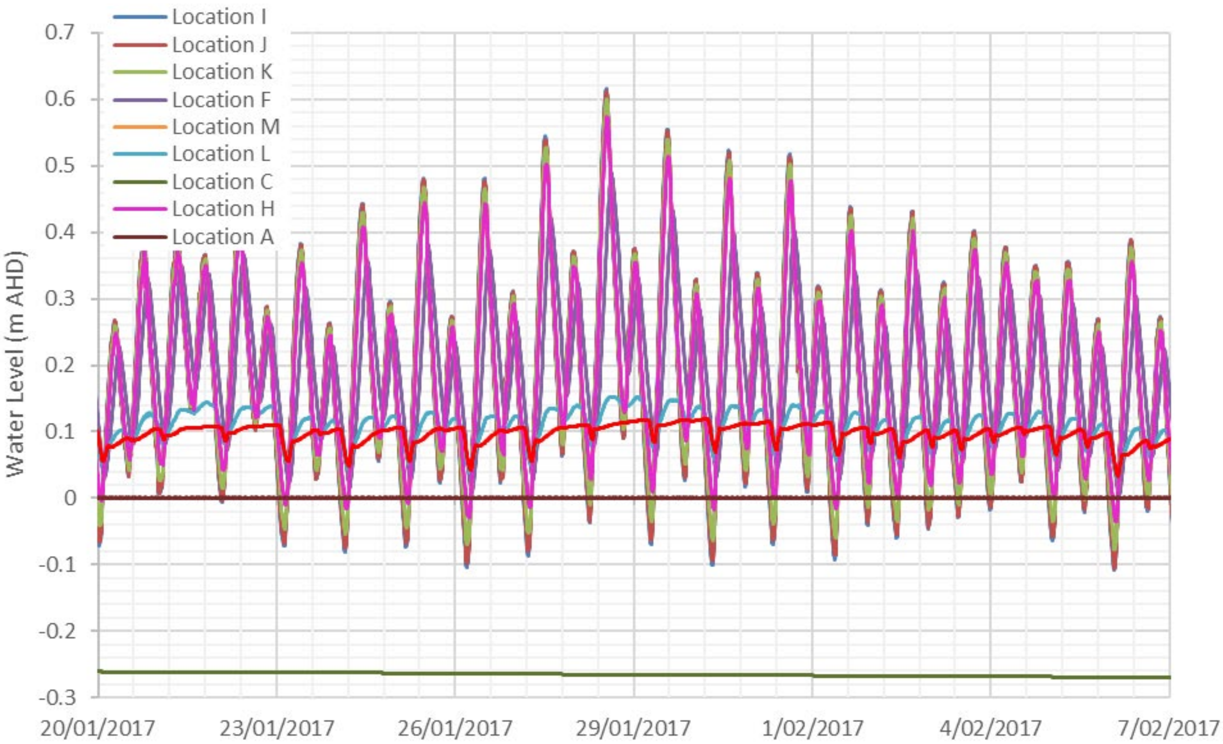


Figure F.33: 1D Drainage Channel Water Levels – Scenario 10

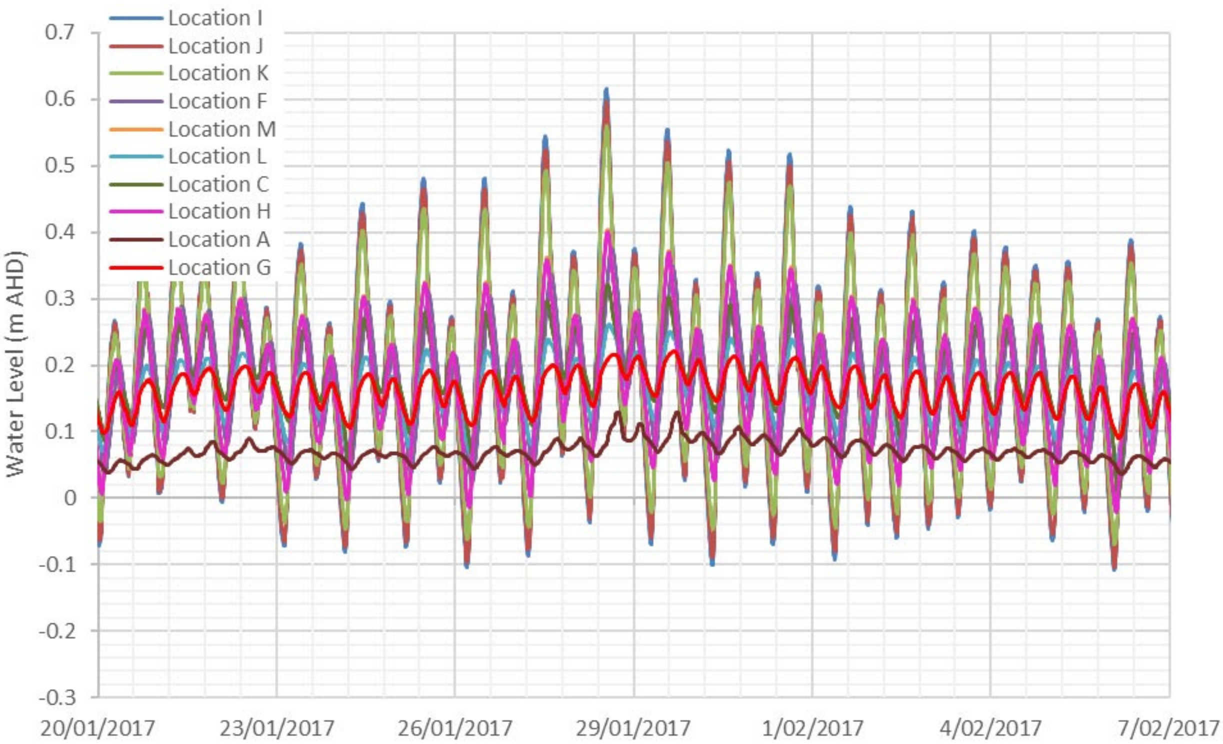


Figure F.34: 1D Drainage Channel Water Levels – Scenario 11

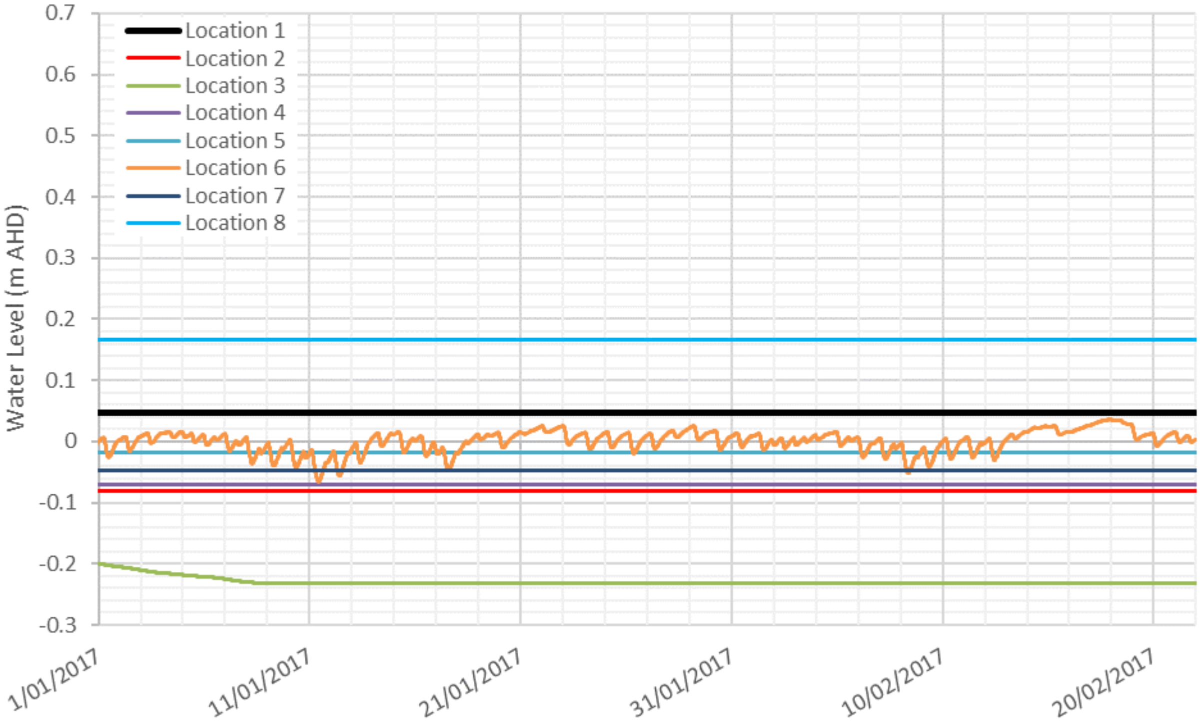


Figure F.35: 2D Floodplain Water Levels – Scenario 1

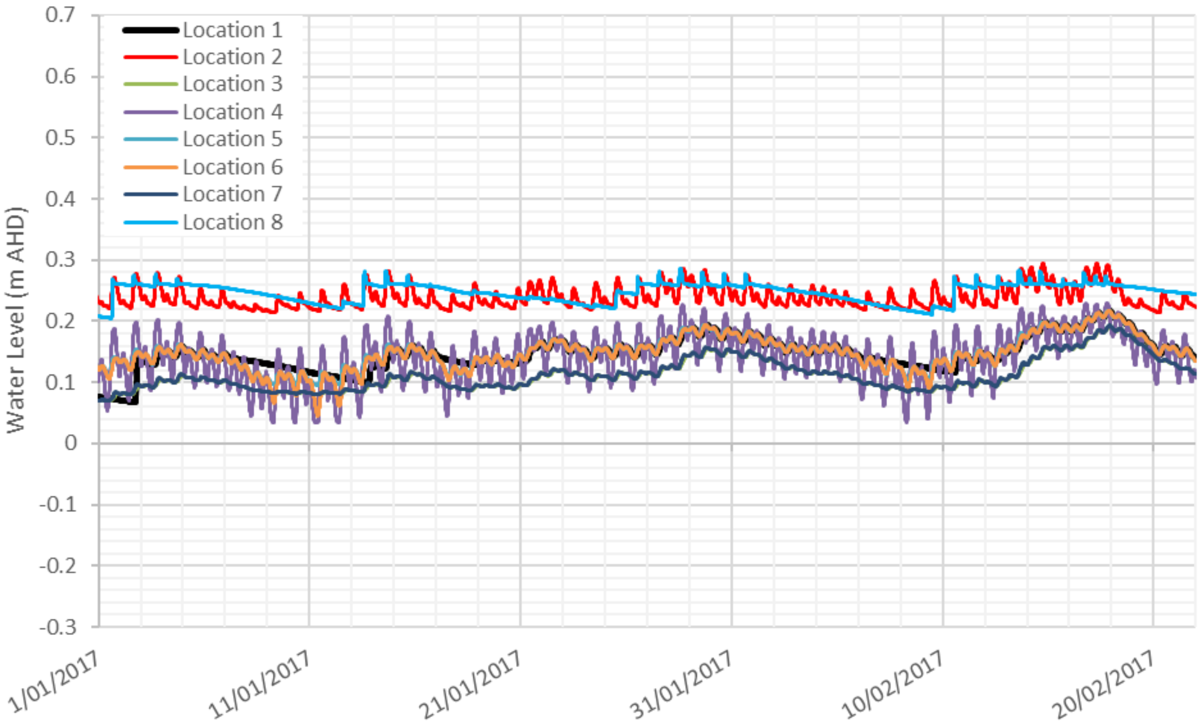


Figure F.36: 2D Floodplain Water Levels – Scenario 2

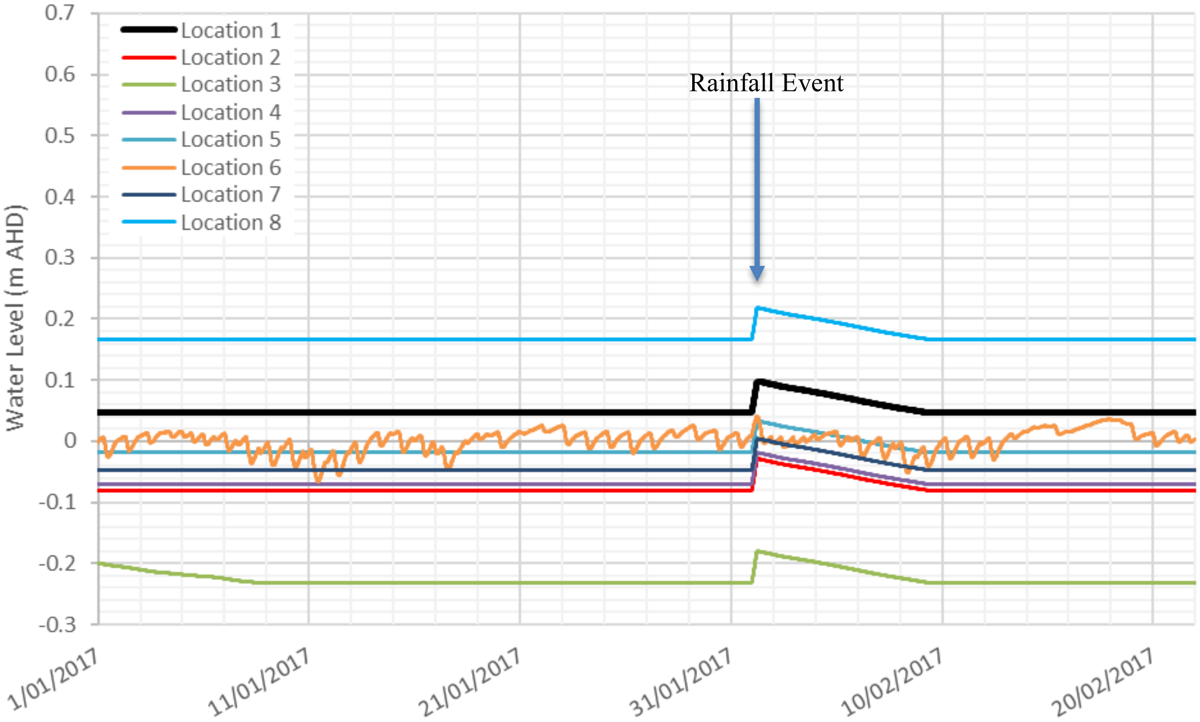


Figure F.37: 2D Floodplain Water Levels – Scenario 3

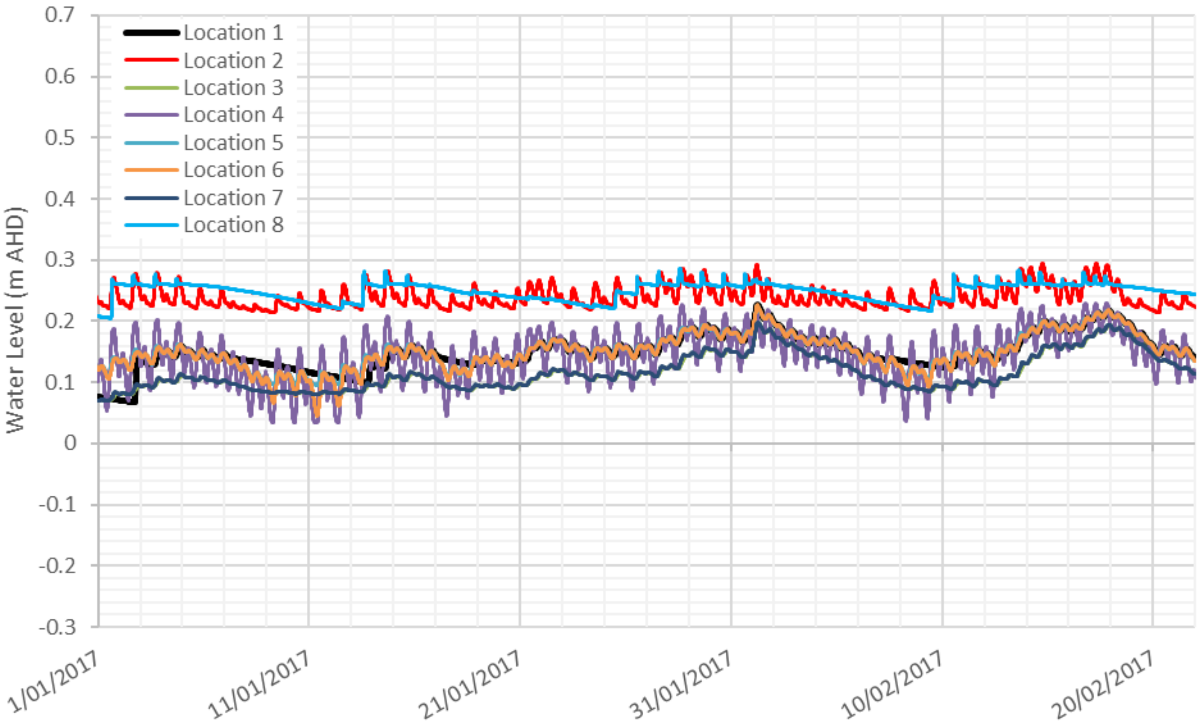


Figure F.38: 2D Floodplain Water Levels – Scenario 4

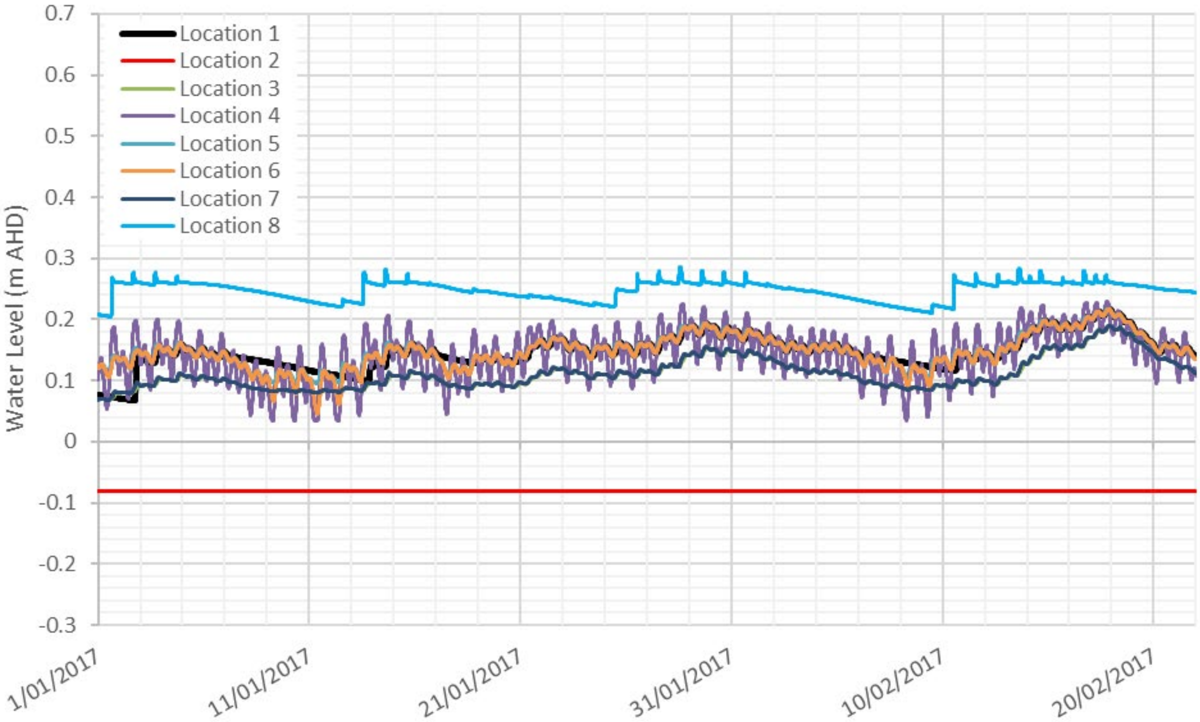


Figure F.39: 2D Floodplain Water Levels – Scenario 5

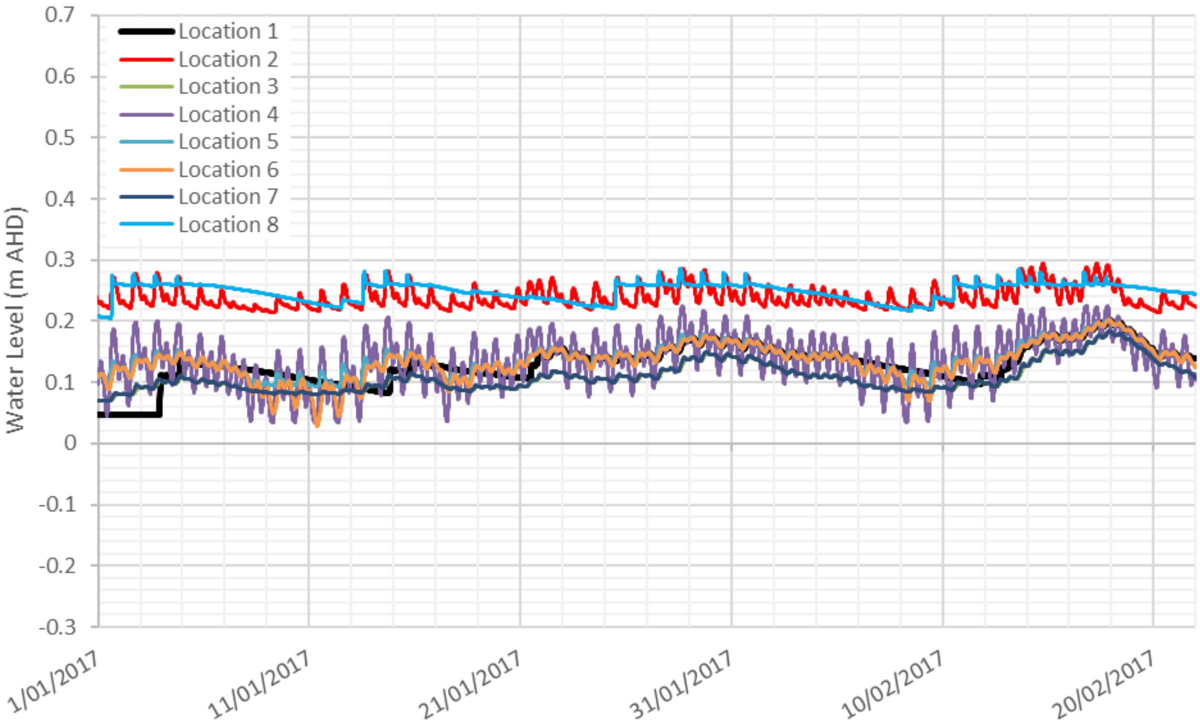


Figure F.40: 2D Floodplain Water Levels –Scenario 6

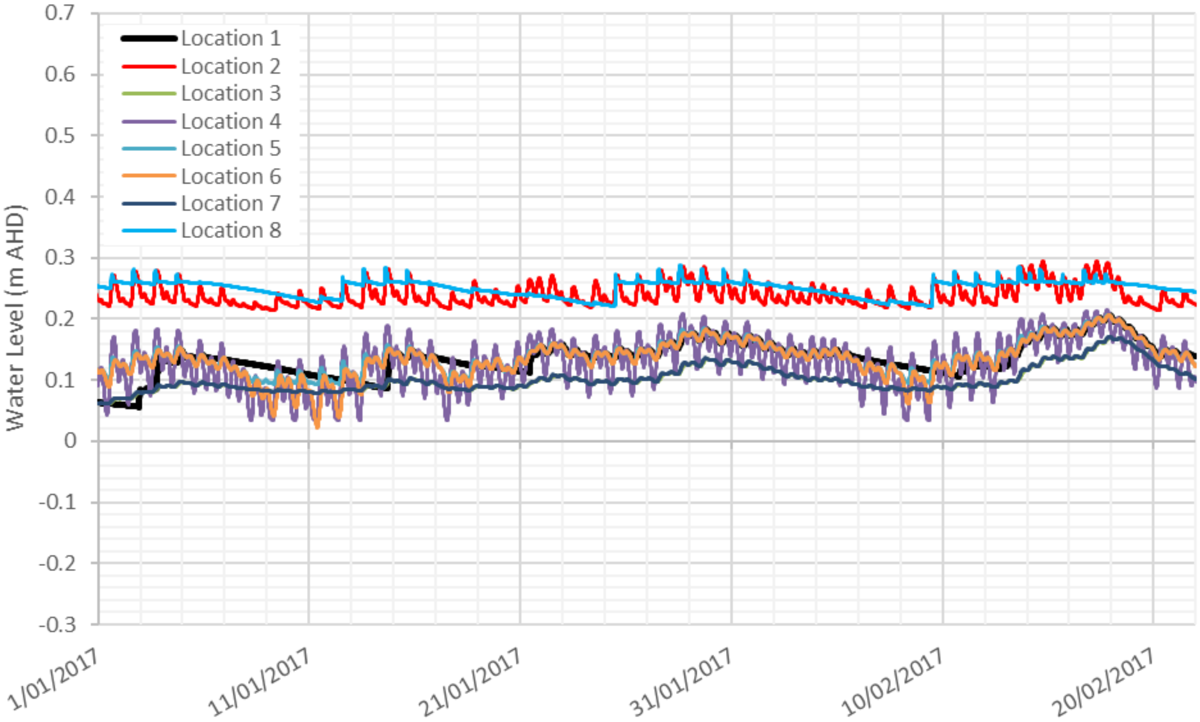


Figure F.41: 2D Floodplain Water Levels –Scenario 7

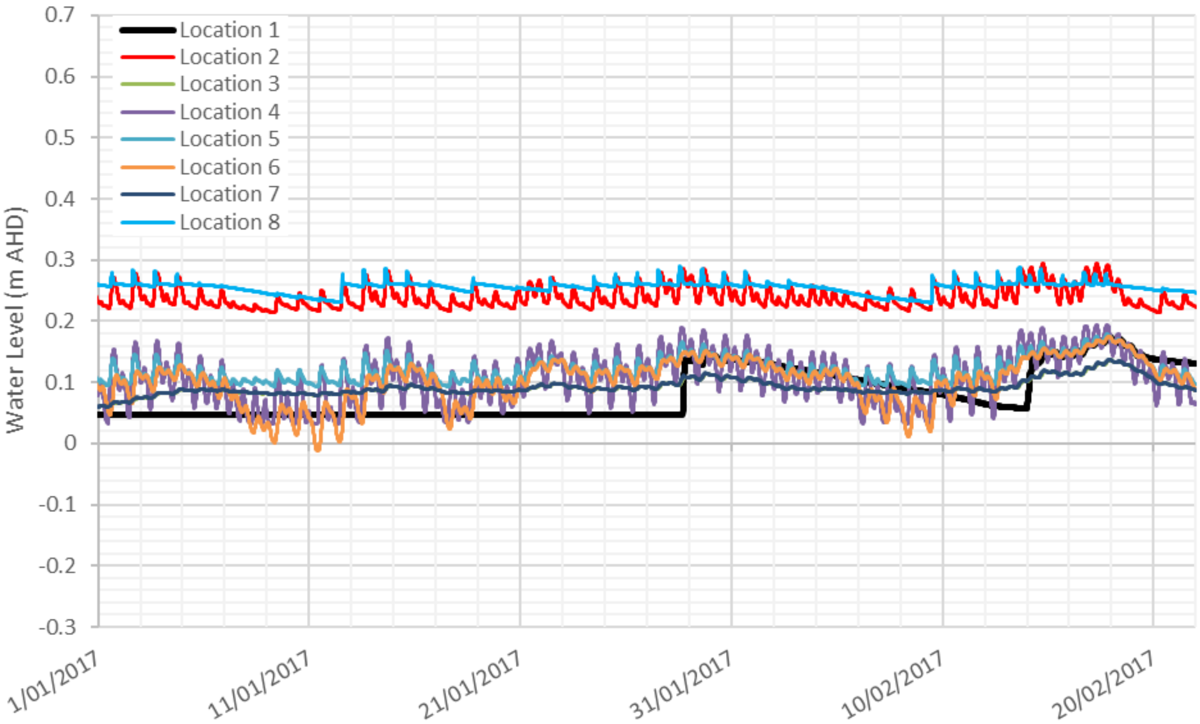


Figure F.42: 2D Floodplain Water Levels –Scenario 8

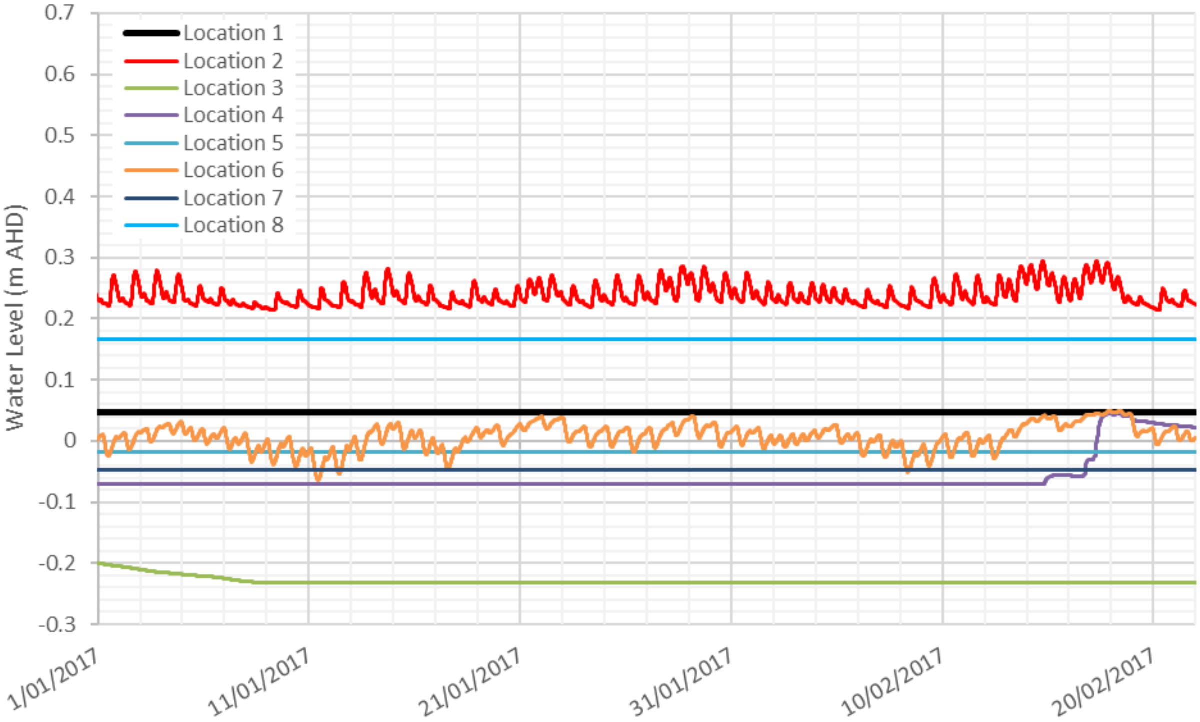


Figure F.43: 2D Floodplain Water Levels –Scenario 9

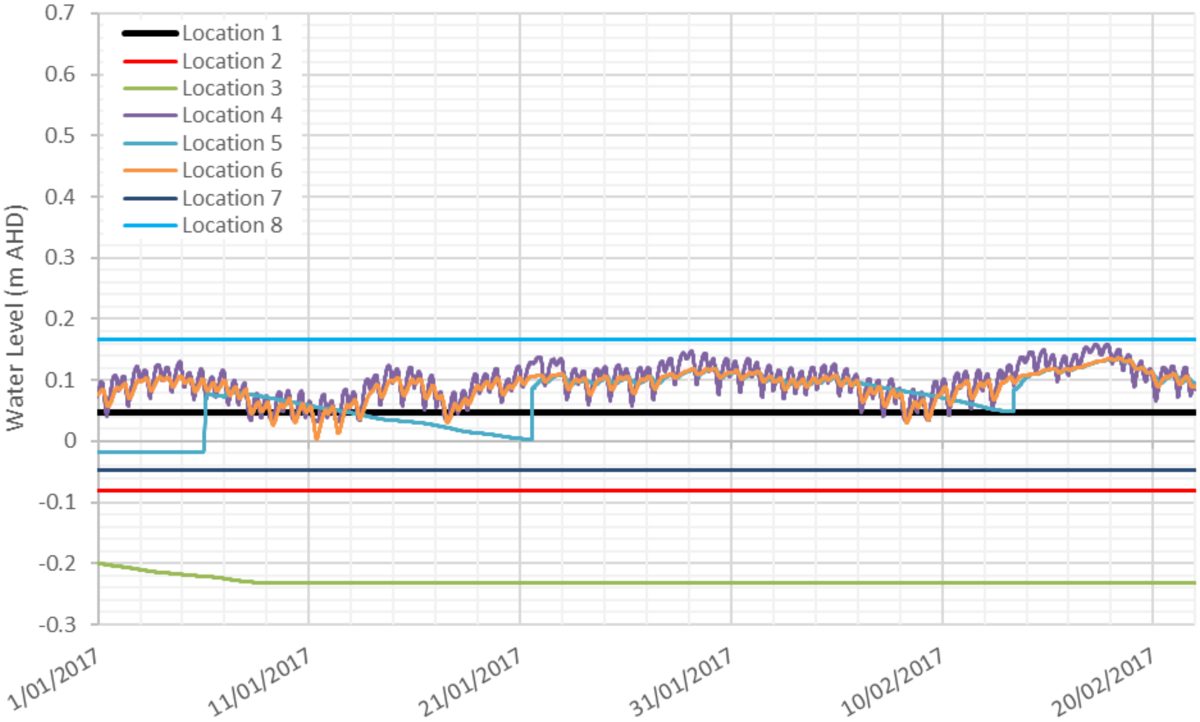


Figure F.44: 2D Floodplain Water Levels –Scenario 10

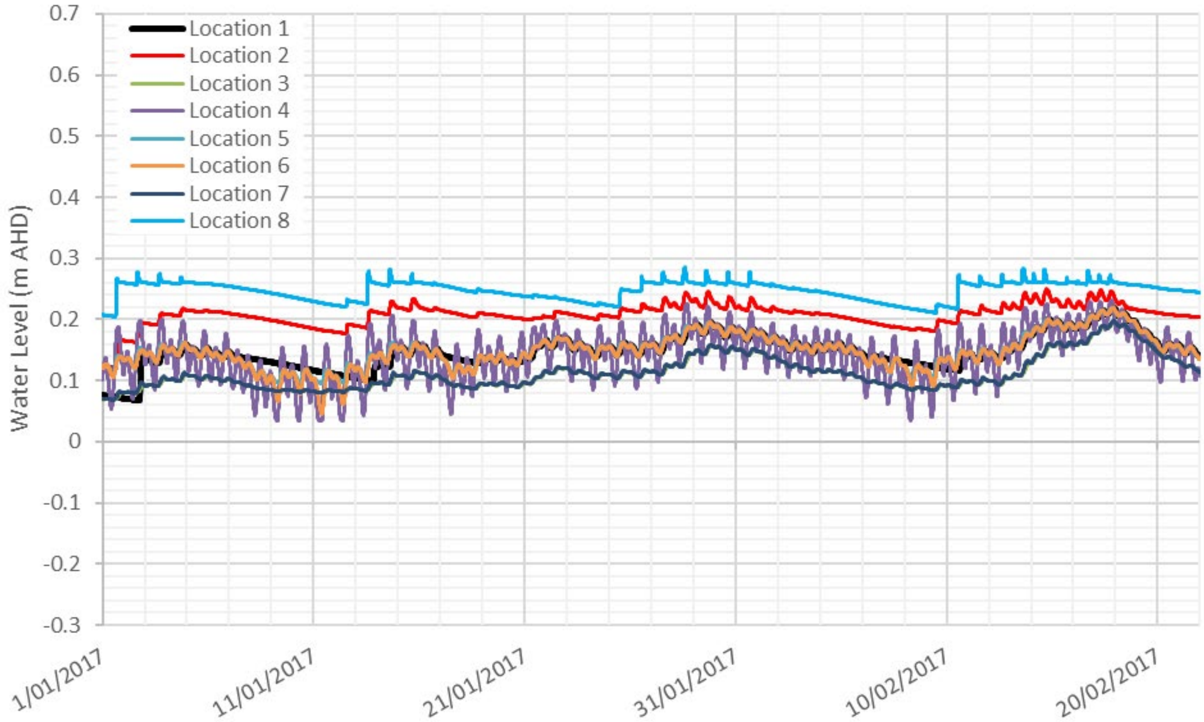


Figure F.45: 2D Floodplain Water Levels –Scenario 11

Table F.2: Summary Statistics - 2D Inundation Levels (m AHD) from 1 January to 22 February 2017 - Scenario 1 (Base Case)

Location	1	2	3	4	5	6	7	8
90th	0.046	-0.081	-0.222	-0.071	-0.019	0.020	-0.048	0.166
50th	0.046	-0.081	-0.232	-0.071	-0.019	0.003	-0.048	0.166
10th	0.046	-0.081	-0.232	-0.071	-0.019	-0.024	-0.048	0.166
Max	0.046	-0.081	-0.200	-0.071	-0.019	0.036	-0.048	0.166
Min	0.046	-0.081	-0.232	-0.071	-0.019	-0.066	-0.048	0.166

Table F.3: Summary Statistics - 2D Inundation Levels (m AHD) from 1 January to 22 February 2017 - Scenario 3

Location	1	2	3	4	5	6	7	8
90th	0.065	-0.062	-0.206	-0.052	0.000	0.021	-0.029	0.185
50th	0.046	-0.081	-0.232	-0.071	-0.019	0.004	-0.048	0.166
10th	0.046	-0.081	-0.232	-0.071	-0.019	-0.024	-0.048	0.166
Max	0.098	-0.029	-0.180	-0.019	0.033	0.041	0.004	0.218
Min	0.046	-0.081	-0.232	-0.071	-0.019	-0.066	-0.048	0.166

Table F.4: Summary Statistics - 2D Inundation Levels (m AHD) from 1 January to 22 February 2017 - Scenario 2 (Full Restoration)

Location	1	2	3	4	5	6	7	8
90th	0.186	0.267	0.153	0.193	0.186	0.186	0.154	0.261
50th	0.147	0.232	0.106	0.145	0.149	0.148	0.107	0.252
10th	0.118	0.222	0.084	0.088	0.114	0.113	0.084	0.224
Max	0.218	0.294	0.193	0.229	0.217	0.218	0.193	0.286
Min	0.067	0.214	0.070	0.034	0.095	0.045	0.070	0.205

Table F.5: Summary Statistics - 2D Inundation Levels (m AHD) from 1 January to 22 February 2017 - Scenario 4

Location	1	2	3	4	5	6	7	8
90th	0.190	0.268	0.161	0.194	0.190	0.190	0.161	0.261
50th	0.149	0.233	0.108	0.147	0.150	0.149	0.108	0.254
10th	0.120	0.222	0.084	0.089	0.115	0.113	0.085	0.226
Max	0.227	0.294	0.199	0.229	0.226	0.226	0.199	0.286
Min	0.067	0.214	0.070	0.034	0.095	0.045	0.070	0.205

Table F.6: Summary Statistics - 2D Inundation Levels (m AHD) from 1 January to 22 February 2017 - Scenario 5

Location	1	2	3	4	5	6	7	8
90th	0.186	-0.081	0.151	0.192	0.186	0.186	0.152	0.261
50th	0.147	-0.081	0.106	0.145	0.149	0.148	0.106	0.252
10th	0.118	-0.081	0.084	0.088	0.114	0.113	0.084	0.223
Max	0.218	-0.081	0.190	0.229	0.217	0.217	0.190	0.286
Min	0.067	-0.081	0.068	0.034	0.095	0.045	0.068	0.205

Table F.7: Summary Statistics - 2D Inundation Levels (m AHD) from 1 January to 22 February 2017 - Scenario 6

Location	1	2	3	4	5	6	7	8
90th	0.170	0.267	0.146	0.189	0.172	0.170	0.146	0.261
50th	0.130	0.232	0.103	0.140	0.138	0.137	0.104	0.254
10th	0.096	0.222	0.084	0.082	0.104	0.096	0.084	0.226
Max	0.202	0.294	0.184	0.225	0.202	0.202	0.184	0.286
Min	0.046	0.214	0.069	0.033	0.093	0.029	0.069	0.205

Table F.8: Summary Statistics - 2D Inundation Levels (m AHD) from 1 January to 22 February 2017 - Scenario 7

Location	1	2	3	4	5	6	7	8
90th	0.174	0.267	0.133	0.179	0.176	0.175	0.134	0.261
50th	0.138	0.232	0.095	0.131	0.139	0.138	0.095	0.256
10th	0.101	0.222	0.082	0.074	0.104	0.096	0.082	0.229
Max	0.207	0.294	0.171	0.215	0.207	0.207	0.171	0.288
Min	0.056	0.214	0.061	0.033	0.093	0.022	0.061	0.220

Table F.9: Summary Statistics - 2D Inundation Levels (m AHD) from 1 January to 22 February 2017 - Scenario 8

Location	1	2	3	4	5	6	7	8
90th	0.142	0.267	0.112	0.160	0.149	0.145	0.113	0.262
50th	0.046	0.232	0.088	0.110	0.118	0.110	0.088	0.258
10th	0.046	0.222	0.081	0.051	0.099	0.050	0.082	0.240
Max	0.174	0.294	0.137	0.194	0.179	0.174	0.138	0.290
Min	0.046	0.214	0.060	0.032	0.093	-0.013	0.060	0.230

Table F.10: Summary Statistics - 2D Inundation Levels (m AHD) from 1 January to 22 February 2017 - Scenario 9

Location	1	2	3	4	5	6	7	8
90th	0.046	0.267	-0.222	-0.044	-0.019	0.033	-0.048	0.166
50th	0.046	0.232	-0.232	-0.071	-0.019	0.009	-0.048	0.166
10th	0.046	0.222	-0.232	-0.071	-0.019	-0.021	-0.048	0.166
Max	0.046	0.294	-0.200	0.046	-0.019	0.049	-0.048	0.166
Min	0.046	0.214	-0.232	-0.071	-0.019	-0.064	-0.048	0.166

Table F.11: Summary Statistics - 2D Inundation Levels (m AHD) from 1 January to 22 February 2017 - Scenario 10

Location	1	2	3	4	5	6	7	8
90th	0.046	-0.081	-0.222	0.133	0.116	0.116	-0.048	0.166
50th	0.046	-0.081	-0.232	0.101	0.083	0.095	-0.048	0.166
10th	0.046	-0.081	-0.232	0.059	0.003	0.056	-0.048	0.166
Max	0.046	-0.081	-0.200	0.158	0.135	0.136	-0.048	0.166
Min	0.046	-0.081	-0.232	0.032	-0.019	0.004	-0.048	0.166

Table F.12: Summary Statistics - 2D Inundation Levels (m AHD) from 1 January to 22 February 2017 - Scenario 11

Location	1	2	3	4	5	6	7	8
90th	0.187	0.228	0.155	0.193	0.187	0.187	0.156	0.261
50th	0.147	0.209	0.106	0.145	0.149	0.148	0.106	0.252
