Crookhaven River floodgate tidal flushing assessment

By D S Rayner

WRL TR 2020/19, May 2021

UNSW Water Research Laboratory

UNSW Sydney

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Project details

Report title	Crookhaven River Floodgate Tidal Flushing Assessment
Authors(s)	D S Rayner
Report no.	2020/19
Report status	Final
Date of issue	May 2021
WRL project no.	2019077
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Client reference	PO4500024244

Document status

Version	Reviewed by	Approved by	Date issued
Draft	G P Smith	G P Smith	15 May 2020
Draft v2	G P Smith	G P Smith	20 May 2020
Draft v3	G P Smith	G P Smith	22 May 2020
Draft v4	G P Smith	G P Smith	29 May 2020
Final Draft	G P Smith	G P Smith	16 March 2021
Final	G P Smith	G P Smith	03 May 2021

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Executive summary

The aim of this study is to undertake a tidal flushing assessment of the upper Crookhaven River. Controlled tidal flushing of the upper Crookhaven River upstream of Culburra Road is proposed by modifying the existing floodgate structure to incorporate a controlled auto-tidal gate. The floodgate structure is owned and managed by Shoalhaven City Council (Asset ID: P10G1). An example of an auto-tidal gate (buoyancy controlled) is shown in Figure ES.1. A similar assessment was completed by NSW DPI Fisheries in 2009, however unanimous agreement from all upstream landholders could not be achieved and the proposed installation of a buoyancy controlled auto-tidal gate did not proceed. Feedback from landholders provided in 2009 has been incorporated in this latest assessment.

Auto-tidal floodgates operate by allowing a controlled volume of tidal water to flow upstream of the floodgate structure until a set water level cut-off is reached; whereby the rising tide actuates the float trigger and closes the gate. When the downstream water level is below the tidal cut-off level, the float lowers and the gate is opened, allowing for tidal flushing. The cut-off level for closing the gate can be easily adjusted and managed to provide the required tidal flushing and ensure no impacts to upstream floodplain land.

When considering introduction of controlled tidal flushing to floodgated waterways, it is critical that the following criteria are satisfied:

- No impact to private landholder productivity through inundation or saltwater ingress on productive private land;
- The drainage capacity and efficiency of the existing system is not impacted;
- All stakeholders and landholders are consulted regarding the proposed change to the tidal gates;
- The auto-tidal structure is able to be adjusted and adaptively managed in response to upstream conditions and landholder feedback;
- Risk mitigation measures have been identified and are able to be implemented as required; and
- All environmental impacts have been adequately assessed.

As part of this study, an investigation of controlled tidal flushing at the Culburra Road floodgates (Council asset ID: P10G1) in the upper Crookhaven River was completed including:

- an assessment of flushing dynamics;
- auto-tidal gate design; and
- assessment of potential impacts/risks.

Critical information such as tidal water levels, floodgate geometry, floodplain ground level survey (topography), land ownership and waterway connectivity were incorporated into the tidal flushing assessment. Multiple auto-tidal floodgate configurations were assessed.

Key findings from the tidal flushing assessment include:

- Tidal flushing has benefits for water quality and fish passage in upstream waterways;
- A maximum upstream tidal level below 0.0 m AHD is recommended to maintain tidal waters within the existing waterway;
- Tidal flushing at elevations above 0.0 to + 0.1 m AHD may result in connectivity to private floodplain areas, and significant on-ground works (e.g. levees) may be required to limit undesired inundation of landholdings;
- Risk to productive private floodplain land is limited at tidal flushing below 0.0 m AHD, with tidal flushing to this lower elevation limit further reducing risk;
- Monitoring and an adaptive management approach should be utilised when considering the tidal flushing proposal;
- Drainage capacity and efficiency of the existing system will be maintained or improved (i.e. reduced aquatic freshwater weeds);
- Drainage efficiency via the floodgate structure could be improved via installation of lighter floodgate flaps (e.g. aluminium floodgates as opposed to the existing steel gates);
- Optimal tidal flushing is achieved with two (2) auto-tidal gates, however one (1) auto-tidal gate also provides benefits to water quality and fish passage;
- Auto-tidal gate dimensions of 0.7 m (wide) x 0.9 m (high) with an invert of approximately - 0.35 m AHD are suitable;
- Existing culverts beneath Springbank Road may require altered management, including the installation of one-way floodgates to limit tidal flows upstream of Springbank Road;
- A trial flushing period with monitoring is recommended, with adjustment of the tidal cut off level as required based on monitoring (of water quality and water levels) and landholder feedback;
- Any auto-tidal gate(s) should be adaptively managed by adjusting the tidal flushing regime in response to upstream water levels and upstream landholder feedback;
- Private drainage floodgate infrastructure would require refurbishment prior to implementing any tidal flushing proposal;
- Ongoing adaptive management of the system should be informed by monitoring of water levels and salinity in the lower and upper Crookhaven River waterways (i.e. upstream and downstream of the Culburra Road floodgates) and landholder feedback.

Figure ES.1: Example of a buoyancy controlled auto-tidal floodgate installed on a similar structure (Photo: S. Nichols/DPI)

Concerns raised by upstream floodplain landholders included:

1. A potential reduction in drainage due to an increase in tidal water in the upper Crookhaven Creek; which is unlikely given the capacity of the existing drainage infrastructure but could be mitigated by improving the drainage efficiency of the existing floodgates at Culburra Road via installation of lighter floodgate flaps (e.g. aluminium).

2. The risk of saline impacts to private land; which can be managed by adjustment/setting of the auto-tidal mechanism to have a low tidal cut off level (i.e. only allow tidal flushing to a low elevation) that would only provide tidal flushing and aquatic connectivity for a limited period of time per day (e.g. 1 hour per tidal cycle).

3. Adequate ongoing management and maintenance of the drainage infrastructure; which would require a commitment from Shoalhaven City Council to manage and maintain the infrastructure as required utilising an adaptive management approach.

Ongoing consultation with landholders, Council and project stakeholders is recommended regarding these issues.

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1 Introduction

The Shoalhaven River and Crookhaven River floodplains are low-lying agricultural floodplains with extensive man made drainage networks that discharge via one-way floodgates to the tidal estuary. Construction of the drainage infrastructure in the lower Shoalhaven River floodplain began in 1840 with Berry's Canal. The first drainage floodgates were installed in 1872 and were widely implemented during the early 20th century with the construction of 210 km of drainage channels. Drainage infrastructure was constructed to improve floodplain drainage for agricultural productivity and flood mitigation. The main flood mitigation infrastructure that discharges immediately to the estuary are flood mitigation assets owned and managed by Shoalhaven City Council (Council). An extensive network of secondary floodplain drainage channels is not managed by Council, but the responsibility of local landholders.

The drained section of the upper Crookhaven River, located upstream of Culburra Road, drains an extensive area of low-lying floodplain which is made up of private agricultural land holdings and large Nature Reserves managed by NSW National Parks and Wildlife Service (Figure 1-1). This area was historically a tidal floodplain, however the installation of a set of one-way floodgates at Culburra Road prohibits upstream tidal flows and limits backwater flooding from the lower Crookhaven River. The upper Crookhaven River waterway and flood mitigation infrastructure drains the Saltwater Swamp and Brundee Swamp Nature Reserves. The two sections of the upper Crookhaven River are connected via open culverts at Springbank Road with drainage of the Brundee Swamp area via floodgates at Mayfield Road (Asset ID: P7D1G1) and the lower Saltwater Swamp area via floodgates at Culburra Road (Asset ID: P10G1).

There are approximately 28 km of waterway and 300 hectares of wetland upstream of existing floodgate infrastructure. A review of the coastal waterways and fish barriers in the southern rivers region (Wollongong to the Victorian border) identified the upper Crookhaven River as the highest priority area in the southern region for improving water quality and aquatic habitat connectivity (DPI, 2007).

Following identification as a high priority site, the floodgates at Culburra Road (Asset ID: P10G1) were subsequently investigated for implementing tidal flushing via installation of an auto-tidal floodgate (DPI, 2009). Monitoring and design was completed, however unanimous agreement from all upstream landholders could not be achieved and the proposed installation of a buoyancy controlled auto-tidal gate did not proceed. Glamore and Rayner (2014) also identified tidal flushing as a potential remediation option for the upper Crookhaven River P10D1 drainage area.

When considering the introduction of controlled tidal flushing, it is important that all potentially affected stakeholders, including landholders, are consulted throughout the assessment, design and implementation phases of the project (Figure 1-2). Incorporation of stakeholder feedback into the technical assessment and design process ensures that potential risks and issues can be identified and mitigated, with monitoring and contingency strategies established at an early stage. Landholder feedback received during development of the 2009 management plan has been reviewed and incorporated into this report/assessment. Landholder consultation regarding this latest study was initiated in October 2019, with landholder feedback a key component of the tidal flushing assessment process.

The introduction of tidal flushing of the upper Crookhaven River is again being considered as funding via the Marine Estate Management Strategy (MEMS) has been made available. A priority action of the MEMS is to improve the overall health of coastal waterways, improve water quality, and increase waterway connectivity. Landholders indicated interest and support for the tidal flushing proposal during initial project discussions in October 2019.

There are numerous benefits associated with restoring controlled tidal flushing to floodgated coastal waterways, including:

- Reduction of aquatic freshwater weeds within the drain and improvement in drainage efficiency;
- Improved fish passage and aquatic connectivity;
- Reduction in acid sulfate soil impacts;
- Establishment of intertidal habitats; and
- Improvement in general water quality, including acidity (pH), dissolved oxygen (DO) and nutrients (N and P).

The aim of this study was to assess the modification of exiting floodgates (Asset ID P10G1) at Culburra Road on the Crookhaven River to establish controlled tidal flushing. Using existing data, a 1-D computer (numerical) model was developed to estimate the water level and salinity throughout the drainage network to develop and optimise the tidal flushing regime, optimise the design of an auto-tidal gate, determine possible impacts of the floodgate modifications, and assess the extent of on-ground works required (if any) to limit the extent of inundation to targeted areas.

This report is comprised of the following sections:

- Section 2 provides an overview of existing floodplain drainage;
- Section 3 details the site topography and existing water level and salinity data;

- Section 4 details the tidal flushing assessment completed to optimise auto-tidal gate design and operation;
- Section 5 outlines the proposed floodgate design, functional specification, operational considerations and contingency actions.

Additional information is provided in the following appendices:

- Appendix A provides detailed drawings of the existing floodgate infrastructure;
- Appendix B outlines land tenure (i.e. ownership) in the study area;
- Appendix C identifies coastal wetlands as mapped under the State Environmental Planning Policy (SEPP) (Coastal Management) 2018;
- Appendix D identifies tidal vegetation (mangroves, saltmarsh and seagrasses) near the study area;
- Appendix E provides detailed floodplain topography on a property scale.

Other considerations relevant to the study that should be noted :

- Site inspection postponed due to COVID-19. Note that a range of data has informed this assessment including:
    - previous tidal flushing proposal (DPI, 2009);
    - landholder feedback on previous tidal flushing proposal (DPI, 2009);
    - previous site inspections and measurements (DPI, 2009);
    - existing water level monitoring data (DPI, 2009);
    - Council asset survey and aerial footage of waterway condition;
    - aerial LiDAR topographic survey data; and
    - NSW government spatial database (e.g. land tenure, lot boundaries etc.).
- A Review of Environmental Factors (REF) is currently in progress.

Funding for this project was provided by the Marine Estate Management Strategy (MEMS).

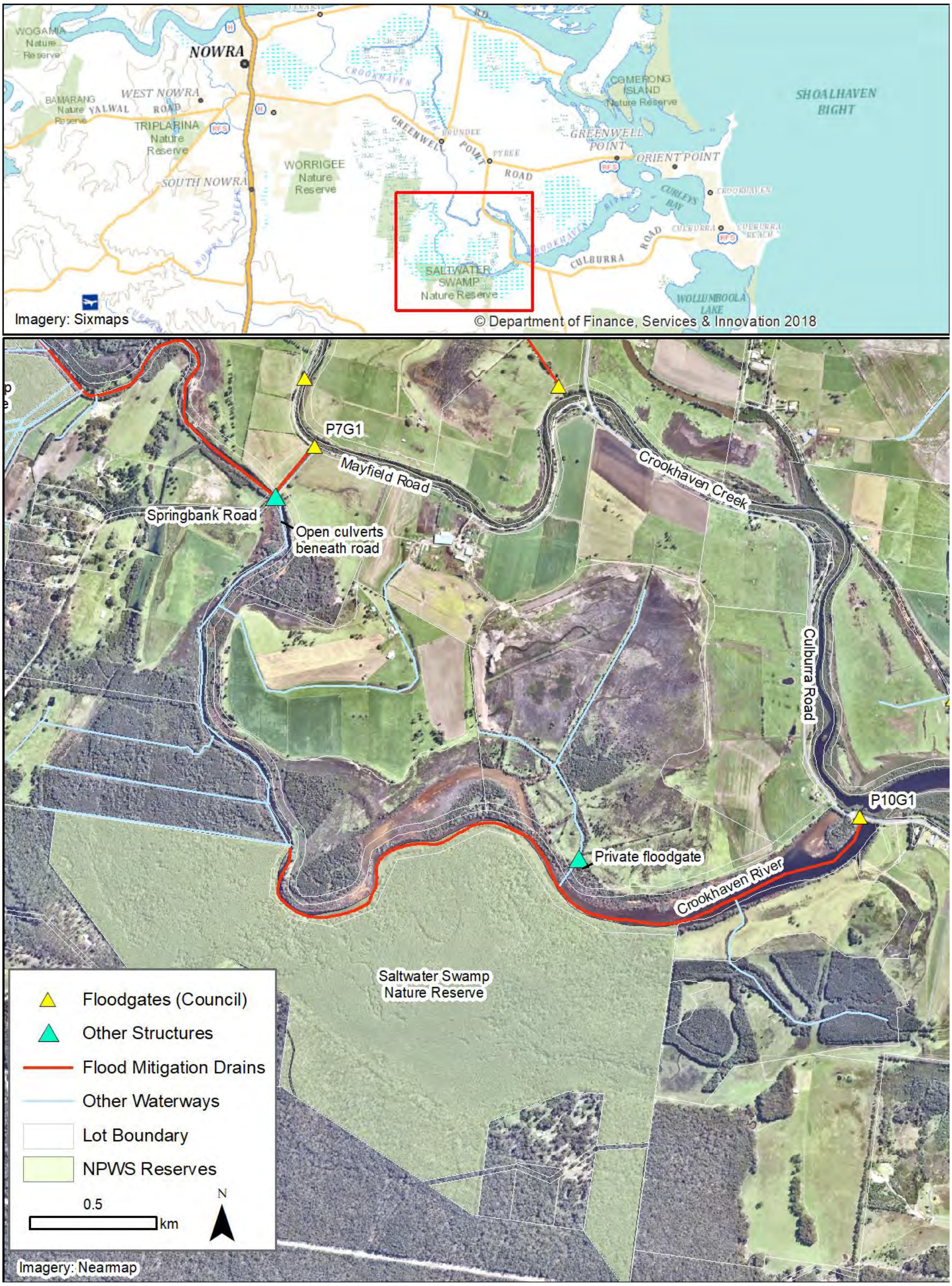

Figure 1-1: Overview of study location and Crookhaven River floodplain drainage

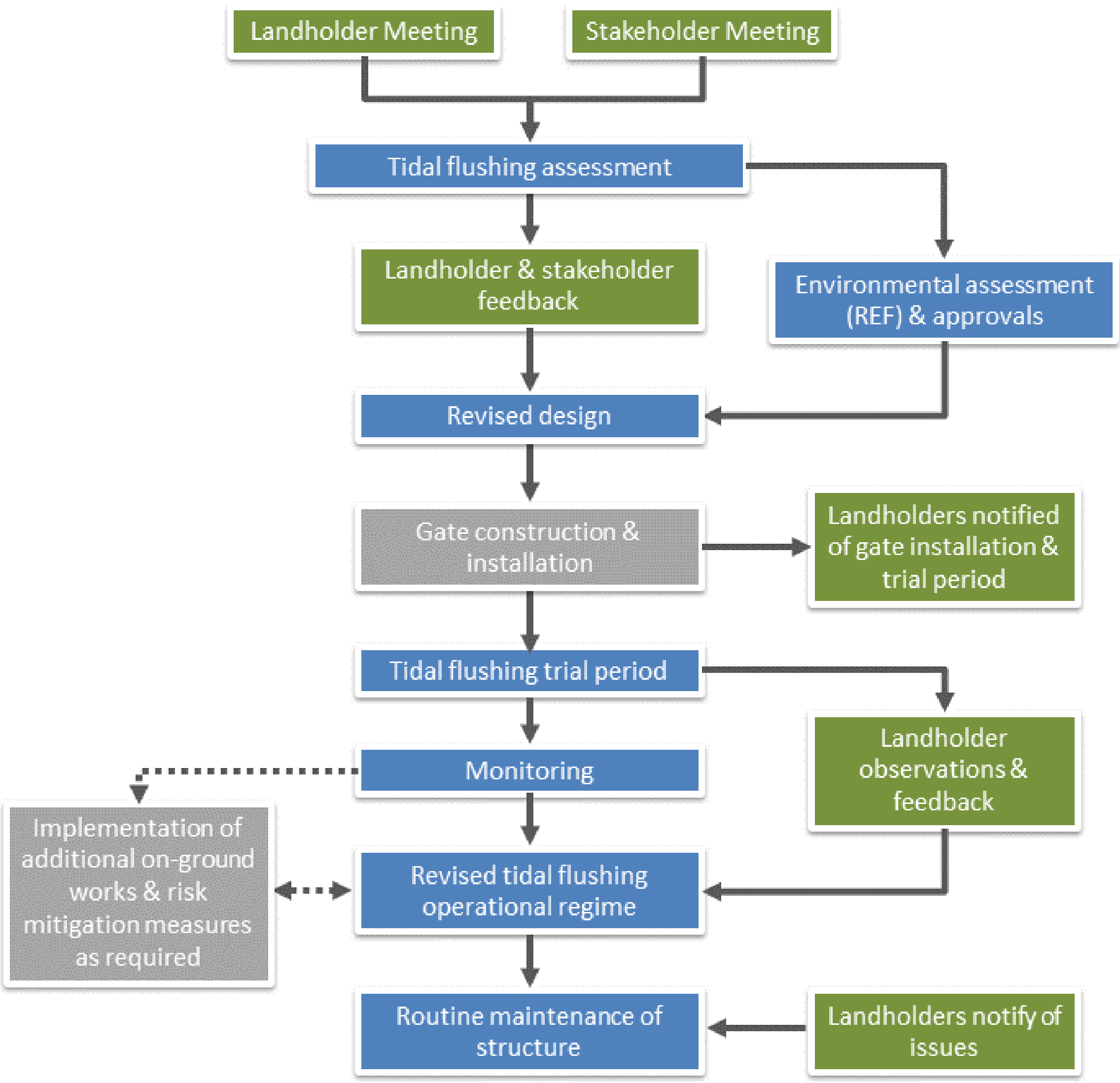

Figure 1-2: Recommended implementation pathway

2 Drainage infrastructure

The upper Crookhaven River floodplain is drained by primary flood mitigation drains and flood mitigation floodgate structures, with a network of secondary drainage providing drainage on a 'paddock' scale. An overview of the drainage network is provided in Figure 1-1.