10th	0.118	0.186	0.084	0.088	0.114	0.113	0.084	0.224
Max	0.219	0.249	0.198	0.231	0.219	0.219	0.198	0.285
Min	0.067	0.121	0.068	0.034	0.095	0.045	0.069	0.204

F.2.2 Stage 2: Additional Field Data and Model Update

A recent report by Gordos (2012) titled, 'Sportsmans Creek Weir Management Options Report', identified several low-lying areas in the upper reaches of Sportsmans Creek that were considered likely to be affected by the removal of Sportsmans Creek Weir. These areas were previously included in the baseline (Stage 1) model as 2-D features (based on LiDAR) in the floodplain bathymetry. The baseline model runs showed that under a full-restoration scenario (i.e. removal of Sportsmans Creek Weir and all internal floodgates) these areas were not at risk of tidal inundation. However, further investigations were required to verify these preliminary model findings and to assess the potential risk of tidal inundation in these areas.

WRL and NPWS staff completed additional field investigations of the study area from 15 to 16 August 2017. This field work involved extensive on-ground and bathymetric surveys of several areas of the site, including low-lying areas in the upper reaches of Sportsmans Creek, Woody Creek connection to Coxs Swamp, Teal Lagoon connection to Bullock Swamp, Blanches drain connection to south-east paddocks, as well as other key hydrologic features. This information was used to update the important topographic features across the study domain that were not being captured by the resolution of the previous 2-D model bathymetry.

Note that despite several efforts to obtain adequate field data in the low-lying areas in the upper reaches of Sportsmans Creek, some areas were inaccessible and have been left as 2-D features (based on LiDAR) in the model floodplain bathymetry. A stage-volume analysis showed that below 1.5 m AHD, these inaccessible low-lying areas in the upper reaches of Sportsmans Creek are less than 1% of the total volume of the Everlasting Swamp floodplain. Further site investigations would be required to ground-truth these areas should the removal of the Sportsmans Creek Weir be the preferred option for the future management of Everlasting Swamp wetland complex.

Figure F.46 and Figure F.47 provide the existing conditions of the site using the updated model for the baseline simulation period. The inundation extents and hydroperiods for the updated model under existing conditions are comparable to the previous model runs for the same simulation period. As expected during this relative dry period, Teal Lagoon and the adjacent water bodies fed by Reedy Creek are the main permanent water bodies at Everlasting Swamp. Note that a relatively small catchment rainfall event provided some inflow to model domain through Duck Creek on the northern boundary. However, this area of the site remained wet for between 20-40% of the model simulation period, with a mean inundation depth of less than 5 cm.

Figure F.48 and Figure F.49 provide the model results for the full restoration scenario using the updated model for the baseline simulation period. As was observed in the previous baseline model runs, the model results for the full restoration scenario indicate that Teal Lagoon, Reedy Creek and Coxs Swamp are the key areas experiencing frequent tidal inundation, remaining wet for 80-100% of the time. While the mean inundation extents for this scenario are generally contained within the NPWS boundary, some inundation of neighbouring properties was predicted on the eastern and western borders of the Everlasting Swamp National Park during larger spring tides. Increased inundation was also predicted for the areas of Duck Creek and the northern parts of Imesons Swamp.

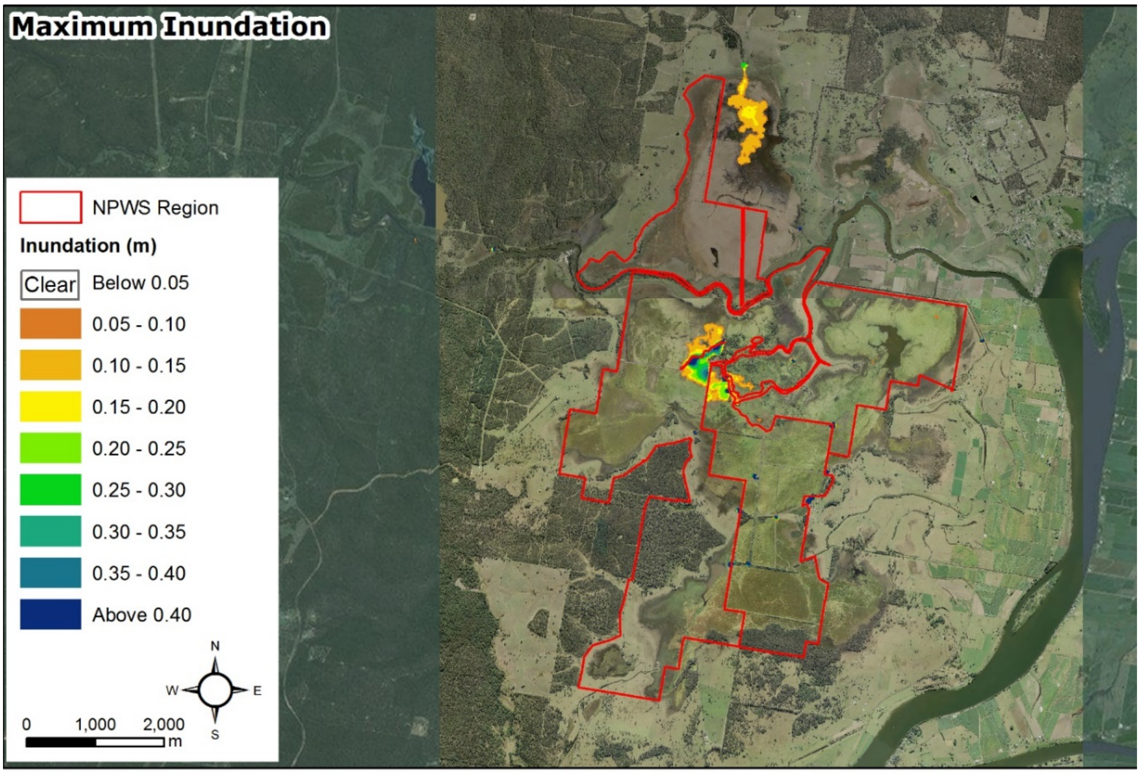
Note that an area of low-lying land just upstream of Imesons Swamp on the left bank of Sportsmans Creek was surveyed during the August 2017 field investigation. At the time of the inspection, this area was observed to be isolated and was completely inundated with less than approximately 0.2 m of water from what was likely remaining from recent rainfall events. Furthermore, a possible connection to Sportsmans Creek was observed as a short meandering channel and a short, regular culvert, however this culvert appeared to be fully choked. This area was subsequently incorporated into the updated model as a short 1-D channel connected to the 2-D bathymetry through a short, regular culvert. Assuming a fully operational culvert without a floodgate, and under a full restoration scenario, this area could be inundated between 40-100% of the time, with maximum inundation depths of up to 0.2 – 0.3 m. Indeed, if purchased, this area could compliment the wider Everlasting Swamp wetland complex and be a stand-alone mosaic of freshwater and saltwater wetland.

Figure F.50 to Figure F.53 provide the model results for the existing conditions and full restoration scenario using the updated model for the long duration simulation period. These model scenarios simulate the natural wetting-drying patterns of the floodplain through direct rainfall, catchment runoff, tidal inundation and evaporation. However, the model does not include surface-groundwater interactions or infiltration. While infiltration of surface water to groundwater is generally considered as a loss term, groundwater can also recharge surface water areas, such as Teal Lagoon. Nonetheless, the model is conservative by neglecting these terms, because these wetland environments generally have a high groundwater table near or at the surface.

Figure F.52 and Figure F.53, in comparison to Figure F.50 and Figure F.51, clearly showed for the simulation period from January to September 2010, that a full restoration scenario would have implications for increased flooding for some neighbouring properties to Everlasting Swamp. Potential areas of concern, include the northern portion of Imesons Swamp, the south-east paddocks behind Blanches Drain, and the some of the low-lying areas in the upper reaches of Sportsmans Creek. Under full restoration, these areas along the NPWS boundary would likely experience increased inundation and longer hydroperiods (i.e. be wetter for longer). This outcome is because the floodgates across the site are open and the tail water is higher compared to existing conditions, resulting in reduced drainage gradients across the site. The Horseshoe may also require further investigation as to observed hydroperiods following rainfall and the overland drainage connection to the Coxs Swamp area. However, based on these modelling results, it appears that The Horseshoe area would not experience increased flooding under full restoration, when compared to the existing conditions at the site.

A range of statistics have been extracted from the model outputs to support the figures of inundation and hydroperiods, and are provided Table F.13 to Table F.18. Table F.13 to Table F.18 provides the predicted areas and depths associated with each hydroperiod range for each scenario tested. Note that the depths are calculated as a weighted-average to account for the difference in cell sizes across the model domain. Furthermore, the maximum depth reported in the 80-100% hydroperiod range is skewed by the fact that cells around the ends of drains throughout the model domain were artificially lowered to smooth the 1-D and 2-D connections in the model and to improve model stability. The table footnotes provide an indication of the likely number of cells that are above a certain depth limit for each scenario, without completing a detailed forensic analysis.

Table F.13 and Table F.14 summarise the results for the preliminary model runs for the existing conditions and full restoration scenarios, and are provided for comparison with Table F.15 and Table F.16 for the updated model. These statistics show that there is little difference to the overall model results for the two models, and remove the need to re-run previously tested model scenarios. These statistics were used to inform the potential ecological response of the site.



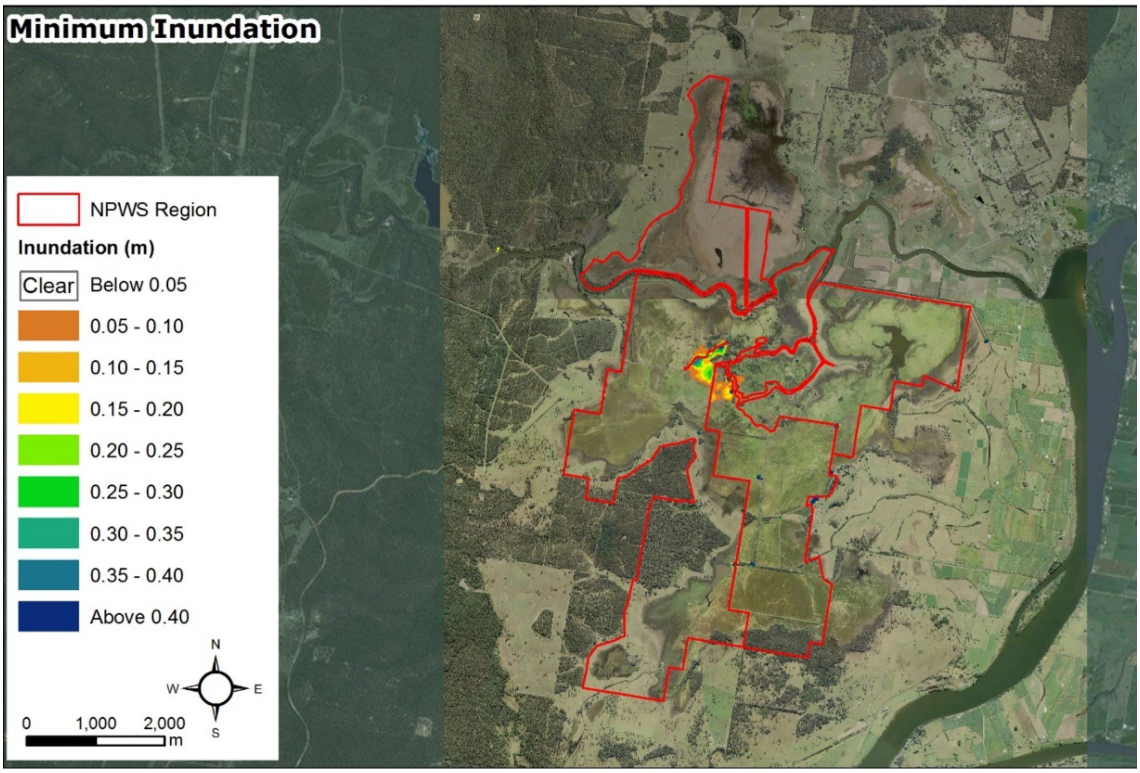


Figure F.46: Updated Model - Existing Conditions (Scenario 12) - Maximum and Minimum Inundation Extents - 1 January to 22 February 2017

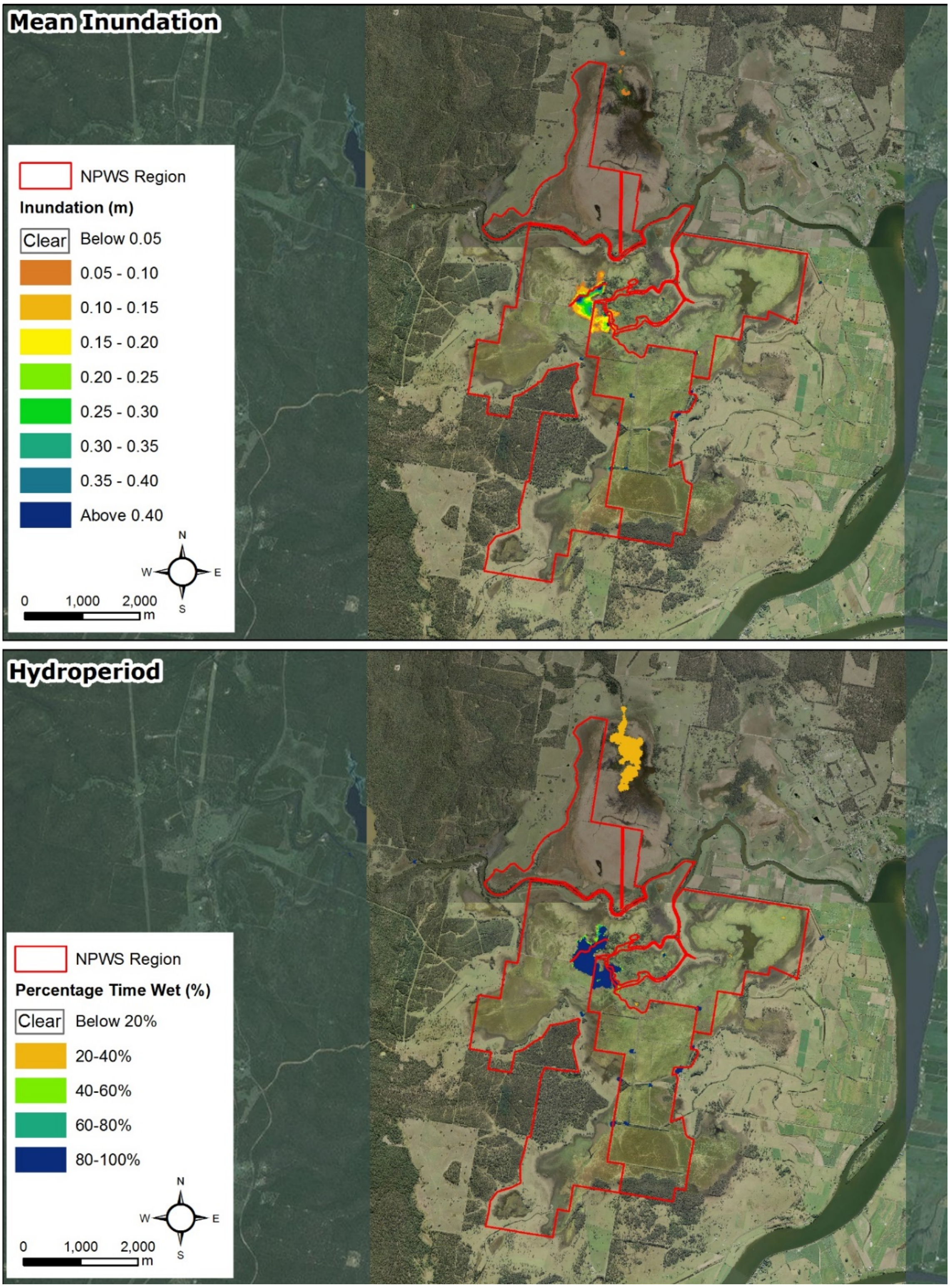


Figure F.47: Updated Model - Existing Conditions (Scenario 12) – Mean Inundation Extent and Hydroperiod Analysis - 1 January to 22 February 2017

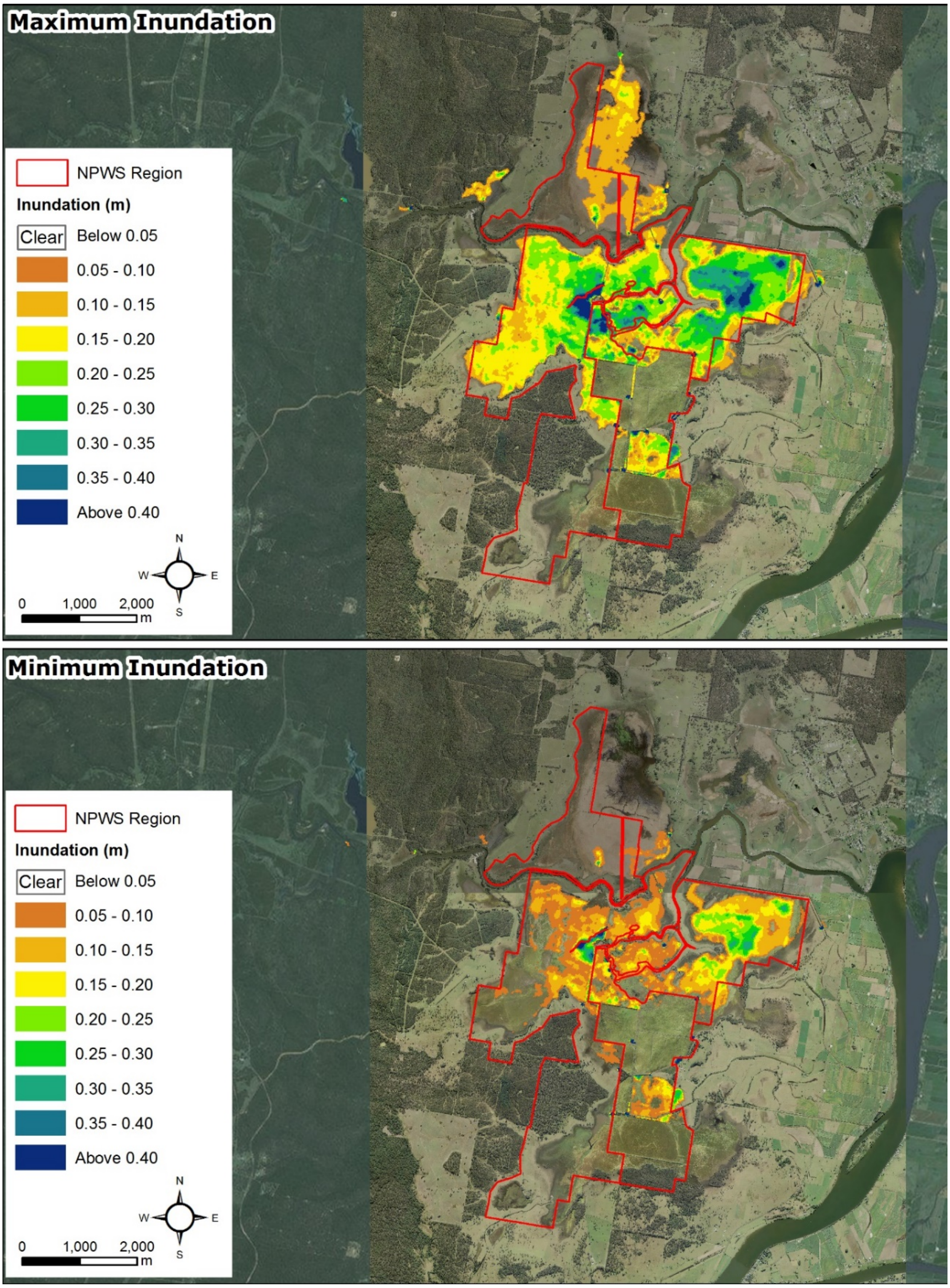


Figure F.48: Updated Model – Full Restoration (Scenario 13) - Maximum and Minimum Inundation Extents - 1 January to 22 February 2017

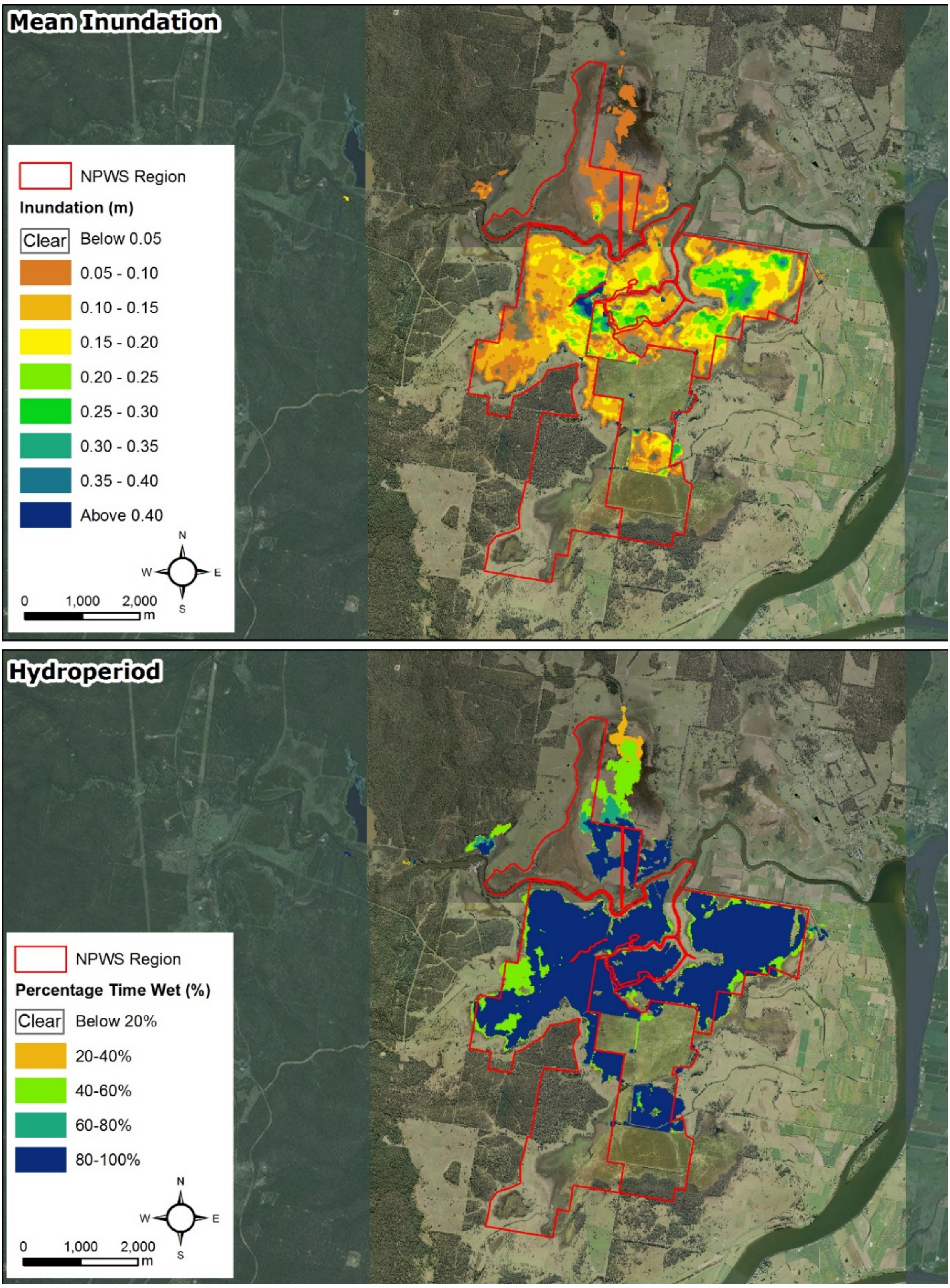


Figure F.49: Updated Model - Full Restoration (Scenario 13) – Mean Inundation Extent and Hydroperiod Analysis - 1 January to 22 February 2017

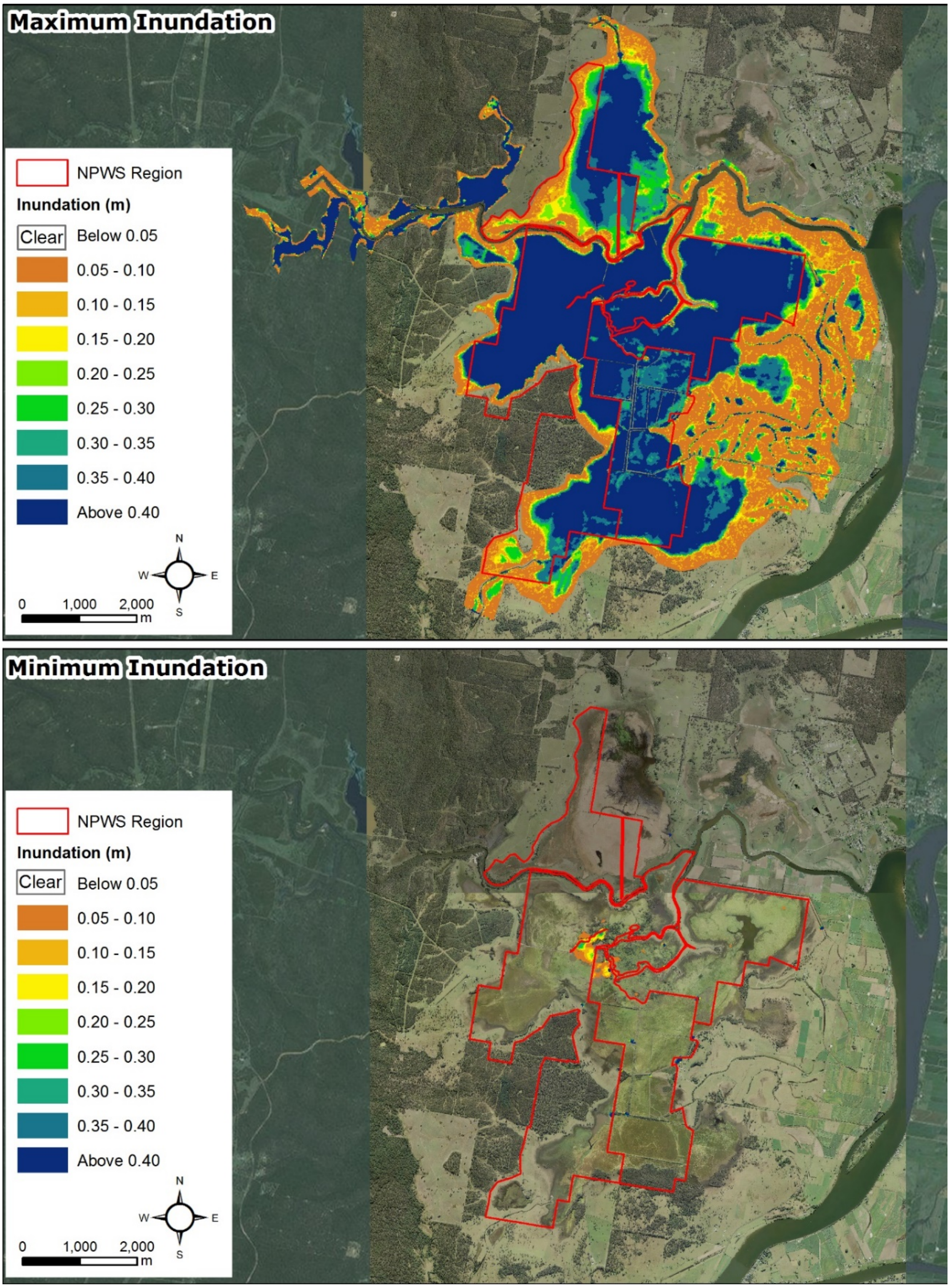


Figure F.50: Updated Model - Existing Conditions (Scenario 14) - Maximum and Minimum Inundation Extents - 1 January to 30 September 2010

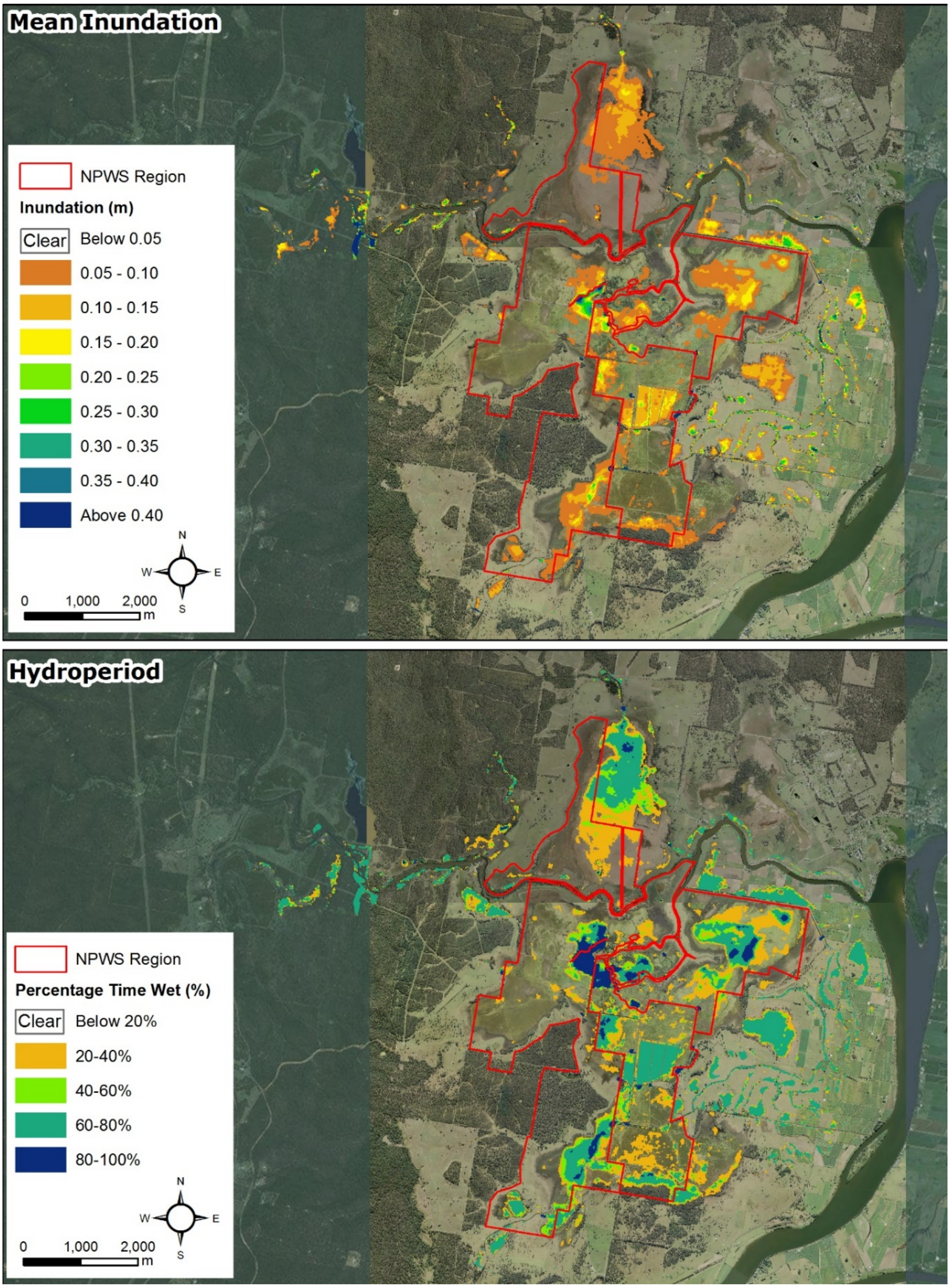


Figure F.51: Update Model - Existing Conditions (Scenario 14) – Mean Inundation Extent and Hydroperiod Analysis - 1 January to 30 September 2010