The major end-of-system floodgate structures are identified as Council asset P10G1 at Culburra Road (Figure 2-1), and Council asset P7G1 at Mayfield Road (Figure 2-2). The upper P7D1 sub-catchment area provides drainage for the Brundee Swamp Nature Reserve and surrounding private floodplain land, and the lower P10D1 sub-catchment area provides drainage for Saltwater Swamp Nature Reserve and the surrounding private floodplain land. These two systems are connected via a set of four (4) open culverts beneath Springbank Road (Figure 2-3), which are owned by Council. A single privately owned floodgate culvert is located on a left-bank drain approximately 1.5 km upstream of the main P10G1 floodgates at Culburra Road (Figure 2-4).

Structures were inspected and surveyed during July 2020. Flood mitigation structures P10G1 and P7G1 were observed to be in good condition. The private landholder floodgate was observed to be in poor-to-average condition. No floodgates were observed on the culverts beneath Springbank Road, and the culverts do not protrude beyond the rock rubble headwall.

The details of identified drainage structures in the study area are provided in Table 2.1. Survey of structures was completed during site inspections on 7 - 8 July 2020.

Table 2.1: Drainage infrastructure

Structure	Type	Number of pipes/cells	Invert (m AHD)	Headwall Level (m AHD)	Dimensions (m)	Responsibility
P10G1	Floodgate	3	-0.5	2.23	1.7 (w) x 1.8 (h)	Council
P7G1	Floodgate	4	-0.95	1.50	2.3 (w) x 1.55 (h)	Council
Landholder	Floodgate	1	-0.75	1.00	1.2 (dia)	Landholder
Springbank Rd	Open Culvert	4	-0.8	1.10	0.9 (dia)	Council

Detailed dimensions of the P10G1 floodgates at Culburra Road are presented in Appendix A .

Figure 2-1: P10G1 Crookhaven River floodgates at Culburra Rd (Photo: S. Nichols/DPI)

Figure 2-2: P7G1 floodgates at Mayfield Rd (Photo: Shoalhaven City Council)

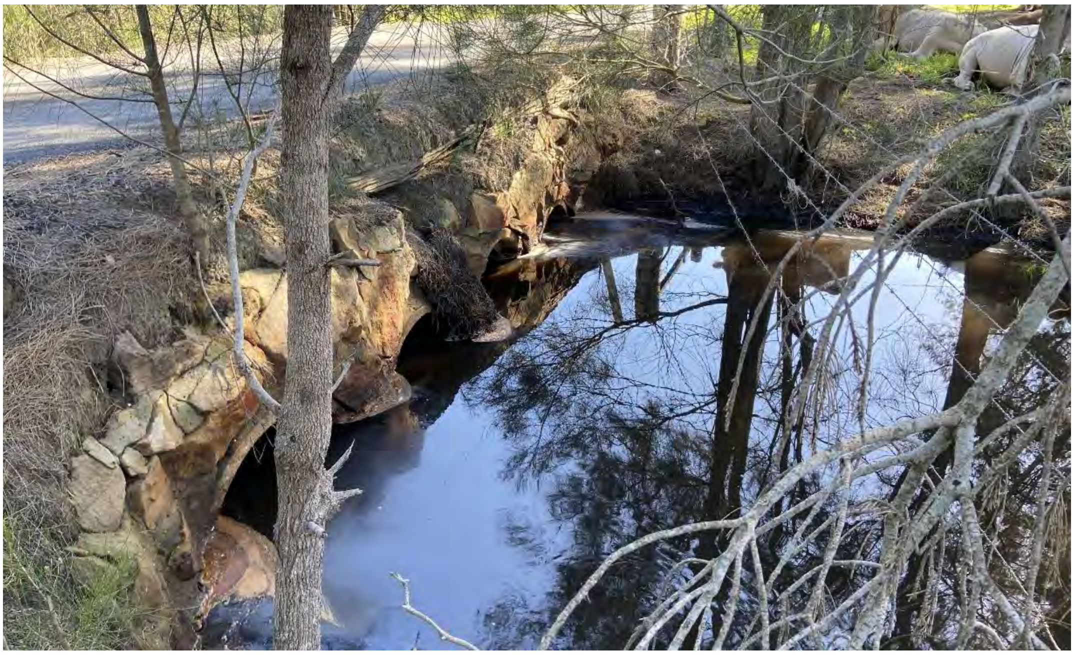

Figure 2-3: Culverts beneath Springbank Rd (Photo: Shoalhaven City Council)

Figure 2-4: Private structure on side drain (Photo: S. Nichols/DPI)

3 Water levels and topography

3.1 Floodplain topography

Topographic data of the Crookhaven River floodplain was obtained from the Elevation Information System (ELVIS). The aerial LiDAR dataset was captured in April 2011 and provides high resolution coverage of the bare earth elevation. Note that in areas of dense vegetation or open water, the LiDAR technology can measure the top of the vegetation or the surface of the water as the 'ground level' since the vegetation and water are impenetrable by the laser signal. Therefore particular care must be taken when interpreting LiDAR data in low-lying wetland environments where dense vegetation and standing open water areas are common.

Topographic data of the study area (Figure 3-1) shows significant areas of low-lying coastal backswamps at elevations below + 0.5 m Australian Height Datum (AHD) (where 0 m AHD is approximately equal to mean sea level). Mean high water springs tidal level at Greenwell Point is approximately + 0.5 m AHD (MHL, 2012). Note also that some floodplain areas measured are below mean sea level (i.e. below 0 m AHD).

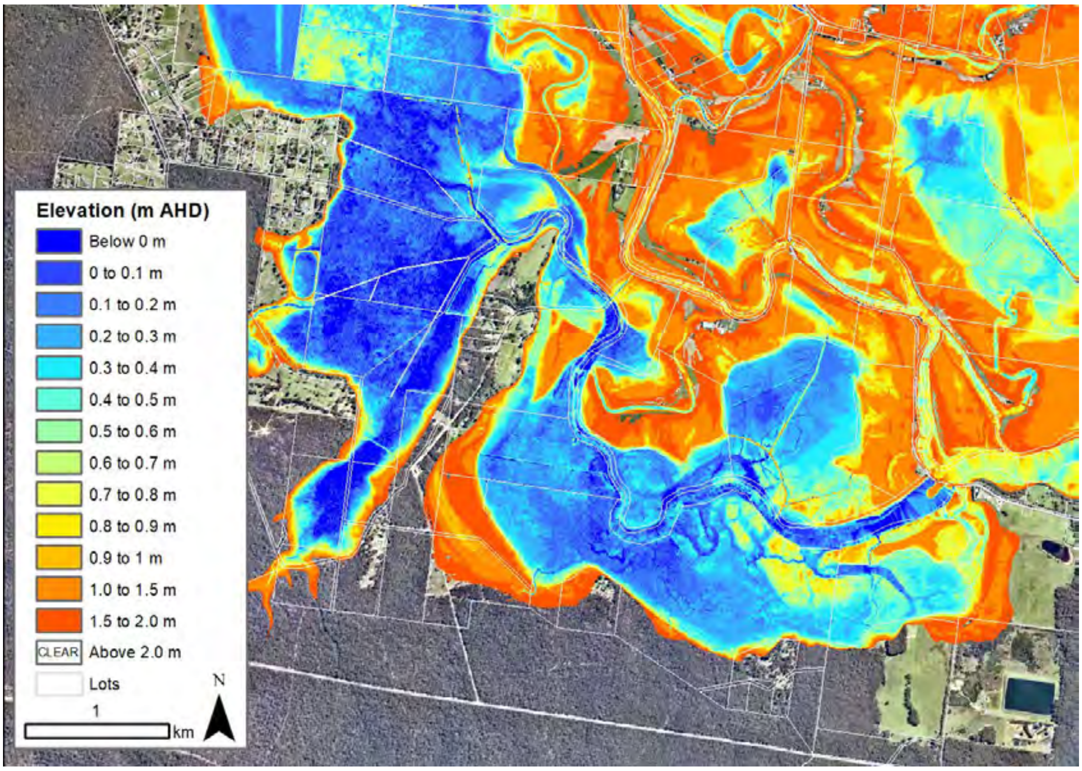

Figure 3-1: Elevation of Crookhaven River study area

Detailed mapping of floodplain elevations upstream of Culburra Road is presented in Appendix E on a property scale at a 10 cm vertical resolution.

3.2 Site inspection

Floodplain properties upstream of Culburra Road were inspected during the period 7th – 8th July 2020. Properties were inspected to confirm topography elevations and identify hydrological connectivity between the upper Crookhaven River and the floodplain. All private property was inspected with the permission of the landholder. Survey locations are shown in Figure 3-2.

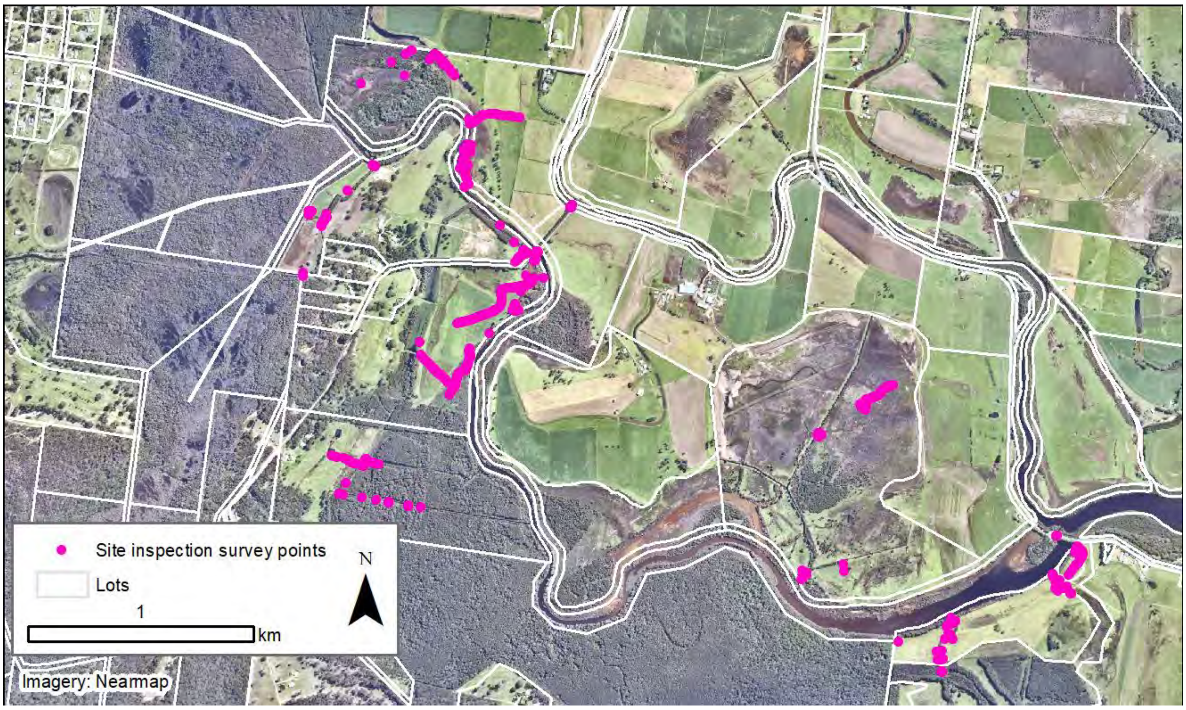

Figure 3-2: Site inspection survey locations

3.2.1 Ground elevations

The ground survey data was collected across the site where access and GPS signal permitted. Collected RTK GPS survey data was compared to the LiDAR data where the datapoints coincided to assess the accuracy of the LiDAR DEM across the site at different elevations (Figure 3-3). The LiDAR data was generally higher for all elevations, which was not unexpected for low-lying coastal floodplain environments, as it confirmed that dense ground cover (e.g. pasture grasses) influenced the remote sensing LiDAR survey data values.

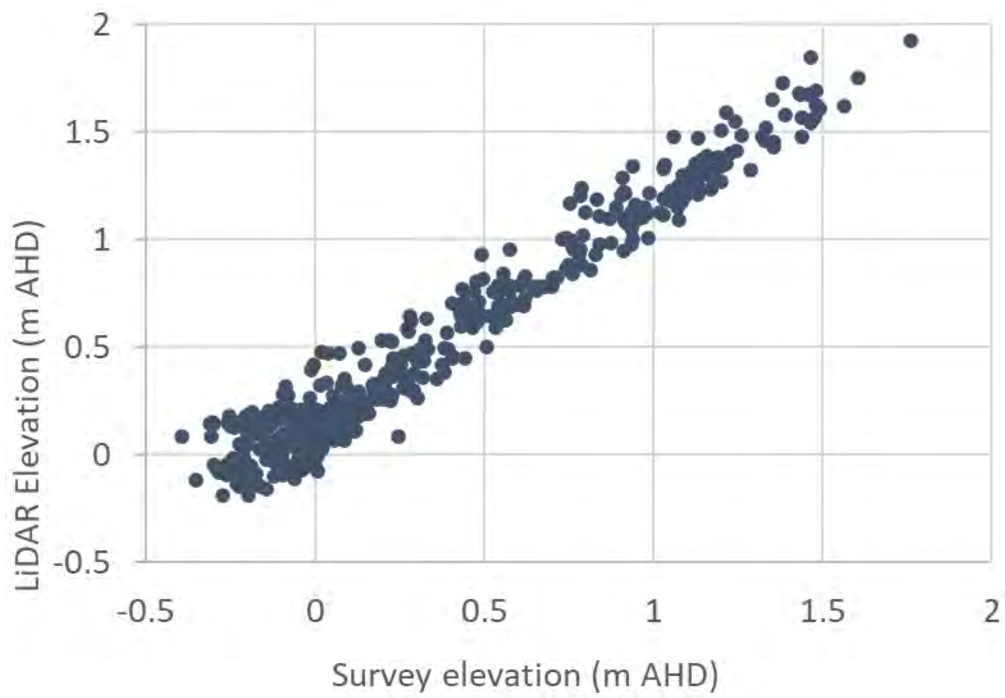

Figure 3-3: Comparison of surveyed points with LiDAR topography

Inspection of hydrological connectivity (e.g. channels, low points in levee banks etc.) between the upper Crookhaven River and the floodplain confirmed that connections which are visible in aerial imagery and the LiDAR topography data are present and provide a reasonable representation of actual connectivity. Low-lying areas and direct connectivity was observed on all inspected properties. There were differences noted in landholder utilisation of low-lying areas, with some landholders actively utilising all property areas for agricultural activities (i.e. grazing or cropping), and other landholders not actively farming directly connected low-lying areas. Note that evidence of elevated salinity (surface salts and salt tolerant vegetation) was observed on low-lying areas situated below + 0.2 m AHD. Potential suitable risk mitigation measures with regards to these connections are discussed further in Section 5.6.

Low-lying areas surveyed to be situated below 0.0 m AHD are shown in Figure 3-4. Floodplain locations at or below 0.0 m AHD were found situated in constructed channels and historical relic channels that were part of the upper Crookhaven River estuarine water ways, or connector feeder channels to historical backswamp areas.

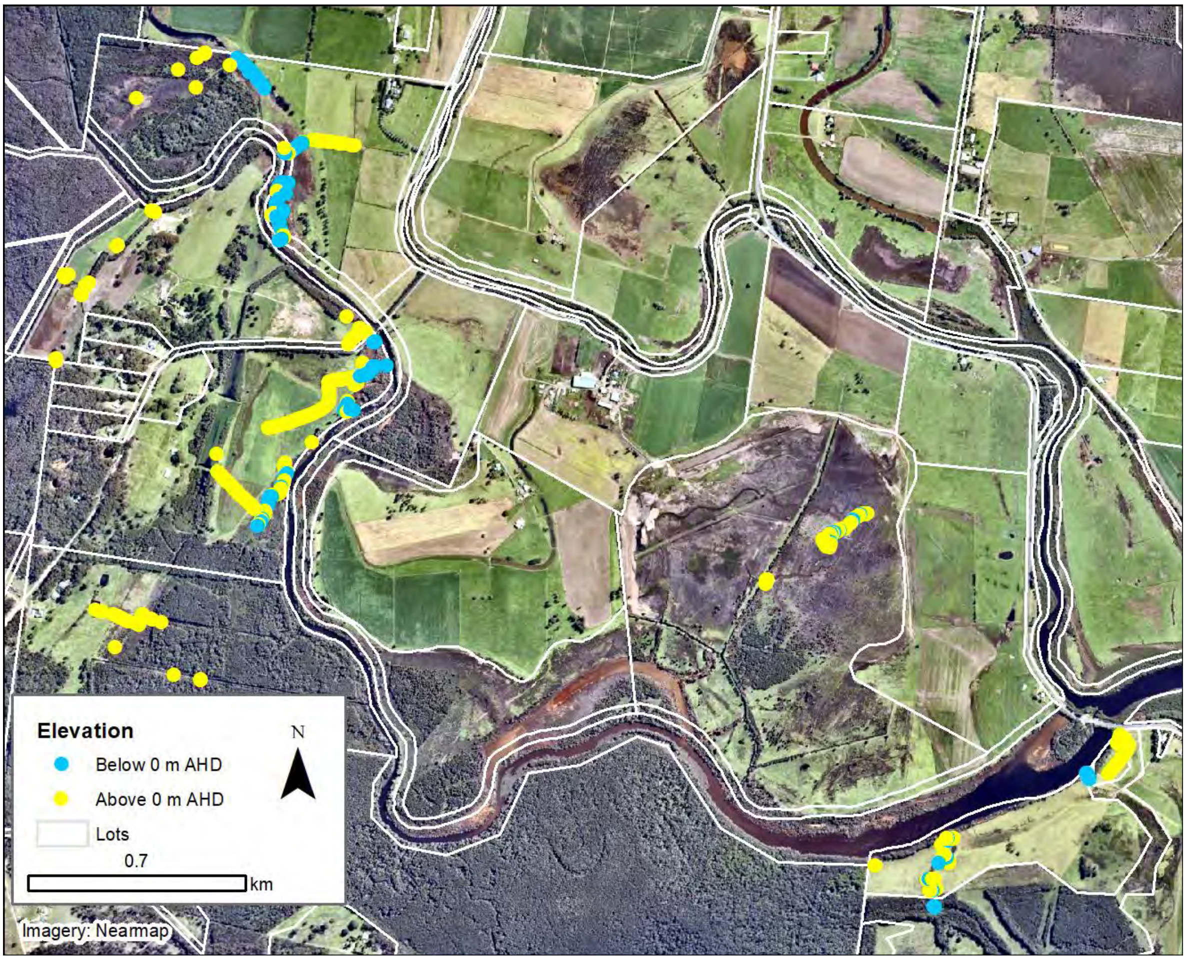

Figure 3-4: Survey points above and below 0 m AHD.