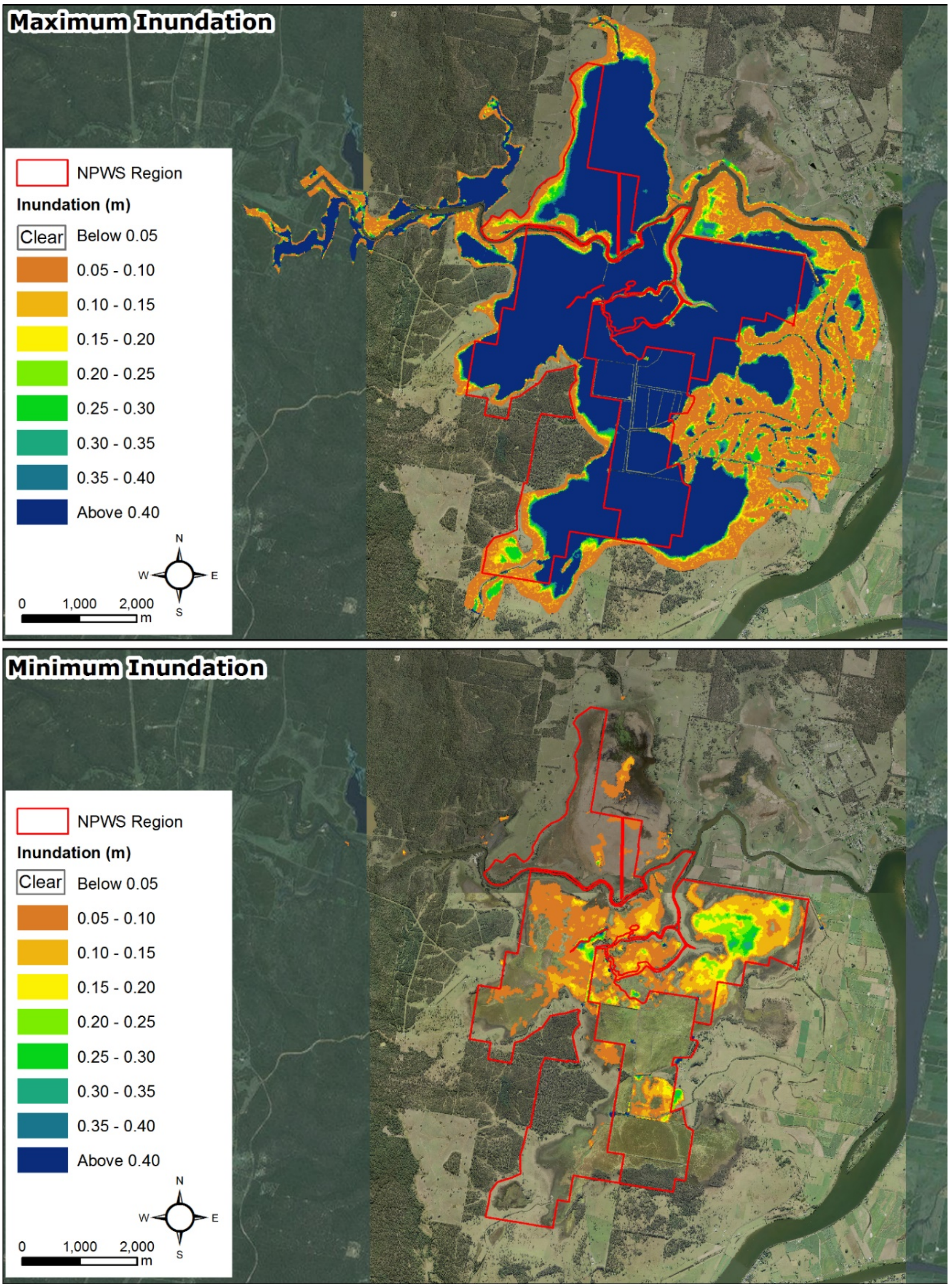


Figure F.52: Update Model – Full Restoration (Scenario 15) - Maximum and Minimum Inundation Extents - 1 January to 30 September 2010

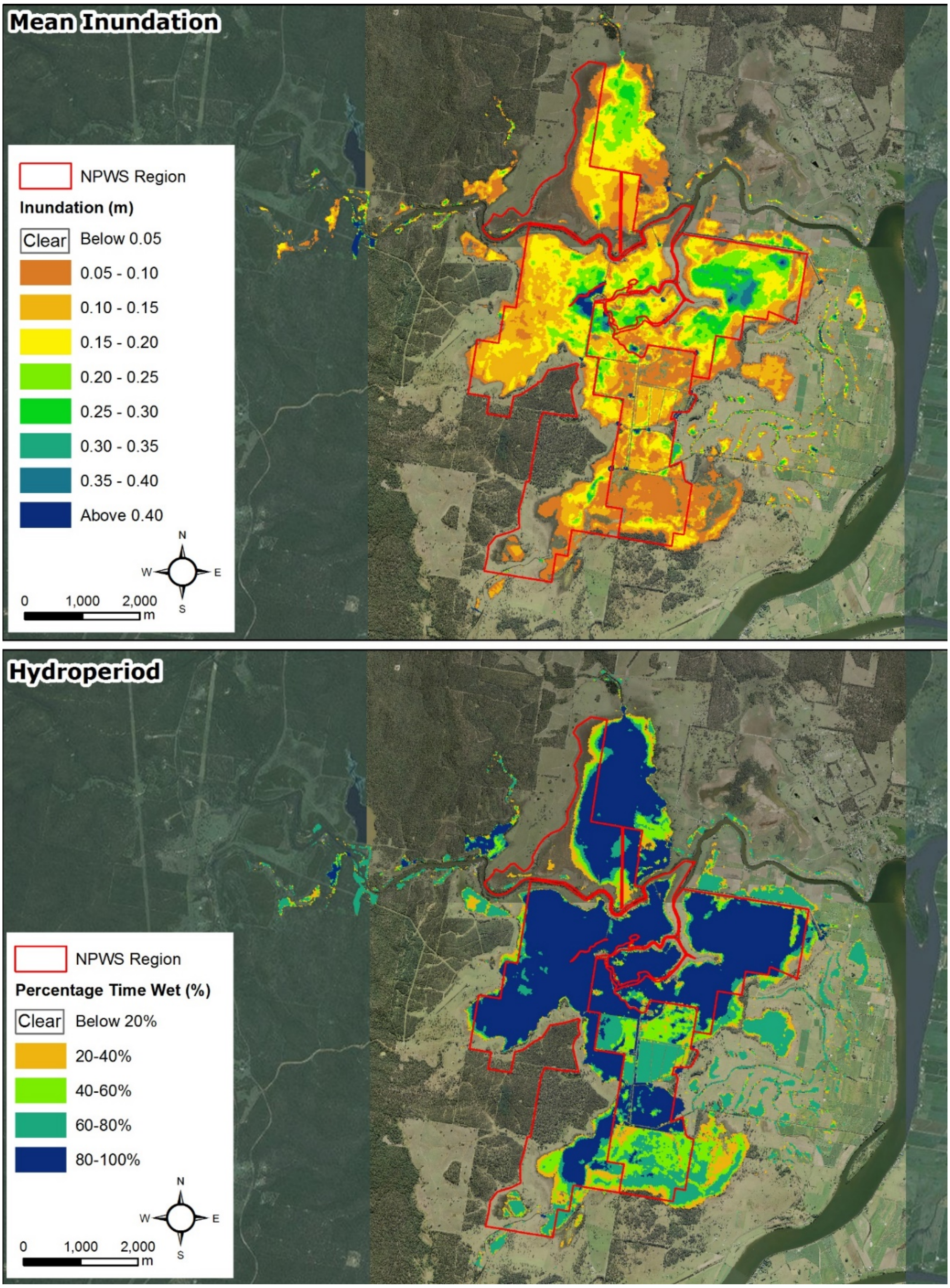


Figure F.53: Update Model – Full Restoration (Scenario 15) – Mean Inundation Extent and Hydroperiod Analysis - 1 January to 30 September 2010

Table F.13: Summary of Depth-Area Statistics and Hydroperiod for Scenario 1

Hydro-period (% Time Wet)	Total Area (m^2)	Percent Total Area (%)	Maximum Depth (m)	Weighted Avg. Min Depth (m)	Weighted Avg. Max Depth (m)	Weighted Avg. Mean Depth (m)
80-100	479,086	1.1	1.55*	0.21	0.31	0.27
60-80	9,201	<0.1	0.18	0.00	0.12	0.04
40-60	32,514	0.1	0.15	0.00	0.10	0.03
20-40	354,577	0.8	0.25	0.00	0.12	0.03
0-20	41,606,106	97.9	0.13	0.00	0.00	0.00

* Note that <10% of the total cells in this category have a value >0.65 m depth.

Table F.14: Summary of Depth-Area Statistics and Hydroperiod for Scenario 2

Hydro-period (% Time Wet)	Total Area (m^2)	Percent Total Area (%)	Maximum Depth (m)	Weighted Avg. Min Depth (m)	Weighted Avg. Max Depth (m)	Weighted Avg. Mean Depth (m)
80-100	9,241,454	21.8	1.97*	0.10	0.23	0.16
60-80	346,255	0.8	0.51	0.00	0.13	0.06
40-60	1,639,823	3.9	0.44	0.00	0.14	0.04
20-40	393,336	0.9	0.39	0.00	0.11	0.03
0-20	30,860,617	72.6	0.38	0.00	0.00	0.00

* Note that <10% of the total cells in this category have a value >0.33 m depth.

Table F.15: Summary of Depth-Area Statistics and Hydroperiod for Scenario 12

Hydro-period (% Time Wet)	Total Area (m^2)	Percent Total Area (%)	Maximum Depth (m)	Weighted Avg. Min Depth (m)	Weighted Avg. Max Depth (m)	Weighted Avg. Mean Depth (m)
80-100	479,086	1.1	1.54*	0.21	0.30	0.26
60-80	9,201	<0.1	0.18	0.00	0.12	0.05
40-60	32,514	0.1	0.17	0.00	0.10	0.03
20-40	354,577	0.8	0.28	0.00	0.12	0.03
0-20	41,606,106	97.9	0.12	0.00	0.00	0.00

* Note that <10% of the total cells in this category have a value >0.65 m depth.

Table F.16: Summary of Depth-Area Statistics and Hydroperiod for Scenario 13

Hydro-period (% Time Wet)	Total Area (m^2)	Percent Total Area (%)	Maximum Depth (m)	Weighted Avg. Min Depth (m)	Weighted Avg. Max Depth (m)	Weighted Avg. Mean Depth (m)
80-100	9,499,368	22.4	1.95*	0.10	0.23	0.16
60-80	310,528	0.7	0.34	0.00	0.12	0.05
40-60	1,625,706	3.8	0.46	0.00	0.14	0.04
20-40	375,381	0.9	0.45	0.00	0.12	0.03
0-20	30,669,696	72.2	0.39	0.00	0.00	0.00

* Note that <10% of the total cells in this category have a value >0.33 m depth.

Table F.17: Summary of Depth-Area Statistics and Hydroperiod for Scenario 14

Hydro-period (% Time Wet)	Total Area (m^2)	Percent Total Area (%)	Maximum Depth (m)	Weighted Avg. Min Depth (m)	Weighted Avg. Max Depth (m)	Weighted Avg. Mean Depth (m)
80-100	3,816,644	8.98	2.24*	0.02	0.58	0.18
60-80	4,853,155	11.42	1.57	0.00	0.48	0.07
40-60	3,567,179	8.40	1.49	0.00	0.50	0.04
20-40	26,168,457	61.60	1.43	0.00	0.29	0.02
0-20	4,075,244	9.59	1.38	0.00	0.18	0.01

* Note that <1% of the total cells in this category have a value >1.5 m depth.

Table F.18: Summary of Depth-Area Statistics and Hydroperiod for Scenario 15

Hydro-period (% Time Wet)	Total Area (m^2)	Percent Total Area (%)	Maximum Depth (m)	Weighted Avg. Min Depth (m)	Weighted Avg. Max Depth (m)	Weighted Avg. Mean Depth (m)
80-100	17,631,020	41.50	2.42*	0.05	0.70	0.17
60-80	5,079,013	11.96	1.41	0.00	0.54	0.07
40-60	2,064,881	4.86	1.32	0.00	0.49	0.04
20-40	13,168,691	31.00	1.27	0.00	0.16	0.01
0-20	4,537,074	10.68	1.20	0.00	0.19	0.01

* Note that <1% of the total cells in this category have a value >1.5 m depth.

F.2.3 Stage 3: Model Refinement and Additional Model Scenarios

The previous numerical model domain of the Everlasting Swamp National Park (ESNP) and surrounding properties, included representation of an extensive drainage network in 1D and large areas of the floodplain in 2D. Following discussions with Council, properties located immediately upstream of Sportsmans Creek Weir and outside of the ESNP were investigated to assess the potential land impacts from the removal of the weir. However, it was determined that the model domain needed to be refined in this area to make a full assessment of this scenario. This involved connecting low-lying areas of the floodplain to Sportsmans Creek by the addition of a drain in the existing 1D drainage network and increasing the resolution of the 2D model domain below approximately 2 m AHD. Ground survey data collected by Council and WRL was used to update the bathymetry in this area of the 2D model domain. A comparison of the changes made to the model domain is provided in Figure F.54.

Prior to running new model scenarios as requested by Council, several model checks were completed to assess the impact of the refined model domain immediately upstream of Sportsmans Creek Weir. Firstly, the refined model domain was run for existing conditions and under a full-restoration scenario. The results of these model runs showed that there were no significant changes to inundation extents or hydroperiods outside of the refined model area. This was anticipated as this area is an isolated hydrological unit, with a relatively small storage area (<1%) compared to the wider Everlasting Swamp complex of wetlands, and would have negligible effect on water levels across the site. Inundation extents and hydroperiods for the refined model area under a full-restoration scenario are provided in Figure F.55 and Figure F.56.

Additional model checks were completed before running the new model scenarios, including a detailed forensic assessment of all 1D-2D connections, boundary conditions, and bathymetry across the model domain. It was found that a 1D-2D connection in the Round Mountain area of the model domain could be further optimised to improve flow connection. As such, this 1D-2D connection was refined to better represent the likely flow conditions in this area of the model domain. All future modelling scenarios will include this change.

Scenarios 16 and 17 were re-run to compare the latest changes to the model with previous model runs under the same conditions. Figure F.57 and Figure F.58 provide the existing conditions of the site using the latest model for the baseline simulation period. The inundation extents and hydroperiods using the latest model for existing conditions are comparable to the previous model runs for the same simulation period. As expected during this relative dry period, Teal Lagoon and the adjacent water bodies fed by Reedy Creek are the main permanent water bodies at Everlasting Swamp. Note that a relatively small catchment rainfall event provided some inflow to model domain through Duck Creek on the northern boundary. However, this area of the site remained wet for between 20-40% of the model simulation period, with a mean inundation depth of less than 5 cm.

Figure F.59 and Figure F.60 provide the model results for the full restoration (i.e. floodgates removed) scenario using the latest model for the baseline simulation period. As observed in the previous model run under the same conditions, the model results for the full restoration scenario indicated that Teal Lagoon, Reedy Creek and Coxs Swamp are the key areas experiencing frequent tidal inundation, remaining wet for 80-100% of the model run. Further, the full restoration scenario showed a slight increase in water depths across these areas, when compared to the previous model run for the same scenario. While the mean inundation extents for this scenario are generally contained within the NPWS boundary, there was some inundation of neighbouring properties on eastern and western borders of the study site during larger spring tides.

It is worth noting that Figure F.59 and Figure F.60 show increased inundation in the Warragai/Blanches Drain area of the floodplain. This is particularly evident for the maximum inundation extents shown in Figure F.59. This inundation area is controlled by water levels in the main drain running from Reedy Creek to the old pump station within the old tea-tree plantation area, between Round Mountain and Andersons Point. The model results showed that the amplitude of water levels in this drain, and the adjacent sub-drains, are significantly dampened compared to water levels further downstream in Sportsmans Creek. The maximum water level difference observed between the old pump station and Sportsmans Creek Weir was approximately 0.35 m in late January 2017. Furthermore, there were differences in the observed and modelled water levels at the old pump station due to the modelling assumptions and approximations included in the existing model, the extremely complex drainage network and continually changing roughness of the drains in this area.

While it is noted that there are some differences in the inundation areas across certain parts of the study site following the latest model runs, WRL did not believe there was a need to re-run previous modelled scenarios. This was because the modelled changes in inundation extents are only observed in the full restoration scenario, with differences occurring at the peak of larger spring tides. Further, there are flow control structures within the existing drainage network that can contain tidal inundation within the ESNP, as shown in the baseline model runs and other scenarios previously discussed in Stage 1 of the modelling. If stakeholders decided to implement a full restoration scenario, and intend on making changes to the existing drainage network at the site, WRL would recommend any management change are monitored to ensure the agreed site outcomes are achieved.

Figure F.61 and Figure F.62 provide the inundation extents and hydroperiod results associated with opening the gates on Sportsmans Creek Weir, while the internal floodgates in the existing drainage network remained closed. This scenario was modelled to show the effectiveness of the existing levees across the site in protecting low-lying areas of the floodplain from tidal inundation. The results of this scenario showed some inundation of low-lying areas along Sportsmans Creek that are not currently protected by floodgates or levees.

Figure F.63 and Figure F.64 provide the inundation extents and hydroperiod results associated with opening the floodgates on Reedy Creek, Sportsmans 35/1 and the Sportsmans Creek Weir, while all other internal floodgates remained closed. This scenario was modelled to maximise flushing of Teal Lagoon, while controlling the extent of tidal inundation across the wider ESNP. The model results show that for the baseline simulation period, all inundation was contained within the ESNP with regular tidal flushing mainly within the Teal Lagoon/Reedy Creek area, remaining wet for approximately 80-100% of the model run. Less frequent inundation occurred in Coxs Swamp, remaining wet for approximately 40-60% of the model run, with average water depths of 0.1 m. As shown in Scenario 18, this scenario also resulted in inundation of low-lying areas along Sportsmans Creek that are not currently protected by floodgates or levees.

Statistics of results have been extracted from the model outputs to depict the inundation and hydroperiod maps from the latest model runs and are provided in Table F.19 to Table F.22. Note that Table F.13 and Table F.14 summarise the results for the previous model runs for the existing conditions and full restoration scenarios, and are provided for comparison with Table F.19 and Table F.20 for the latest model runs. For the latest full restoration model run, inundation increased by approximately 6% across the ESNP for hydroperiods greater than 20%, with changes to mean inundation depths of up to 2 cm. These statistics show that there are minor differences between the overall model results for the two models, and remove the need to re-run previously tested model scenarios.

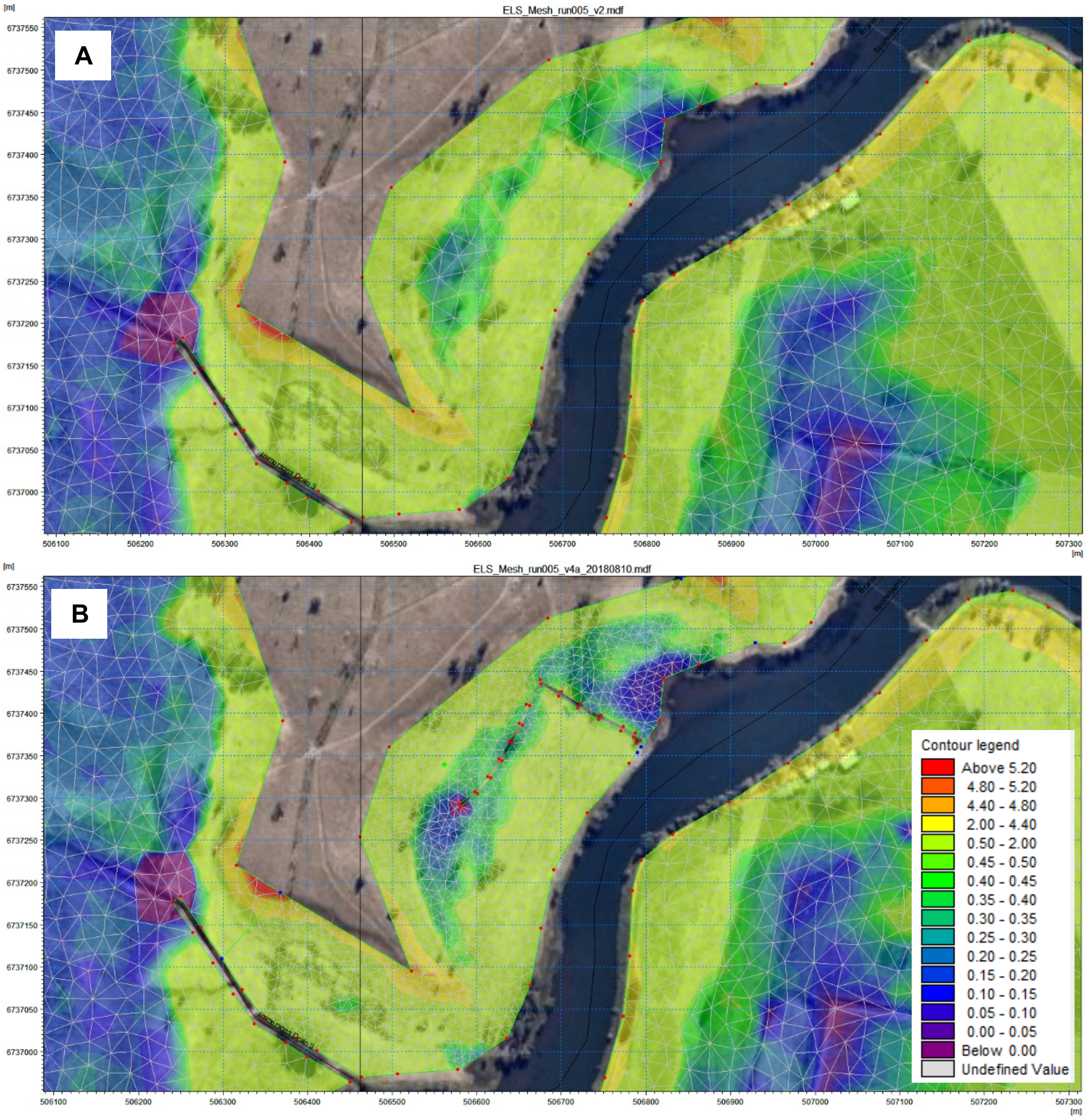


Figure F.54: Model Mesh Refinement Immediately Upstream of Sportsmans Creek Weir; Panel A – Before and Panel B – After

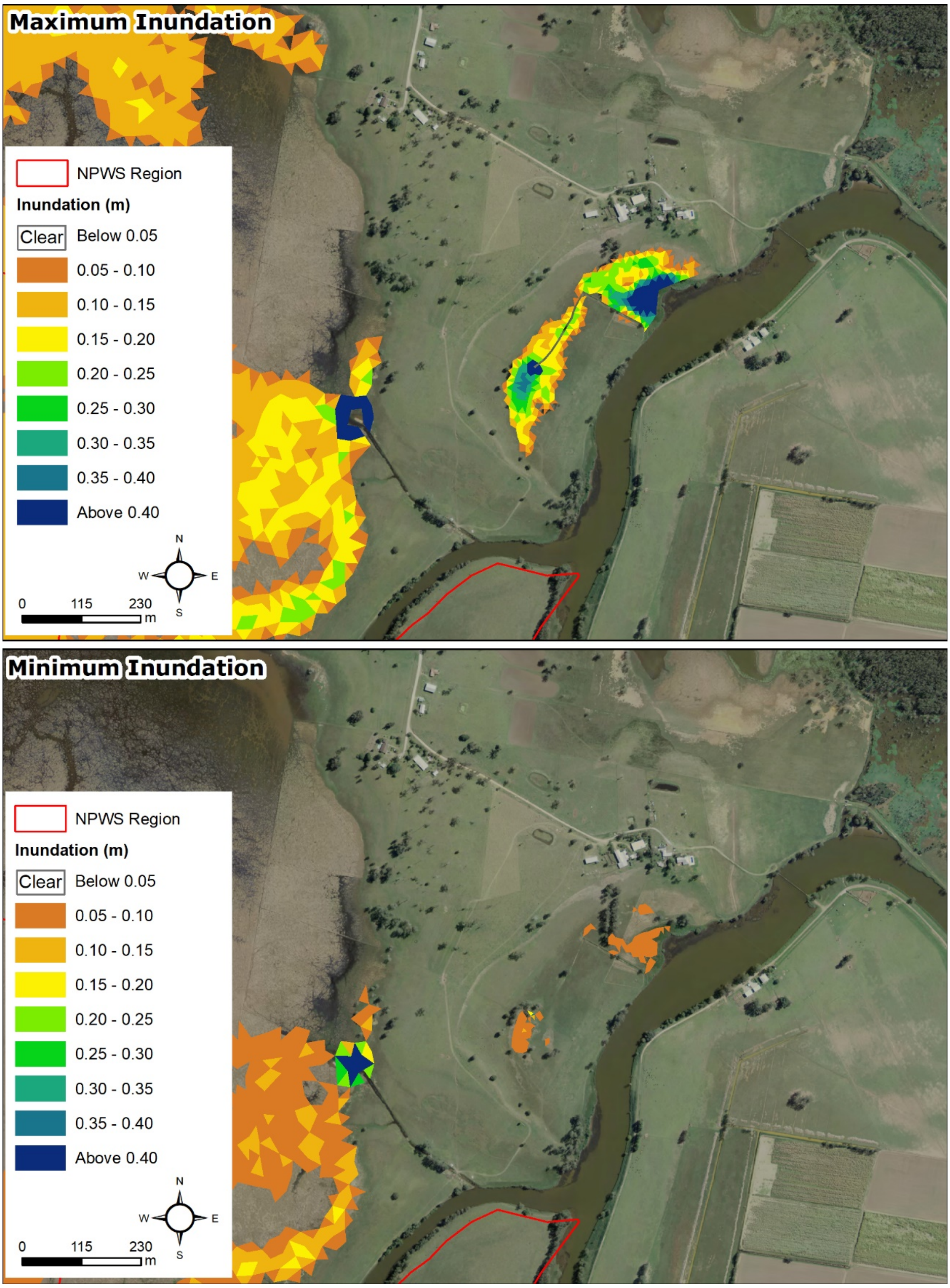


Figure F.55: Updated Model – Full Restoration (Scenario 17) - Maximum and Minimum Inundation Extents – Zoom on Property Detail - 1 January to 22 February 2017