3.3 Water level and salinity data

Water level and salinity data was collected between 2008 and 2010 by DPI (2009) as a part of the previous tidal flushing proposal for the upper Crookhaven River. Monitoring was undertaken upstream and downstream of the P10G1 floodgates at Culburra Road (Figure 3-5).

Comparison of measured water levels at Culburra Road with those measured 7 km downstream at Greenwell Point (Figure 3-6) indicates that the high tide levels downstream of the main P10G1 floodgates are similar to those near the ocean entrance at Greenwell Point. The low tide levels however, are significantly attenuated. Low tide levels at Greenwell Point of - 0.65 m AHD during spring tides are attenuated to a level of - 0.3 m AHD at the P10G1 floodgates. Attenuation of tidal dynamics is likely due to the geometry of the lower Crookhaven River bathymetry.

Analysis of water levels upstream of the gates measured during 2008 shows that elevated water levels following rainfall events drain efficiently through the floodgates. Periods of elevated average water levels in the lower Crookhaven River do not appear to have a significant impact on average water levels upstream of the floodgates. The DPI (2009) dataset does indicate a change in measurement from November 2008 onwards. Comparison of water levels immediately upstream of the P10G1 floodgates with those measured 1.5 km upstream shows minimal differences in observed water levels, indicating efficient drainage of the system. Measured water levels are noted to deviate from the long-term trend after November 2008.

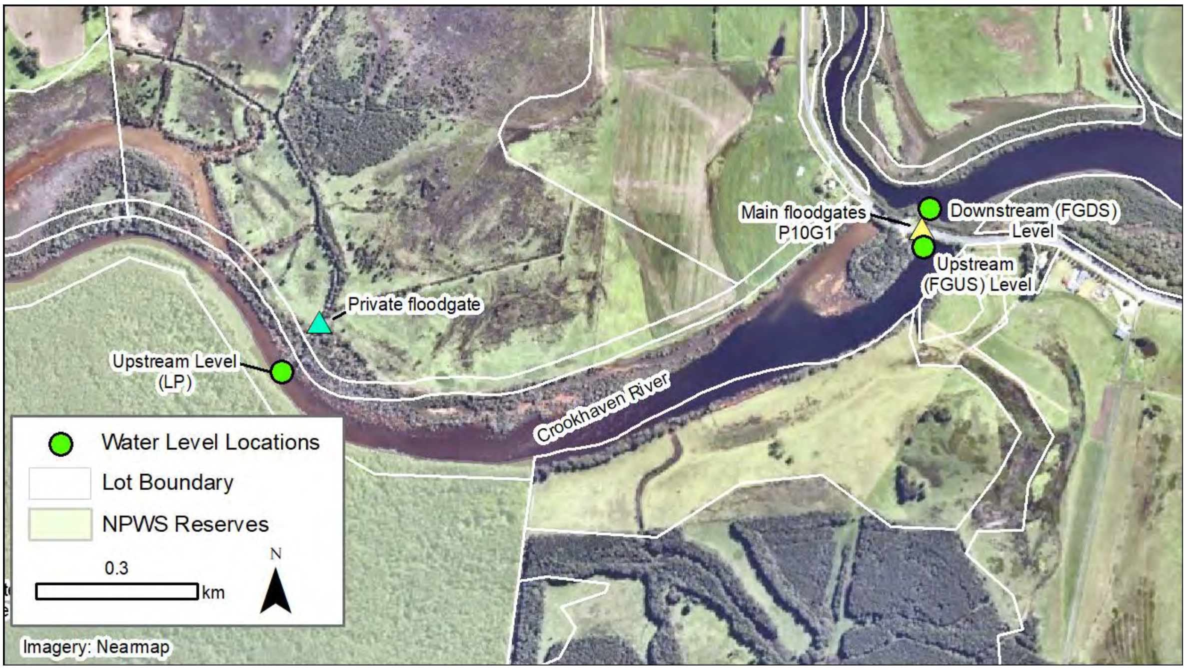

Figure 3-5: Water level monitoring locations during 2008 (DPI, 2009)

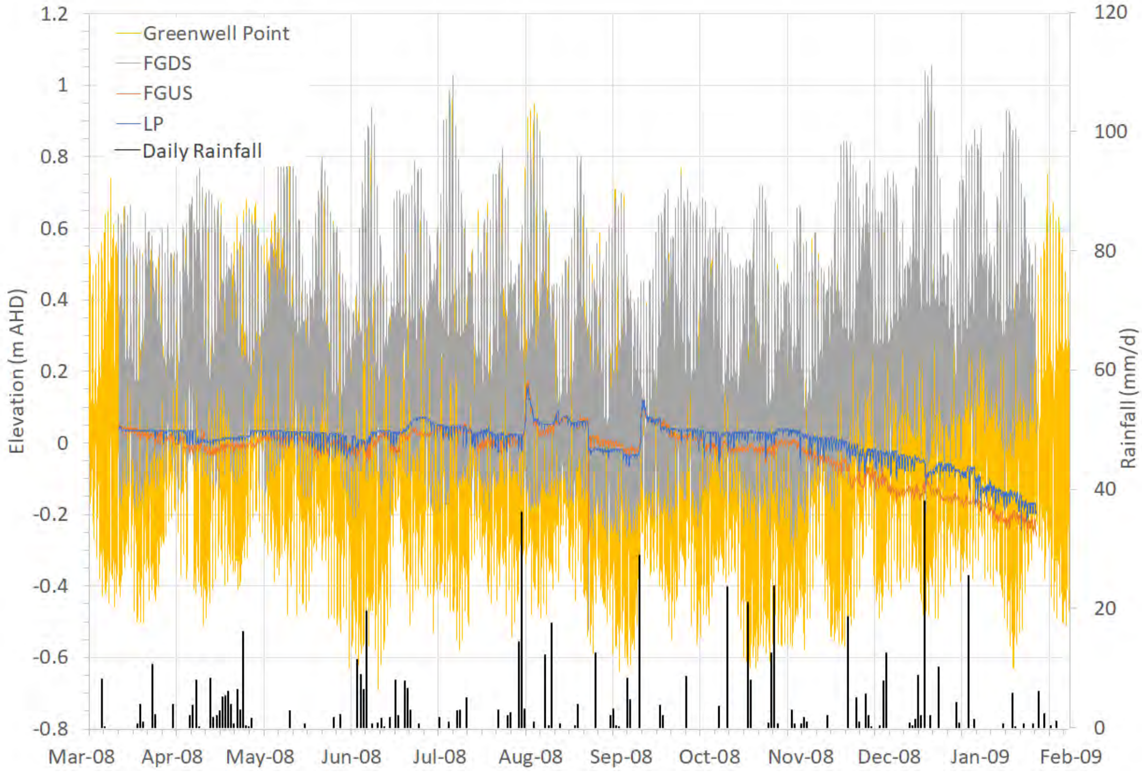

Figure 3-6: Water levels during 2008 (DPI, 2009)

DPI (2009) collected electric conductivity (EC) data upstream and downstream of the Culburra Road floodgates during 2010. Electrical conductivity is a proxy for salinity. Note that the EC of ocean water is approximately 55 mS/cm. Measured EC data indicates that the floodgate flaps were leaking during or prior to the 2010 monitoring period, with elevated upstream EC levels measured. The data indicates that the Crookhaven River experiences elevated salinity during dry to average rainfall periods. This is due to the relatively close proximity of the site to the ocean entrance.

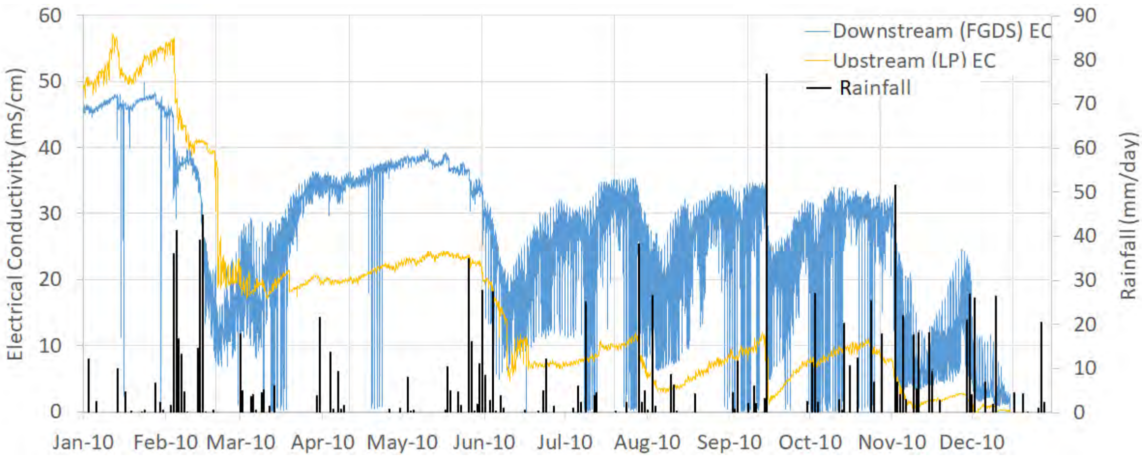

Figure 3-7: Electrical conductivity either side of P10G1 floodgates during 2010 (DPI, 2009)

4 Tidal flushing assessment

A numerical model was developed to assess the impacts of tidal flushing on Crookhaven River upstream of the existing floodgates at Culburra Road (Asset ID: P10G1). This model was based on existing datasets and allows the geometry of the system to be represented via channel cross-sections, off channel storage, and hydraulic control structures (e.g. culverts, auto-tidal floodgates etc). The results should be used to provide an indication of potential impacts and benefits.

4.1 Numerical model

The 1-D numerical modelling software used for this study was MIKE-11 (DHI, 2017). WRL has successfully used the MIKE suite of models to simulate multiple drainage networks on coastal floodplains, including: numerous sites in the Hunter River, Georges River, Macleay River, Clarence River and the Richmond River.

The Crookhaven River model extends from the Crookhaven River downstream of Culburra Road, through Springbank Road and into the Brundee Swamp area (Figure 4-1). This area was selected as the drainage areas of Crookhaven River (Asset ID: P10D1) and Brundee Swamp (Asset ID: P7D1) are connected via culverts beneath Springbank Road.

The model was constructed using the following elements:

Geometry: The main channel and hydraulic structures (i.e. culverts and floodgates) were represented in 1D, with low-lying areas directly connected to the Crookhaven River channel included via an elevation-volume relationship to ensure off channel storage areas are accounted for. All geometry and land elevation information was obtained from existing LiDAR aerial survey data (Figure 3-1).

Existing hydraulic structures: All structure data obtained from existing surveys/measurements (Table 2.1) from Shoalhaven City Council and DPI Fisheries, and confirmed during site inspections.

Boundary Conditions: Boundary conditions are the water levels that are applied at the downstream extent of the channel and represent the measured tidal levels. Water level and salinity data was obtained from the previous investigation undertaken by DPI Fisheries during 2008 to 2010 (DPI, 2009).

Channel roughness: Channel roughness influences the efficiency of water movement with higher roughness associated with channels that have flow restrictions such as debris and weeds. When the amount of flow restriction increases due to extensive weed growth, the efficiency decreases and, in-turn, water movements are restrained. The channel roughness, represented in the model by the Manning's 'n' coefficient, was estimated based on existing literature (Chow, 1959), experience at other similar systems (Glamore and Wasko, 2009; Glamore and Tucker, 2018), and aerial imagery of Crookhaven River obtained from Nearmap and Google Earth, as well as drone footage provided by Shoalhaven City Council (dated 26th February 2019). It was estimated that the Manning's 'n' could vary from 0.027 to 0.100.

Antecedent conditions: The model was simulated assuming a dry period with limited rainfall prior to, and during the simulation. These catchment and floodplain conditions were assumed to enable the model outputs to focus on and test the maximum effectiveness of opening the floodgates on tidal flushing, and enable the potential impacts on upstream water levels to be assessed without the influence of catchment inflows.

Salinity: Salinity was tested utilising a 'relative' salinity approach, whereby salinity upstream of the Culburra Road floodgates is represented as percentage of salinity in the main Crookhaven River. That is, a salinity of 100% is equal to the salinity at the boundary of the model in the main Crookhaven River. The model outputs for salinity upstream of the gates are therefore reported as a percentage relative to the main river salinity.

Monitoring in the Crookhaven River downstream of the Culburra Road floodgates during 2010 showed that salinity ranges from near oceanic levels during dry periods, to fresh during wet periods (Figure 3-7) with average salinity levels at approximately 50% of ocean levels. A model dispersion coefficient of D = 1 m^2/s was assumed based on knowledge of dispersion in similar NSW rivers.

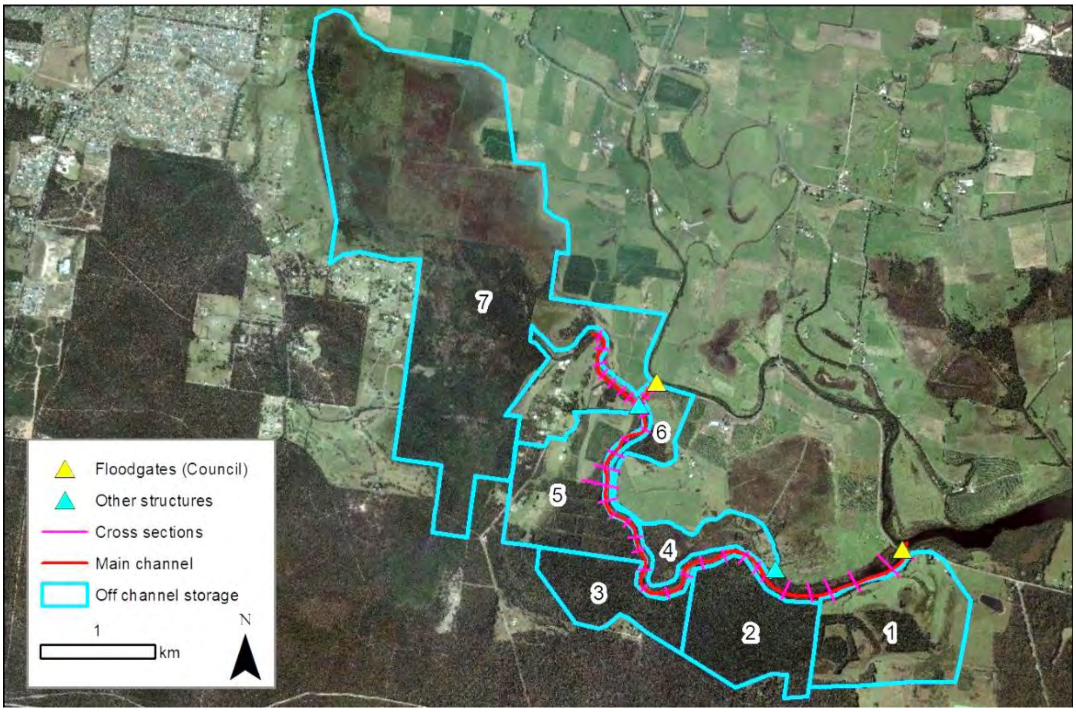

Figure 4-1: Model domain and extent

4.2 Auto-tidal floodgate designs

Tidal flushing of waterways upstream of one-way floodgates can be achieved by several common designs illustrated in Figure 4-2, including:

- Manually operated sluice gate;
- Hinging open floodgate flap;
- Buoyancy controlled auto-tidal gate; and
- Electronic SmartGates which open based on specified input controls (e.g. upstream water level, salinity level, rainfall forecast etc.).

With these different types of tidal flushing gates, a limited or controlled volume of water is allowed to flow upstream, whilst maintaining the drainage function of the existing floodgate structure. That is, the drainage capacity of the system is not altered.

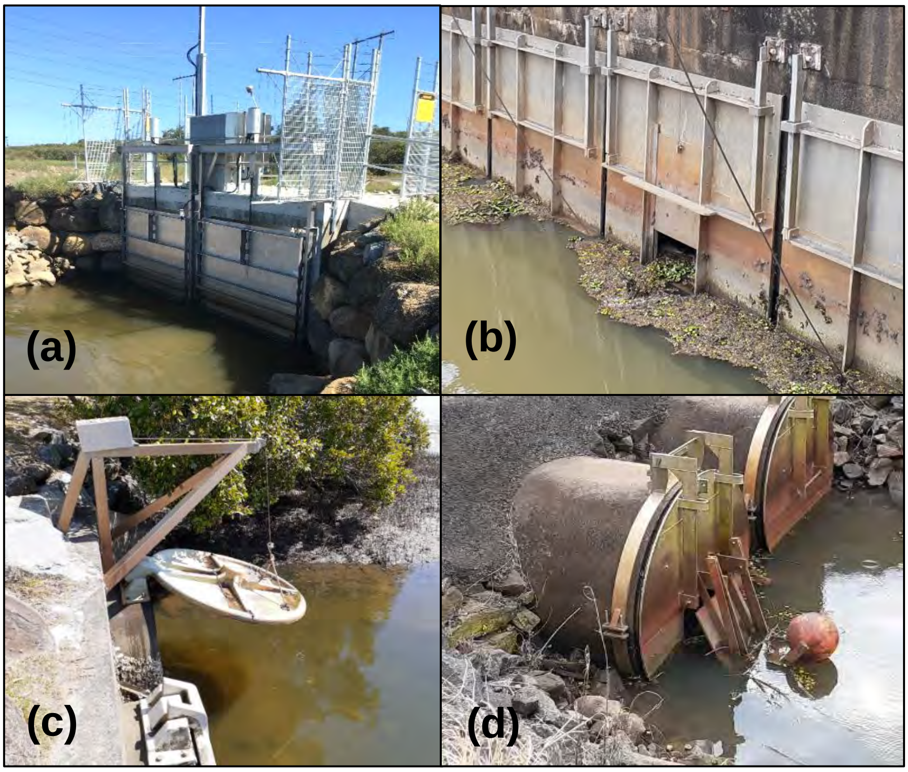

Figure 4-2: Example of floodgates with different modifications installed to control tidal flushing including (a) SmartGates, (b) manual sluice gate, (c) a floodgate hinged open and (d) a buoyancy controlled floodgate

For assessing the tidal flushing of Crookhaven River upstream of the Culburra Road floodgates (Asset ID: P10G1), it was assumed that a buoyancy controlled auto-tidal gate mechanism would be implemented (Figure 4-2d). Note that this style of buoyancy controlled auto-tidal structure has been installed on other Council floodgates within the Shoalhaven area including at: Shoalhaven Heads (P9D1G1), and P3D4G1 and Parkers Drain (P3D6G1) on Broughton Creek.