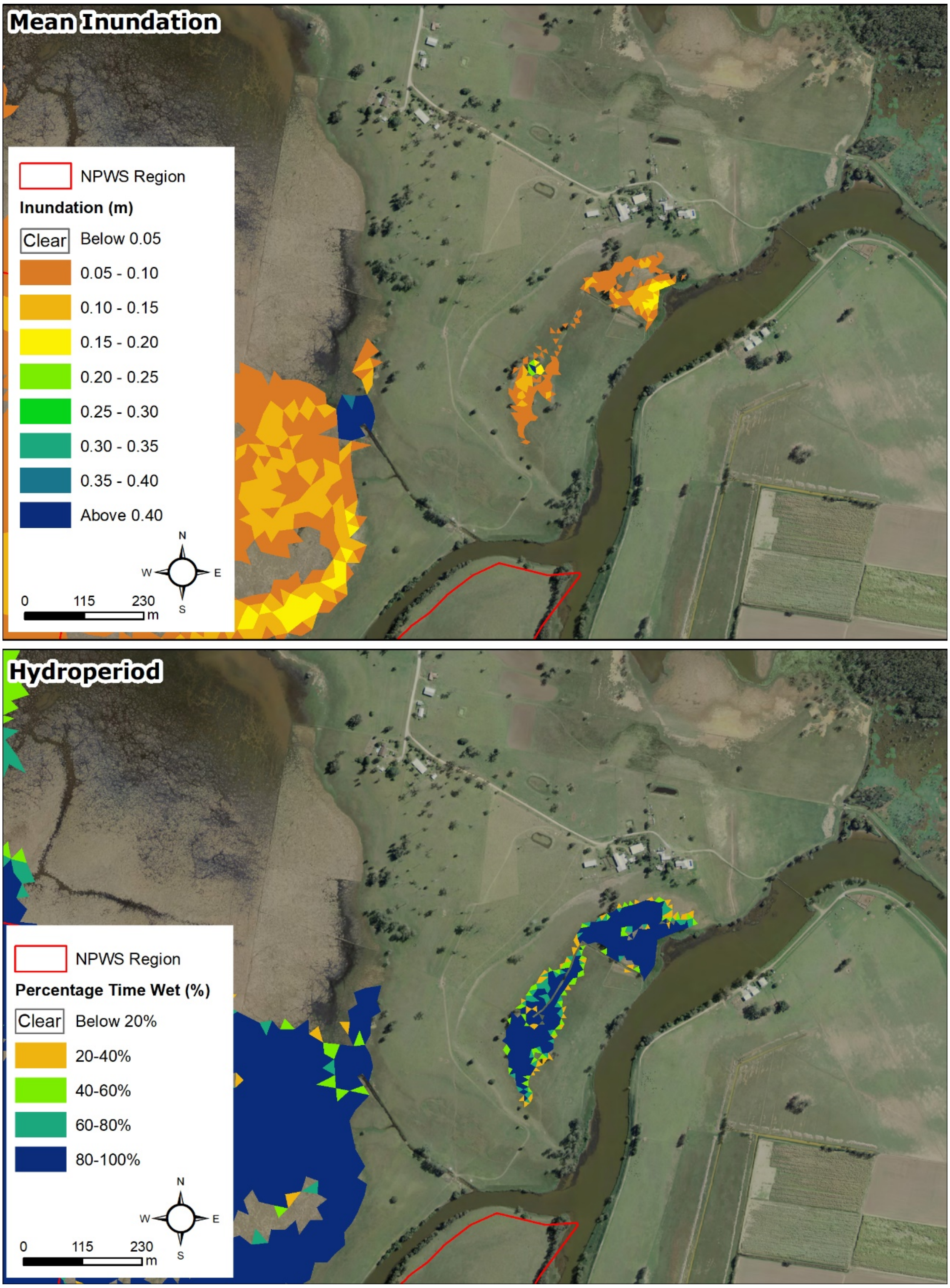
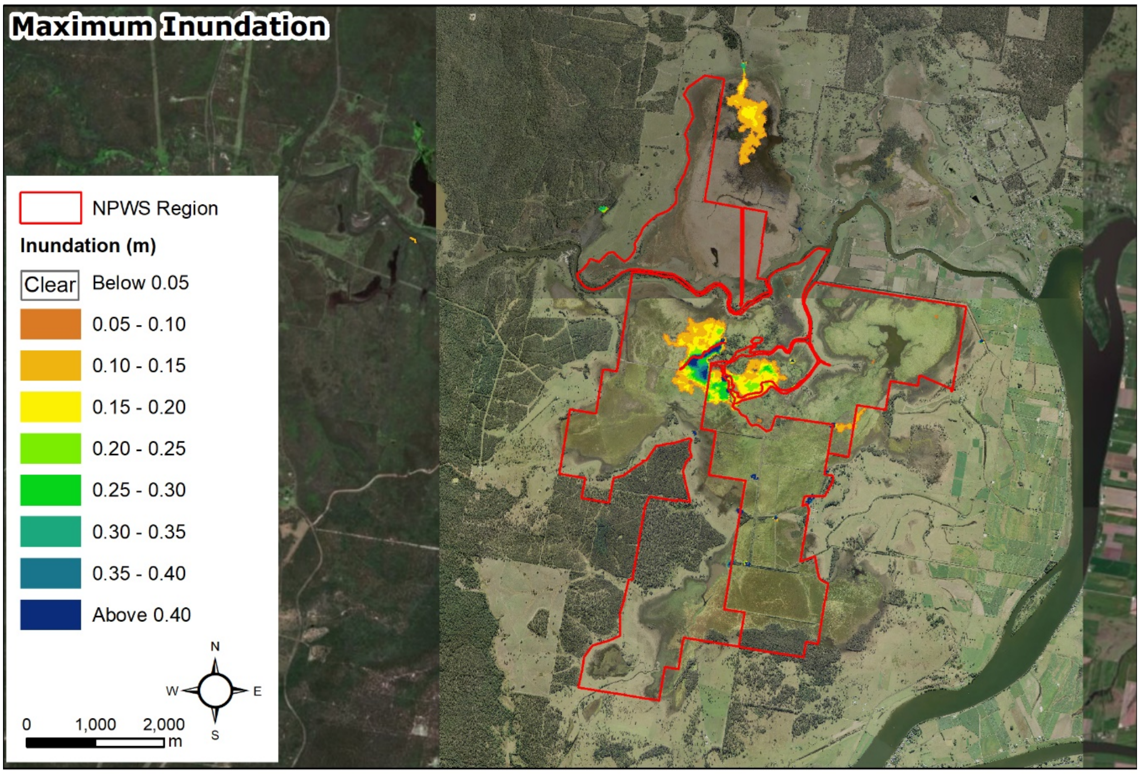


Figure F.56: Updated Model - Full Restoration (Scenario 17) – Mean Inundation Extent and Hydroperiod Analysis – Zoom on Property Detail - 1 January to 22 February 2017



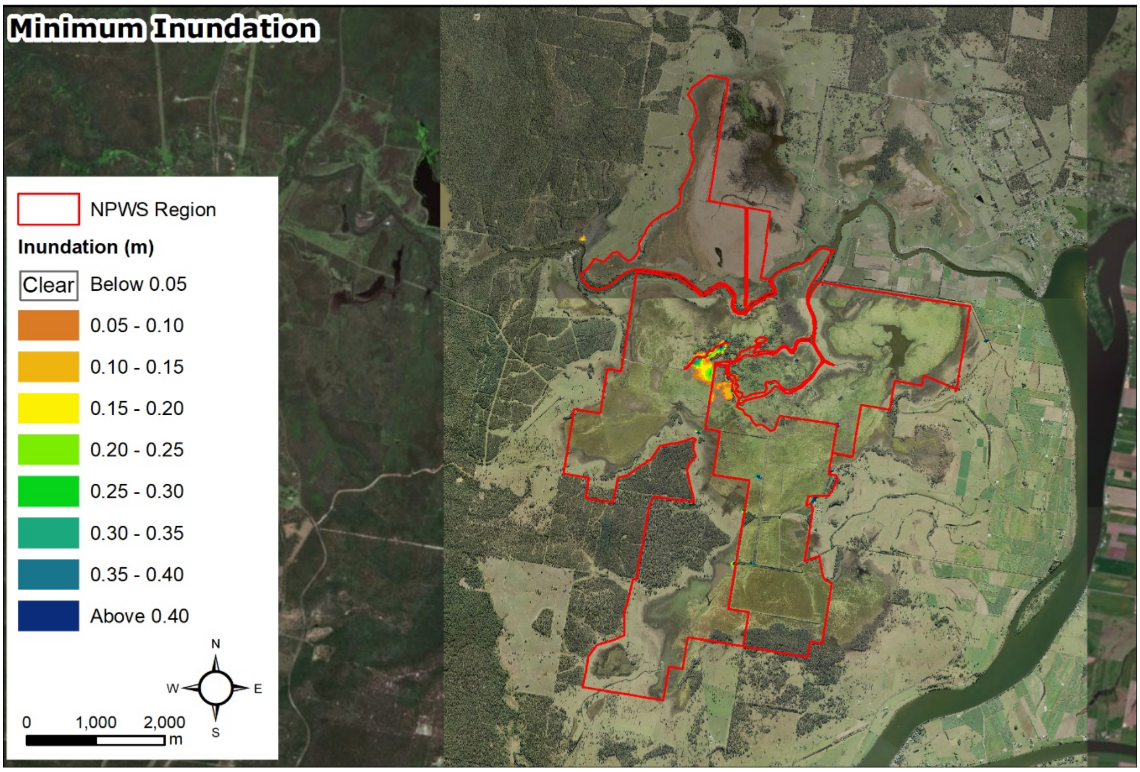
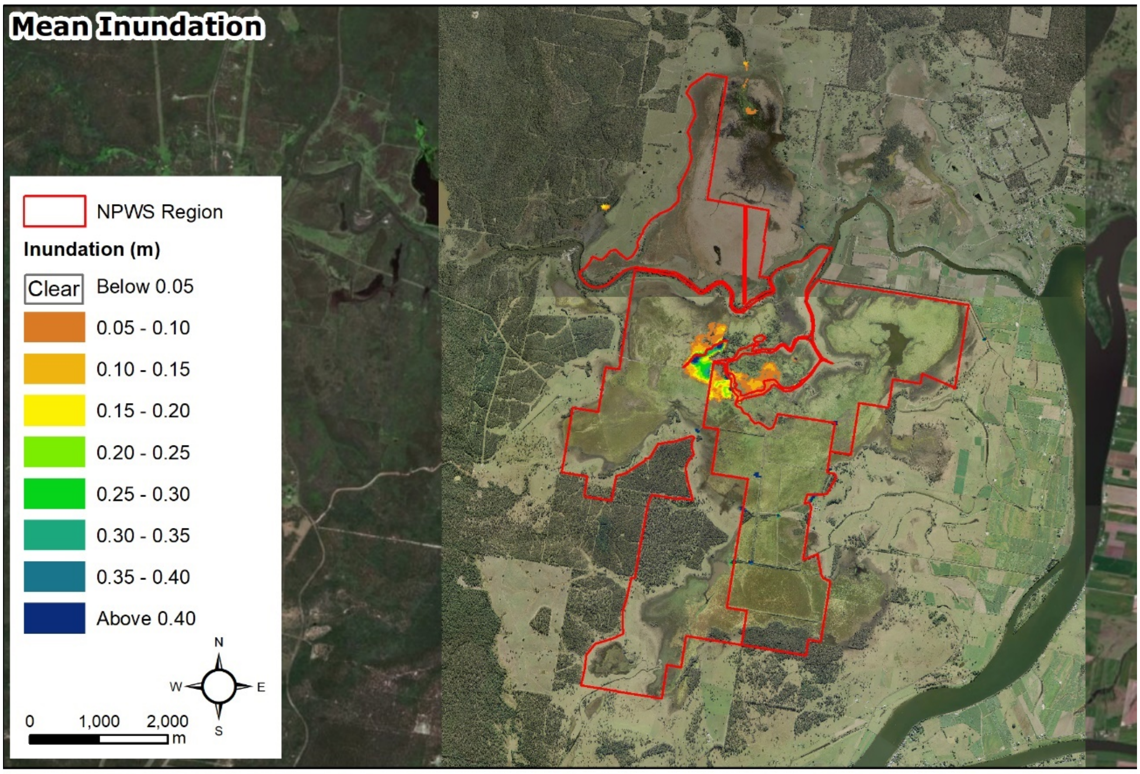


Figure F.57: Updated Model - Existing Conditions (Scenario 16) - Maximum and Minimum Inundation Extents - 1 January to 22 February 2017



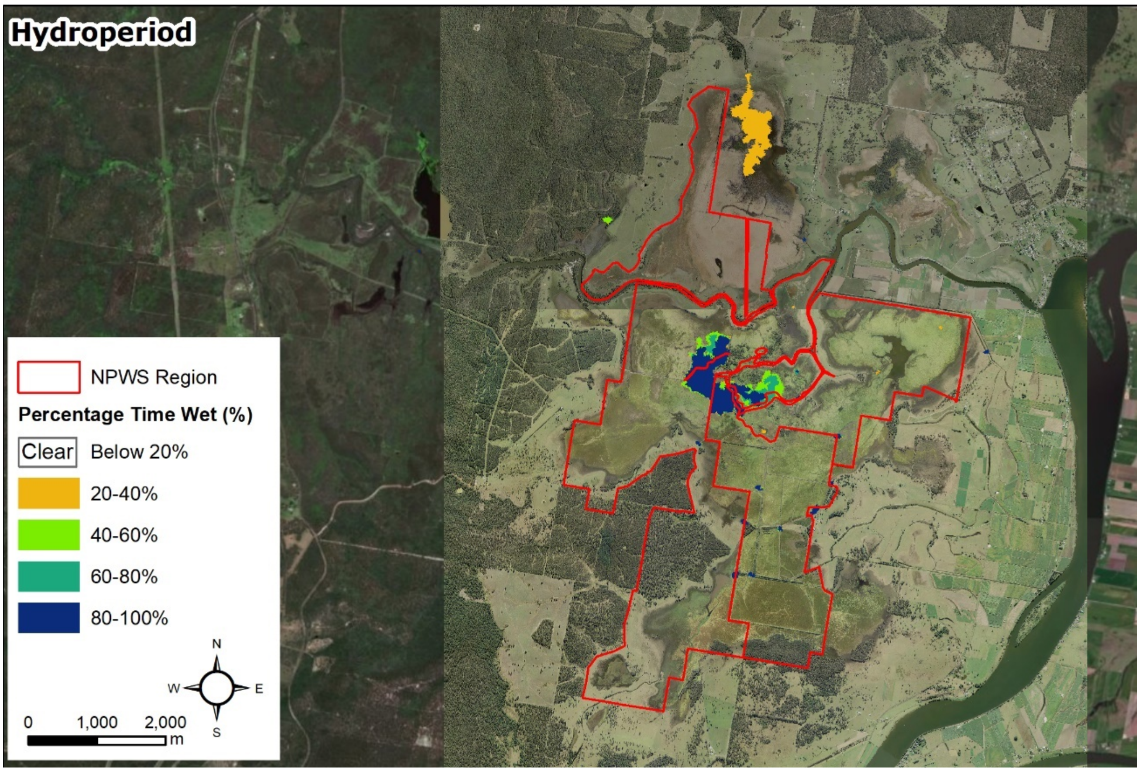


Figure F.58: Updated Model - Existing Conditions (Scenario 16) – Mean Inundation Extent and Hydroperiod Analysis - 1 January to 22 February 2017

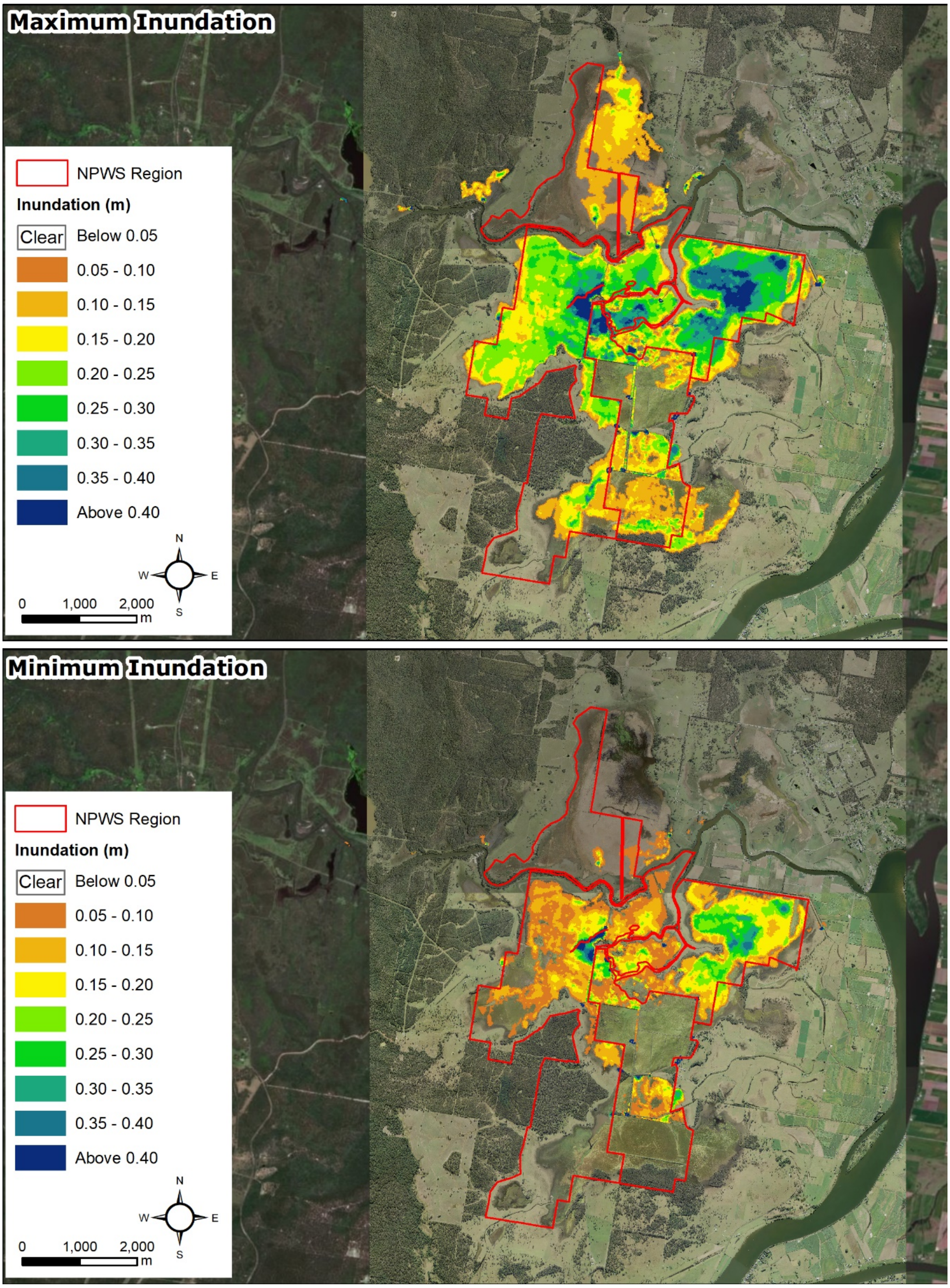


Figure F.59: Updated Model - Full Restoration (Scenario 17) - Maximum and Minimum Inundation Extents - 1 January to 22 February 2017

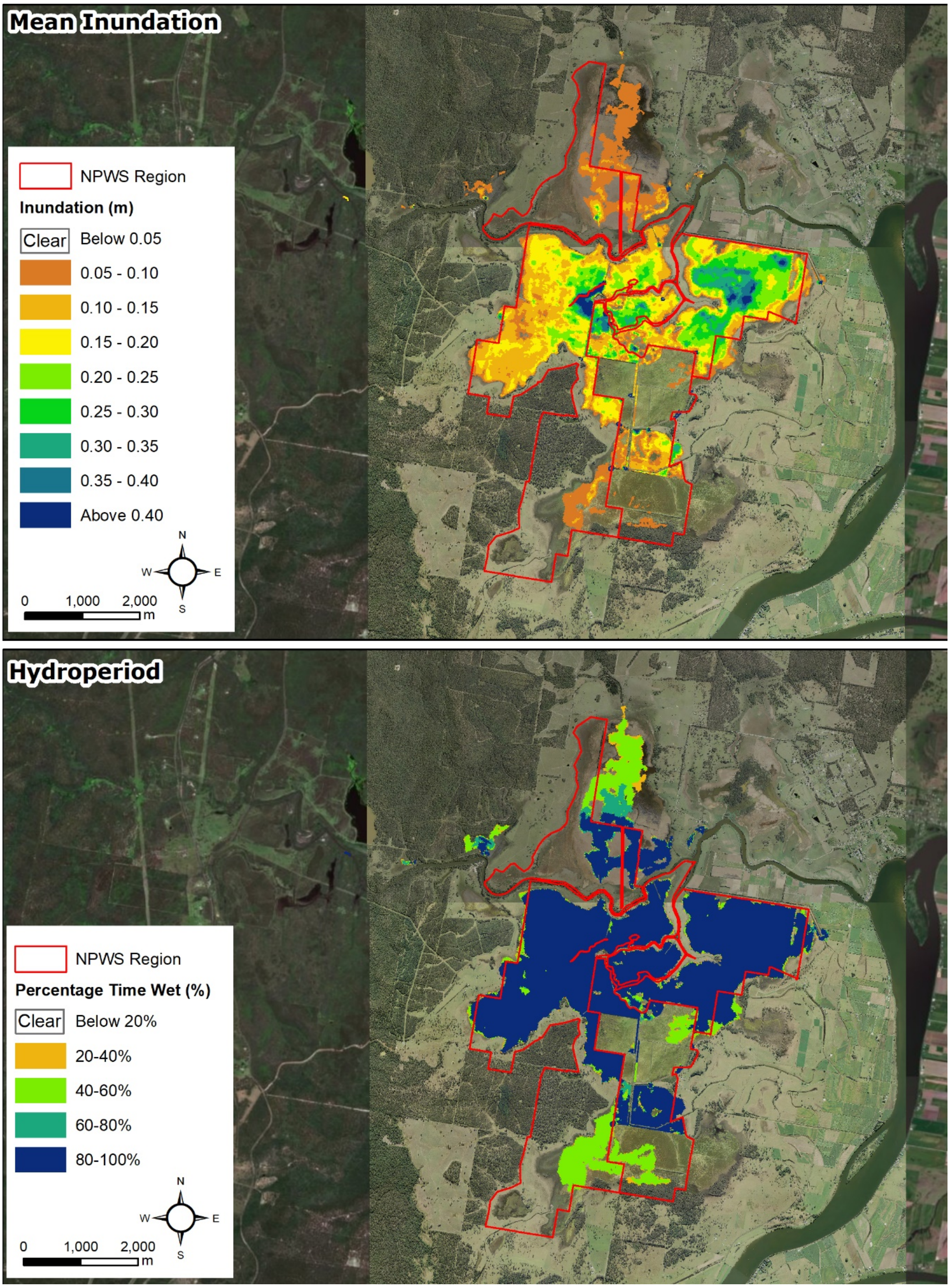


Figure F.60: Updated Model - Full Restoration (Scenario 17) – Mean Inundation Extent and Hydroperiod Analysis - 1 January to 22 February 2017