4.3 Configuration testing

A range of different auto-tidal floodgate configurations were tested to determine a preferable design and operational regime. Testing of different tidal cut off levels and auto-tidal gate dimensions enabled the flushing dynamics to be quantified and risks to upstream landholders identified, as well as informing monitoring and adaptive management requirements.

An auto-tidal gate orifice with dimensions of 0.7 m (wide) x 0.9 m (high) was utilised in the assessment, as this is a common size which could be easily fitted to the floodgates at Culburra

Road (Asset ID: P10G1). The dimensions of the Culburra Road floodgates is presented in Appendix A .

Based on the measured tidal levels in the Crookhaven River, and the dimensions of the existing floodgate structure, an invert elevation (i.e. bottom of the tidal opening) of - 0.35 m AHD was selected.

A maximum upstream water level limit of 0.0 m AHD was selected based on aerial LiDAR survey data (Figure 4-3) and site inspections (Section 3.2). Site inspections identified some areas directly adjacent to the upper Crookhaven River, and constructed and relic channels to be at, or below, approximately 0.0 m AHD. Therefore, an upstream tidal cut off limit of 0.0 m AHD should be considered a maximum upper limit before significant overbank tidal inundation occurs. Analysis of land elevations indicates that at elevations above + 0.3 m AHD, connectivity to the wider floodplain is likely to occur and areas of pasture potentially inundated (Figure 4-4). Note upstream average water levels measured by DPI (2009) were approximately +0.05 m AHD (Figure 3-5). Water levels in the upper Crookhaven River (upstream of the Culburra Road floodgates) during site inspections (July 2020) were measured to be -0.2 m AHD.

Utilising the model setup (see Section 4.1), configurations with one (1), two (2) and three (3) auto-tidal gates were tested. Water level results were extracted from the upstream locations shown in Figure 4-5 and are presented in Figure 4-6 and Figure 4-7. Salinity results are shown in Figure 4-8.

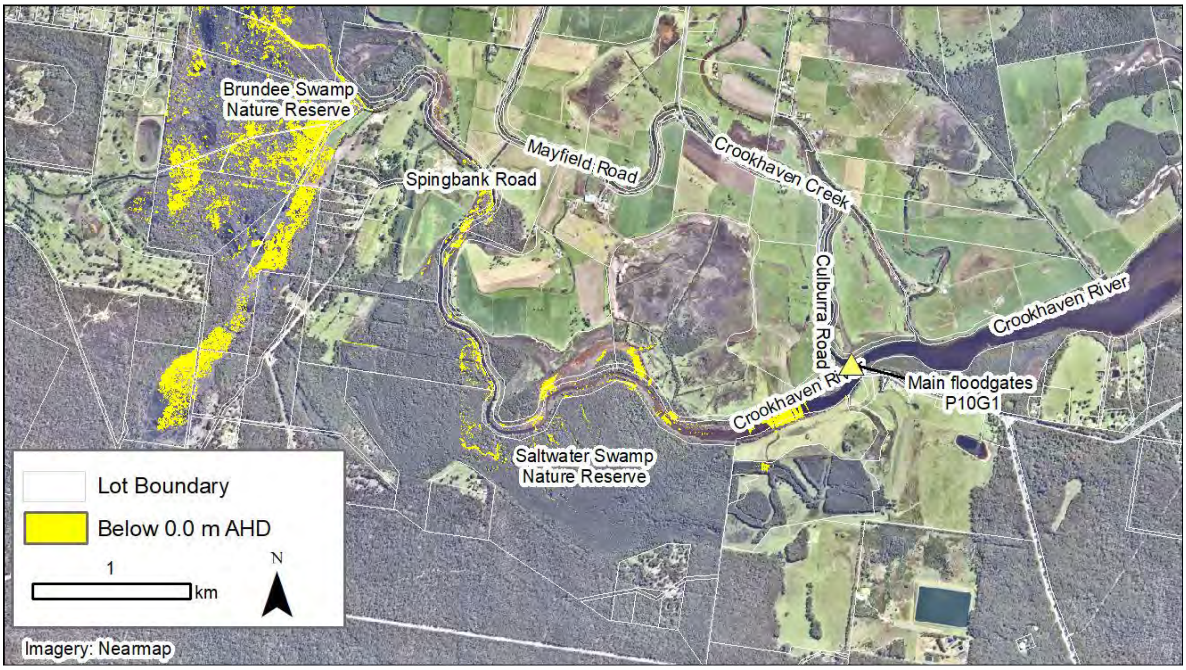

Figure 4-3: Areas below + 0.0 m AHD (based on aerial LiDAR survey data)

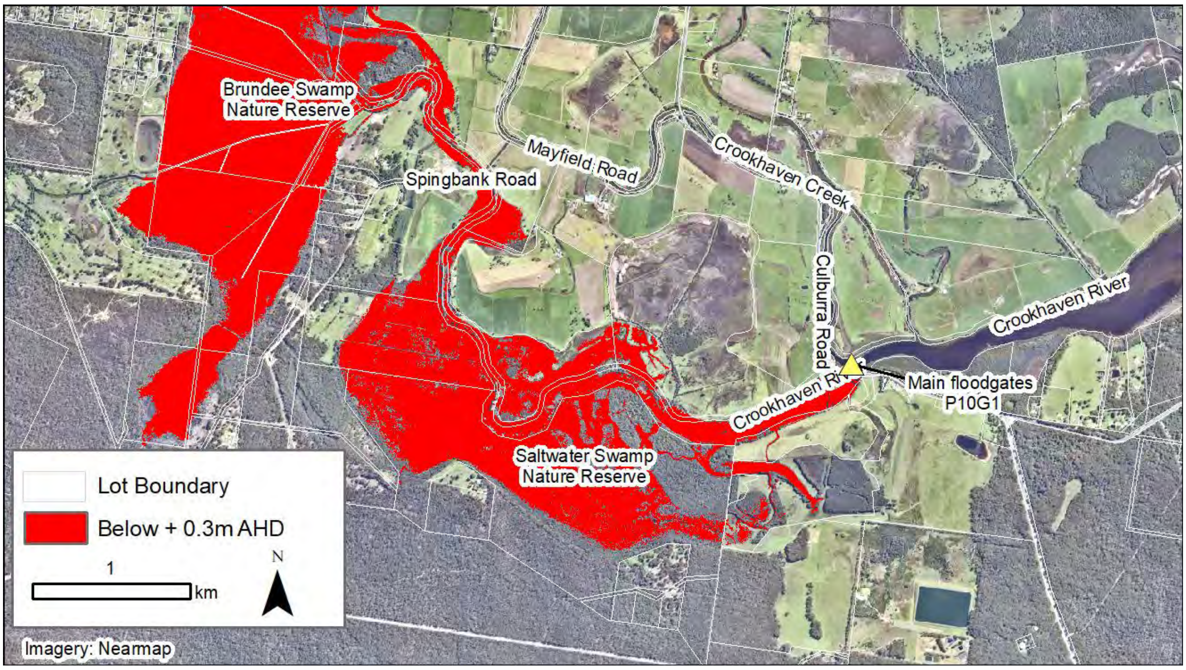

Figure 4-4: Areas below + 0.3 m AHD (based on aerial LiDAR survey data)

Water level results of different auto-tidal gate configurations indicated that tidal flushing increases as the number of installed auto-tidal gates increases, however the increase in flushing with additional gates is not a linear relationship. One (1) auto-tidal gate allows some tidal flushing, but the 0.0 m to +0.1 m AHD cut off level is not reached on a regular basis. That is, the gate does not allow sufficient upstream flow over a tidal cycle to flush the upstream waterway to an elevation of +0.1 m AHD. The addition of a second auto-tidal gate (2 gates total) provides increased flushing, with the 0.0 m to +0.1 m AHD cut off level reached on a regular basis. A third auto-tidal gate (3 gates total) further increases the rate of tidal flushing.

When assessing salinity (Figure 4-8), all floodgate configurations are estimated to provide significant flushing of the waterway with 100% flushing predicted to occur within 10 days. Note that this assumes dry conditions with zero freshwater inflows. In reality, catchment runoff and groundwater inflow as well as salinity flushing dynamics in the wider Crookhaven River estuary will all influence actual day-to-day salinity levels.

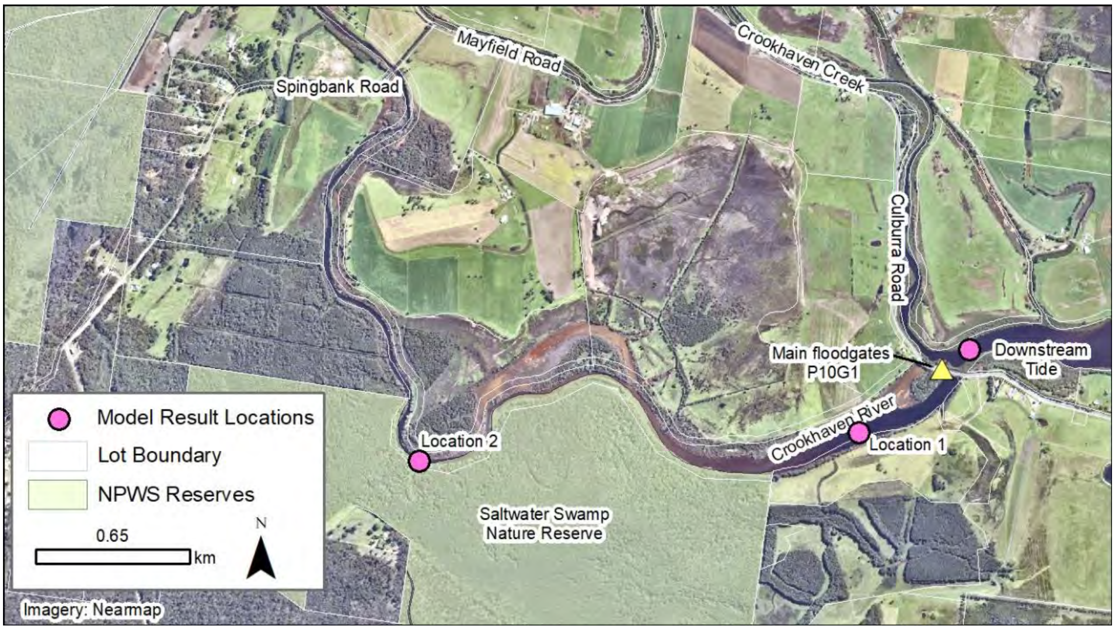

Figure 4-5: Model testing result locations

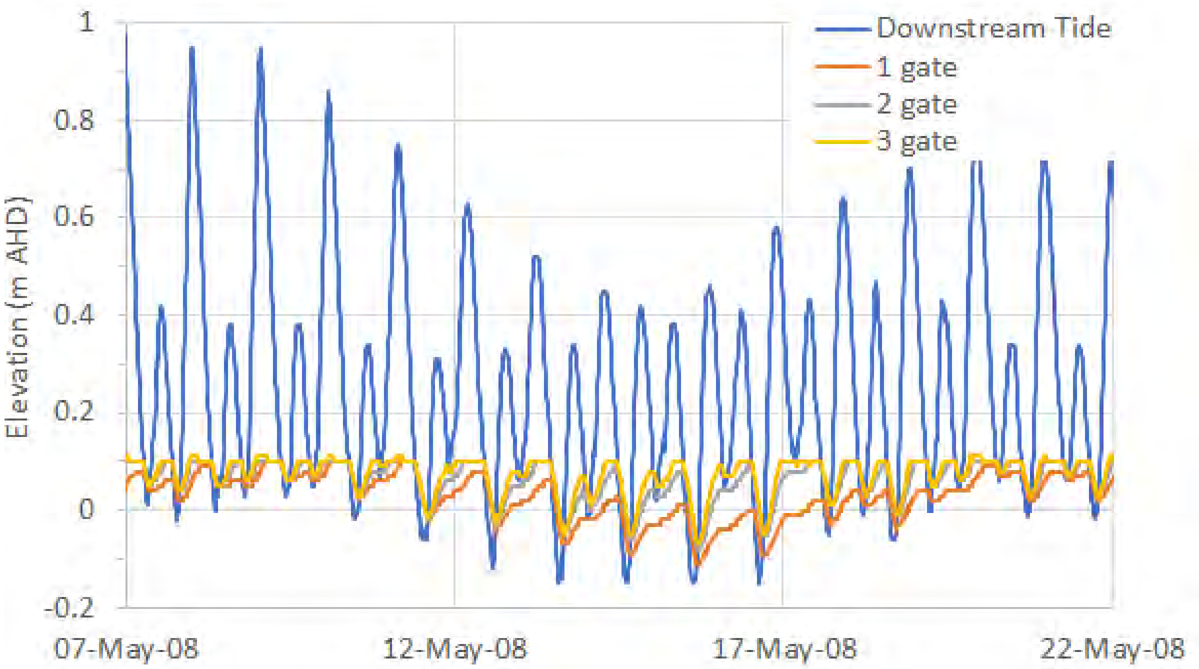

Figure 4-6: Water levels upstream (Location 1) of Culburra Road (P10G1) with different auto-tidal floodgate configurations with a +0.1 m AHD tidal cut-off level

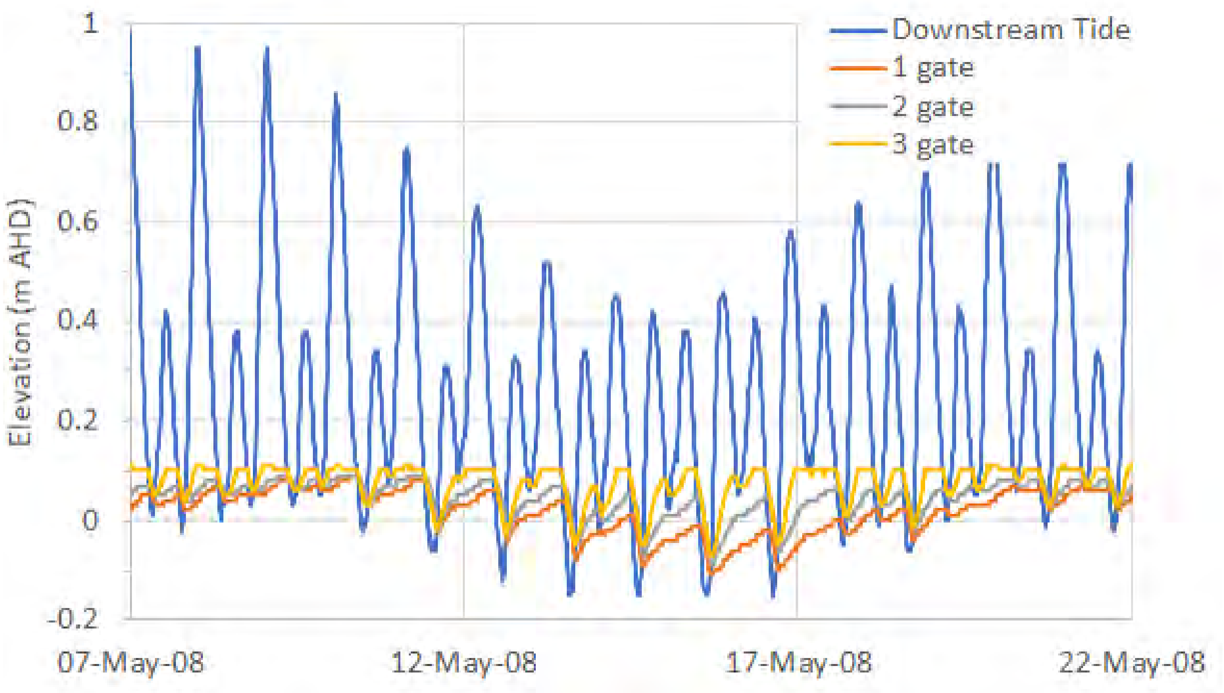

Figure 4-7: Water levels near Saltwater Swamp (Location 2) with different auto-tidal floodgate configurations with a +0.1 m AHD tidal cut-off level

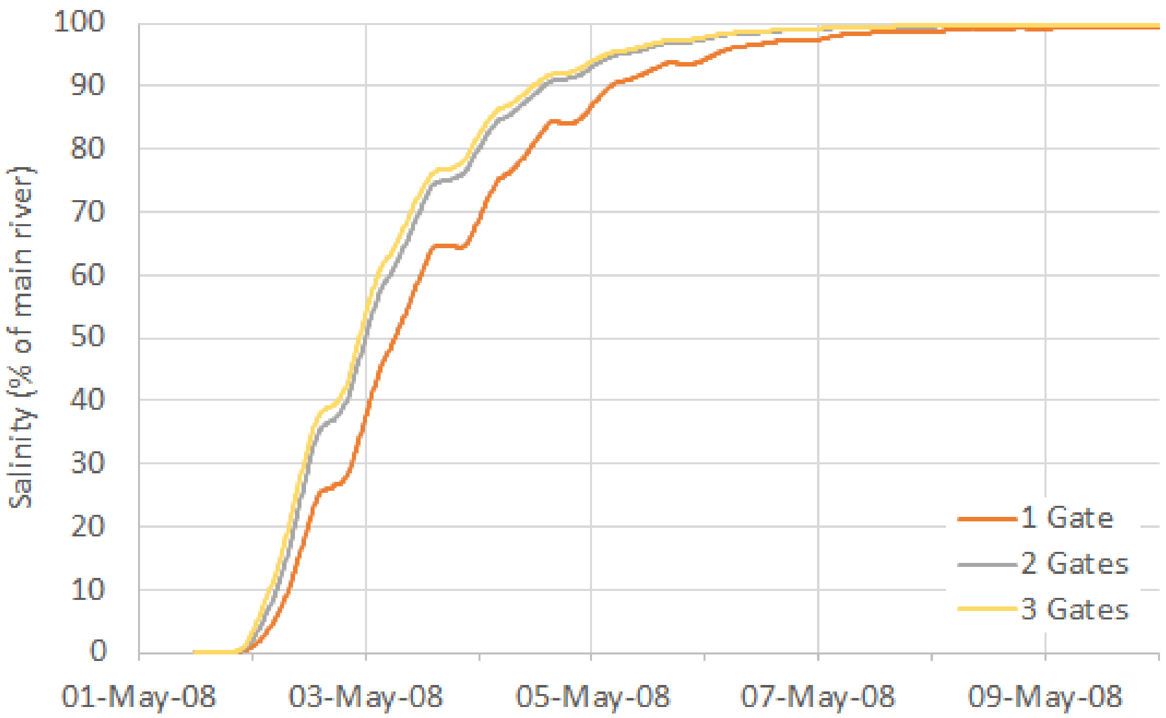

Figure 4-8: Salinity levels (compared to Crookhaven River salinity) near Saltwater Swamp (Location 2) with different auto-tidal floodgate configurations with a +0.1 m AHD tidal cut-off level

5 Tidal floodgate specification and operation

5.1 Design

A buoyancy controlled auto-tidal style gate is recommended to facilitate controlled tidal flushing of the Crookhaven River upstream of the Culburra Road floodgates (Asset ID: P10G1). A buoyancy controlled style of gate allows the opening/closing level to be set and only allow water to flow upstream until a pre-determined level is reached, whereby the force of the rising tide lifts the float to actuate the hinging mechanism which closes the orifice. Figure 5-1 to Figure 5-3 show drawings of the auto-tidal gate mechanism opening and closing. This style of auto-tidal gate is used extensively across coastal NSW floodplains. This style of buoyancy controlled auto-tidal floodgate is the same design that was proposed by DPI Fisheries in 2009.

One (1) modified gate can provide improved flushing and water quality outcomes, however two (2) modified gates were predicted to provide optimal tidal flushing.

Recommended dimensions:

Invert = - 0.35 m AHD; Orifice width = 0.70 m; Orifice height = 0.90 m

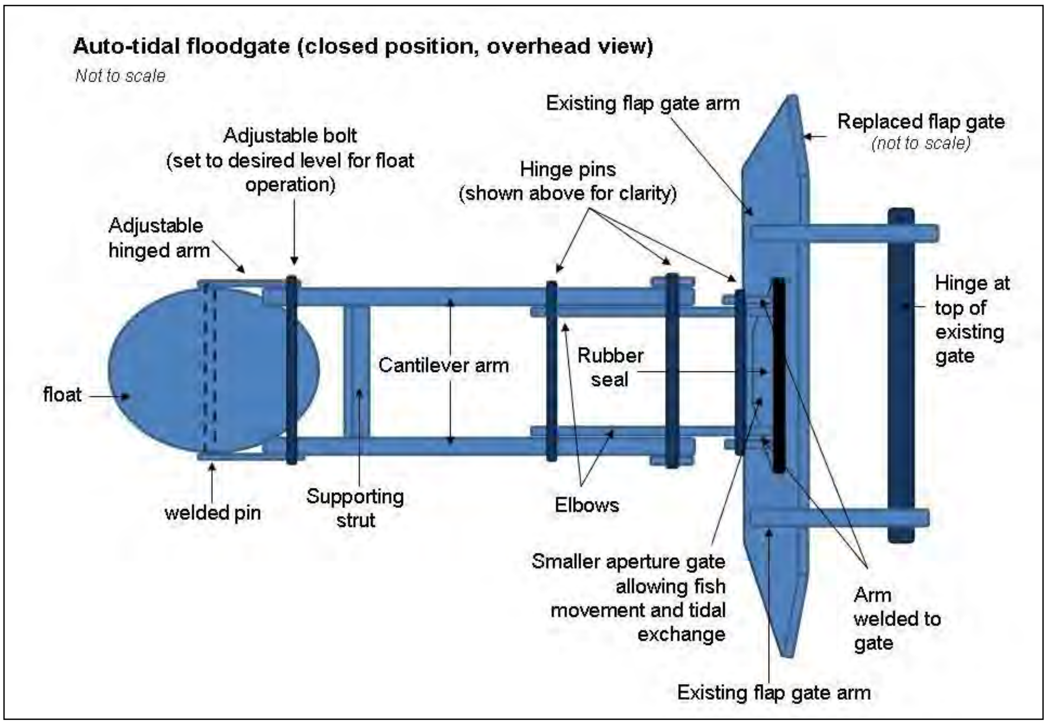

Figure 5-1: Auto-tidal floodgate mechanism in the open position on decreasing and low tide (DPI, 2009)

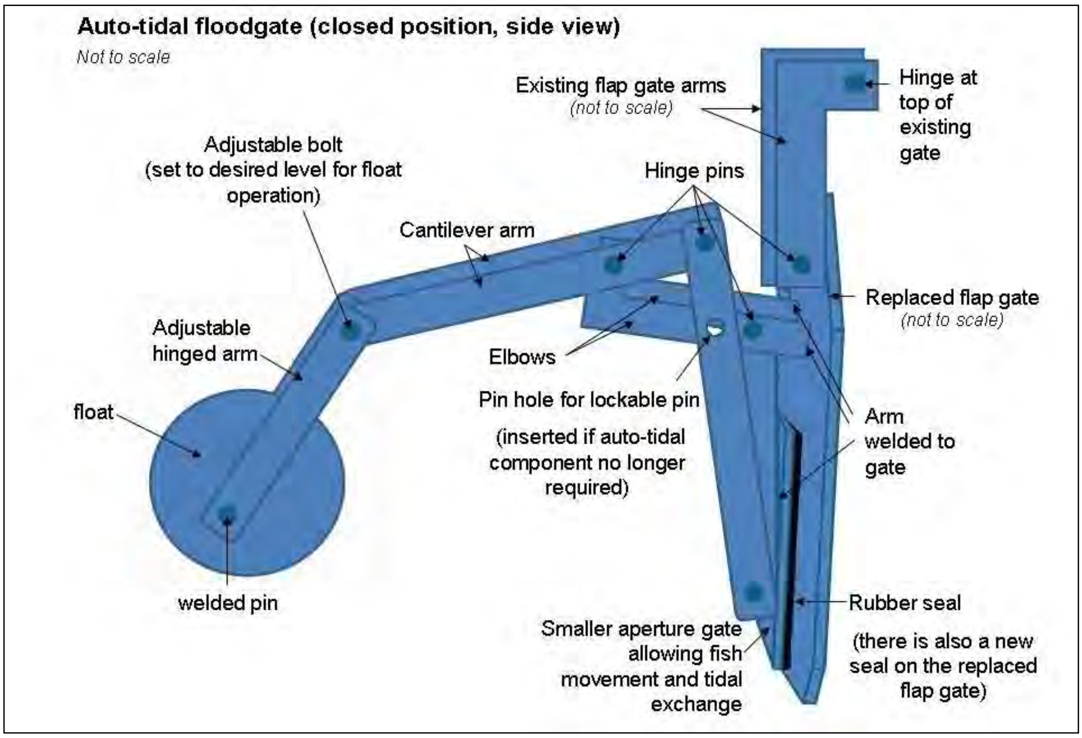

Figure 5-2:Auto-tidal floodgate mechanism in the fully closed position approaching high tide (the cantilever arm and water pressure will force the smaller aperture closed) (DPI, 2009)

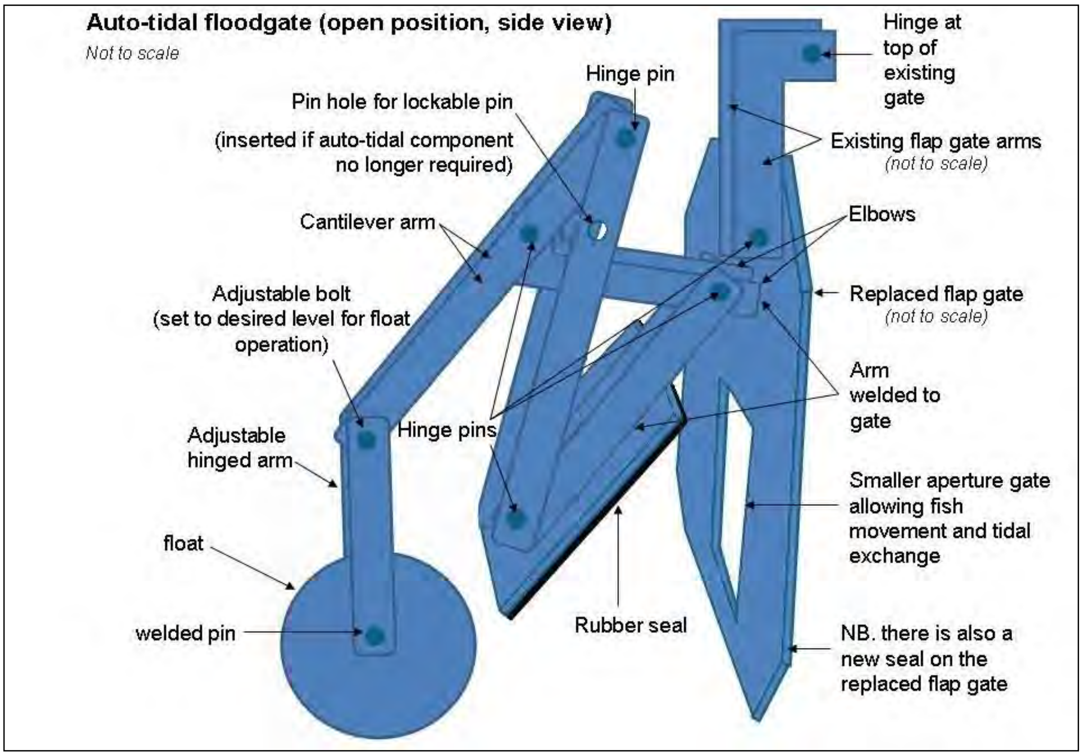

Figure 5-3: Auto-tidal floodgate mechanism in the open position on decreasing and low tide (DPI, 2009)

5.2 Floodgate operation

The normal drainage function of the existing floodgate will continue to operate and maintain the present level of drainage. Modification of a floodgate flap to include an auto-tidal gate will not influence the downstream drainage efficiency or drainage capacity of the structure. Present day flooding will also be unchanged. The existing floodgate structure has the capacity to easily drain all water introduced by the auto-tidal gate during a tidal cycle.

The amount of water that flows upstream through an auto-tidal gate can be controlled by adjusting the level at which the float trigger is actuated. The size and range of the tide in the downstream Crookhaven River does not influence the amount of water that is allowed to flow upstream through the auto-tidal gate. The auto-tidal gate can also be closed completely by lowering the float trigger to a level below the bottom of the gate.

The auto-tidal gate level setting needs to be agreed upon by all upstream landholders and can be easily adjusted as required to allow more or less tidal flushing. Analysis presented in this report shows that a maximum upstream water level of approximately 0.0 to + 0.1 m AHD will limit impacts to floodplain areas adjacent to the drains. Tidal flushing to water levels higher than 0.0 to + 0.1 m AHD may require additional management actions (such as on-ground works) to limited undesired inundation of landholdings. Indicative tidal cut-off levels (during dry times) to achieve upstream water levels of 0.0 to + 0.1 m are provided in Table 5.1.

Table 5.1: Gate operational regime during dry conditions

Number of Gates	Invert (m AHD)	Dimensions (w x h) (m)	Maximum upstream cutoff level (m AHD)	Corresponding downstream cutoff level (m AHD)
1	- 0.35	0.70 x 0.90	+ 0.1	+ 0.7
2	- 0.35	0.70 x 0.90	+ 0.1	+ 0.4
3	- 0.35	0.70 x 0.90	+ 0.1	+ 0.3

Concerns were raised by some floodplain landholders regarding a potential reduction in drainage efficiency (due to an increased upstream tidal signal). Modification of the Culburra Road floodgates to provide controlled tidal flushing would not reduce the drainage efficiency of the existing floodgates. However, the drainage efficiency of the existing floodgates could be further improved via a number of strategies, including:

- Installation of lighter floodgate flaps; and
- Optimisation of the angle of the P10G1 floodgates (which currently are at an angle less than vertical).

Note that these strategies would require further assessment and consideration. The time of drainage and wider floodplain inundation following wet weather events is ultimately determined by downstream water levels in the Crookhaven River estuary.

5.3 Trial period and monitoring

A tidal flushing trial enables the functionality, flushing efficiency, and potential impacts to be identified during a short period when the auto-gate levels can be adjusted to optimise the flushing regime based on real-time water level and salinity monitoring. A trial period of one (1) to two (2) months is recommended to test and refine the operational regime of the auto-tidal gates. During this period landholders should monitor their properties for changes, particularly in low-lying areas. The tidal cut-off level would initially be set at a conservative elevation (e.g. below 0 m AHD) for an initial period, with the level adjusted based on monitoring and landholder feedback. An upstream level of below 0.0 m AHD is preferred based on the assessment outlined in this report, whereby overbank connectivity would occur at elevations above +0.1 m AHD. The final operational level for the auto-tidal gate should be determined following the trial period based on monitoring data and landholder feedback.

Monitoring of water levels and water quality at key locations is recommended to:

- Quantify upstream water levels in response to auto-tidal gate operation;
- Quantify extent of tidal flushing and corresponding changes in water quality;
- Identify connected floodplain areas that may be experiencing adverse impacts;
- Correlate landholder observations to measured data;
- Determine connectivity to P7D1 drainage system upstream of Springbank Road; and
- Provide data to enable additional on-ground works to be designed (e.g. levee reinforcement, installation of one-way floodgate flaps at Springbank Road etc.) if required.

Monitoring before and during the trial period is recommended. The location and type of monitoring recommended is shown in Figure 5-4.

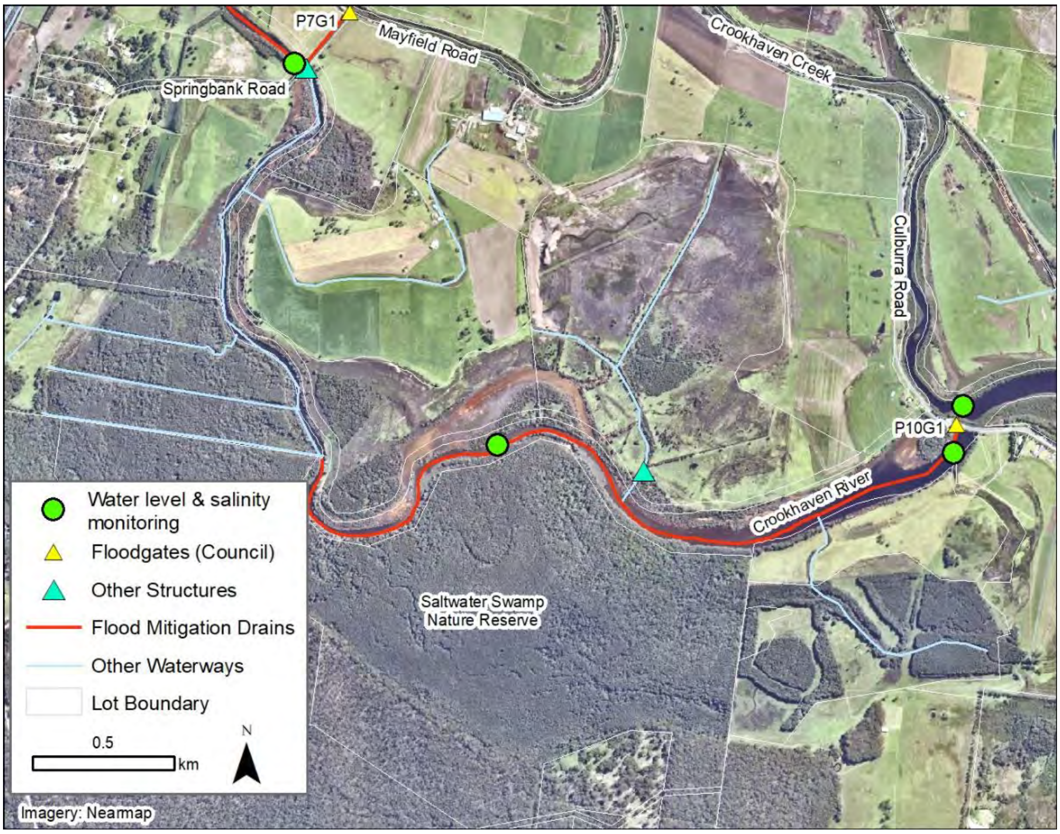

Figure 5-4: Recommended monitoring

5.4 Floodgate maintenance and adjustment

The existing floodgate structure at Culburra Road is owned and maintained by Shoalhaven City Council as part of Council's network of flood mitigation infrastructure. Council will continue to be the agency responsible for operation and maintenance of the floodgate structure.

Landholders will continue to notify Council of issues with the floodgate (e.g. blockages, leakage etc). Landholders are also able to report issues with the auto-tidal floodgate including whether the tidal cut-off level should be modified. Landholders should be advised not to attempt to modify the floodgate themselves as this could be a risk to personal safety as well as the integrity of the floodgate structure.

5.5 Contingency

The auto-tidal gate can be closed, or the cut off level lowered, if the gate causes unintended impacts to upstream landholders. The auto-tidal gate can be closed or disabled by Council and the floodgate structure will continue to operate as normal.

5.6 Risk mitigation

Due to the low-lying elevation of the Crookhaven River floodplain, there is a risk of undesired impacts to private land holdings if tidal flushing at high elevations is permitted. High tidal levels upstream of the Culburra Road floodgates could result in tidal overbank inundation of floodplain areas.

There are several adaptive management options available to mitigate any potential risks or adverse impacts resulting from the proposed tidal flushing strategy. These include:

- Lowering the tidal cut off level to reduce the level (and time per day) of tidal flushing;
- Temporarily disabling of the auto-tidal mechanism whilst additional control measures are put in place;
- Levee re-enforcement at low points in the drain levee banks to reduce overbank connectivity whilst still allowing floodplain drainage;
- Maintenance of private drainage structures;
- Fitting of additional floodgates to culverts beneath Springbank Road to prohibit upstream flows into the Brundee Swamp Nature Reserve and other low-lying floodplain land in the Brundee area; and
- Installation of lighter floodgate flaps (e.g. aluminium gates) to improve drainage efficiency of the existing floodgate structure (as less upstream water pressure/level is required to open the floodgate flaps).