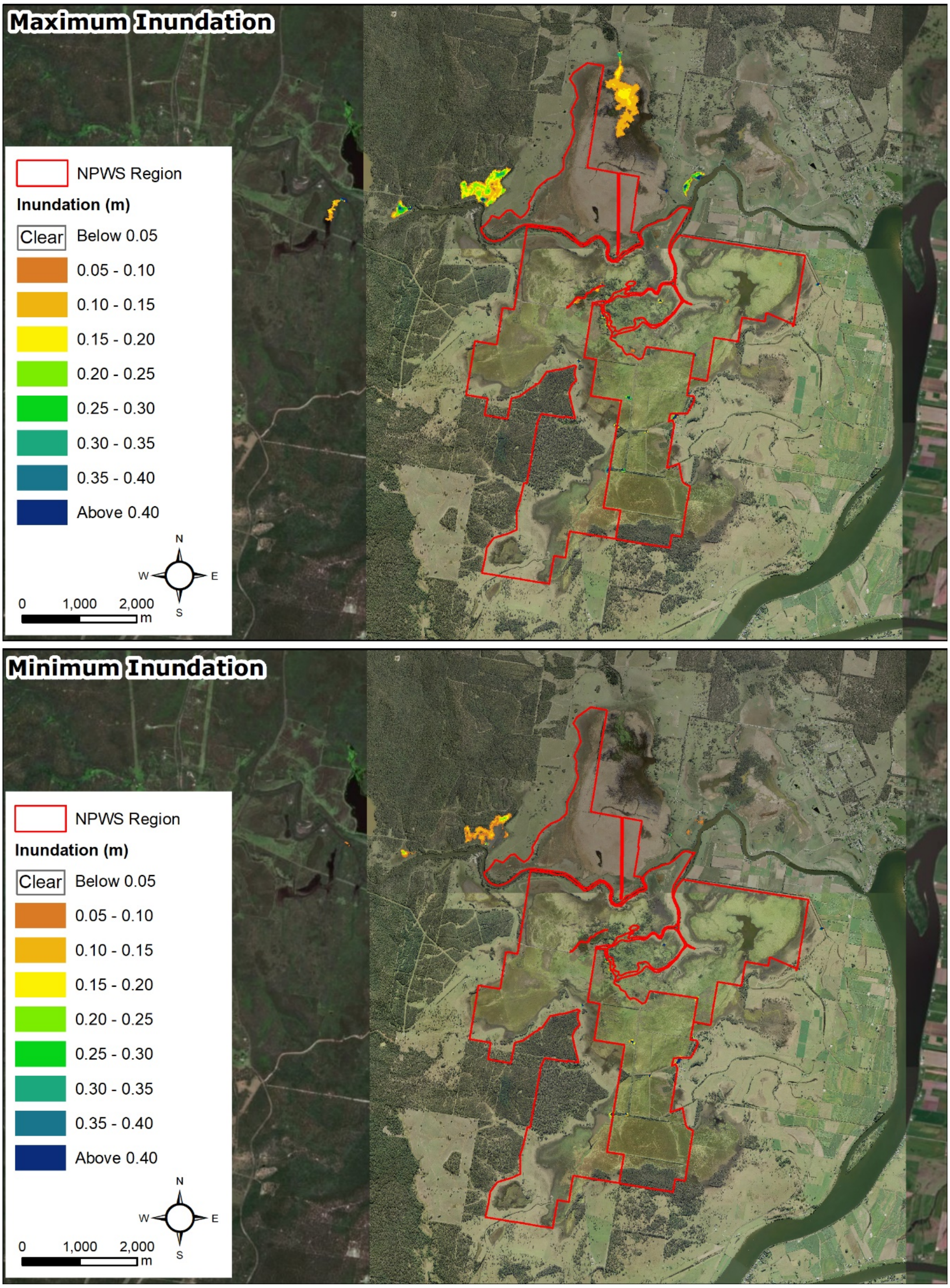


Figure F.61: Updated Model - Internal Floodgates Closed, Sportsmans Creek Weir Open (Scenario 18) - Maximum and Minimum Inundation Extents - 1 January to 22 February 2017

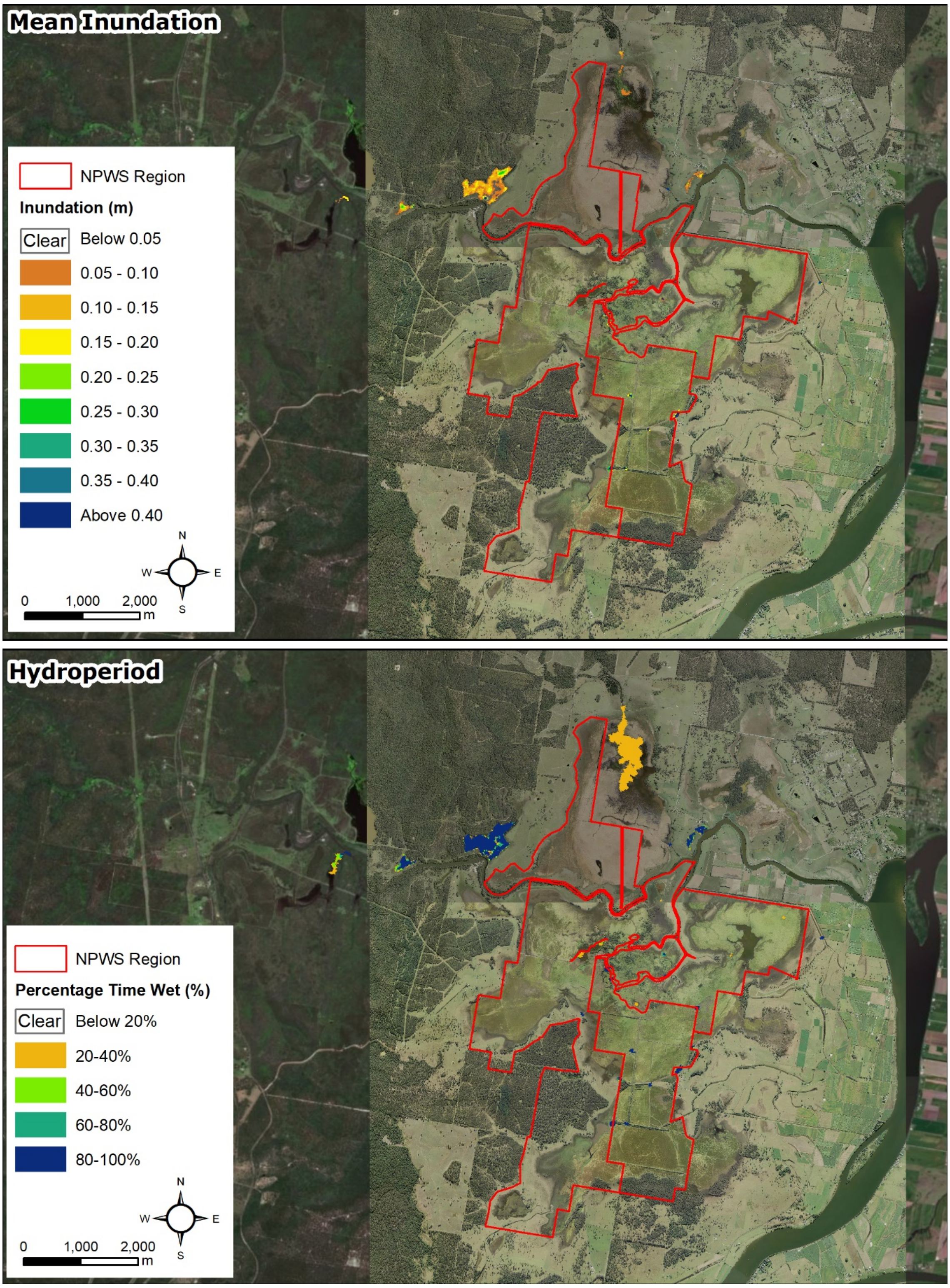


Figure F.62: Updated Model - Internal Floodgates Closed, Sportsmans Creek Weir Open (Scenario 18) – Mean Inundation Extent and Hydroperiod Analysis - 1 January to 22 February 2017

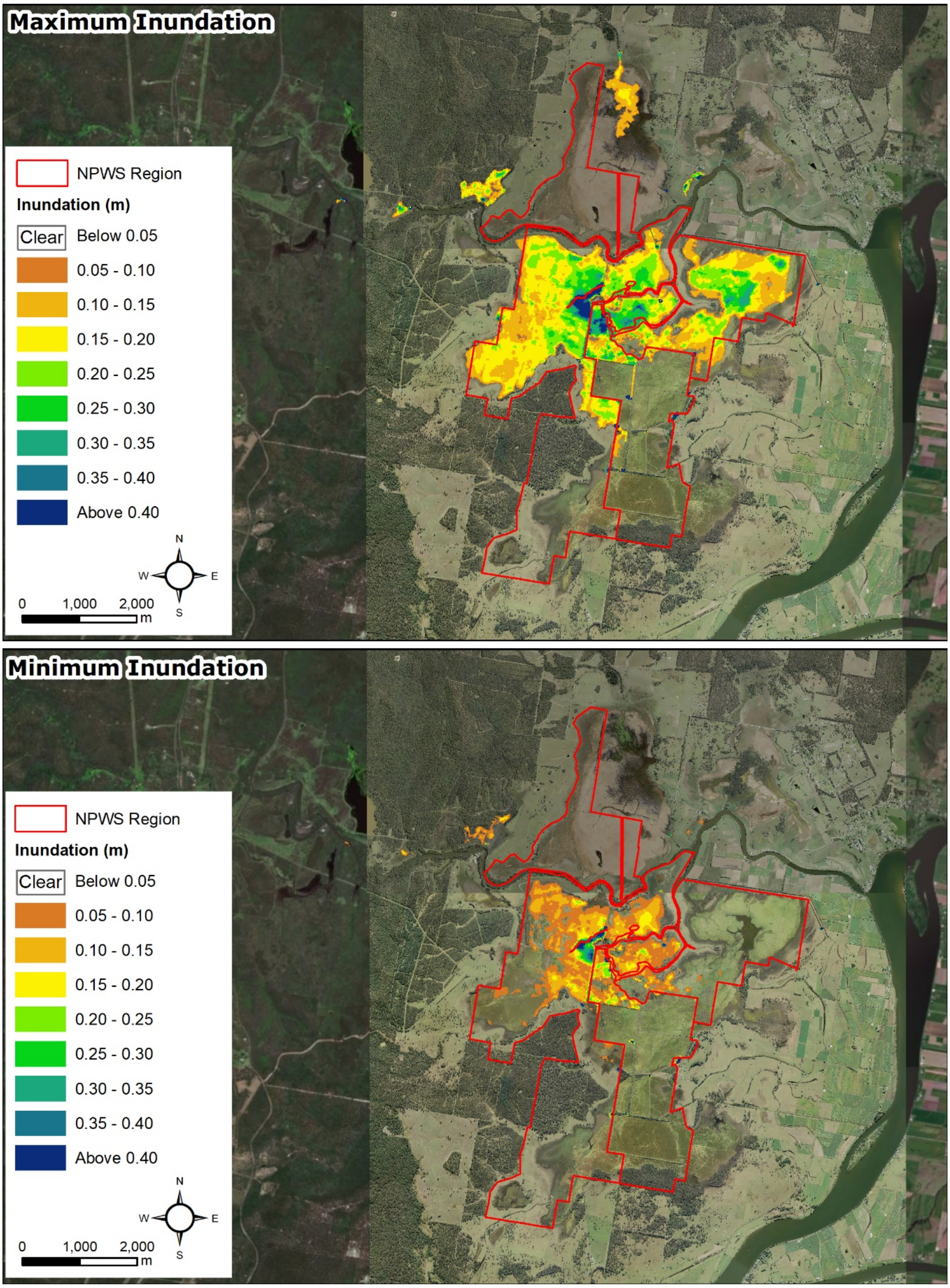
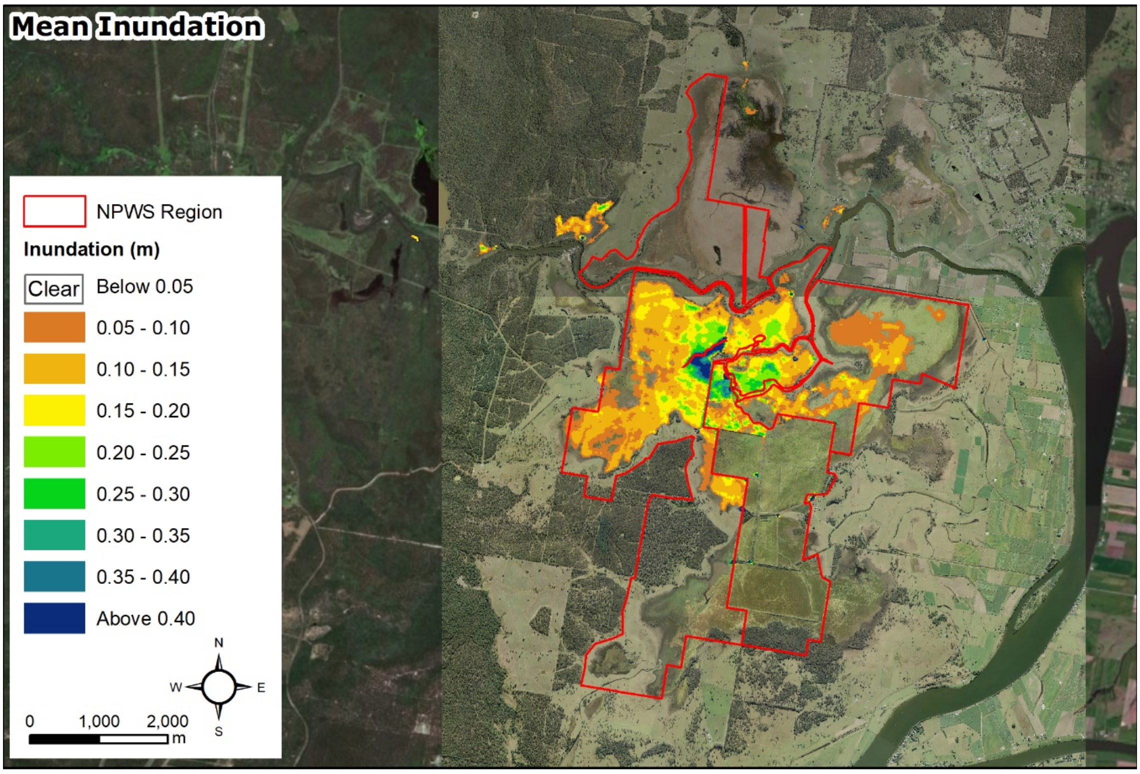


Figure F.63: Updated Model – Reedy Creek, Sportsmans 35/1 and Sportsmans Creek Weir Open Only (Scenario 19) - Maximum and Minimum Inundation Extents - 1 January to 22 February 2017



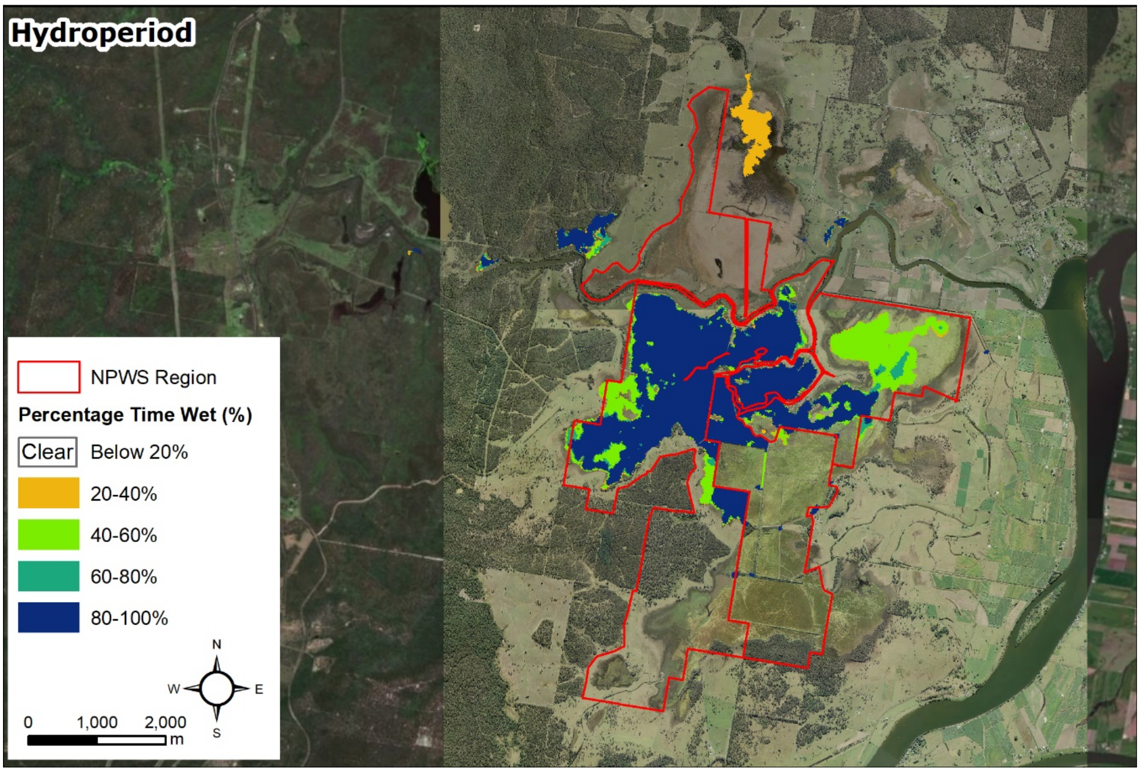


Figure F.64: Updated Model – Reedy Creek, Sportsmans 35/1, Sportsmans Weir Open (Scenario 19) – Mean Inundation Extent and Hydroperiod Analysis - 1 January to 22 February 2017

Table F.19: Summary of Depth-Area Statistics and Hydroperiod for Scenario 16

Hydroperiod (% Time Wet)	Total Area (m^2)	Percent Total Area (%)	Maximum Depth (m)	Weighted Avg. Min Depth (m)	Weighted Avg. Max Depth (m)	Weighted Avg. Mean Depth (m)
80-100	571,196	1.5	1.60*	0.14	0.31	0.22
60-80	117,337	0.3	0.30	0.00	0.18	0.07
40-60	147,589	0.4	0.37	0.00	0.15	0.04
20-40	362,809	1.0	0.34	0.00	0.12	0.03
0-20	36,942,836	96.9	0.22	0.00	0.00	0.00

* Note that <10% of the total cells in this category have a value >0.53 m.

Table F.20: Summary of Depth-Area Statistics and Hydroperiod for Scenario 17

Hydroperiod (% Time Wet)	Total Area (m^2)	Percent Total Area (%)	Maximum Depth (m)	Weighted Avg. Min Depth (m)	Weighted Avg. Max Depth (m)	Weighted Avg. Mean Depth (m)
80-100	11,211,518	26.4	1.97*	0.12	0.25	0.18
60-80	391,795	0.9	0.31	0.00	0.13	0.06
40-60	2,383,041	5.6	0.43	0.00	0.16	0.05
20-40	359,695	0.8	0.34	0.00	0.11	0.02
0-20	28,133,030	66.2	0.33	0.00	0.01	0.00

* Note that <10% of the total cells in this category have a value >0.36 m.

Table F.21: Summary of Depth-Area Statistics and Hydroperiod for Scenario 18

Hydroperiod (% Time Wet)	Total Area (m^2)	Percent Total Area (%)	Maximum Depth (m)	Weighted Avg. Min Depth (m)	Weighted Avg. Max Depth (m)	Weighted Avg. Mean Depth (m)
80-100	390,850	0.9	1.45*	0.13	0.27	0.18
60-80	32,407	0.1	0.23	0.00	0.13	0.04
40-60	31,512	0.1	0.40	0.00	0.13	0.02
20-40	397,661	0.9	0.36	0.00	0.12	0.03
0-20	41,626,649	98.0	0.28	0.00	0.00	0.00

* Note that <10% of the total cells in this category have a value >0.51 m.

Table F.22: Summary of Depth-Area Statistics and Hydroperiod for Scenario 19

Hydroperiod (% Time Wet)	Total Area (m^2)	Percent Total Area (%)	Maximum Depth (m)	Weighted Avg. Min Depth (m)	Weighted Avg. Max Depth (m)	Weighted Avg. Mean Depth (m)
80-100	5,613,842	13.2	1.92*	0.09	0.22	0.16
60-80	297,343	0.7	0.43	0.00	0.18	0.08
40-60	1,646,674	3.9	0.41	0.00	0.17	0.06
20-40	482,660	1.1	0.34	0.00	0.12	0.03
0-20	34,438,561	81.1	0.29	0.00	0.00	0.00

* Note that <10% of the total cells in this category have a value >0.30 m.

Appendix G – Community Feedback and Discussions

G.1 Preamble

This document provides a summary of the community feedback and discussion forums held at the Lawrence Public Hall from 29 to 30 November 2017. These forums were organised by Peter Wilson and conducted by WRL staff, Will Glamore and Jamie Ruprecht, with support from resident ecologist, Adam Smith. Over two (2) days, over 30 face-to-face discussions (both individual and in groups) where held with landholders representing different areas of the Everlasting Swamp wetland complex, including Round Mountain/Blanches Drain, Coxs Swamp/The Horseshoe, Warragai Creek/southern area, Grasshopper Swamp, Imesons Swamp, north of the Sportsmans Creek-Everlasting Swamp levee. The forums also included a meeting with the Directors of the Sportsmans Creek Drainage Union (SCDU). The aim of these forums was to identify the concerns of landholders adjacent to the National Park's area and the potential risks associated with changes to the existing hydrology of Everlasting Swamp and Imesons Swamp (a component of the Everlasting Swamp wetland complex). While broader stakeholder engagement and further community discussion forums are planned, information gathered from these initial sessions have been integrated with the model outputs and ecological study results to provide management recommendations to NPWS, as provided in Section 4.

G.2 Priority Community Feedback

A summary of the community feedback of priority concerns was gathered during the discussion forums, and was collated and tabulated, as provided in Table G.1 and Table G.2. These priority concerns were labelled from P1 to P7. This information was categorised as follows: (i) existing concerns, (ii) associated risks, and (iii) landholder suggested management outcomes. WRL recommendations are also provided to address each concern raised by the community during the discussion forums. Note that Table G.1 provides a summary of the overarching feedback for Everlasting Swamp and Imesons Swamp, as a single management unit. The concerns/risks provided in Table G.1 were recorded in every discussion forum and are highlighted as the top priorities for future management of the site, while Table G.2 provides area specific community feedback that may require management actions that are not applicable across the whole site.

Table G.1: Overarching Feedback for Everlasting Swamp and Imesons Swamp as a Single Management Unit

Existing Concern	Associated Risk	Landholder Suggested Management Outcome	WRL Recommendation
Re-introduced tidal inundation of private properties (P1).	Increased ground salinity, reduced agricultural and drainage capacity.	Modified floodgates to control inundation extent and timing of inundation. Landholders suggested that Spring is a good time to start managing water levels, with more water in Summer (up to 3-5 inches), less water in winter.	Management plan should consider modified floodgates (automated or buoyancy controlled) that can control the amount and timing of water entering the site.
Changed antecedent conditions (P2).	Increased impact on flooding, increased inundation and longer residence times of floodwaters on private properties.	Manage swamp water levels to minimise impact from wet antecedent conditions, landholders willing to assist with floodgate management, improve drainage efficiency.	Management plan should address actions to encourage a staged, adaptive management approach that provides a balance between ecology values and productive agricultural land.
Sportsmans Creek Weir (P3).	Failure of the weir, ongoing cost of maintenance and potential litigation.	Removal of the weir is a risk that could be managed from an engineering point of view, provided the u/s gates and drains on Imesons are operating efficiently.	Community sees value in weir, however the risk (failure or litigation) outweighs the benefits (prevents powerboats, maintains WL, allows freshwater fish to breed). Options include removal of gates, complete removal of weir, upgrade of existing weir, complete replacement (unlikely).

Table G.2: Management Area Specific Feedback

Existing Concern	Associated Risk	Landholder Suggested Management Outcome	WRL Recommendation
Levees and drains between Anderson's Point and Round Mountain have changed historical flow paths from Warragai Creek to Sportsmans Creek, and diverted flow to Blanches drain (P4).	Increased inundation and residence time of floodwaters on properties south and west of Blanches Drain.	Remove levees and restore natural flow paths.	Management plan should address these actions and the impacts of Harrisons Creek weir on holding back flows to Blanches drain, as well as the risk associated with removing this weir and opening floodgates on Blanches drain.
Coxs Creek and Harrisons Creek drain east-west and flooding of Everlasting Swamp can impact drainage of farmland if antecedent conditions are wet (P5).	Reduced drainage gradient to the swamp from properties to the east of the site, increased flooding and longer residence times of floodwaters.	Manage swamp water levels to minimise impact from wet antecedent conditions.	Management plan should address actions to encourage a staged, adaptive management approach that provides a balance between ecology values and productive agricultural land.
For landholders north of the levee (off Weir Road), 1) Minimise impact from the National Park on drainage (antecedent conditions) 2) Minimise chances of further levee breaches 3) Minimise mosquitoes (P6).	Inundation and damage to properties, longer residence times of floodwaters. Weir provides protection from backwater flooding from Clarence River.	Manage swamp water levels to minimise impact from wet antecedent conditions.	Management plan should address actions to encourage a staged, adaptive management approach that monitors water levels and minimises the potential impact of stagnant water levels. Future management plan is unlikely to impact large floods that could result in levee breaches.
Low lying land across Imesons Swamp is always wet, less than 100 mm of rain and the swamp areas are unusable (P7).	Floodgates and drains on Imesons Swamp are not managed well because it is gazetted as SEPP14 wetlands. No levees on Imesons Swamp to protect properties from flooding.	Improved drainage of Duck Creek and floodwaters, but would also like to see regular flushing of land and improved ecology.	Management plan should address actions for improving floodgate management and drainage efficiency of Imesons Swamp, particularly in the case of removing Sportsmans Creek Weir.

G.3 General Community Feedback

There were additional general concerns raised by the community during the forums and these are provided in Table G.3, and the dot points below, and a labelled from G1 to G12. Table G.3 provides general comments comprising opinions on the current management of the National Park. These opinions were shared by most of the adjacent landholders.