It is recommended that these risk mitigation strategies are considered and implemented based on observations and monitoring during the trial tidal flushing period.

Increased salinity of the wider floodplain groundwater table is not expected, however some localised changes may occur in the area immediately adjacent to the waterway. Lateral propagation of tidal waters into floodplain groundwaters, and the subsequent increased salinity of groundwater is unlikely due to the positive groundwater gradient from the higher water table of the floodplain flowing towards lower elevation surface waters. Furthermore, the falling tide and low surface water levels will continue to promote the flow of groundwater from the floodplain into Crookhaven Creek.

As mentioned in Section 3.1, if a large amount of tidal flushing or uncontrolled tidal flows were to occur, then large areas of the floodplain that are owned by both private landholders and NPWS would be regularly inundated by saline waters. Significant on-ground works (e.g. approximately 7.5 km of levee bank) and additional drainage infrastructure (e.g. approximately 11 new structures to provide floodplain drainage) would need to be constructed to allow a significant increase in tidal flushing or full natural tidal inundation range to occur. Minor works may be required for tidal flushing above 0.0 to +0.1 m AHD, with more significant works required at elevations exceeding +0.3 m AHD. Potential works required are outlined in Figure 5-5. Alternatively a change in land use would be required to facilitate large scale tidal flushing and tidal inundation in the upper Crookhaven River area. A change of ecology within Saltwater Swamp Nature Reserve would also occur.

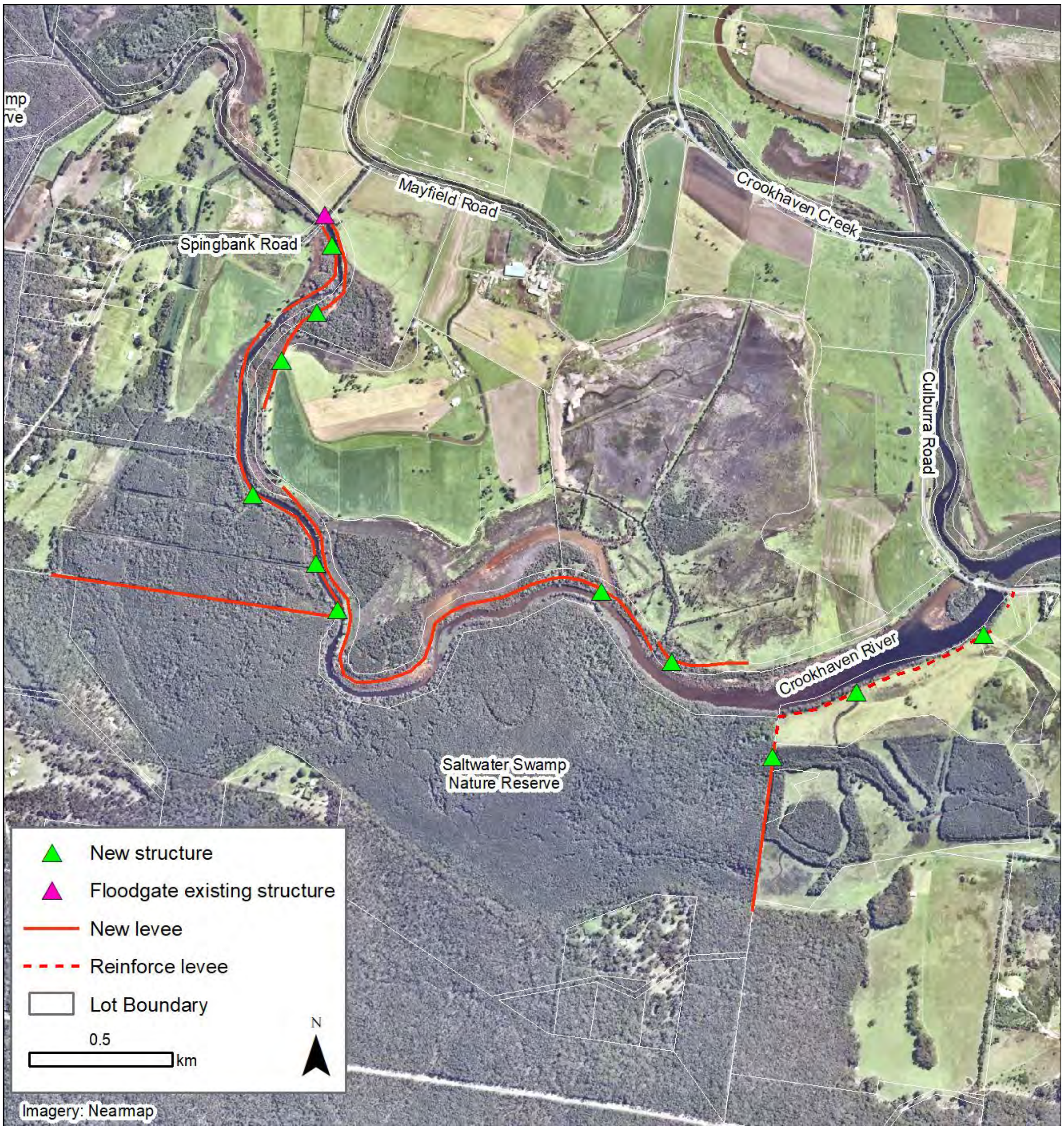

Figure 5-5: Indicative on-ground works required to increase tidal flushing significantly above the +0.1 m AHD cut off level and reduce impacts to private landholders

6 Conclusions

Introducing controlled tidal flushing to floodgated waterways has many benefits including; reduced aquatic weeds, improved water quality, improved drought resilience through elevated groundwater levels, creation of tidal habitat, and fish passage.

To investigate controlled tidal flushing at the Culburra Road floodgates (Council asset ID: P10G1) in the upper Crookhaven River, an assessment of flushing dynamics, auto-tidal gate design, and potential impacts/risks was completed. Critical information such as tidal levels, floodgate geometry, floodplain ground level survey (topography), land ownership and waterway connectivity were incorporated into the tidal flushing assessment. Multiple auto-tidal floodgate configurations were assessed.

Key findings from the tidal flushing assessment include:

- Tidal flushing has benefits for water quality and fish passage in upstream waterways;
- A maximum upstream tidal level below 0.0 m AHD is recommended to maintain tidal waters within the existing waterway;
- Tidal flushing at elevations above 0.0 to + 0.1 m AHD may result in connectivity to private floodplain areas, and significant on-ground works (e.g. levees) may be required to limited undesired inundation of landholdings;
- Risk to productive private floodplain land is limited at tidal flushing below 0.0 m AHD, with tidal flushing to a lower elevation limit further reducing risk, and monitoring and an adaptive management approach should be utilised when considering the tidal flushing proposal;
- Drainage capacity and efficiency of the existing system will be maintained or improved (i.e. reduced aquatic freshwater weeds);
- Drainage efficiency via the floodgate structure could be improved via installation of lighter floodgate flaps (e.g. aluminium floodgates as opposed to the existing steel gates);
- Optimal tidal flushing is achieved with two (2) auto-tidal gates, however one (1) auto-tidal gate also provides benefits to water quality and fish passage;
- Auto-tidal gate dimensions of 0.7 m (wide) x 0.9 m (high) with an invert of approximately - 0.35 m AHD are suitable;
- Existing culverts beneath Springbank Road may require altered management, including the installation of one-way floodgates required to limit tidal flows upstream of Springbank Road;
- A trial flushing period with monitoring is recommended, with adjustment of the tidal cut off level as required based on monitoring (of water quality and water levels) and landholder feedback;

- Any auto-tidal gate(s) should be adaptively managed by adjusting the tidal flushing regime in response to upstream water levels and upstream landholder feedback;
- Private drainage floodgate infrastructure would require refurbishment prior to implementing any tidal flushing proposal;
- Ongoing adaptive management of the system should be informed by monitoring of water levels and salinity in the lower and upper Crookhaven River waterways (i.e. upstream and downstream of the Culburra Road floodgates) and landholder feedback.

Concerns raised by upstream floodplain landholders included:

1. A potential reduction in drainage due to an increase in tidal water in the upper Crookhaven Creek; which is unlikely given the capacity of the existing drainage infrastructure but could be mitigated by improving the drainage efficiency of the existing floodgates at Culburra Road via installation of lighter floodgate flaps (e.g. aluminium).

2. The risk of saline impacts to private land; which can be managed by adjustment/setting of the auto-tidal mechanism to have a low tidal cut off level (i.e. only allow tidal flushing to a low elevation) that would only provide tidal flushing and aquatic connectivity for a limited period of time per day (e.g. 1 hour per tidal cycle).

3. Adequate ongoing management and maintenance of the drainage infrastructure; which would require a commitment from Shoalhaven City Council to manage and maintain the infrastructure as required utilising an adaptive management approach.

Ongoing consultation with landholders, Council and project stakeholders is recommended regarding these issues.

7 References

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Appendix A P10G1 Existing floodgates

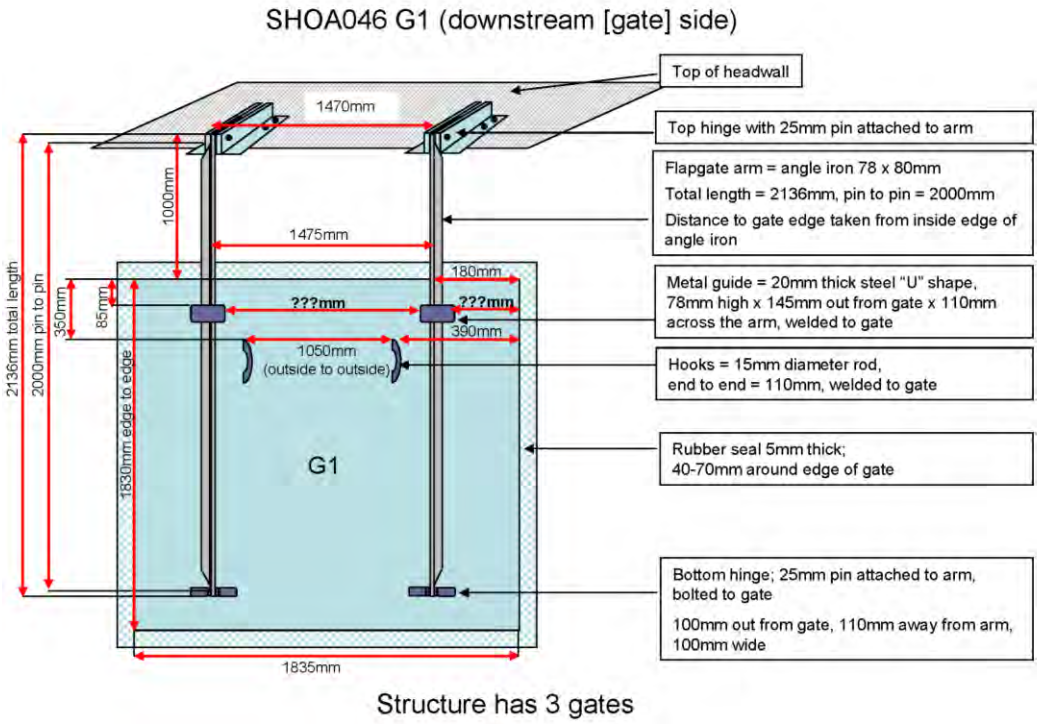

Figure A.1: Floodgate flap and dimensions (downstream side) (DPI, 2009)

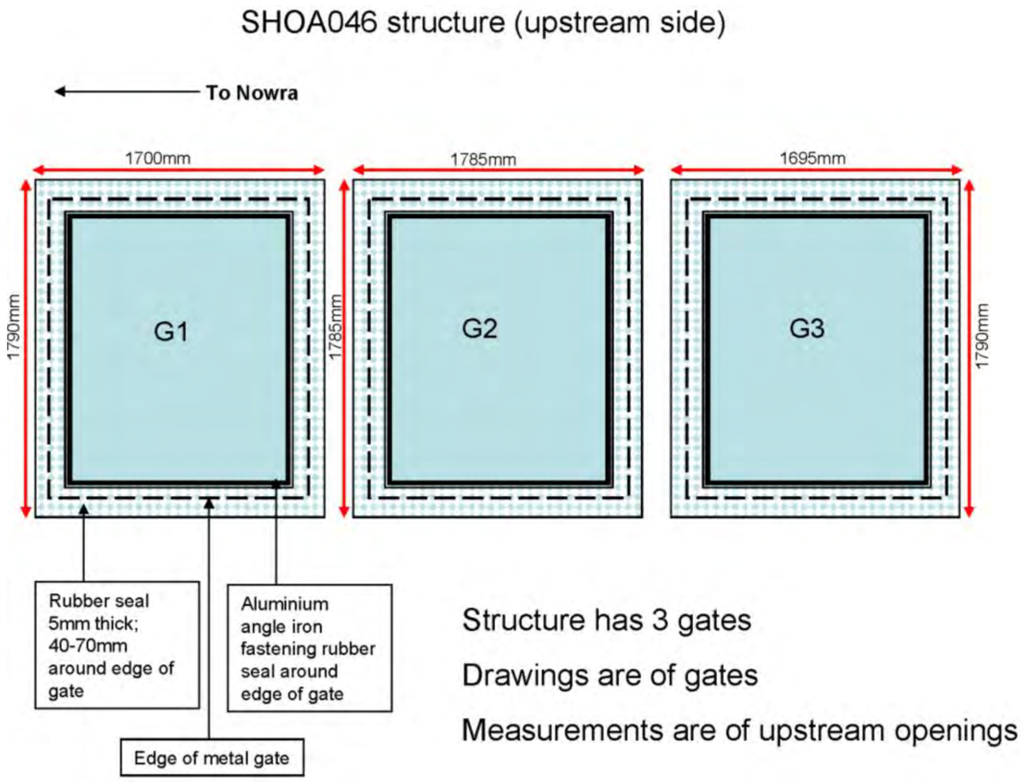

Figure A.2: Culvert dimensions (upstream side) (DPI, 2009)

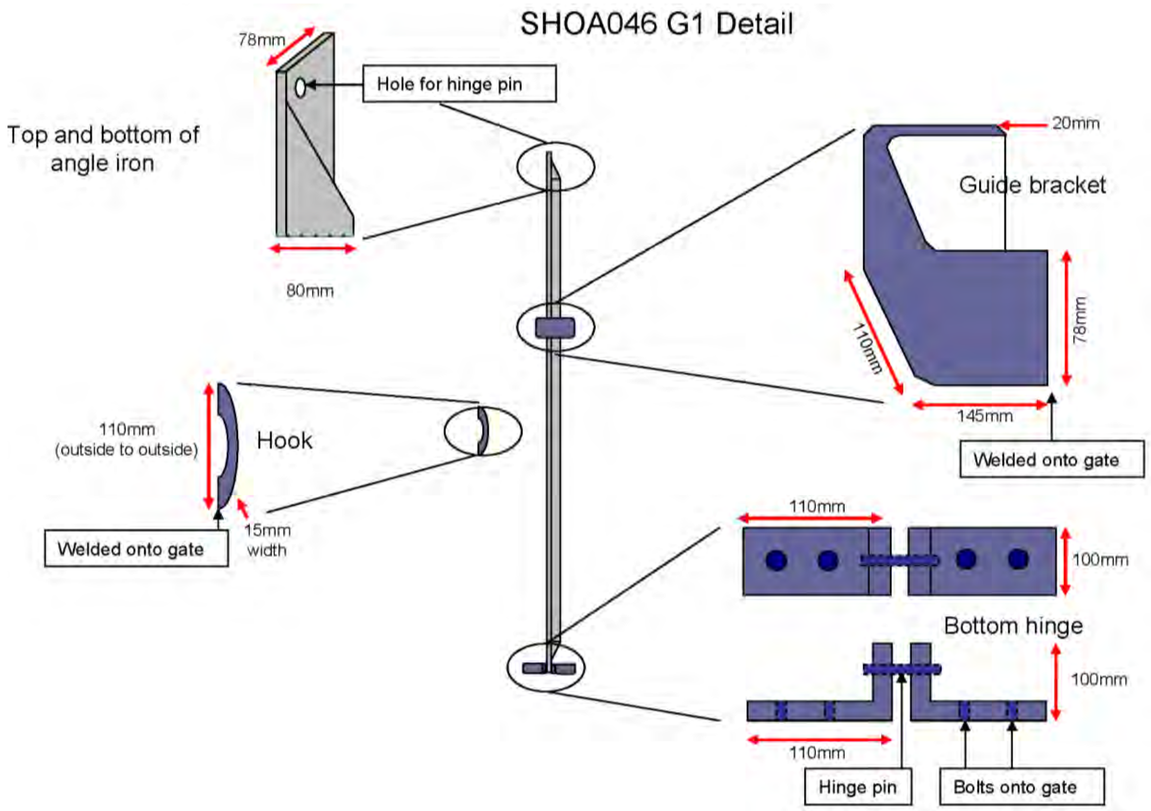

Figure A.3: Floodgate details (DPI, 2009)

Appendix B Land tenure

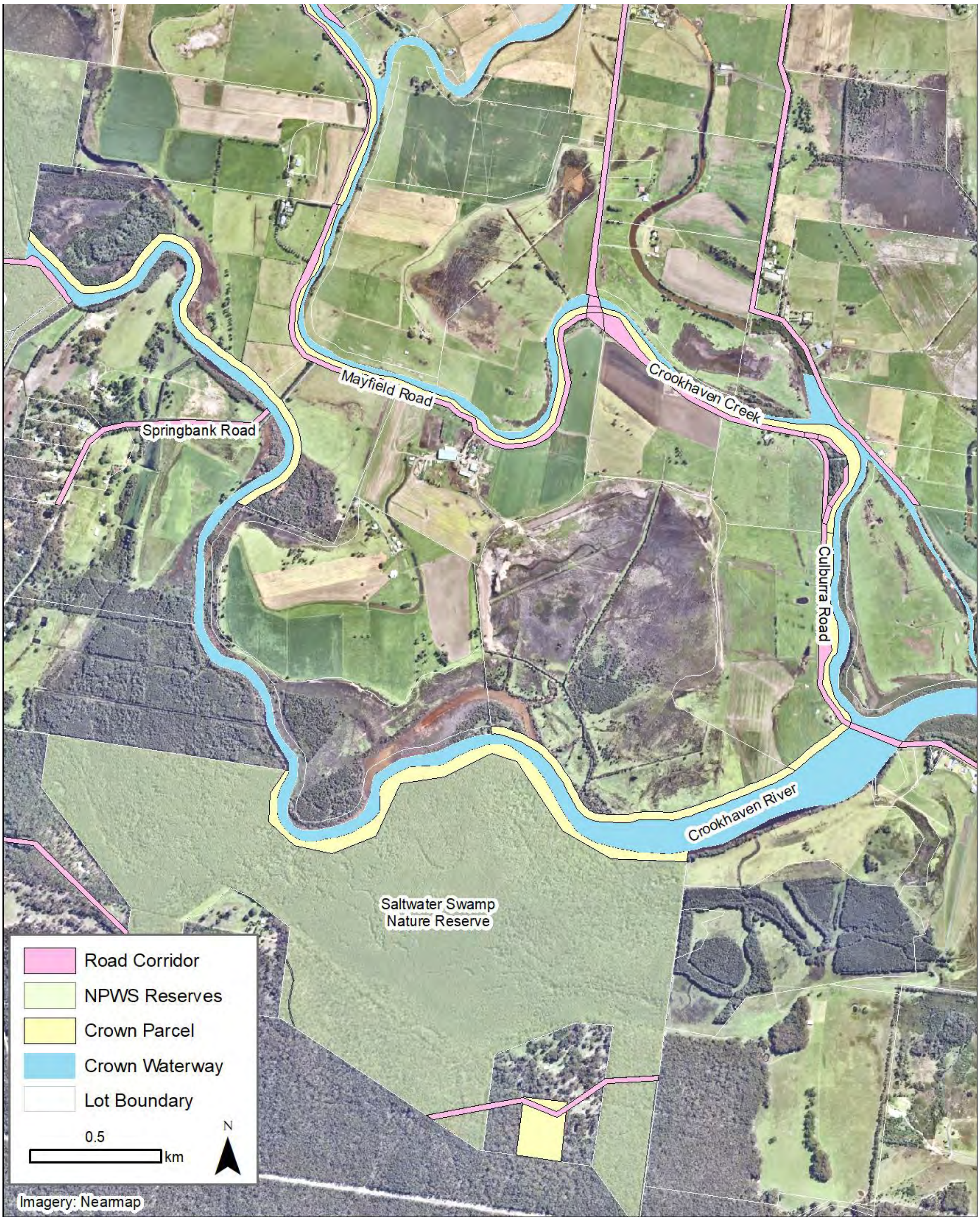

Figure B.1: Land tenure in the study area

Appendix C Coastal Management SEPP Wetlands

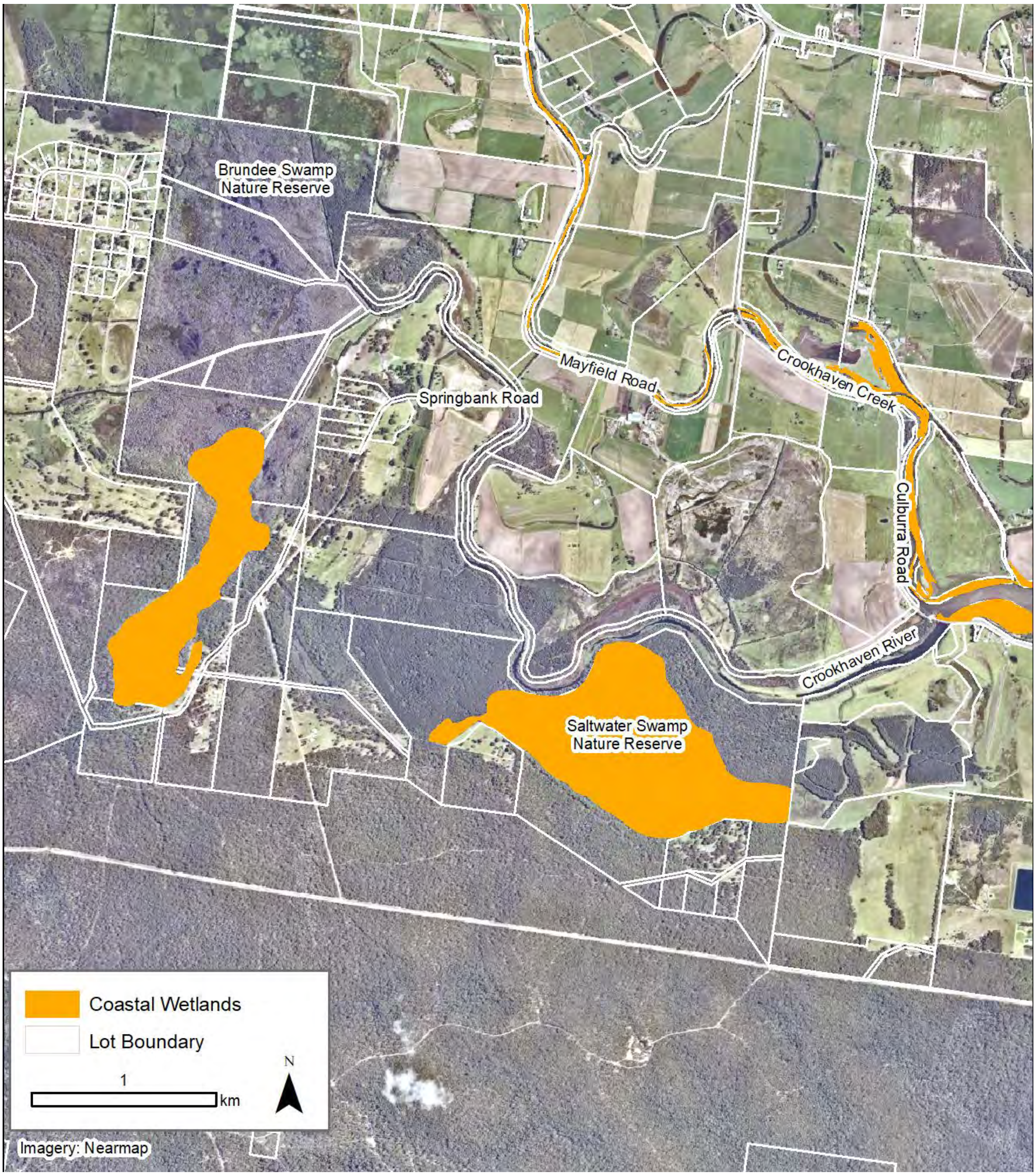

Figure C.1: Identified coastal wetlands in the study area

Appendix D Estuarine vegetation

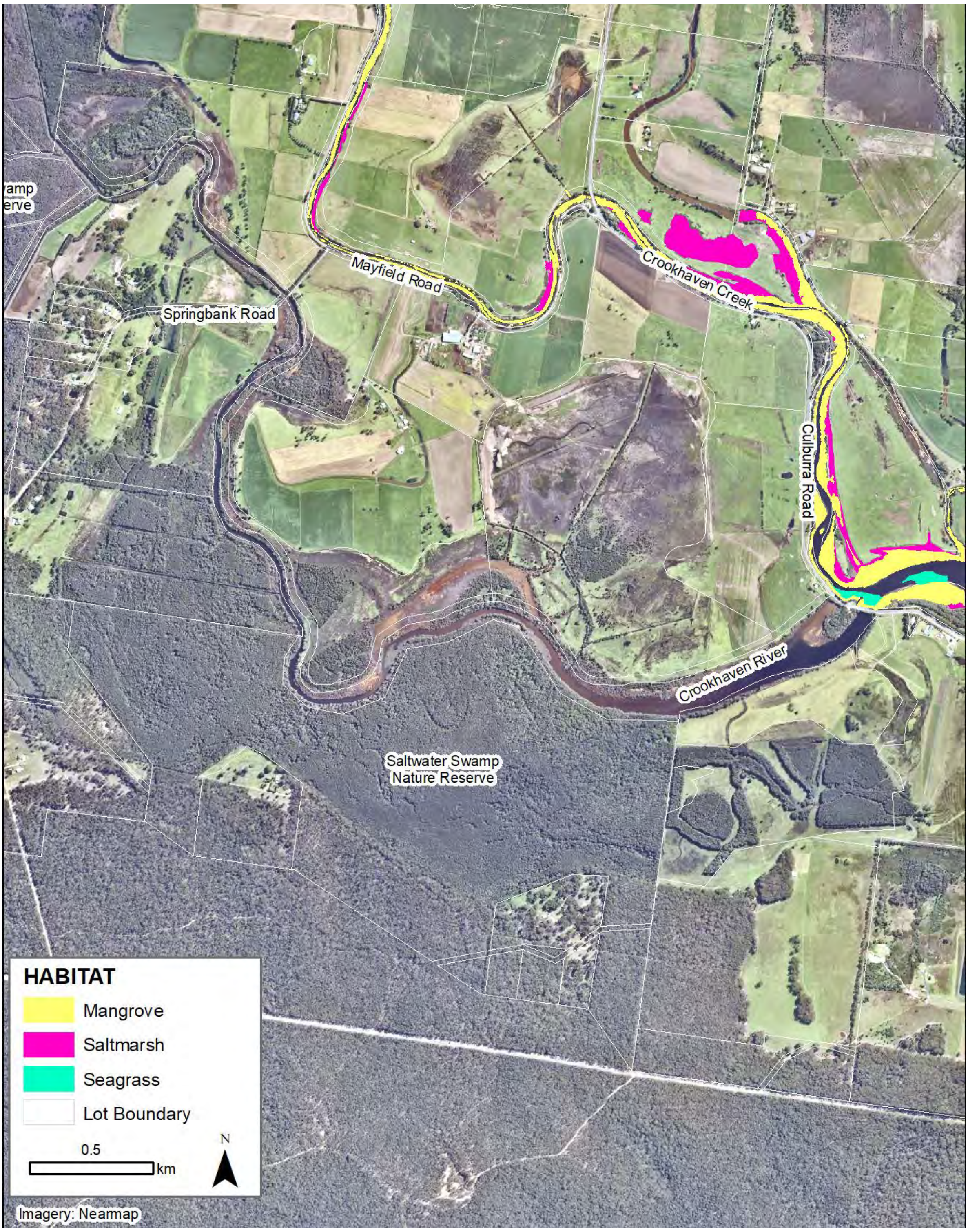

Figure D.1: Identified estuarine vegetation (macrophytes) (Creese et al., 2009)