Table G.3: Non-Water Related Feedback

Existing Concern	Perceived Risk	Landholder Suggested Management Outcome	WRL Recommendation
Poor land management by NPWS (G1).	Swamp has become overgrown in areas, outbreak of wild pigs/dogs/foxes, reduction in birds and bird habitat.	Regular flushing of landscape with shallow water flows to kill and manage vegetation, and to maintain bird habitat (e.g., water holes). Allow crash grazing (by cattle) to manage vegetation.	Management plan should address actions to protect and enhance bird habitat and bird population diversity.
Lack of communication between NPWS and impacted landholders (G2).	Anger and conflict between landholders and NPWS.	Formation of a community working group, biannual community meetings, regular updates through social media and postal letters.	Management plan should address actions to improve engagement and communication with impacted landholders, an agreed plan of how things are going to be managed and operated, and who is responsible.
Poor management of drainage infrastructure by Council and NPWS (G3).	Inundation of private properties, decline in agricultural productivity over recent years, increased risk of black water.	Landholder willingness to assist with floodgate management. Lack of water quality monitoring by NPWS and Council after opening the gates.	There was strong support for a staged-adaptive management approach to improve the health and biodiversity of the site. Management plan should also consider a water level and water quality monitoring program, and an option to make data publicly accessible. An online data repository could also accept data collected by landholders.

Other general community feedback noted for possible future reference, is summarised as follows:

G4. Technical terminology and theory was sometimes confusing, whereby, 'tidal inundation' is synonymous with high salinity inundation; surface calcification from ASS-leachate is synonymous with salt deposits from tidal water inundation; 'full restoration' suggests completely restoring pre-drainage flow paths; and 'flooding' is appropriate when water breaches riverbanks, otherwise it is overland inundation.

G5. Landholders do not want their traditional knowledge of the swamp to be devalued.

G6. Consensus that historical draining of the swamp and flood mitigation was an environmental disaster, with some landholders suggesting that "when the land is dry, the land is poor" and "Sportsmans Creek/Levee 32 should never have been built due to its' impact on flooding and geomorphological processes".

G7. Community members support the concept of "restore forward, rather than restore back".

G8. The SCDU was particularly interested in what is the most likely/useful long-term outcome for Sportsmans Creek Weir, while protecting the productive capacity of the land, as well as achieving desirable environmental outcomes for the Everlasting Swamp wetland complex. Note that several landholders at Imesons Swamp were not aware of their accountability to the drainage union at the time they purchased their properties.

G9. Consensus that landholders were keen to maintain drainage capacity and productive land, however they are also interested in knowing how to use grazing and water management for the best environmental outcomes across the site.

G10. Observations of changing swamp geomorphology and land features, such as a new sandbar forming at mouth of Warragai Creek.

G11. A concern was raised that that Lawrence bridge upgrade works restricted flows up Sportsmans Creek and impacted water levels across the site during construction.

G12. New floodgates built by Council at the mouth of the Little Broadwater appear to be allowing more runoff and potentially affecting drainage of Everlasting Swamp by raising tailwater levels in Sportsmans Creek.

Appendix H – Ecological Assessment Report

Ecological Factors in the Hydrological Restoration of the Everlasting Swamp, north-east NSW: aquatic plants and waterbirds

A report to the University of New South Wales Water Research Laboratory (WRL)

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Contents

1 Introduction

1.1 Current Study

This report presents background information and discuses some possible ecological implications of undertaking hydrological restoration of wetlands within the Everlasting Swamp National Park (ESNP). The report focuses on aquatic vegetation and waterbirds.

Engineering scientists from the University of New South Wales Water Research Laboratory (WRL) have proposed at least 15 model scenarios as options for the future management of water to and within the ESNP. These scenarios range from maintaining the current regime through to a full restoration involving the removal or active management of floodgates and drains. The various scenarios each would result in different distribution, retention time, quantity and quality of water within the ESNP. Possible ecological consequences of some scenarios are considered in this report.

1.2 Background

From the early 2000s the New South Wales National Parks ad Wildlife Service (NPWS) made a series of land purchases in the Everlasting Swamp wetland complex leading to the establishment of a national park there. The site was believed to hold outstanding conservation potential.

The retention times of water in coastal wetlands of NSW was much reduced following regional drainage and flood mitigation in the 1950s and 1960s (Smith, 2010; 2011). As a consequence, the ecological functioning of the Everlasting Swamp changed dramatically (Smith, 2010). Personal historical accounts of the effects of drainage often describe the change in terms of the sudden decrease in numbers of waterbirds and fish (Terry Harrison, Doug Short, pers. comms.). The visual difference was the conversion of the large, mostly-wet tracts of marshlands and open water to mostly-dry land supporting cattle pastures.

Since the 1990s restoration projects have been undertaken across the Clarence River floodplain (Clarence Valley Council Floodplain Project), with varying success in restoring hydrological flows and achieving subsequent ecological responses. A wetland restoration project of most relevance to the current project included the studies and monitoring undertaken at Little Broadwater, a wetland within the Everlasting Swamp complex of wetlands, north and east of Everlasting Swamp and Imesons Swamp.

Scientific research, and management plans and strategies were implemented at Little Broadwater from the 1990s to 2000s (Peter Wilson (CVC), John Duggin, Justine Graham (UNE): pers. comm.s). Drainage infrastructure was modified, particularly the floodgate, and the hydrology of the wetland was altered to regulate water flows, depth and salinity, and to attenuate acidity. This resulted in increased hydroperiod and positive responses from aquatic macrophytes, fish and waterbirds, and improved water quality (Johns, 2008; White, 2009; Smith, 2010). Little Broadwater consistently recorded the highest numbers of waterbirds and waterbird species during 2005-08 studies on Clarence River floodplain wetlands (Smith, 2010). Restoration of other areas of the wetland complex, i.e. Everlasting Swamp and Imesons Swamp, could be expected to deliver similarly positive ecological outcomes.

1.3 Ecological Components

This report focuses on aquatic vegetation and waterbirds. Other ecological components are important in natural resource management locally and further afield, and for biodiversity conservation. These are mentioned here below as they await further separate review, research and discussion. They include:

- *Non-waterbirds.* A range of non-waterbirds typical of north coast NSW agricultural areas occur in the Everlasting Swamp NP in habitats of dry woodland, riparian woodland and grassland. Over 30 species occur there and often observed in riparian woodland there is the Grey-crowned Babbler (threatened) and interestingly, an active nest of Little Eagles (Smith, 2010; Smith, unpub. data). [A list of non-waterbird species observed during 2016-17 is provided in Appendix Table Two.]
- *Trees*. Naturally growing trees at the site include Sheoaks (*Casuarina*), eucalypts (*Eucalyptus*), paperbarks (*Melaleuca*) and mangroves (*Avicennia*). A range of tree species were planted at riparian sites in 2016-17 by NPWS (pers obs; Dean Egan, pers. comm.).
- *Weeds*, both aquatic and terrestrial such as, Parrott's Feather *Myriophyllum aquticum,* Tropical Soda Apple *Solanum viarum,* Salvinia *Salvinia molesta,* and Water Hyacinth *Eichhhornia crassipes,* Azolla *Azolla sp.*
- *Invertebrates* Aquatic, terrestrial Mosquitoes
- *Fish* including eels, and including recreational and commercial species at larval and juvenile stages.
- *Frogs*
- *Reptiles* including Eastern Water dragon, Turtle, Red-bellied Black Snake, skinks, geckos.
- *Mammals*, such as Eastern Grey Kangaroo.
- *Pest animals*, such as Feral Pig.

2 Vegetation (Wetland Plants)

A small number (~10) of plant species tend to dominate the Everlasting Swamp landscape (Table 1) although at least 150 species of plants could possibly occur, varying in locations in and around the wetland depending on the presence and quality of water (Johns, 2008: Appendix 6 Vegetation). Two species are particularly dominant and predictable in their presence, Spike Rush *Eleocharis equisetina* and Water Couch *Paspalum distichum*.

Table 1. Wetland plants commonly observed in Everlasting Swamp and other wetlands of Clarence River floodplain (approximate order from most common) (after Johns, 2008; C. Johns, unpub. data, 2005).

Name	***Species***
Spike Rush	*Eleocharis equisetina*
Couch	*Cynodon dactylon*
Water Couch	*Paspalum distichum*
Waterbuttons	*Cotula coronipifolia*
Brahmi	*Bacopa monnieri*
Common Reed	*Phragmites australis*
Marsh Clubrush	*Bolboschoenus caldwellii*
Dwarf Spike Rush	*Eleocharis minuta*
Common Rush	*Juncus usitatus*
Clubrush	*Schoenoplectus litoralis*
Waterlily	*Nymphaea caerulea*
sedge	*Cyperus polystachyos*
Saltwater Couch	*Paspalum vaginatum*
other grasses	
Trees and shrubs	
Swamp Sheoak	*Casuarina glauca*
Broad-leaf Paperbark	*Melaleuca quinquenervia*
Grey Mangrove	*Avicennia marina*
River Mangrove	*Aegiceras corniculatum*

2.1 Effects of Salinity and Inundation

Studies of Clarence River floodplain wetland plants (Johns, 2008) indicated that many species, including the most abundant aquatic macrophytes in Everlasting Swamp, have extended periods of tolerance to salinity and water depth. This was summarised as follows:

> "The inundation tolerance thresholds of all species decreased with increasing salinity although tolerance to salinity and inundation varied considerably between species. For example, based on survivorship *C. dactylon* [common couch] was least tolerant of high salinity in waterlogged conditions, while *P. distichum* [water couch] was most tolerant, and when submerged *E. equisetina* [spike rush] and *P. distichum* grew rapidly to the water surface, while *C. dactylon* did not." (Johns, 2008: p. v Abstract)

Experiments on selected aquatic plant species (Table 2) and broader research data on a larger number of these species (Table 3) shows the types of wetlands preferred by these species (Johns, 2008). Six categories of wetlands categorised by salinity and inundation patterns are recognised (Table 2 and Table 3), and the species most commonly observed at Everlasting Swamp (Table 2) generally occur at fresh to moderately saline wetlands, for example spike rush, water couch and common reed. Some species such as *Persicaria* spp. and the water lily *Nymphaea caerulea* prefer freshwater, while some species such as samphire and salt couch would be expected only on saline wetlands (Table 3).

Table 2. Predicted distribution of aquatic plant species at the floodplain scale; species generally common at Everlasting Swamp (after Johns, 2008: Table 5.6).

Wetland salinity / tidal influence category **Species**	**Category 1: Freshwater wetlands**	**Category 2: Fresh to mildly brackish wetlands**	**Category 3: Mildly to moderately brackish wetlands**	**Category 4: Moderately to strongly brackish wetlands**	**Category 5: Strongly brackish to saline wetlands**	**Category 6: Saline to hypersaline wetlands**
†Bacopa monnieri	+	+	+	+	+	–
†Bolboschoenus caldwellii	+	+	+	–	–	–
†Casuarina glauca	+	+	+	–	–	–
†Cynodon dactylon	+	+	+	+	–	–
Cotula coronipifolia	+	+	+	+	+	
†Eleocharis equisetina	+	+	+	–	–	–
Eleocharis minuta	+	+	+	+		
Juncus usitatus	+					
Melaleuca quinquenervia	+	+	+			
Nymphaea caerulea	+	+				
†Paspalum distichum	+	+	+	+	–	–
†Phragmites australis	+	+	+	+	–	–
Schoenoplectus litoralis	+	+				

Habitat ranges predicted based on experimental data (*†)* and/or survey records ("+" indicates habitat predicted suitable for species survival, "–" indicates areas with salinity exceeding experimental salt tolerance threshold). Site salinity / tidal influence categories only include areas located below the high water mark.

Table 3. Classification of Clarence wetland macrophyte species into functional groups based on salinity* and inundation tolerance data (after Johns, 2008: Appendix 8) (See definitions below.)

Species	Salinity category*	Functional group
Centipeda sp. (sneezeweed)	1	Terrestrial
Ludwigia peploides ssp. *montevidensis* (water primrose)	1	Amphibious
Nymphoides indica (water snowflake)	1	Aquatic
Ottelia ovalifolia (swamp lily)	1	Aquatic
Persicaria hydropiper (water pepper)	1	Amphibious
Persicaria orientalis (princess feathers)	1	Amphibious
Philydrum lanuginosum (frogsmouth)	1	Amphibious
Potamogeton octandrus (syn. P javanicus) (pondweed)	1	Aquatic
Salvinia molesta (salvinia) [aquatic weed]	1	Aquatic
Utricularia sp. (bladderwort) (fixed or floating)	1	Various
Viola hederacea	1	Terr./Aquatic
Centella asiatica (Indian pennywort)	1 -2	Terrestrial
Nymphaea caerulea (Cape waterlily)	1 -2	Aquatic
Bolboschoenus caldwellii (marsh clubrush)	1 -3	Amphibious
Casuarina glauca (swamp oak)	1 -3	Terrestrial
Eleocharis equisetina (soft rush)	1 -3	Amphibious
Potamogeton tricarinatus (floating pondweed)	1 -3	Aquatic
Triglochin procerum (water ribbons)	1 -3	Amphibious
Cynodon dactylon (couch)	1 -4	Terrestrial
Eleocharis minuta	1 -4	Amphibious
Lachnagrostis filiformis (blown grass)	1 -4	Terrestrial
Paspalum distichum (water couch)	1-4	Amphibious
Phragmites australis (common reed)	1 -4	Amphibious
Bacopa monnieri (brahmi)	1 -5	Amphibious
Isolepis inundata (Swamp clubrush)	2	Amphibious
Cyperus polystachyos (Cyperus)	2 -3	Terrestrial
Melaleuca quinquenervia (paperbark)	2 -4	Terrestrial
Cotula coronopifolia (waterbuttons)	2 -6	Amphibious
Aster subulatus (wild aster)	3	Terrestrial
Epaltes australis (spreading nut-heads)	3	Amphibious
Juncus usitatus (common rush)	3	Amphibious
Ruppia sp.	3	Aquatic
Aegiceras corniculatum (river mangrove)	3 -4	Amphibious
Apium prostratum subsp. Prostratum (sea celery)	3 -4	Terrestrial
Juncus kraussii (sea rush)	3 -4	Amphibious
Schoenoplectus litoralis (river clubrush)	3 -4	Amphibious
Diplachne fusca (brown beetle grass)	4	Amphibious
Triglochin striatum (streaked arrowgrass)	4	Amphibious
Fimbristylis ferruginea	4 -6	Amphibious
Avicennia marina (grey mangrove)	6	Amphibious
Sarcocornia quinqueflora (samphire)	6	Amphibious
Sporobolus virginicus (salt couch)	6	Amphibious

*Wetland salinity/tidal influence category: **Category 1**: Freshwater wetlands; Above extent of tidal influence. **Category 2**: Fresh to mildly brackish wetlands, relatively fresh (<5 ppt); **Category 3**: Mildly to moderately brackish wetlands. water <5 ppt, or occasionally >5 ppt; **Category 4**: Moderately to strongly brackish wetlands with sites subject to tidal inundation with water <25 ppt; **Category 5**: strongly brackish to saline wetlands receiving water 25–35 ppt; **Category 6**: saline to hypersaline, tidal, receiving water ≥35 ppt.

3 Waterbirds

3.1 General

Everlasting Swamp is historically an important waterbird habitat, and prior to drainage probably sustained very high numbers of waterbirds (possibly >100,000) for extended periods each year, and was also an important habitat for now threatened species (Smith, 2011). Many of the waterbird species observed on Clarence River floodplain wetlands can be expected to occur at Everlasting Swamp due to the diversity of habitat there. [A list of waterbird species observed on Clarence River floodplain wetlands is in Appendix Table One.]

Waterbird surveys at the Everlasting Swamp in 2006-07 (16 counts) and 2016-17 (five counts) (Smith, unpub.) observed 39 and 34 species respectively (Table 4) although usually in low numbers. The often abundant species such as some ducks (Black Duck and Grey Teal) were only occasionally observed in numbers over 100.

The threatened species Brolga, Comb-crested Jacana and Jabiru (Black-necked Stork) are sometimes observed in the Everlasting Swamp complex, as are migratory waders (as listed under international agreements JAMBA, CAMBA, RoKAMBA) such as Latham's Snipe and Sharp-tailed Sandpiper (Table 4). The Osprey, Magpie Goose and Cotton Pygmy Goose (all threatened in NSW) could also occur.

Table 4. Waterbirds observed at Everlasting Swamp in two survey periods: 2006-07 (16 site visits); and 2016-17 (five site visits) (Smith, unpub. data).

Species	2006-07	(39 spp.)	2016-17	(34 spp.)
	No. times obs. (of 16)	Max. no	No. times obs. (of 5)	Max. no
Australasian Grebe	2	6	0	
Australian Pelican	5	5	4	13
Australasian Darter	2	1	3	3
Great Cormorant	0		1	3
Pied Cormorant	0		1	1
Little Black Cormorant	5	1	5	8
Little Pied Cormorant	13	3	5	3
Cattle Egret	11	280	2	20
White-necked Heron	9	55	2	4
White-faced Heron	14	29	3	15
Striated Heron	0		1	1
Eastern Great Egret	12	81	4	20
Little Egret	2	1	0	
Intermediate Egret	15	101	2	3
Black-necked Stork	1	1	3	4
Brolga	8	7	4	32
Glossy Ibis	5	10	2	10
Australian White Ibis	7	30	3	19
Straw-necked Ibis	9	9	3	110
Royal Spoonbill	4	20	2	8
Yellow-billed Spoonbill	2	11	0	
Plumed Whistling Duck	2	22	0	
Black Swan	14	127	5	44
Pacific Black Duck	16	106	5	65
Grey Teal	8	120	3	20
Chestnut Teal	9	21	3	32
Australasian Shoveler	2	7	0	
Pink-eared Duck	1	16	0	
Hardhead	2	46	1	4
Australian Wood Duck	4	16	1	2
Swamp Harrier	8	2	3	1
White-bellied Sea Eagle	3	2	4	2
Eastern Osprey	0		1	1
Comb-crested Jacana	4	2	0	
Buff-banded Rail	0		1	2
Dusky Moorhen	1	5	3	3
Purple Swamphen	14	30	5	7
Eurasian Coot	2	36	1	1
Masked Lapwing	14	25	5	36
Sharp-tailed Sandpiper	1	1	0	
Latham's Snipe	1	2	1	1
Black-winged Stilt	8	16	1	82
Whiskered Tern	1	10	0	
Crested Tern	1	22	0	

3.2 Water and Waterbird Habitat

Hydroperiod, depth and salinity are important factors in the presence and abundance of waterbirds in wetlands, determining the foraging and nesting landscape, and affecting other factors such as food sources.

The numbers and numbers of species of waterbirds can increase as the wet area of a wetland increases (Figure 1). However, the ecological response can be highly dependent on the bathymetric profile of the wetland, for example steep-sided deep wetlands versus flat-sided shallow wetlands (Figure 2).

3.3 Depth

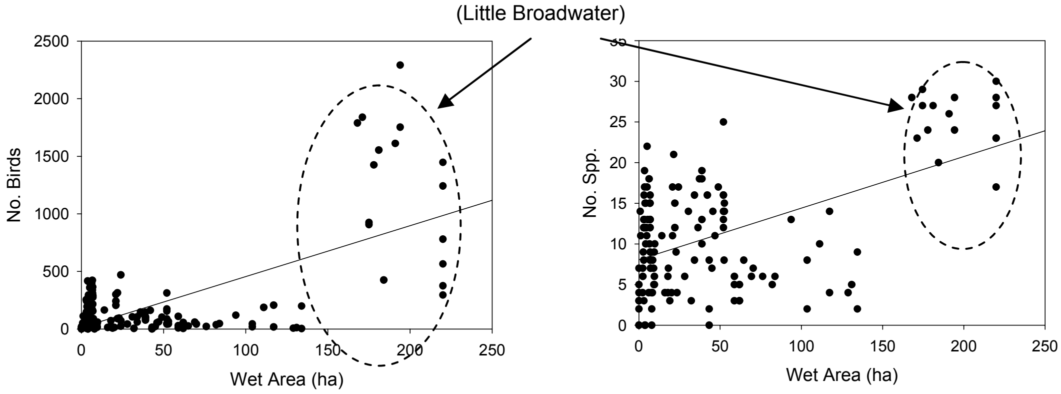
The following points (from Smith, 2010) are important in understanding the role of water depth on waterbirds in wetlands:

- Waterbird foraging is limited by water depth
- Different species of waterbirds forage at different depths
- Waterbird ecologies are closely tied to the distribution and abundance of their food
- Waterbirds are most abundant in shallow water (<1m) with maximum preferred depths often being about 20 to 30 cm
- Important depths for some species are: <10 cm (particularly for shorebirds); , 20cm for wading birds and dabbling duck species; >20 cm for some waterfowl; and, >1m for larger diving piscivores such as cormorants
- Disturbance to the water regimes of wetlands usually increases their stability to be either more continuously-inundated or continuously-dry, and thus disrupting the flood-pulse regime, an important factor for change and renewal in foraging habitat for waterbirds.

Studies (Smith, 2010) indicate that most species of waterbirds increase in number with increasing wet area of a wetland (Table 5) but this is mostly limited to depths under 1m over which there is no effect or the effect is negative. Diving omnivores such as the Australian Grebe are the exception, and appear to increase in number with increased area of deeper (>1m) water and also in water over 20cm.

3.4 Salinity

Studies (Smith, 2010) indicate that at least 13 species of waterbird prefer wetlands with salinity less than 5 ppt, with five of these preferring freshwater (<2ppt), species such as Comb-crested Jacana, Whistling Duck and Dusky Moorhen (Table 6).



(a) (b)

Figure 1. (a) number of waterbirds, and (b) number of species: at 10 wetlands on the Clarence River floodplain, 2006-07. Data points for the Little Broadwater wetland are highlighted. (From Smith, 2010, Figure 4.3)

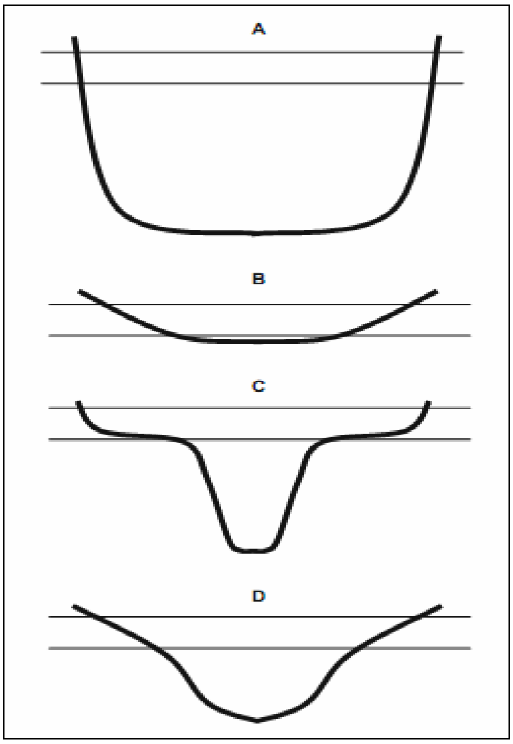


Figure 2. Wetland morphology types (from Smith, 2010) **indicating the importance of water-level fluctuations (minimum and maximum water levels indicated by horizontal lines): (A) Large, deep wetland with steep banks, (B) Shallow wetland, entirely influenced by the flood pulse, (C) Combined type of A and B with deep central trough and extensive shallow areas, (D) "Average" wetland with moderate shallow areas and permanent central trough.**

Table 5. The response of waterbirds (+ positive, - negative) to increasing total wet area of a wetland and to increasing areas of water of certain depths: by foraging groups and selected species of each group (threatened species (T) and most abundant species) (after Smith, 2010).

Depth (cm)

	dry	**0-10**	**10-20**	**20-30**	**30-100**	**>100**	**total wet**
Species / Group							
Total No.s (all species)	-	+	+	+	+		+
No. Spp	-		+	+	+		+
Foraging Groups							
Dabbling Ducks	-	+	+	+	+		+
Diving Omnivores	-	-	-			+	
Diving Piscivores	-		+	+	+		+
Herbivorous Grazers		+	+	+	+		+
Large Wading Omn.s		+	+	+	+	-	+
Small Waders		+	+	+	+	-	+
[migratory waders]			+	+			+
[non-migratory waders]		+	+	+	+		+
Wading Piscivores		+	+	+	+	-	+
Birds of Prey	+	+	+	+	+	-	+
Selected Individual Species							
Dabbling Duck							
Pacific Black Duck	-		+	+	+		+
Grey Teal		+	+	+	+		+
Diving Omnivore							
Australasian Grebe	-			+	+	+	+
Diving Piscivore							
Little Pied Cormorant	-		+	+	+		+
Herbivorous Grazer							
Black Swan		+	+	+	+		+
Large Wading Omnivore							
Brolga (T)		+	+	+		-	+
Strawnecked Ibis		+	+	+	+		+
Small Wader							
Comb-crested Jacana (T)	-	-	-			+	-
Sharp-tailed Sandpiper			+	+			+
Wading Piscivore							
Black-necked Stork (T)			+	+	+		+
Bird of Prey							
Swamp Harrier	+	+	+	+		-	+

Table 6. Summary of salinity tolerances for waterbirds on Clarence River floodplain wetlands, ( ) = indicative only (n <10). (From Smith, 2010, Table 5.4.)