Appendix E Detailed floodplain topography of property lots

Figure E.1: Overview of property boundary extents and lot and plan numbers

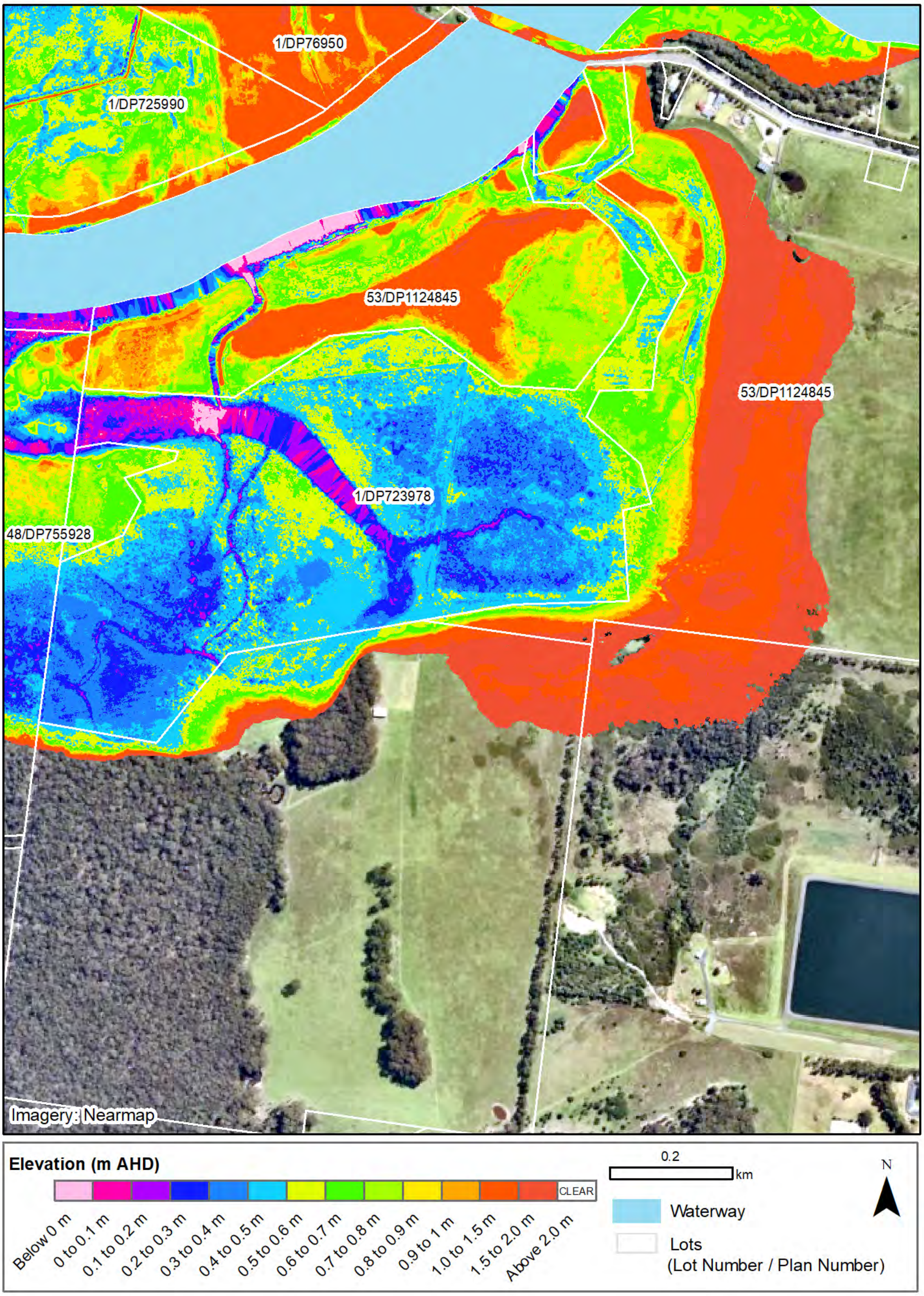

Figure E.2: 1/DP723978 and 53/DP1124845

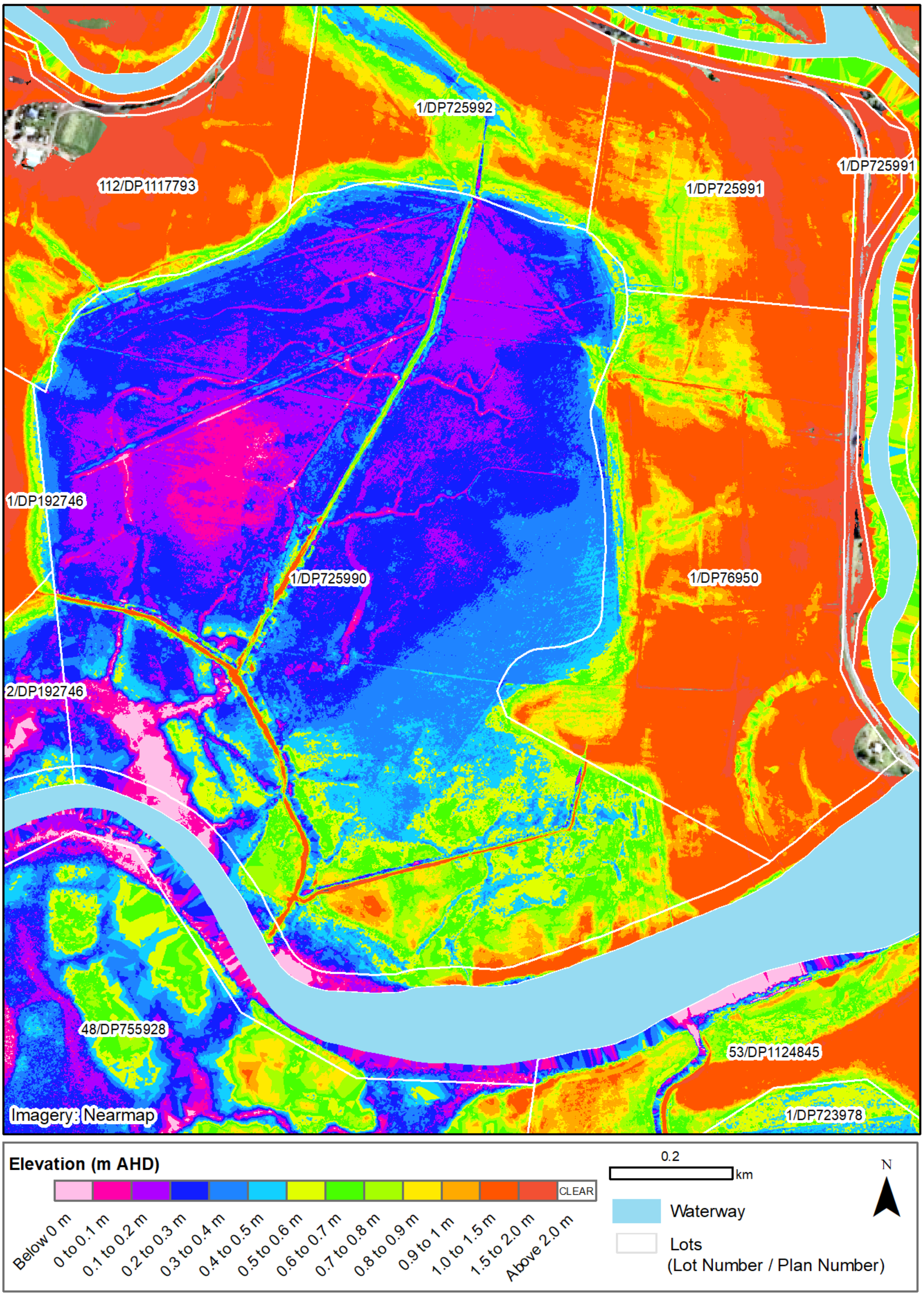

Figure E.3: 1/DP725990 and 1/DP76950

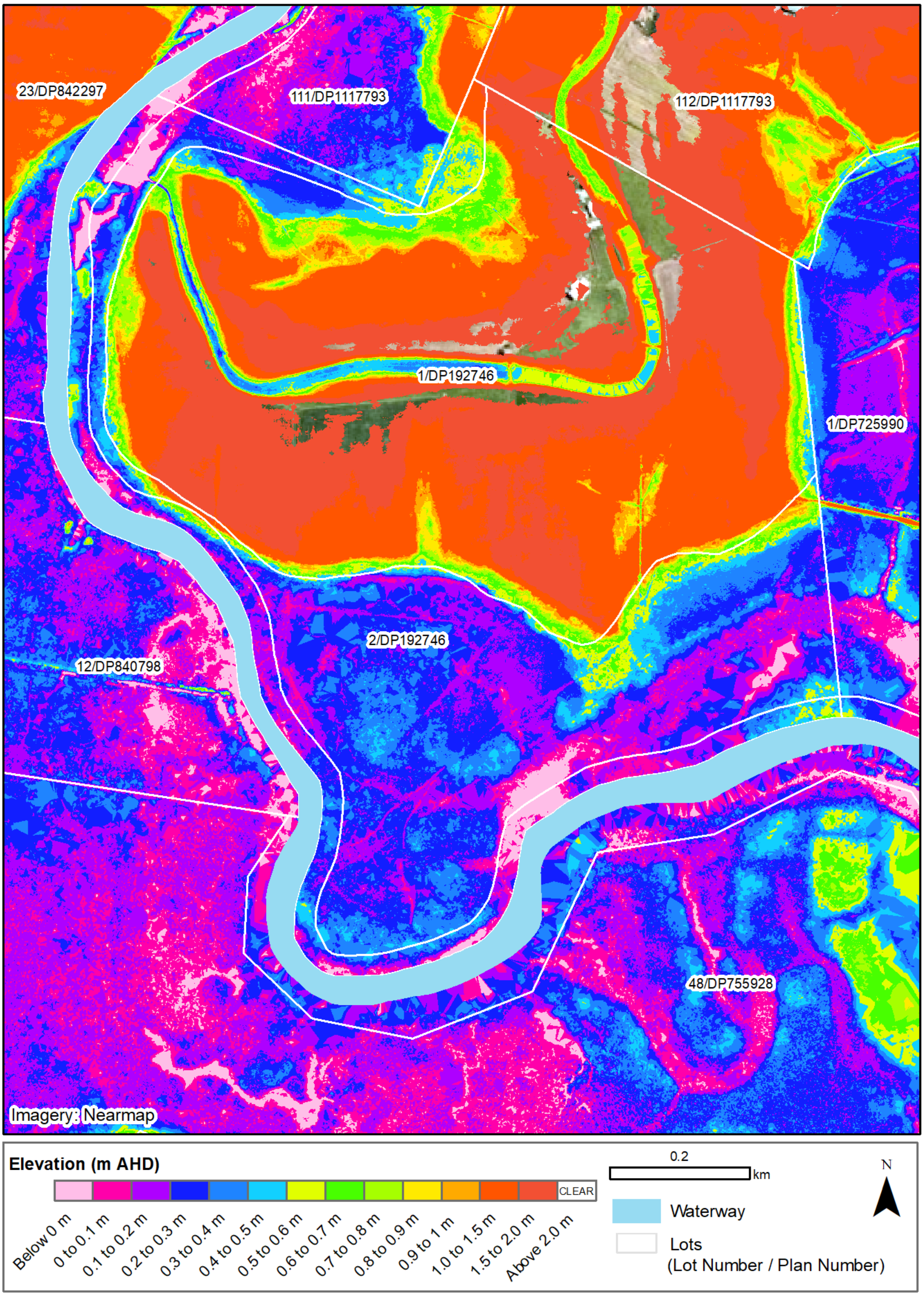

Figure E.4: 1 and 2/DP192746

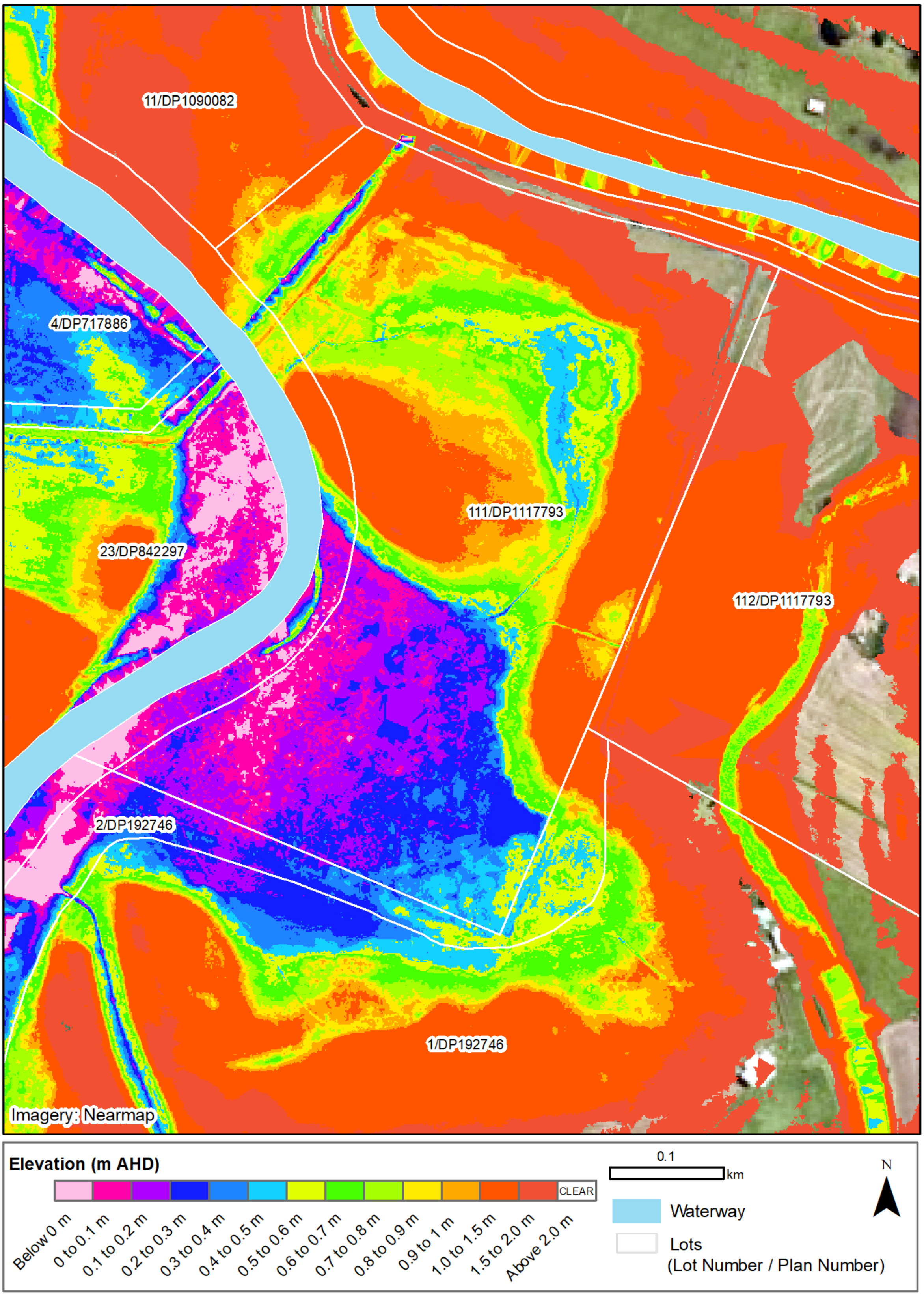

Figure E.5: 111/DP1117793

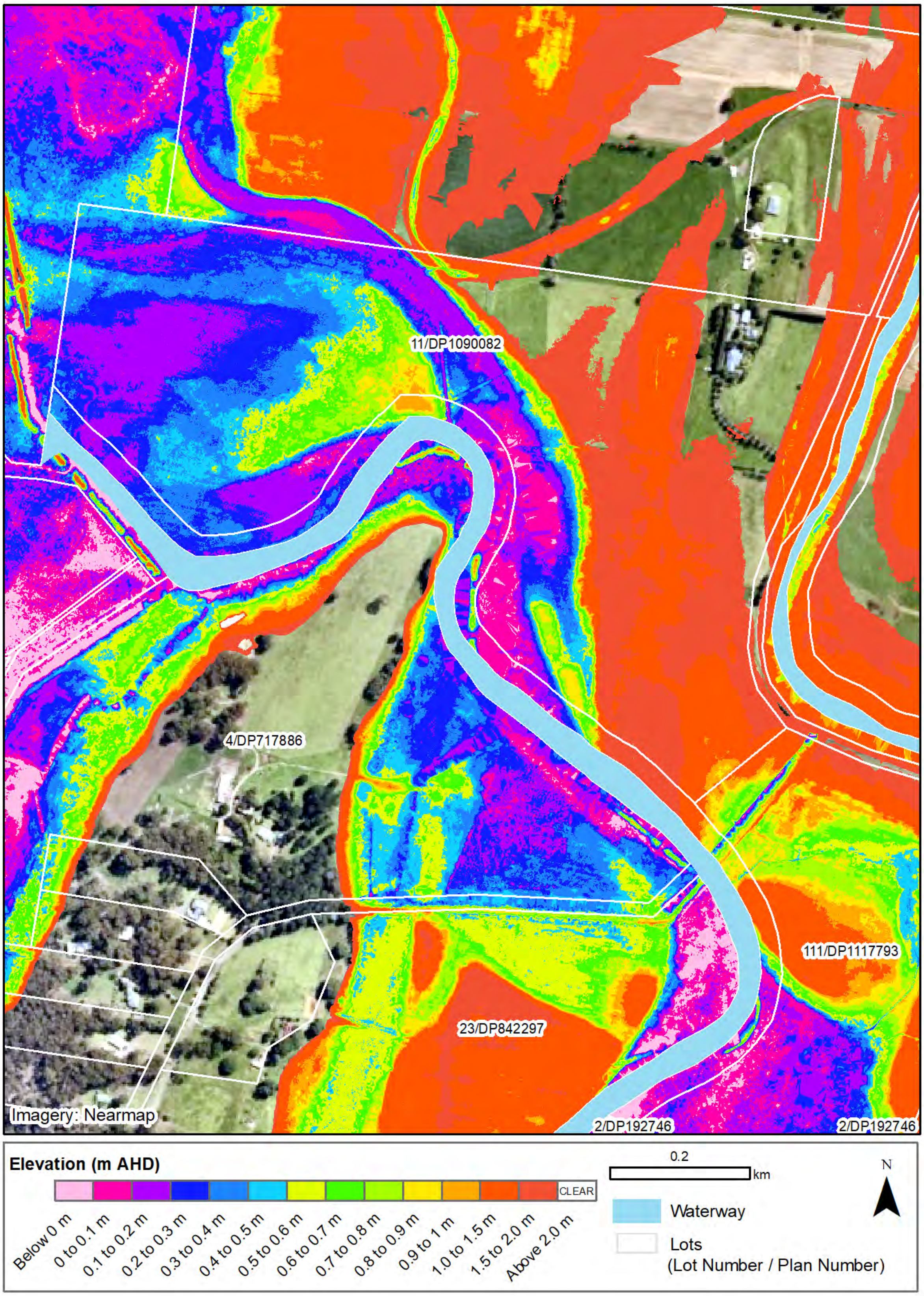

Figure E.6: 11/DP1090082 and 4/DP717886

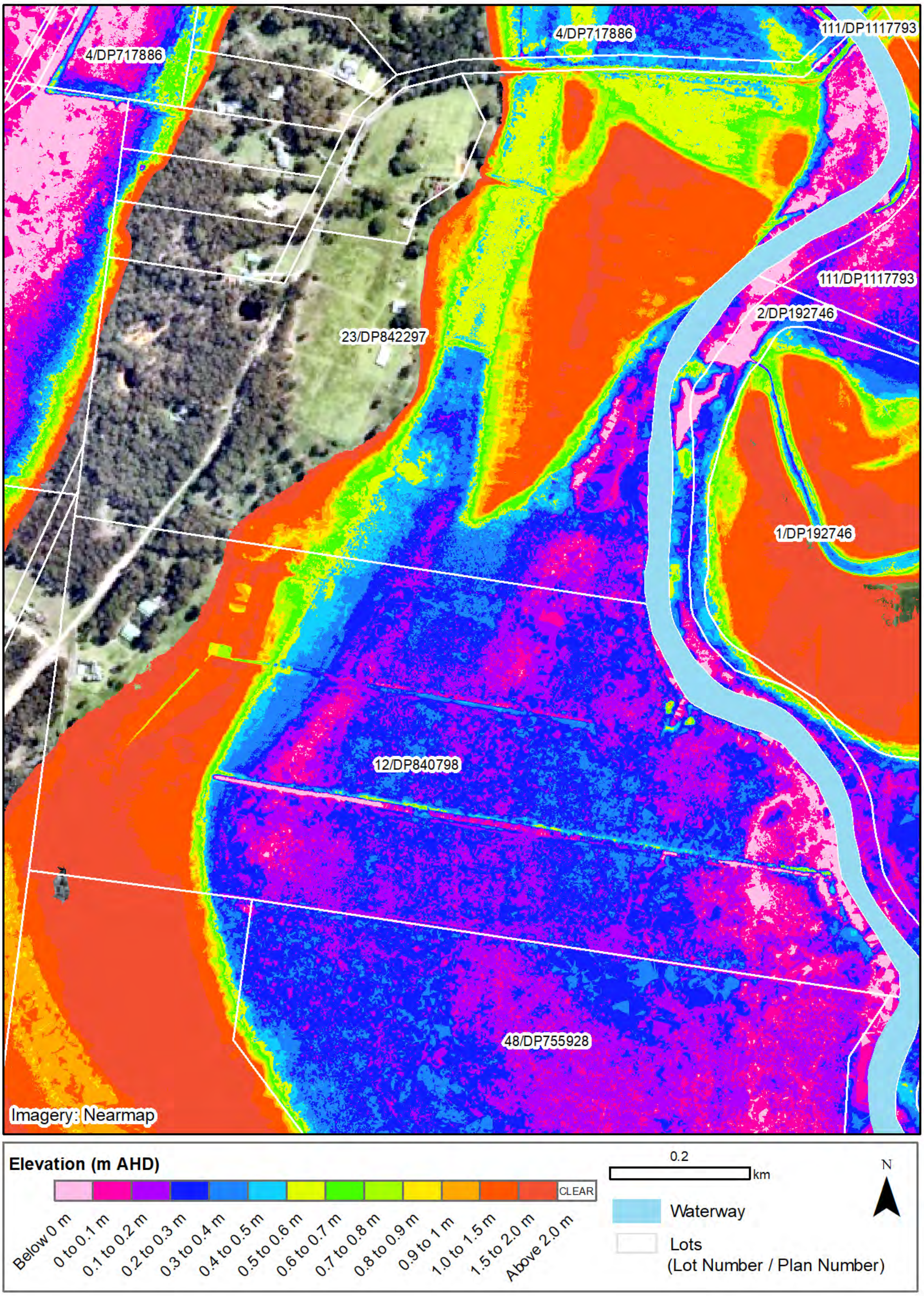

Figure E.7: 23/DP842297 and 12/P840798

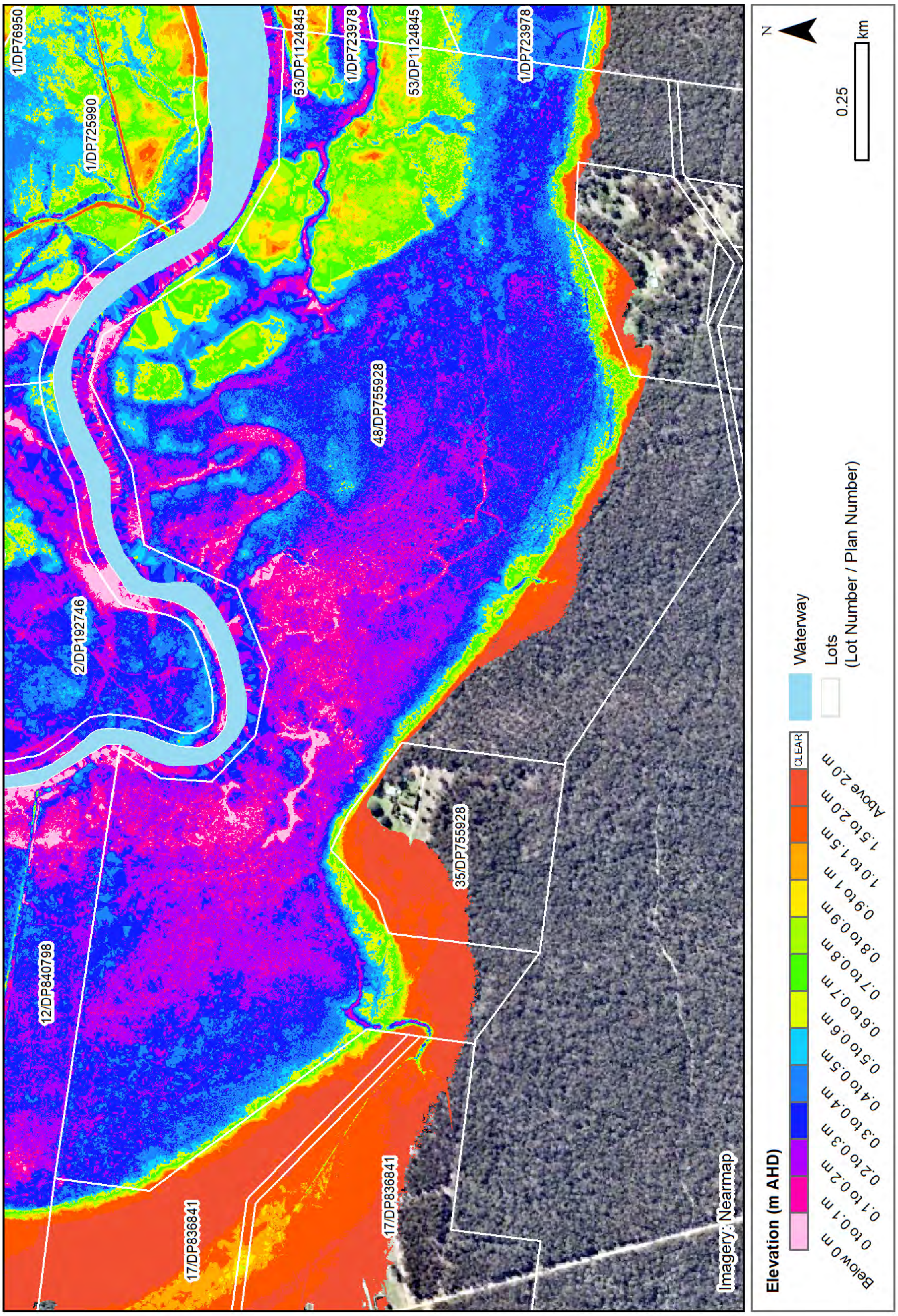

Figure E.8: Saltwater Swamp Nature Reserve (48/DP755928)