Species (n)	**Salt-intolerant (<5 ppt)**	**Salt-tolerant (>5ppt)**	**Unknown (n<10)**	**Tolerance (ppt) ~ 95% C.I.**
Australasian Grebe (72)	●			4
Pelican (59)		●		16
Australasian Darter (29)		●		10
Great Cormorant (6)			●	(7)
Pied Cormorant (2)			●	(2)
Little Black Cormorant (43)	●			5
Little Pied Cormorant (72)		●		9
Cattle Egret (83)		●		6
White-necked Heron (77)	●			5
White-faced Heron (147)		●		7
Great Egret (81)		●		7
Little Egret (36)		●		7
Intermediate Egret (90)	●			4
Black-necked Stork (18)		●		8
Brolga (37)		●		6
Glossy Ibis (43)		●		6
White Ibis (81)		●		15
Straw-necked Ibis (97)		●		15
Royal Spoonbill (44)		●		16
Yellow-billed Spoonbill (10)	●			5
Plumed Whistling Duck (17)	●			2
Magpie Goose (2)			●	(1)
Black Swan (126)		●		6
Pacific Black Duck (173)		●		7
Grey Teal (131)		●		7
Chestnut Teal (85)		●		15
Australasian Shoveler (45)	●			5
Pink-eared Duck (13)	●			2
Hardhead [Duck] (47)	●			3
Australian Wood Duck (55)	●			5
Musk Duck (4)			●	(1)
Swamp Harrier (39)		●		6
White-bellied Sea Eagle (17)		●		19
Eastern Osprey (9)			●	(22)
Comb-crested Jacana (51)	●			2
Buff-banded Rail (2)			●	(4)
Dusky Moorhen (38)	●			2
Purple Swamphen (130)		●		6
Eurasian Coot (45)	●			4
Black-fronted Dotterel (8)			●	(10)
Red-kneed Dotterel (2)			●	(2)
Pacific Golden Plover (3)			●	(9)
Masked Lapwing (158)		●		8
Sharp-tailed Sandpiper (20)		●		14
Bar-tailed Godwit (1)			●	(7)
Latham's Snipe (34)		●		18
Common Greenshank (8)			●	(10)
Marsh Sandpiper (12)		●		8
Black-winged Stilt (84)		●		8
Whiskered Tern (7)			●	(7)
Crested Tern (2)			●	(2)
Caspian Tern (1)			●	(5)
Gull-billed Tern (1)			●	(5)

4 Predicted Responses to Hydrological Restoration

4.1 General Factors

Restoration of ecological processes can happen quickly after hydrological restoration (Middleton, 1999). A range of factors and variables will influence the nature and pace of any restoration at Everlasting Swamp including:

- hydrology – water source, water movement (standing or running water), depth, stratification
- water quality – salinity, pH, temperature, nutrients
- hydroperiod (duration of wetting) and pulse (wetting-drying regimes)

Factors such as these will determine the vegetation and wildlife habitat that appears in the wetland, for example, by creating the functional water depths at which different species prefer to forage (Table 5).

Other factors make determining species' occurrences and abundances less predictable, for example, the highly mobile nature of many waterbirds and the availability of a waterbird species' food source which is different depending on, whether they are herbivores, filter feeders, fish-eaters, birds of prey, waders or other. Also, for example, there are regional and extra-regional influences of weather events such droughts and floods that affect breeding and mobility that can also determine where and when various species occur. The adage of "build it and they will come" could be modified to "build it and there is a much higher possibility that they will be present at the site sooner or later for the short or long term."

4.2 Hydrological Scenarios

Five hydrological scenarios were selected from those developed by WRL (unpub. data). These were selected to cover a range from the least water retained on the wetland to the most. The five scenarios represent, approximately, the functional wet areas each of about 90, 160, 300, 1160 and 1240 ha (Table 7), where functional wet area is land area that is expected to have at least some water over it for at least 80% of the time; some of this area will be permanently wet. Much of the remainder of the wetland area is either dry most of the time or comprises the Aquatic-Terrestrial Transition Zone, the area of the wetland that wets and dries, and often within indistinct boundaries.

Table 7. Hydrological Restoration scenarios at Everlasting Swamp: hydroperiod and corresponding area of water, and maximum and minimum water depths: 20-100% is mostly wet area, 0-20% is mostly dry area (WRL: unpub. data, 2017).

Hydro-period (% Time Wet)	Area (ha)	Maximum Depth (m)	Av. Min Depth (m)	Av. Max Depth (m)	Av. Mean Depth (m)
[1]**Base**					
0-20	4,161	0.13	0	0	0
20 to 100	**88**	0.25 – 1.55	0 – 0.21	0.12 – 0.31	0.03 – 0.27
[2]**Full**					
0-20	3,086	0.38	0	0	0
20 to 100	**1,162**	0.39-1.97	0-0.1	0.11-0.23	0.03-0.16
[3]**Option E**					
0-20	4,091	0.25	0	0	0
20 to 100	**158**	0.25-1.77	0-0.15	0.12-0.25	0.03-0.2
[4]**Option F**					
0-20	3,946	0.31	0	0	0
20 to 100	**302**	0.32-1.67	0-0.11	0.12-0.24	0.03-0.19
[5]**Option G**					
0-20	3,009	0.39	0	0	0
20 to 100	**1,239**	0.4-1.97	0-0.09	0.11-0.23	0.03-0.16

[1]Base: Base Case, existing condition
[2]Full Restoration Case, Harrisons Weir Existing
[3]Option E – Site Open, Sportsmans Weir Existing Conditions (with Leakage)
[4]Option F – Site Closed, Sportsmans Weir Open, Modified Reedy Creek Gates Open
[5]Option G – Full Restoration, Harrisons Weir Removed

Scenario 1 Base Case, existing condition

This scenario represents the current situation in the Everlasting Swamp. The wetland represents a relatively large wetland area compared to others on the floodplain, but most of the Everlasting Swamp wetland area is now dry most (>80%) of the time. The wetland area that is mostly wet (88 ha) has sufficient internal bathymetric differences to maintain habitats of relatively high flora and fauna species diversities.

If no restoration actions proceed, and this current base case continues, the species diversity is likely to be maintained although there will be no habitat gains or any significant increase in numbers of waterbirds.

Grazing

Grazing pressure from cattle has been much reduced on Everlasting Swamp in recent years. This has led to an overgrowth particularly of spike rush in the marsh areas, and also an incursion of trees, particularly swampoak along tracks, levees and drier margins. If there is no hydrological restoration or intervention by mechanical or agricultural means, the overgrowth will remain and incursion of trees will continue. While this may provide additional roosting habitat for some waterbirds it may be negative overall as many waterbirds prefer to forage in open landscapes.

Other Scenarios (2, 3 4 and 5)

The other scenarios of restoration involve the maintenance or water on the Everlasting Swamp at higher levels and for longer periods with the different scenarios ranging up to an area of the wetland with 1,240 ha of land being wet for at least 80% of the time.

Thresholds – and Grazing by Black Swans

Salinity and water depth thresholds (Tables 2, 3, 5 and 6) are useful indicators of the species of plants and waterbirds that could be expected to occur as water depth and hydroperiod increases on the wetland. However other thresholds could also be important in the functioning of the ecosystem. For example, grazing by black swans is known to be a modifier of the marsh vegetation, and can remove 6 tonnes per hectare of vegetation in a few months (Smith et al, 2012), and so create open water and habitat for wading birds and dabbling ducks.

Black swans prefer larger water ways and require a minimum of 40m to takeoff. So, increasing water levels to a certain threshold may provide suitable habitat for black swans to occur in sufficient numbers to instigate the process of gazing, a function that does not occur until the threshold is reached, and may not increase correspondingly with further increases in the aerial extent of water.

4.3 General Predictions

Overall it is difficult to provide precise ecological predictions in the restoration process although possible responses can be estimated given research at other similar sites on the floodplain (Table 8). Research at Little Broadwater (Smith, 2010) suggests that numbers of some waterbird species would increase approximately corresponding to the increase in wet area which among the scenarios could be from two to 10 times current numbers (Table 8).

The number of species occurring overall at the site is likely to increase although this is limited by the actual number of aquatic plant and waterbird species that exist. The site already has high species diversity due to its large area and range of habitats within. A more noticeable difference in species numbers is likely to be a higher number observed at any given time, i.e. more species are likely to occupy the site at one time due to the increased number and extent of habitat types. However, aerial extent of aquatic plants and numbers of many individual waterbird species such as dabbling ducks and waders are likely to increase (Table 8) as more water is retained on the wetland. The site diversity is due to the wetland being mostly very flat but with isolated bathymetric features creating occasional deeper pools and lagoons.

The flatness and relatively large area of wetland means that freshwater pools could be maintained upstream in the wetland despite brackish and salty water entering the wetland during hydrological restoration, this saltier water moving as a wedge rather than infiltrating the entire wetland (Will Glamore, pers. comm.). If so, this would maintain refugia habitat for freshwater species despite the introduction of tidal water into the wetland, and overall maintaining high species diversity.

Overall, small increases in water depth could lead to large changes in the extent of water. Therefore, increased wet area is likely to lead to increases in:

- available area for aquatic plants to establish and be maintained, although this will depend on the salinity regime as per individual species preferences
- areas of open water
- areas of spike rush and water couch
- habitat generally for all waterbirds although this will depend on the salinity regime as per individual species preferences
- foraging habitat for wading birds
- number and depth of water pools for diving waterbird species
- the aquatic-terrestrial transition zone which expands with a slow drying wetland and favours waders probing into soft soil
- increase in nesting sites either directly on the water or in trees conveniently located near to foraging areas.

Corresponding to the increases in the aerial extent of wetland plants would be the expected decrease in the aerial extent of dryland species such common couch.

Table 8. General predictions of the effects of hydrological restoration on selected ecological parameters (plant/animal species or groups): different scenarios with functional wet areas of 90, 160, 300, 1160 and 1240 ha. (See table 7 for definition of scenarios [1] to [5].)

(a). Estimate of effect of various scenarios of hydrological restoration on vegetation – area and aquatic plant species including the current (90 ha) situation (> increase; < decrease; ≥ same or increase; ≤ same or decrease)

Restoration Scenario (Wet Area 80% time)	No. Spp. Wetland Plants	Area of Spike Rush *E. equisetina*	Area of Water Couch *P. distichum*	Area of Common Couch *C. dactylon*	Area of Trees
90 ha [1 current]	≥	≤	≤	≤	>
160 ha [2]	≥	>	>	<	≤
300 ha [3]	≥	>	>	<	≤
1,160 ha [4]	≥	>	>	<	≤
1,240 ha [5]	≥	>	>	<	≤

(b). Estimate of effect of various scenarios of hydrological restoration on waterbirds – habitat and waterbirds including the current (90 ha) situation (> increase; < decrease; ≥ same or increase; ≤ same or decrease). (Figures based on waterbirds and wet area at Little Broadwater, see Figure 1.)

Restoration Scenario (Wet Area 80% time)	Open Water	Total W'bird numbers	No. W'bird species	No. Ducks	Threat'd spp.
90 ha [1]	≤	≤	≤	≤	≤
160 ha [2]	> x 1.5	> x 2 to 5	≥	> 2 to 5	≥
300 ha [3]	> x 2	> x 2 to 4	≥	> 2 to 5	≥
1,160 ha [4]	> x 3	> x 5 to 10	≥	> x 5 to 10	≥
1,240 ha [5]	> x 4	> x 5 to 10	≥	> x 5 to 10	≥

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5 Conclusions and Recommendations

This report has provided information for understanding the wetland biota at the Everlasting Swamp. Hydrological restoration will affect this biota by increasing the amount of water that is held on the wetland and therefore increase the functional wet area. There are many possible responses from aquatic plants and waterbirds depending on water depth and salinity, and even from feedback responses such as the grazing effects of black swans.

Generally, it is predicted that the more water that is delivered into the wetland landscape, the greater will be the biodiversity gains for the wetland. A pulsing wetland with a wet-dry cycle predominating over the area is likely to be highly productive and of high quality fish and wildlife habitat.

It s expected that any restoration will be conducted in an experimental fashion. Therefore, monitoring (recording) of the restoration process is essential with an adaptive management approach to be adopted. Monitoring should include parameters of:

- hydrology
- water quality, and
- terrestrial and aquatic flora and fauna.

Key performance criteria are required to be set within these parameters, for example, aerial extent of water and vegetation over time, presence and abundance of species, water depths and salinity.

Within the restoration process there is much scope for experimentation. Where possible, trials / experiments should be conducted so that comparisons of different techniques can be made in the short and long term. Such experiments could be, for example, responses of plants and waterbirds to different salinity and water depths over different time periods.

The coastal zone of NSW experiences continued development pressures from urban expansion and associated infrastructure. The Everlasting Swamp is one of few large wetlands that are relatively intact in this zone. Hydrological restoration of the site has the potential to assist in greatly increasing the biodiversity values of this state-owned asset.

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Appendix Table One
List of Waterbird Species observed on wetlands of Clarence River floodplain (after Smith, 2010, Table 3.7)

FAMILY **Common Name**	**Species**
PODICIPEDIDAE	
Australasian Grebe	*Tachybaptus novaehollandiae*
PELICANIDAE	
Australian Pelican	*Pelecanus conspicillatus*
ANHINGIDAE	
Australasian Darter	*Anhinga novaehollandiae*
PHALACROCORACIDAE	
Great Cormorant	*Phalacrocorax carbo*
Pied Cormorant	*Phalacrocorax varius*
Little Black Cormorant	*Phalacrocorax sulcirostris*
Little Pied Cormorant	*Microcarbo melanoleucos*
ARDEIDAE	
Cattle Egret	*Ardea ibis*
Eastern Great Egret	*Ardea modesta*
Intermediate Egret	*Ardea intermedia*
White-necked Heron	*Ardea pacifica*
Striated Heron	*Butorides striata*
Little Egret	*Egretta garzetta*
White-faced heron	*Egretta novaehollandiae*
Nankeen Night Heron	*Nycticorax caledonicus*
CICONIIDAE	
Black-necked Stork	*Ephippiorhynchus asiaticus*
GRUIDAE	
Brolga	*Grus rubicunda*
THRESKIORNITHIDAE	
Glossy Ibis	*Plegadis falcinellus*
Australian White Ibis	*Threskiornis molucca*
Straw-necked Ibis	*Threskiornis spinicollis*
Royal Spoonbill	*Platalea regia*
Yellow-billed Spoonbill	*Platalea flavipes*
ANSERANATIDAE	
Magpie Goose	*Anseranus semipalmata*
ANATIDAE	
Black Swan	*Cygnus atratus*
Plumed Whistling-Duck	*Dendrocygna eytoni*
Pacific Black Duck	*Anas superciliosa*
Mallard (feral species)	*Anas platyrhynchos*
Grey Teal	*Anas gracilis*
Chestnut Teal	*Anas castanea*
Australasian Shoveler	*Anas rhynchotis*
Pink-eared Duck	*Malacorhynchus membranaceus*
Hardhead	*Aythya australis*
Australian Wood Duck	*Chenonetta jubata*
Musk Duck	*Biziura lobata*
ACCIPITRIDAE	
Swamp Harrier	*Circus approximans*
White-bellied Sea-Eagle	*Haliaeetus leucogaster*
Eastern Osprey	*Pandion cristatus*

FAMILY **Common Name**	**Species**
JACANIDAE	
Comb-crested Jacana	*Irediparra gallinacea*
RALLIDAE	
Buff-banded Rail	*Gallirallus philippensis*
Dusky Moorhen	*Gallinula tenebrosa*
Purple Swamphen	*Porphyrio porphyrio*
Eurasian Coot	*Fulica atra*
CHARADRIIDAE	
Black-fronted Dotterel	*Elseyornis melanops*
Red-kneed Dotterel	*Erythrogonys cinctus*
Pacific Golden Plover	*Pluvialis fulva*
Banded Lapwing	*Vanellus tricolor*
Masked Lapwing	*Vanellus miles*
SCOLOPACIDAE	
Sharp-tailed Sandpiper	*Calidris acuminata*
Bar-tailed Godwit	*Limosa lapponica*
Latham's Snipe	*Gallinago hardwickii*
Common Greenshank	*Tringa nebularia*
Marsh Sandpiper	*Tringa stagnatilis*
Whimbrel	*Numenius phaeopus*
Eastern Curlew	*Numenius madagascariensis*
HAEMATOPODIDAE	
Australian Pied Oystercatcher	*Haematopus longirostris*
RECURVIROSTRIDAE	
Black-winged Stilt	*Himantopus himantopus*
Red-necked Avocet	*Recurvirostra novaehollandiae*
LARIDAE	
Whiskered Tern	*Chlidonias hybrida*
Crested Tern	*Sterna bergii*
Caspian Tern	*Hydroprogne caspia*
Gull-billed Tern	*Gelochelidon nilotica*
Silver Gull	*Chroicocephalus novaehollandiae*

Appendix Table Two

Non-waterbirds observed at Everlasting Swamp National Park 2016-17 (A. Smith, unpub. data).

Bird Common Name
Wedge-tailed Eagle
Whistling Kite
Hobby
Black-shouldered Kite
Grey Butcherbird
Pied Butcherbird
Eastern Rosella
Reed Warbler
Grey-crowned Babbler
Tree Martin
Pee Wee
Magpie
Superb Wren
Blue-faced Honeyeater
Noisy Miner
Willy Wagtail
Kestrel
Welcome Swallow
Rainbow Lorikeet
Crested Pigeon
Pheasant Coucal
Grey Fantail
Little Eagle
Restless Flycatcher
Indian Myna
Australian Raven
Kookaburra
unidentified Woodswallow (possibly Dusky)
Sacred Kingfisher
Satin Bowerbird (possible siting)
Black-faced Cuckoo Shrike
Pheasant Coucal

Appendix Table Three

Species observed in quadrats at Everlasting Swamp State Conservation Area, 2005 (C. Johns, unpub. data)

Spike Rush	*Eleocharis equisetina*
Water Couch	*Paspalum distichum*
Common Couch	*Cynodon dactylon*
Small Spike Rush	*Eleocharis minuta*
Waterbutton	*Cotula coronipifolia*
Swamp Sheoak	*Casuarina glauca*
Sedge	*Cyperus polystachyos*
Broad-leaf Paperbark	*Melaleuca quinquenervia*
Marsh Clubrush	*Bolboschoenus caldwellii*
Common Reed	*Phragmites australis*
Waterlily	*Nymphaea caerulea*
Unknown weed	

Appendix Table Four

Hydrological scenarios: fives cases each with hydroperiods and corresponding total wet area and water depths (WRL, unpub. data, 2018).

(a) Base Case: Run004_v6f

Hydro-period (% Time Wet)	Total Area (m^2)	Percent Total Area (%)	Max. Depth (m)	Weighted Avg. Min Depth (m)	Weighted Avg. Max Depth (m)	Weighted Avg. Mean Depth (m)
80-100	479,086	1.1	1.55*	0.21	0.31	0.27
60-80	9,201	<0.1	0.18	0.00	0.12	0.04
40-60	32,514	0.1	0.15	0.00	0.10	0.03
20-40	354,577	0.8	0.25	0.00	0.12	0.03
0-20	41,606,106	97.9	0.13	0.00	0.00	0.00

*Note that <10% of the total cells in this category have a value >0.65 m.

(b) Full Restoration Case: Run004_v6g-2, Harrisons Weir Existing

Hydro-period (% Time Wet)	Total Area (m^2)	Percent Total Area (%)	Max. Depth (m)	Weighted Avg.Min Depth (m)	Weighted Avg. Max Depth (m)	Weighted Avg. Mean Depth (m)
80-100	9,241,454	21.8	1.97*	0.10	0.23	0.16
60-80	346,255	0.8	0.51	0.00	0.13	0.06
40-60	1,639,823	3.9	0.44	0.00	0.14	0.04
20-40	393,336	0.9	0.39	0.00	0.11	0.03
0-20	30,860,617	72.6	0.38	0.00	0.00	0.00

*Note that <10% of the total cells in this category have a value >0.33 m.

(c) Option E – Site Open, Sportsmans Weir Existing Conditions (with Leakage)

Hydro-period (% Time Wet)	Total Area (m^2)	Percent Total Area (%)	Max. Depth (m)	Weighted Avg. Min Depth (m)	Weighted Avg. Max Depth (m)	Weighted Avg. Mean Depth (m)
80-100	1,098,862	2.59	1.77*	0.15	0.25	0.20
60-80	17,895	0.04	0.20	0.00	0.11	0.04
40-60	94,793	0.22	0.22	0.00	0.12	0.04
20-40	364,264	0.86	0.25	0.00	0.12	0.03
0-20	40,905,671	96.29	0.25	0.00	0.00	0.00

*Note that <10% of the total cells in this category have a value>0.45 m.

(d) Option F – Site Closed, Sportsmans Weir Open, Modified Reedy Creek Gates Open

Hydro-period (% Time Wet)	Total Area (m^2)	Percent Total Area (%)	Max. Depth (m)	Weighted Avg. Min Depth (m)	Weighted Avg. Max Depth (m)	Weighted Avg. Mean Depth (m)
80-100	1,721,465	4.05	1.67*	0.11	0.24	0.19
60-80	128,083	0.30	0.44	0.00	0.14	0.06
40-60	769,562	1.81	0.25	0.00	0.13	0.05
20-40	405,065	0.95	0.32	0.00	0.12	0.03
0-20	39,457,309	92.88	0.31	0.00	0.00	0.00

*Note that <10% of the total cells in this category have a value>0.4 m.

(e) Option G – Full Restoration, Harrisons Weir Removed

Hydro-period (% Time Wet)	Total Area (m^2)	Percent Total Area (%)	Max. Depth (m)	Weighted Avg. Min Depth (m)	Weighted Avg. Max Depth (m)	Weighted Avg. Mean Depth (m)
80-100	9,839,717	23.16	1.97*	0.09	0.23	0.16
60-80	380,251	0.90	0.52	0.00	0.13	0.06
40-60	1,748,901	4.12	0.45	0.00	0.14	0.04
20-40	423,344	1.00	0.40	0.00	0.11	0.03
0-20	30,089,271	70.83	0.39	0.00	0.00	0.00

*Note that <2% of the total cells in this category have a value>0.5 m.

Appendix Table Five

Species distributions according to relative elevation and water depth zones (from Johns, 2008, Appendix 2).

Species (n = total quadrats)	Depth (cm) min – max	Above edge	Edge	Depth zones Damp	Shallow	Deeper
Aegiceras corniculatum (n=1)	10			*		
Apium prostratum subsp. *Prostratum* (n=2)	10 — 20			*		*
Aster subulatus (n=2)	0 – 10	*			*	
Avicennia marina (n=2)	10 – 15				*	
Axonopus fissifolius (n=2)	0	*				
Bacopa monnieri (n=12)	0 – 20		*	*	*	*
Bolboschoenus caldwellii (n=9)	0 – 25			*	*	*
Casuarina glauca (n=9)	0 – 10			*	*	
Centella asiatica (n=5)	0	*	*			
Centipeda sp. (n=2)	0	*	*			
Cirsium vulgare (n=3)	0	*				
Cotula coronipifolia (n=13)	0 – 10	*	*	*	*	
Cynodon dactylon (n=21)	0	*	*	*		
Cyperus polystachyos (n=5)	0	*		*		
Diplachne fusca (n=1)	0		*			
Eleocharis equisetina (n=32)	0 – 75		*	*	*	*
Eleocharis minuta (n=5)	5 – 20		*		*	*
Epaltes australis (n=1)	0			*		
Fimbristylis ferruginea (n=3)	0 – 15		*		*	
Hydrocotyle sp. (n=1)	0	*				
Hypochaeris microcephala (n=1)	0	*				
Isolepis inundata (n=1)	0			*		
Isotoma sp. (n=1)	0	*				
Juncus krausii (n=3)	0	*		*		
Juncus sp. (n=2)	0 – 5		*		*	
Juncus usitatus (n=5)	0	*		*		
Lachnagrostis filiformis (n=8)	0	*	*	*		
Ludwigia peploides ssp. *montevidensis* (n=1)	0		*			
Melaleuca quinquenervia (n=6)	0	*		*		
Nymphaea caerulea (n=4)	25 – 120					*
Nymphoides indica (n=1)	0			*		
Ottelia ovalifolia (n=1)	50					*
Paspalum dilatatum (n=3)	0	*				
Paspalum distichum (n=27)	0 – 20	*	*	*	*	*
Paspalum vaginatum (n=3)	0-5			*	*	

Species (n = total quadrats)	**Depth (cm) min – max**	**Above edge**	**Edge**	**Depth zones Damp**	**Shallow**	**Deeper**
Pennisetum clandestinum (n=3)	0	*				
Persicaria hydropiper (n=1)	0		*			
Persicaria orientalis (n=1)	0			*		
Persicaria sp. (n=1)	0	*				
Philydrum lanuginosum (n=1)	0			*		
Phragmites australis (n=10)	0 – 25			*	*	*
Potamogeton octandrus (n=1)	50					*
Potamogeton tricarinatus (n=1)	0			*		
Ruppia sp. (n=1)	75					*
Salvinia molesta (n=1)	70					*
Sarcocornia quinqueflora (n=2)	0		*	*		
Schoenoplectus litoralis (n=5)	5 – 75				*	*
Senecio madagascariensis (n=5)	0	*				
Sisyrinchium sp. A (n=1)	0	*				
Sporobolus virginicus (n=7)	0 – 15		*	*	*	*
Trifolium repens (n=1)	0	*				
Triglochin procerum (n=1)	0		*			
Triglochin sp. (n=1)	0		*			
Triglochin striatum (n=1)	0		*			
Utricularia sp. (n=1)	70					*
Viola hederacea (n=1)	0			*		
Various (13 spp.) unidentified plants incl. grasses	Mostly 0 (≤10)	~	~	~	~	